AIR QUALITY IMPACT ASSESSMENT: BRISBANE AIRPORT LINK PROJECT

July 2006

EXECUTIVE SUMMARY

The following report presents an analysis of the air quality impacts of the proposed Brisbane Airport Link Project (the “Project”). The Project involves the construction and operation of a road tunnel approximately six kilometres in length from Bowen Hills to Wooloowin in Brisbane. The study focuses on air quality impacts arising from the operation of the tunnel.

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 (2012+), arising from motor vehicles, would be expected to be similar to existing (2004) 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.

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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
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 Airport Link (AL) Tunnel in Brisbane.

The proposal involves the construction of a twin road tunnel in central Brisbane between Bowen Hills and Wooloowin. **Figure 1** shows the study area and proposed route for the AL.

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 proposal;
- Air quality standards and goals relevant for this 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;
- Three lanes in each direction from North-South Bypass Tunnel (NSBT) connection to Gympie Road connection. Two lanes in each direction from Gympie Road connection to East West Arterial connection;
- Tunnel portals at Bowen Hills, Gympie Road and East West Arterial;
- Safety systems including egresses, fire protection and monitoring systems;
- A ventilation system to manage air quality in the tunnel and near portals including elevated outlets near the portals in Bowen Hills, Kedron and Toombul;
- Surface road changes to connect the tunnels to the existing road/bus network;
- Tunnel Control Centre;
- Traffic management systems including signage, lighting, CCTV and radio / mobile rebroadcast capability; and
- Electronic tolling, plant monitoring and control systems.

A construction period of approximately three to four years would be required with 2012 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 portals and ventilation inlets. 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 three ventilation outlets. **Figure 3** shows the preferred location for the tunnel ventilation outlets.

The ventilation outlets are referred to as the southern connection (SC), northwest connection (NW) and northeast connection (NE). **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 proposed 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 DEC)
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 Conservation (DEC) long-term goal has been included to provide a benchmark for comparison with the 24-hour NEPM goal.

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 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.

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:

- <u>In-tunnel filtration</u> aimed at reducing pollutant concentrations for motorists using the tunnel; and

- <u>Ventilation outlet filtration</u> aimed at reducing pollutant concentrations emitted to the outside ambient air.

Dispersion modelling studies (see **Holmes Air Sciences, 2001, 2004**) 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 regional and larger 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

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

5.1 Dispersion Meteorology

The meteorology in the study area 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 (see **Figure 2** for a representation of the local terrain). 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 landuse in the study area, differences in wind patterns at different locations in the study area 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. **Figure 5** shows the location of meteorological monitoring sites which were used to compare localised wind patterns throughout the area.

In the air quality assessment undertaken in this report it is not necessary to document the complex mechanisms that affect air movements in the area, it is simply necessary to ensure that these air movements are incorporated into the dispersion modelling studies that are done. A limitation of common Gaussian plume dispersion models (such as AUSPLUME) is that they assume that the meteorological conditions are the same spatially over the entire modelling domain for any given hour. This may be adequate for sources in relatively uncomplicated terrain however when the terrain or landuse is more complex the meteorological conditions can be more accurately represented using wind field and puff models.

In the last decade there has been a significant improvement in the capability of dispersion models to handle dispersion in areas where complex wind flows occur. In this assessment we have made extensive use of the CALPUFF dispersion model. The CALPUFF model makes use of wind fields generated by the CALMET model. CALMET generates a three-dimensional wind field on an hourly basis by taking observations of winds at selected locations and interpolating these to produce information on wind speed and direction at a grid of regularly spaced points covering the area of interest. Modifications that are imposed on this interpolated wind field (by topography and differential heating and differential surface roughness) are then applied to the winds at each grid point to develop a final wind field.

The final wind field reflects the effect of local topography and the effects of different temperatures experienced by water bodies and land surfaces as well as different surface roughness that arise because of changes in vegetation or other variations in land use such as the presence of residential and industrial developments. **Figure 6** shows the model extents, terrain and landuse information used as input to the CALMET model.

The CALMET and CALPUFF models have undergone many validation studies in Australia, New Zealand and in the United States. The CALPUFF modelling system is the US EPA's preferred model for assessment of long range pollutant transport and for near field applications with complex meteorology. In NSW, the DEC have listed CALPUFF as an "approved" air dispersion model for regulatory impact assessments (**DEC, 2005**). The Queensland EPA do not list "approved" air dispersion models in the EPP (Air) (**1997**).

Meteorological and ambient air quality monitoring data from a number of years has been reviewed to determine the most suitable year for the CALMET and CALPUFF modelling. Typically, one year of 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. The year 2004 was chosen for the purposes of this assessment based on the completeness of both the meteorological and ambient air quality monitoring records. The latter are required to account for background pollution levels.

A wind field has been generated by CALMET for each hour of the 2004 calendar year using meteorological data from Bureau of Meteorology (BoM) and EPA monitoring sites. Further details are discussed below. The CALMET model has essentially used the data from these sites to determine wind patterns over the entire modelling domain given information on the local landuse and terrain features.

In addition to surface meteorological records, the CALMET model requires upper air data in order to generate a year-long three-dimensional wind-field. Upper air data records collected by the BoM in 2004 at Brisbane Airport were used to provide the CALMET model with the required information on pressure changes, higher altitude winds and temperature profiles. These data included twice daily records of wind speed, wind direction, temperature, pressure and height and were processed into a form suitable for the CALMET model.

There were occasional missing soundings in the BoM upper air data for 2004 which were 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 *et al.,* 1997**). TAPM is further discussed in the user manual (**Hurley, 2002**).

Figure 7 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 2**.

Table 2 : Summary of meteorological parameters used for this study

TAPM (v 2.0)	
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 2004 to Dec 2004
Centre of analysis	Brisbane (27^{o}25.5' S, 153^{o}4' E)
Meteorological data assimilation	Wind velocity data from BoM Airport and EPA Eagle Farm sites
CALMET (v 5.5)	
Meteorological grid domain	20 km x 20 km
Meteorological grid resolution	0.5 km
Surface meteorological stations	2 sites: BoM Airport and EPA Eagle Farm (for temperature, relative humidity and wind velocity). Cloud cover from Brisbane Airport (BoM). Ceiling height and pressure at the two 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	8784 hours (Jan 2004 to Dec 2004)

In a built-up urban environment like central Brisbane, wind dispersion patterns will be complicated by the turbulence induced by buildings. Wind data collected in the study area and reviewed for the purposes of this study are from Brisbane Airport, Bowen Hills, Eagle Farm and Kedron. These locations are shown in **Figure 5**.

The meteorological data collected from all meteorological monitoring sites included hourly records of temperature, wind speed and wind direction. As discussed, data for 2004 have been selected for development of the meteorological wind field. Wind-roses have been created from the wind data and the pattern of winds observed at each site are discussed below.

Bowen Hills

Simtars commenced meteorological monitoring at Bowen Hills in June 2004. This coincided with the environmental assessment stage of the NSBT. Monitoring stopped around November 2005.

Figure 8 presents annual and seasonal wind-roses for the 2004/2005 period from the Bowen Hills site. On an annual basis the winds are predominantly from the southwestern quadrant, although there are some winds observed from the north-northeast and southeast. The cooler months, autumn and winter, show that winds from the southwest and south-southwest are the most common, while in spring the winds come mainly from the north-northeast. Summer shows slightly different trends to any other season with relatively similar proportions of winds from the north clockwise through to the southeast. The only areas showing very little wind flow are the west and west-northwestern sectors.

Annually, the Bowen Hills site has recorded 17% calm periods – that is, when the wind speed was less than or equal to 0.5 m/s. Mean wind speed for the 2004/2005 period was 1.9 m/s.

Brisbane Airport

Figure 9 shows annual and seasonal wind-rose diagrams for the Airport, based on data collected by the Bureau of Meteorology in 2004. Annually, the most common winds at this site are from the north to north-northeast, southwest to south-southwest and east-southeast to southeast. The pattern of winds are similar to the Bowen Hills site, albeit with slightly stronger winds. At the Brisbane airport site, large areas of cleared land with unobstructed wind flow, will result in higher than average local wind speeds compared to the surrounding residential and industrial areas.

In summer, winds at the airport are predominantly from the north which is a typical sea breeze condition. The sea breeze usually commences in the late morning and is well established in the afternoon. Spring exhibits a similar pattern to summer.

In contrast to summer and spring, the most common winds in autumn and winter are from the southwest and south-southwest.

The average wind speed in 2004 at the airport was 4.4 m/s with a maximum hourly average wind speed of 13.3 m/s. The frequency of calm conditions was 2.2%.

Eagle Farm

Figure 10 presents annual and seasonal wind-roses for 2004 data from Eagle Farm. The distribution of winds for Eagle Farm on an annual and seasonal basis is similar to that at both Bowen Hills and Brisbane Airport. This would be expected given the relatively close proximity of the Eagle Farm site to the other sites – less than approximately five kilometres.

Eagle Farm typically has lower wind speeds than the Airport with a maximum hourly average wind speed of 7.3 m/s and an annual average of 2.0 m/s. The percentage of calms is 8.4%. The lower speed winds at the Bowen Hills and Eagle Farm sites are consistent with their location within residential and industrial areas, where buildings and terrain provide some shielding from the prevailing winds, compared with the more exposed BoM Airport site.

The similarities in the wind data for both Eagle Farm and Bowen Hills may be expected given that there are not many significant terrain features between the two sites.

Kedron

Collection of meteorological data in the vicinity of the proposed northwest connection of the AL commenced in January 2006. These data will provide additional information on wind patterns in the central part of the study area and will be analysed as they become available.

For the purposes of this study the Airport and Eagle Farm data have been considered to be the most suitable datasets for CALMET to establish wind patterns over the entire study area. This is based on the completeness of the monitoring records for the CALMET simulation year. Also, 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 area. Furthermore, the data from Eagle Farm and Bowen Hills show a similar distribution of winds.

5.2 Atmospheric Stability

Dispersion models typically require information on atmospheric stability class[1] and mixing height[2]. Plume dispersion models 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 3** provides the frequency of occurrence of the six stability classes as determined by CALMET for the Airport and Eagle Farm sites.

It can be seen from **Table 3** that, at the Airport, the most common stability class is determined to be D-class. The prevalence of D-class is due to the relatively high wind speed recorded at this site. Dispersion of pollutants is rapid under these circumstances as D-class stabilities are generally associated with strong winds. At Eagle Farm, F-class stabilities have been determined to occur most often, although D-class stabilities are also common. 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.

Table 3 : Frequency of occurrence of atmospheric stability class

Pasquill-Gifford-Turner stability class	Frequency (Airport, %)	Frequency (Eagle Farm, %)
A	0.0	3.2
B	4.4	14.0
C	15.3	17.1
D	46.5	20.4
E	16.4	6.3
F	17.3	39.0
TOTAL	100	100

Joint wind speed, wind direction and stability class frequency tables generated from the Airport and Eagle Farm monitoring sites are presented in **Appendix B**.

[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.

5.3 Local Climatic Conditions

The Bureau of Meteorology collects climatic information from Brisbane Aerodrome, to the east of the study area. A range of meteorological data collected from this station are presented in **Table 4** (**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 and minimum temperatures. Rainfall data consist of mean and median monthly rainfall and the average number of raindays per month.

Table 4 : Climate information for the study area

Brisbane Aerodrome	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.

The annual average humidity reading collected at 9 am from the Brisbane Aerodrome site is 66 percent, and at 3 pm the annual average is 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 Aerodrome shows that the wettest month is February, during the wetter summer season, with an average rainfall of 171.7 mm over 14.2 days. The lowest rainfall on average is in 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 over an average of 122 raindays.

The data from **Table 4** show that the climate in Brisbane is characterised by wet summers and low rainfall in winter. This is typical of the subtropical climate of southeast 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 is less dispersion of pollutants.

5.4 Existing Air Quality

This section discusses the concept of background air pollution as it applies to this study and presents a review of air quality monitoring data that can be used to estimate background pollution levels.

5.4.1 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 source. 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 AL 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 emissions that will change as a result of the Project are 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.

5.4.2 Air Quality Monitoring

Data from three air quality monitoring sites have been assessed for the purposes of this study – Eagle Farm, Bowen Hills and Kedron. Situated at various locations around the proposed tunnel route, these sites are considered to be representative of the existing air quality environment.

The monitoring sites are summarised as follows:

- Eagle Farm, operated by the EPA but now decommissioned, included measurements of NO_x, O_3, SO_2 and PM_{10}.

- Bowen Hills, operated by Simtars but now decommissioned, included measurements of CO, NO_x, PM_{10} and $PM_{2.5}$.

- Kedron, currently monitoring and operated by Simtars. Measurements include CO, NO_x, PM_{10} and $PM_{2.5}$.

The Eagle Farm site was located in a light industrial area at the DPI Quarantine Centre and was decommissioned in mid 2005. A site at Pinkenba commenced operation in 2001 and has essentially replaced the Eagle Farm site.

The Bowen Hills site was located to the north of Campbell Street in the vicinity of the proposed southern connection. This station was decommissioned in November 2005 and moved to its current position at Kedron. Monitoring commenced at Kedron in mid January 2006. These data will be reviewed as the information becomes available.

In addition, the Queensland EPA operate monitoring stations at Brisbane CBD, Rocklea, South Brisbane and Woolloongabba. Data from these sites were reviewed as part of the NSBT air quality assessment (**Holmes Air Sciences, 2004**) but have not undergone a major investigation for this study.

Table 5 summarises each of the air pollutants and compares these data with the relevant air quality goal.

Table 5 : Summary of air quality monitoring data

Parameter	Bowen Hills (Jul 2004 to Jun 2005)	Eagle Farm (2003 and 2004)	Kedron Brook (Jan 2006 to May 2006)	Goal
CO, 8-hour maximum (mg/m^3)	2.5	-	2.2	10
NO_2, 1-hour maximum ($\mu g/m^3$)	129	125	83	246
NO_2, Annual average ($\mu g/m^3$)	51	25	20	62
PM_{10}, 24-hour* maximum ($\mu g/m^3$)	63	85	34	50
PM_{10}, Average ($\mu g/m^3$)	18	21	14	30
$PM_{2.5}$, 24-hour* maximum ($\mu g/m^3$)	35	-	13	25#
$PM_{2.5}$, Average ($\mu g/m^3$)	9	-	6	8#
SO_2, 1-hour maximum ($\mu g/m^3$)	-	114	-	570
SO_2, 24-hour maximum ($\mu g/m^3$)	-	29	-	225
SO_2, Annual average ($\mu g/m^3$)	-	6	-	60
O_3, 1-hour maximum ($\mu g/m^3$)	-	193	-	210
O_3, 4-hour maximum ($\mu g/m^3$)	-	150	-	170

** 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.

From **Table 5** the pollutants which recorded levels above their respective air quality goals included 24-hour average PM_{10}, 24-hour and annual average $PM_{2.5}$. There were no other measurements of pollutants above air quality goals. Exceedances of the particulate matter air quality goals (PM_{10} and $PM_{2.5}$) are usually attributed to widespread events such as dust storms or bushfires.

The location of the Bowen Hills and Eagle Farm sites ensures that the data collected may be most representative of air quality in suburban and residential areas of Brisbane, removed from very busy streets. Time series of the hourly averages are presented in **Figures 11** and **12**.

Bowen Hills
Measured CO concentrations at Bowen Hills over the monitoring period were well below the ambient air quality goal of 10 mg/m^3. The maximum 8-hour average CO concentration was 2.5 mg/m^3. It can been from **Figure 11** that slightly higher CO levels occurred in the winter months. This trend is also evident in the monitoring data presented in the NSBT Environmental Impact Statement (EIS) and is attributable to the more stable conditions that apply during busy morning and evening peak traffic periods in winter.

Measured NO_2 concentrations over the monitoring period were below the ambient air quality goal of 246 $\mu g/m^3$ with the maximum hourly average NO_2 concentration at 129 $\mu g/m^3$. This value is in the same range of maxima recorded at the five EPA monitoring sites in the NSBT EIS. The average NO_2 concentration at the Bowen Hills site was 51 $\mu g/m^3$.

Measurements of particulate matter (PM_{10} and $PM_{2.5}$) at the Bowen Hills site showed that there were occasional exceedances of the 24-hour average air quality goals. It should be noted however, that 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. Exceedances of the 24-hour PM_{10} goal were also recorded in the EPA air quality monitoring data, presented in the NSBT EIS. Average PM_{10}

concentrations at Bowen Hills (18 $\mu g/m^3$) were similar to those reported in the EIS (between 17 and 28 $\mu g/m^3$) and below the 30 $\mu g/m^3$ air quality goal.

Eagle Farm

Figure 12 shows the time series of monitoring data from Eagle Farm. Measured SO_2 levels were well below the 570 $\mu g/m^3$ goal. There are some infrequent spikes in the hourly data which reach about a quarter of the goal. There are no significant seasonal trends evident in these data.

Concentrations of NO_2 have been below the 246 $\mu g/m^3$ goal – the maximum hourly average for 2003 and 2004 was 125 $\mu g/m^3$.

The one hourly average ozone goal was almost reached late in 2004 with a measurement of 193 $\mu g/m^3$ compared with the goal of 210 $\mu g/m^3$.

Measurements of PM_{10} at Eagle Farm have indicated four exceedances of the 50 $\mu g/m^3$ goal for 24-hour averages over the 2003 and 2004 period. Historical EPA data, as presented in the NSBT EIS, have shown that many EPA sites in the Brisbane region record occasional exceedances of the 24-hour PM_{10} goal each year.

The measured concentrations of each pollutant are determined by all sources that at some stage have been upwind of the monitoring station. CO and NO_x nitrogen would have predominately originated from motor vehicle emissions in this area. In the case of particulate matter (PM_{10}), a number of different types of sources would have contributed to the PM_{10} measurements. These sources may have included emissions from bushfires, industry, motor vehicles, wind blown dust from nearby and remote areas, fragments of pollens, moulds, sea-salts and so on.

Some analysis of the percentage of 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 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. The presence of NO_x emissions can be of concern in urban environments where the control of photochemical smog is important.

Ultimately, however, all nitric oxides 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.

Analysis of the NO_x monitoring data reveals that the percentage of NO_2 in the air is inversely proportional to the total NO_x concentration. **Figure 13** shows this relationship for Eagle

Farm and Bowen Hills. The ratios of NO_2 to NO_x in the data had average values of 65% and 55% from the Eagle Farm and Bowen Hills sites respectively. These ratios (65% and 55%) 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.

For comparison, the EPA's South Brisbane air quality monitoring site is adjacent to the South-East Freeway and was located to collect information at the boundary of major traffic corridors. In 2001/2002 the average NO_2 to NO_x fraction from this site was 39% (**Holmes Air Sciences, 2004**).

Generally, for plumes impacting close to the source, the time interval for oxidation is not sufficient to have converted a large proportion of the plume to the more harmful NO_2. For the assessment in this study it has been assumed that the ratio of NO_2 to NO_x would be 10% by weight within the tunnel. This is consistent with the maximum NO_2:NO_x ratios reported in a detailed joint study within the Sydney Harbour Tunnel (**NSW EPA, CSIRO, RTA, 1996**). This ratio has been assumed to increase to 20% by the time that the plume has reached the point where the maximum ground-level or above ground-level concentrations are predicted. This is a realistic but conservative assumption, as will be seen later in **Section 8.2**, given that the time of day when maximum levels occur is when conversion rates are likely to be low. At locations close to the ventilation tunnel outlets (within 50 metres) it is likely that the conversion rate would result in a ratio closer to 15%. For annual average predictions of NO_2, 39% of the NO_x concentration is taken to be NO_2.

Graphs of PM_{10} (**Figures 11** and **12**) highlight the occasions when 24-hour concentrations were above their respective air quality goals. Bowen Hills is the only site to concurrently measure PM_{10} and $PM_{2.5}$. It can be seen from the graphs that exceedances of both the PM_{10} and $PM_{2.5}$ goals were recorded on the same days, signifying the relationship between the two particulate matter classifications. The high PM_{10} level around August 2004 (54 $\mu g/m^3$ on 10 Aug to be precise) suggest that the exceedance is from a combustion source where the percentage of $PM_{2.5}$ would be relatively high. On 3 Feb 2005 the 24-hour average PM_{10} was 63 $\mu g/m^3$ and the fraction of $PM_{2.5}$ was much lower than the previous event. A major dust storm in Brisbane was reported by the Bureau of Meteorology on 3 Feb 2005 (www.bom.gov.au).

Figure 14 shows the relationship between measured PM_{10} and $PM_{2.5}$ concentrations at the Bowen Hills site for the 2004 to 2005 period. The average ratio of $PM_{2.5}$ to PM_{10} for the monitoring period was calculated to be 50%. Typically, the highest $PM_{2.5}$ to PM_{10} ratios are measured in areas where combustion sources (for example, traffic) are dominant.

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:

- AADT for years 2004 (existing), 2012, 2016 and 2026;
- Scenarios “without AL”, “with AL” and “with AL and Northern Busway”;
- Modelled existing (2004) AADT for selected surface roads;

- Modelled 2012, 2016 and 2026 AADT for selected surface roads; 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 6** 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 6 : Vehicle mix by year of manufacture

Year of manufacture	Percentage of fleet (Queensland) as at March 2003
To 1985	19.7
1986-1990	16.8
1991-1995	21.8
1996-2000	28.0
2001-2003	13.5
Not stated	0.1
TOTAL	100.0

Source: ABS, 2003

The modelled AADT data provided by SKM/CW have been reviewed and are summarised in **Table 7**. 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 road section were determined from the AADT to estimate hourly pollutant emissions.

Table 7 : Summary of AADT on major roads in the study area

Road section	AADT						
	2004	2012		2016		2026	
	DM	DM	DS	DM	DS	DM	DS
Tunnel: N/B, south of Gympie Rd	-	-	33397	-	37686	-	42979
Tunnel: S/B, south of Gympie Rd	-	-	34669	-	37276	-	44067
Bradfield HWY	90490	85510	85380	86930	87630	95380	96010
Brunswick St	47040	32690	30870	33650	32270	34660	33690
Bowen Br Rd	54200	65520	50060	69570	53250	77620	59050
Lutwyche/Gympie Rd	47520	63730	90210	65600	94480	66830	103340
Gympie Rd	51020	71800	90850	75180	93830	78010	99870
Pacific MWY	114700	113370	113690	115870	117020	117510	118390
Hale St	88150	99320	99390	102360	103130	109350	109010
ICB	70050	93910	97780	99360	100320	103950	106390
ICB Nth	49690	71730	54400	76530	57530	75220	59480
Abbotsford Rd N ICB	46500	64140	50390	69180	51920	78130	57690
Sandgate Rd S	29740	42830	29930	46840	30850	51330	35130
Sandgate Rd N	45220	57700	50280	58470	50230	63560	54900
Kingsford Smith DR W	51580	68570	62350	71360	66230	72840	70880
Kingsford Smith DR M	36190	56820	53250	66170	62710	84560	81600
Kingsford Smith DR E	20680	46800	44650	52840	50940	73510	71980
Gateway MWY S Lytton	72840	113280	113020	130800	129390	159540	155310

Road section	AADT						
	2004	2012		2016		2026	
	DM	DM	DS	DM	DS	DM	DS
Gateway MWY N Lytton	90200	141280	141570	163400	162150	209010	203780
Gateway MWY N Curtin	0	67640	65870	80740	77890	102460	101070
Gateway MWY N KingsSmth	0	67640	65870	80740	77890	102460	101070
Gateway MWY N Airport Dr	0	53280	52360	62520	60760	86290	85680
Junction / Lytton Rd	22310	28640	26010	29600	26800	33870	31350
Lytton Rd E MWY	20650	22770	22480	24340	23870	27120	26720
Port of Bris MWY	18510	35330	35980	38500	39400	46670	46960
Creek Rd	19990	26390	26020	29710	29260	34150	33400
Grey St	36170	42360	41580	42160	41290	48190	47380
Countess / Petrie	44560	46560	46280	48250	47440	52770	54550
Kelvin Gr Rd	28130	26190	27020	26710	27040	28700	28540
Kelvin Gr Rd S Newmarket	59250	56200	50820	55680	50700	67530	60330
Enoggera	53140	54380	47900	54350	48230	69280	60500
Samford Rd E Wardell	27880	39840	37020	39930	36550	30300	28390
Samford Rd W Wardell	35660	39610	38130	41290	39640	45530	43630
MiltonRd	53780	64630	64670	66930	66620	73010	73000
Waterworks / Musgrave	24070	25020	24260	26030	25710	28260	27620
Wardell S Samford	41510	44560	40870	47160	43550	50950	46750
Wardell N Samford	45230	46090	39440	47080	41050	55230	48900
South Pine	43310	44750	42460	45360	44510	52710	51720
Stafford Rd E Sth Pine	13720	16980	21750	17360	22500	19650	26270
Stafford Rd E Webster	17860	24610	35910	25090	37430	26320	40420
Webster S Stafford	21100	26640	24010	27530	24730	32620	26140
Webster N Stafford	21220	22730	20210	23380	20430	27840	22850
Rode Rd W Webster	24320	27110	28970	31370	32270	33210	33650
Rode Rd E Webster	23080	24210	25340	25460	25640	27810	27110
Rode Rd E Gympie	25040	27240	22360	28010	22240	30050	25020
Newmarket Rd	22050	37630	28750	39890	30460	45700	35600
Herston Rd	15150	17060	16950	18700	18350	20840	20440
Markwell Tce	12840	16190	20270	18650	22440	21770	25710
Breakfast Ck Rd	33150	36140	36300	36620	37420	44680	44540
Gateway MWY S KS	90200	73650	75700	82680	84270	106540	102720
Gateway MWY N KS	89960	67540	67330	75020	75050	94650	90810
Gateway MWY N Arterial	65420	45030	48350	49380	53230	67140	70340
Gateway MWY N Toombul	48960	23260	25790	22940	26520	33350	35900
EW Arterial	32480	55230	70030	59350	73720	69670	79260
Airport Dr E MWY	55360	69320	71190	78140	80340	107420	109270
Airport DrS E Gateway Ext	46370	28980	29450	38160	38860	54670	54620
Airport DrN E Gateway Ext	0	63480	63000	80600	79890	126580	126570
Toombul Rd	21520	30000	29990	35780	35870	42620	43120
Lutwyche Rd N Maygar	51360	69390	53190	71230	53460	72440	54010

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

Pollutant emissions from each of the road sections presented in **Table 7** 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 AL" and "with AL" 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 15 shows the estimated traffic and pollutant emissions (CO, NO_x and PM_{10}) for each hour of the day for the AL in 2012. 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 8 to **Table 10** provide estimated pollutant emissions from the three 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.

Table 8 : Estimated emissions from AL ventilation outlets in 2012

Vent ID	Southern connection vent (SC-A)				Northwest connection vent (NW-A)				Northeast connection vent (NE-A)			
Location (MGA, m)	503183, 6964546				503603, 6967686				505883, 6968046			
Base elevation (m)	2.8				11.7				4.6			
Height (m)	30				30				30			
Diameter (m)	8.2				10.5				6.9			
Hour	Velocity (m/s)	Emissions (g/s)			Velocity (m/s)	Emissions (g/s)			Velocity (m/s)	Emissions (g/s)		
		CO	NO_X	PM_{10}		CO	NO_X	PM_{10}		CO	NO_X	PM_{10}
1	7.69	2.23	0.34	0.01	8.57	4.71	0.64	0.02	7.27	2.64	0.38	0.01
2	7.69	1.51	0.25	0.01	8.57	3.03	0.44	0.01	7.27	1.65	0.24	0.01
3	7.69	1.38	0.25	0.01	8.57	2.57	0.39	0.01	7.27	1.33	0.20	0.01
4	7.69	1.56	0.27	0.01	8.57	2.51	0.39	0.01	7.27	1.15	0.19	0.01
5	13.85	2.96	0.51	0.02	10.48	3.83	0.62	0.02	7.27	1.35	0.23	0.01
6	18.46	10.21	1.65	0.05	12.38	11.65	1.81	0.06	9.09	3.30	0.58	0.02
7	20	27.00	3.09	0.16	15.24	28.16	3.39	0.18	11.82	8.75	1.12	0.06
8	20	42.74	7.58	0.43	15.24	46.78	10.55	0.62	13.64	16.05	5.00	0.31
9	18.46	42.74	7.58	0.43	15.24	46.78	10.55	0.62	11.82	16.05	5.00	0.31
10	16.15	18.42	2.90	0.09	15.24	28.21	4.26	0.13	11.82	12.33	2.05	0.06
11	13.85	18.44	2.92	0.09	14.29	29.25	4.38	0.13	11.82	13.23	2.15	0.07
12	13.85	18.42	2.88	0.08	14.29	30.15	4.47	0.13	11.82	14.05	2.27	0.07
13	13.85	18.19	2.82	0.08	14.29	30.57	4.45	0.13	13.64	14.57	2.29	0.07
14	13.85	18.24	2.82	0.08	15.24	30.44	4.43	0.13	13.64	14.43	2.28	0.07
15	13.85	18.26	2.83	0.08	16.19	32.67	4.72	0.14	16.36	16.39	2.54	0.08
16	13.85	27.06	2.86	0.14	18.1	45.84	4.87	0.24	19.09	25.84	2.74	0.14
17	15.38	23.24	4.17	0.24	20	60.45	8.95	0.49	20	42.63	5.84	0.32
18	13.85	23.24	4.17	0.24	16.19	60.45	8.95	0.49	16.36	42.63	5.84	0.32
19	12.31	23.12	2.17	0.11	13.33	37.45	3.60	0.17	13.64	20.41	1.98	0.10
20	12.31	11.80	1.63	0.04	13.33	20.40	2.65	0.07	10.91	9.96	1.40	0.04
21	12.31	8.44	1.20	0.03	13.33	15.64	2.06	0.06	10.91	8.04	1.14	0.03
22	10.77	7.10	1.00	0.03	10.48	13.53	1.78	0.05	9.09	7.10	1.01	0.03
23	10.77	5.49	0.79	0.02	10.48	11.16	1.47	0.04	9.09	6.11	0.86	0.02
24	10.77	3.36	0.51	0.01	9.52	7.16	0.98	0.03	7.27	4.04	0.58	0.02
kg/d	-	1351	206	9	-	2172	327	14	-	1095	172	8

Table 9 : Estimated emissions from AL ventilation outlets in 2016

Vent ID	Southern connection vent (SC-A)				Northwest connection vent (NW-A)				Northeast connection vent (NE-A)			
Location (MGA, m)	503183, 6964546				503603, 6967686				505883, 6968046			
Base elevation (m)	2.8				11.7				4.6			
Height (m)	30				30				30			
Diameter (m)	8.2				10.5				6.9			
Hour	Velocity (m/s)	Emissions (g/s)			Velocity (m/s)	Emissions (g/s)			Velocity (m/s)	Emissions (g/s)		
		CO	NO_X	PM_{10}		CO	NO_X	PM_{10}		CO	NO_X	PM_{10}
1	7.69	2.39	0.44	0.01	8.57	5.06	0.84	0.03	7.27	2.85	0.50	0.02
2	7.69	1.62	0.35	0.01	8.57	3.26	0.61	0.02	7.27	1.78	0.34	0.01
3	7.69	1.49	0.36	0.01	8.57	2.79	0.58	0.02	7.27	1.44	0.30	0.01
4	7.69	1.68	0.38	0.01	8.57	2.73	0.61	0.02	7.27	1.26	0.32	0.01
5	13.85	3.19	0.73	0.02	10.48	4.16	0.96	0.03	7.27	1.49	0.41	0.01
6	18.46	10.97	2.22	0.07	12.38	12.61	2.72	0.09	9.09	3.63	1.03	0.04
7	20	29.01	4.52	0.24	15.24	30.60	5.61	0.31	11.82	9.75	2.29	0.13
8	20	40.78	8.09	0.45	15.24	46.89	10.97	0.62	13.64	17.48	5.02	0.30
9	18.46	40.78	8.09	0.45	15.24	46.89	10.97	0.62	11.82	17.48	5.02	0.30
10	16.15	19.76	3.85	0.12	15.24	30.56	6.46	0.21	11.82	13.51	3.47	0.12
11	13.85	19.78	3.88	0.12	14.29	31.65	6.53	0.21	11.82	14.46	3.52	0.12
12	13.85	19.74	3.78	0.12	14.29	32.61	6.65	0.22	11.82	15.34	3.71	0.13
13	13.85	19.49	3.68	0.11	14.29	33.01	6.45	0.21	13.64	15.86	3.58	0.12
14	13.85	19.54	3.66	0.11	15.24	32.88	6.45	0.21	13.64	15.72	3.60	0.12
15	13.85	19.56	3.69	0.11	16.19	35.26	6.78	0.22	16.36	17.82	3.89	0.13
16	13.85	28.91	3.93	0.20	18.1	49.47	7.50	0.39	19.09	28.10	4.60	0.25
17	15.38	24.88	4.40	0.24	20	66.66	9.58	0.50	20	47.49	6.28	0.33
18	13.85	24.88	4.40	0.24	16.19	66.66	9.58	0.50	16.36	47.49	6.28	0.33
19	12.31	24.54	2.70	0.13	13.33	40.06	4.92	0.24	13.64	21.96	2.93	0.15
20	12.31	12.56	1.89	0.05	13.33	21.85	3.30	0.10	10.91	10.71	1.84	0.06
21	12.31	9.00	1.43	0.04	13.33	16.75	2.61	0.08	10.91	8.65	1.50	0.05
22	10.77	7.57	1.18	0.03	10.48	14.50	2.26	0.07	9.09	7.64	1.34	0.04
23	10.77	5.86	0.97	0.03	10.48	11.97	1.87	0.05	9.09	6.57	1.11	0.03
24	10.77	3.59	0.65	0.02	9.52	7.70	1.32	0.04	7.27	4.36	0.81	0.03
kg/d	-	1410	249	11	-	2328	418	18	-	1198	229	10

Table 10 : Estimated emissions from AL ventilation outlets in 2026

Vent ID	Southern connection vent (SC-A)				Northwest connection vent (NW-A)				Northeast connection vent (NE-A)			
Location (MGA, m)	503183, 6964546				503603, 6967686				505883, 6968046			
Base elevation (m)	2.8				11.7				4.6			
Height (m)	30				30				30			
Diameter (m)	8.2				10.5				6.9			
Hour	Velocity (m/s)	Emissions (g/s)			Velocity (m/s)	Emissions (g/s)			Velocity (m/s)	Emissions (g/s)		
		CO	NO_X	PM_{10}		CO	NO_X	PM_{10}		CO	NO_X	PM_{10}
1	7.69	2.83	0.53	0.02	8.57	5.77	0.99	0.03	7.27	3.17	0.58	0.02
2	7.69	1.92	0.43	0.01	8.57	3.73	0.73	0.02	7.27	1.98	0.39	0.01
3	7.69	1.77	0.44	0.01	8.57	3.19	0.71	0.02	7.27	1.61	0.36	0.01
4	7.69	1.99	0.47	0.01	8.57	3.13	0.75	0.02	7.27	1.40	0.39	0.01
5	13.85	3.78	0.90	0.03	10.48	4.82	1.19	0.04	7.27	1.67	0.50	0.02
6	18.46	12.99	2.71	0.08	12.38	14.68	3.35	0.11	9.09	4.06	1.28	0.04
7	20	33.91	5.59	0.28	15.24	35.19	7.01	0.36	11.82	10.81	2.90	0.16
8	20	46.49	10.30	0.55	15.24	52.47	13.32	0.71	13.64	18.91	5.72	0.32
9	18.46	46.49	10.30	0.55	15.24	52.47	13.32	0.71	11.82	18.91	5.72	0.32
10	16.15	23.40	4.67	0.14	15.24	35.20	7.90	0.25	11.82	15.09	4.27	0.14
11	13.85	23.43	4.71	0.14	14.29	36.41	7.97	0.25	11.82	16.14	4.29	0.14
12	13.85	23.38	4.57	0.13	14.29	37.47	8.09	0.25	11.82	17.12	4.52	0.15
13	13.85	23.09	4.46	0.13	14.29	37.89	7.80	0.24	13.64	17.68	4.32	0.14
14	13.85	23.14	4.43	0.13	15.24	37.76	7.81	0.24	13.64	17.53	4.35	0.14
15	13.85	23.17	4.46	0.13	16.19	40.40	8.18	0.25	16.36	19.86	4.68	0.15
16	13.85	33.75	4.79	0.23	18.1	55.86	9.15	0.45	19.09	30.94	5.61	0.29
17	15.38	27.74	4.61	0.23	20	76.15	10.47	0.49	20	54.68	7.01	0.33
18	13.85	27.74	4.61	0.23	16.19	76.15	10.47	0.49	16.36	54.68	7.01	0.33
19	12.31	28.63	3.21	0.14	13.33	45.21	5.85	0.27	13.64	24.13	3.47	0.17
20	12.31	14.86	2.22	0.06	13.33	25.02	3.84	0.10	10.91	11.91	2.11	0.06
21	12.31	10.65	1.69	0.04	13.33	19.15	3.05	0.08	10.91	9.62	1.73	0.05
22	10.77	8.95	1.39	0.04	10.48	16.56	2.64	0.07	9.09	8.50	1.55	0.04
23	10.77	6.94	1.15	0.03	10.48	13.65	2.18	0.06	9.09	7.31	1.28	0.04
24	10.77	4.25	0.78	0.02	9.52	8.77	1.56	0.04	7.27	4.85	0.94	0.03
kg/d	-	1639	300	12	-	2654	498	20	-	1341	270	11

Emissions data for selected surface roads in 2012 are provided below in **Table 11**. With the introduction of the AL 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 11**.

Table 11 : Estimated emissions from selected surface roads

Road section	Section length (km)	2004 (kg/km/d)			2012 without AL (kg/km/d)			2012 with AL (kg/km/d)		
		CO	NO_x	PM_{10}	CO	NO_x	PM_{10}	CO	NO_x	PM_{10}
Bowen Br Rd	1.41	315	114	6	349	106	5	267	83	4
Lutwyche/Gympie Rd	0.85	276	88	5	340	95	4	482	134	6
Gympie Rd	2.29	296	92	5	384	105	5	486	129	6
Sandgate Rd S	2.14	173	55	3	229	64	3	160	46	2
Sandgate Rd N	2.07	263	88	5	308	92	4	268	80	4
Stafford Rd E Webster	1.66	104	30	2	132	37	2	192	51	2
Newmarket Rd	2.36	128	36	2	202	49	2	154	36	2
Gateway MWY N Arterial	1.51	265	135	6	168	73	3	180	79	3
EW Arterial	1.70	189	80	4	293	103	5	373	116	6
Airport Dr E MWY	1.15	322	76	4	372	82	3	382	84	4
Lutwyche Rd N Maygar	2.17	315	114	6	349	106	5	267	83	4

In addition to emissions from the AL 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.

Since the NSBT EIS, the traffic volumes in the tunnel have been revised following modifications to the projection models. Also, there was a refinement to the northern vent location and accompanying ventilation building. The dispersion modelling (using CALPUFF) for this study includes emissions from the NSBT northern ventilation outlet. The key changes which affect model input data are outlined in **Table 12**.

Table 12 : Revisions to NSBT following NSBT EIS

ITEM	NSBT EIS value	Airport Link EIS value
NSBT northbound daily traffic in 2011 (AADT)	26,139	31,500 (2012)
NSBT northbound daily traffic in 2016 (AADT)	38,659	34,200 (2016)
NSBT northbound daily traffic in 2021 (AADT)	30,179	36,300 (2026)
Northern ventilation outlet location (AMG, m)	503180, 6963900	503038, 6963872
Northern ventilation outlet height (m)	30	36
Ventilation building	-	23 m high

Pollutant emissions from the NSBT northern ventilation outlet have been scaled from the EIS estimates according to the modifications to AADT in the northbound tunnel.

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 with 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 aspect 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 5.1**.

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 considered to be 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 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**. 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 17** 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 EPA air quality monitoring data, specifically, Eagle Farm.

In the case of CO and NO_x, emissions contributing to the EPA 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. Eagle Farm 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 Eagle Farm air quality monitoring data. In order to create an hourly background CO data file, the likely CO concentrations at Eagle Farm have been derived from the relationship between CO and NO_X concentrations at the South Brisbane site (**Holmes Air Sciences, 2004**). **Figure 18** shows the almost linear relationship between hourly CO and NO_x concentrations.

There are many sources of particulate matter in the Brisbane area that would contribute to the measurements reported in the EPA 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 5.1**) and the emissions information summarised in **Section 6.3**.

The CALPUFF model simulations include the following scenarios:

- 2004, existing case. Used for model performance analysis and comparison with future scenarios;
- 2012. Intended year for tunnel opening;
- 2016. Five years after intended year for tunnel opening; and
- 2026. Fourteen years after intended year for tunnel opening.

In addition, “do minimal” (no tunnel) scenarios for 2012, 2016 and 2026 have been modelled and form a key component to the assessment.

Predictions were made over a large set of ground-level discrete receptors arranged in the study area. Spacing between receptors was set finer in areas closer to sources and coarser 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.

Eleven surface roadways have been selected for analysis using the Cal3qhcr model. These surface roadways are:

- Bowen Bridge Road
- Lutwyche/Gympie Road
- Gympie Road
- Sandgate Road, south of East-West Arterial Road
- Sandgate Road, north of East-West Arterial Road
- Stafford Road, east of Webster Street
- Newmarket Road
- Gateway Motorway, north of Airport Drive
- East-West Arterial Road
- Airport Drive
- Lutwyche Road north of Maygar Street

Figure 19 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 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.

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

8.1 Regional Effects

Figures 20 to **39** 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 region defined for these results covers an area 17 km by 12 km. 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 20** to **39**) are grouped by criteria pollutants, averaging time and years. **Table 13** has been created to assist with referencing the figures.

Table 13 : Quick reference to dispersion model results figure number

Pollutant and averaging time case	Simulation			
	2004	2012 (DS & DM)	2016 (DS & DM)	2026 (DS & DM)
Maximum 8-hour average CO	Figure 20	Figure 21	Figure 22	Figure 23
Maximum 1-hour average NO_2	Figure 24	Figure 25	Figure 26	Figure 27
Annual average NO_2	Figure 28	Figure 29	Figure 30	Figure 31
Maximum 24-hour average PM_{10}	Figure 32	Figure 33	Figure 34	Figure 35
Annual average PM_{10}	Figure 36	Figure 37	Figure 38	Figure 39

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 simply show the average levels for each location.

In addition to the results presented as absolute pollutant concentrations, **Figures 41** to **45** have been developed to compare the existing situation with future (2012) 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 20** to **23**) 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 20**) shows the predictions for 2004. The 2004 simulation can be considered to represent the modelled "existing" situation. Following 2004 are the 2012, 2016 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 (2004) 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 (2012+) are predicted to be very similar to existing (2004) 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 (2012+) build and no-build cases are very similar.

- The contribution to ground-level concentrations due to tunnel ventilation outlets (with AL 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 24** to **31**) 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 (2004) show that maximum 1-hour average NO_2 concentrations are up to around 200 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 (that is, Bowen Hills, Eagle Farm and Kedron) show that existing maximum 1-hour average NO_2 concentrations are below the goal.

- Predictions for the existing case (2004) 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 (2012+) are predicted to be very similar to existing (2004) 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 (2012+) build and no-build cases are very similar.

- The contribution to ground-level concentrations due to tunnel ventilation outlets (with AL case) appear to be overwhelmed by contributions from the major surface roads.

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

Figures 32 to **39** 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 30 $\mu g/m^3$ for maximum 24-hour and annual averages respectively. Review of the air quality monitoring data for the study area (**Section 5.4**) showed that existing maximum 24-hour background PM_{10} levels can be above 50 $\mu g/m^3$ (up to 85 $\mu g/m^3$) 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 (2004) show that PM_{10} concentrations are below the maximum 24-hour and annual average air quality goals (50 and 30 $\mu g/m^3$) however these predictions are due only to the modelled sources and not events such as bushfires.

- PM_{10} concentrations in future years (2012+) are predicted to very similar to existing (2004) 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 (2012+) build and no-build cases are very similar.

- The contribution to ground-level concentrations due to tunnel ventilation outlets (with AL 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 Bowen Hills shows that 50% of the PM_{10} is $PM_{2.5}$ although this fraction is relevant for 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 40**. 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 with the view that some particles are more harmful than others.

Table 14 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 2004 predictions with the 2004 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 14 : Predicted criteria pollutant concentrations at selected locations

SITE	2004	2012		2016		2026		Goal
	DM	DM	DS	DM	DS	DM	DS	
Bowen Hills monitoring site								
Maximum 8-hour average CO (mg/m^3)	2.2	2.3	2.3	2.4	2.3	2.4	2.4	10
Maximum 1-hour average NO_2 (μg/m^3)	169	174	168	174	168	174	169	246
Annual average NO_2 (ug/m^3)	34	35	34	35	34	35	34	62
Maximum 24-hour average PM_{10} (μg/m^3)*	4.2	4.2	3.9	4.0	3.6	3.7	3.3	50
Annual average PM_{10} (μg/m^3)*	1.1	1.1	1.0	1.0	0.9	0.9	0.8	30
Kedron monitoring site								
Maximum 8-hour average CO (mg/m^3)	2.1	2.1	2.1	2.1	2.1	2.1	2.2	10
Maximum 1-hour average NO_2 (μg/m^3)	146	150	156	151	158	153	162	246
Annual average NO_2 (ug/m^3)	30	30	31	30	31	30	31	62
Maximum 24-hour average PM_{10} (μg/m^3)*	2.3	2.2	2.1	2.1	2.0	1.8	1.8	50
Annual average PM_{10} (μg/m^3)*	0.4	0.4	0.5	0.4	0.5	0.3	0.4	30
Kalinga Park (location 505603 mE, 6968186 mN)								
Maximum 8-hour average CO (mg/m^3)	2.1	2.1	2.1	2.1	2.1	2.1	2.2	10
Maximum 1-hour average NO_2 (μg/m^3)	144	147	147	148	148	151	151	246
Annual average NO_2 (ug/m^3)	30	30	30	30	30	30	30	62
Maximum 24-hour average PM_{10} (μg/m^3)*	1.7	1.7	1.6	1.6	1.5	1.4	1.4	50
Annual average PM_{10} (μg/m^3)*	0.4	0.4	0.4	0.4	0.4	0.4	0.4	30
Albert Bishop Park (location 506853 mE, 6968486 mN)								
Maximum 8-hour average CO (mg/m^3)	2.1	2.1	2.2	2.1	2.2	2.2	2.2	10
Maximum 1-hour average NO_2 (μg/m^3)	148	150	150	152	153	155	156	246
Annual average NO_2 (ug/m^3)	30	30	31	31	31	31	31	62
Maximum 24-hour average PM_{10} (μg/m^3)*	1.7	1.6	1.7	1.6	1.7	1.5	1.5	50
Annual average PM_{10} (μg/m^3)*	0.5	0.4	0.5	0.4	0.5	0.4	0.4	30

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

For the Bowen Hills and Kedron monitoring sites, the dispersion modelling indicates that pollutant concentrations in future years (2012+) would be very similar to existing (2004) 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 2004 model predictions show that CO concentrations at the two monitoring sites are similar. Bowen Hills, however, is simulated to experience slightly higher NO_2 concentrations. This is generally consistent with the spatial variation observed in the most recent air quality monitoring data (see **Section 5.4**), although Kedron has only been collecting data since January 2006.

Table 14 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 15**. It can be seen from this table that maximum 8-hour average CO concentrations were generally well predicted by the modelling at this location. Predictions of maximum 1-hour average NO_2 concentrations were slightly above measured levels while annual average NO_2 concentrations were slightly below measured levels.

Table 15 : Comparison of modelled and measured concentrations

SITE	Modelled existing (2004)	Measured existing (2004*)	Goal
Bowen Hills			
Maximum 8-hour average CO (mg/m^3)	2.2	1.9 (2.0 for Jun 04 to Jun 05)	10
Maximum 1-hour average NO_2 (ug/m^3)	169	127 (129 for Jun 04 to Jun 05)	246
Annual average NO_2 (ug/m^3)	34	45 (51 for Jun 04 to Jun 05)	62

** The available data covers a period from June 2004 to December 2004. Results from a year of data from June 2004 to June 2005 is also shown in parentheses.*

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 41** to **45**.

Figure 41 shows the change in maximum 8-hour average CO concentrations from existing (2004) to 2012. Without AL and with AL 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 -1% (improvement) to +4% (deterioration). The deterioration occurs near roadways with increases in traffic.

When assessing the percentage change at a particular location it is useful to refer to the concentration from which the percentage is derived (2004). In the case of **Figure 41**, the percentages are expressed as a change from the predicted existing concentrations (**Figure 20**). 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 Lutwyche Road. For the no tunnel case, increases to maximum 8-hour average CO concentrations are predicted around the ICB, whereas in the tunnel case the increases are less significant. 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 42 and **43** show the change in NO_2 concentrations from existing (2004) to 2012. The maximum 1-hour average NO_2 concentrations are predicted to change between -2%

and +8%, 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 in the CBD while showing a slightly larger area of deterioration (over the no tunnel case) near the Gympie Road connection.

Figures 44 and **45** show the change in PM_{10} concentrations from existing (2004) to 2012. The percentages shown in these plots have been derived by comparing the existing (2004) PM_{10} concentrations plus maximum background concentrations with the 2012 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 16** shows the highest ground-level pollutant concentrations that are predicted in the study area due only to the emissions from the three 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 16 : Highest ground-level concentrations due to ventilation outlet emissions

Pollutant and averaging time	2012	2016	2026	Relevant air quality goal
Maximum 8-hour average CO (mg/m^3)	0.1	0.1	0.2	10
Maximum 1-hour average NO_2 ($\mu g/m^3$)	15	16	18	246
Annual average NO_2 ($\mu g/m^3$)	0.5	0.7	0.9	62
Maximum 24-hour average PM_{10} ($\mu g/m^3$)	0.5	0.6	0.7	50
Annual average PM_{10} ($\mu g/m^3$)	0.1	0.1	0.1	30

It can be seen from **Table 16** 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 8%. These predictions suggest that the ventilation outlets would not be the cause of exceedances of air quality goals.

Table 17 shows the predicted highest individual contribution from ventilation outlets. Results for an additional site, referred to as NE-B, are also shown in this table. Emissions from this option are predicted to produce slightly higher maximum ground-level concentrations than for the other sites, although the levels are still well below the air quality criteria. The higher levels would be due to building induced turbulence at this location.

Table 17 : Individual contributions from ventilation outlets

Pollutant and averaging time	Maximum ground-level concentrations due to ventilation outlet emissions in 2012				Relevant air quality goal
	SC-A	NW-A	NE-A	NE-B*	
Maximum 8-hour average CO (mg/m^3)	0.1	0.1	0.1	0.2	10
Maximum 1-hour average NO_2 ($\mu g/m^3$)	11	9	15	27	246
Annual average NO_2 ($\mu g/m^3$)	0.3	0.3	0.4	1.1	62
Maximum 24-hour average PM_{10} ($\mu g/m^3$)	0.3	0.3	0.4	1.1	50
Annual average PM_{10} ($\mu g/m^3$)	0.03	0.03	0.05	0.12	30

** Alternative site to NE-A. Regional dispersion modelling has been based on options SC-A, NW-A and NE-A. Replacement of NE-A with NE-B for the regional dispersion modelling would not affect the conclusions of the study.*

Pollutant concentrations at locations above ground-level have also been assessed as part of this project. **Figures 46** to **50** show predicted pollutant concentrations at 30 and 50 m above ground-level due to emissions from the proposed tunnel ventilation outlets. Results for 2012 are presented.

Figure 46 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 2.5 mg/m^3.

Figures 47 and **48** 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 60 $\mu g/m^3$ at 50 m above ground-level and close to vent outlets. This level of impact should demonstrate compliance with the 246 $\mu g/m^3$ air quality goal at all elevated locations even when considering background levels of 129 $\mu g/m^3$. Similarly, for annual average NO_2 concentrations, the highest concentrations are of the order of 5 $\mu g/m^3$ – close to the vent outlets and at 50 m above ground-level. Compliance with the 62 $\mu g/m^3$ should be comfortably achieved at all elevated locations even when considering annual average NO_2 concentrations (in 2004/2005 Bowen Hills reported an annual average NO_2 concentration of 51 $\mu g/m^3$).

Predicted PM_{10} concentrations at elevated locations are provided in **Figures 49** and **50**. Maximum 24-hour average PM_{10} concentrations are predicted to be up to about 5 $\mu g/m^3$. Again, this level is predicted at 50 m above ground-level and close to the vent outlets. This is well below the 50 $\mu g/m^3$ goal and unlikely to be the cause of exceedances at elevated locations. Annual average PM_{10} concentrations are predicted to be less than 1 $\mu g/m^3$ at 30 and 50 m above ground-level at all locations – well below the 30 $\mu g/m^3$ 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 51 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 (2004) 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 (Bowen Hills data from July 2004 to June 2005).

From examination of the model results the highest pollutant concentrations for 2004 are predicted in the vicinity of the Gateway Motorway. This may be expected, given the very high traffic volumes experienced on this road. 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 Gateway Motorway than for many of the other selected roads. The most relevant distances from the Gateway Motorway 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 2004 are highest near the Gateway Motorway.
- Road sections where the with tunnel case is predicted to be lower than the without tunnel case include Bowen Bridge Road, Sandgate Road, Newmarket Road and Lutwyche Road.
- Road sections where the with tunnel case is predicted to be higher than the without tunnel case include Gympie Road, the Lutwyche Road/Gympie Road connection, Stafford Road and East-West Arterial Road.
- Road sections where the differences between the with tunnel case and without tunnel cases are considered negligible include Gateway Motorway and Airport Drive.
- Improvements in local air quality are observed with reductions in surface traffic that occur as a result of diverting traffic to the tunnel.
- Concentrations near the Gateway Motorway are predicted to decrease significantly from 2004 to future scenarios. This is due to reduced traffic on this section as a result of the Gateway duplication project.
- At distances appropriate for the nearest residences, the model predictions for all sections and future years are below the associated air quality goals.

Results for the AL Project with the proposed Northern Busway (NB) are also provided in **Figures 51** to **61** (refer to “AL and NB” in the key). Examination of these results shows that near roadside concentrations for the AL with the busway would be very similar to concentrations without the busway. This is applicable to all modelled sections. Further discussion on the Project with the NB is provided in **Section 9.1**.

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 Airport Link with Northern Busway

This study has considered the AL Project on its own however the NB may proceed in a similar timeframe. This section assesses the potential cumulative impacts of the Project with the NB.

The proposed AL may include the integration of Section 4 and 5 of the proposed Northern Busway (NB). A full description of the NB will be provided in the accompanying EIS, however the key components of the NB would include:

- One bus lane in each direction;
- Tunnel portals at Stoneleigh Street, north of Norman Avenue, south of Stafford Road, at Sadlier Road (N/B) and at Broughton Street (S/B); and
- Surface road changes.

The cumulative impacts of the Project with the NB have been assessed by examining the differences in the traffic data. **Table 18** shows the traffic projections for the AL Project with the NB. The difference between these numbers and the "AL without the NB" is shown as a percentage.

The AL and no NB scenario is comparable to the AL with NB scenario. Most of the road sections are predicted to experience very little change with or without the NB, that is, ±5%.

Table 18 : AADT on major roads for the Airport Link with the Northern Busway

Road section	AADT for Airport Link with NB			Percentage difference from the Airport Link no NB scenario		
	2012	2016	2026	2012	2016	2026
Tunnel: N/B, south of Gympie Rd	34885	38349	44480	4%	2%	3%
Tunnel: S/B, south of Gympie Rd	35623	38239	45282	3%	3%	3%
Bradfield HWY	85400	87920	95690	0%	0%	0%
Brunswick St	29320	30660	31960	-5%	-5%	-5%
Bowen Br Rd	46920	50430	55870	-6%	-5%	-5%
Lutwyche/Gympie Road	83210	87820	97120	-8%	-7%	-6%
Gympie Rd	87640	91420	98380	-4%	-3%	-1%
Pacific MWY	113940	116680	118600	0%	0%	0%
Hale St	99720	102970	109030	0%	0%	0%
ICB	96080	99430	106090	-2%	-1%	0%
ICB Nth	55080	58180	59980	1%	1%	1%
Abbotsford Rd N ICB	52350	54110	60290	4%	4%	5%
Sandgate Rd S	30300	31100	35250	1%	1%	0%
Sandgate Rd N	50520	50320	55290	0%	0%	1%
Kingsford Smith DR W	62370	66250	70950	0%	0%	0%
Kingsford Smith DR M	53310	62720	81540	0%	0%	0%
Kingsford Smith DR E	44670	50970	72090	0%	0%	0%

Road section	AADT for Airport Link with NB			Percentage difference from the Airport Link no NB scenario		
	2012	2016	2026	2012	2016	2026
Gateway MWY S Lytton	113200	129830	154960	0%	0%	0%
Gateway MWY N Lytton	141770	162730	203370	0%	0%	0%
Gateway MWY N Curtin	65940	78360	101420	0%	1%	0%
Gateway MWY N KingsSmth	65940	78360	101420	0%	1%	0%
Gateway MWY N Airport Dr	52360	61390	86090	0%	1%	0%
Junction / Lytton Rd	26160	26920	31220	1%	0%	0%
Lytton Rd E MWY	22490	23890	26570	0%	0%	-1%
Port of Bris MWY	35940	39370	46980	0%	0%	0%
Creek Rd	26050	29100	33270	0%	-1%	0%
Grey St	41580	41330	47100	0%	0%	-1%
Countess / Petrie	46400	47110	54890	0%	-1%	1%
Kelvin Gr Rd	27040	27330	28760	0%	1%	1%
Kelvin Gr Rd S Newmarket	52200	52140	60940	3%	3%	1%
Enoggera	49170	49360	61050	3%	2%	1%
Samford Rd E Wardell	36490	36590	27950	-1%	0%	-2%
Samford Rd W Wardell	38080	39530	43590	0%	0%	0%
MiltonRd	64590	66680	72530	0%	0%	-1%
Waterworks / Musgrave	24980	25810	28460	3%	0%	3%
Wardell S Samford	41940	43740	47500	3%	0%	2%
Wardell N Samford	40170	41310	49100	2%	1%	0%
South Pine	43210	44740	51970	2%	1%	0%
Stafford Rd E Sth Pine	21710	22720	24730	0%	1%	-6%
Stafford Rd E Webster	35950	37550	40440	0%	0%	0%
Webster S Stafford	25000	25920	27360	4%	5%	5%
Webster N Stafford	20700	20830	23860	2%	2%	4%
Rode Rd W Webster	28860	32220	33100	0%	0%	-2%
Rode Rd E Webster	25190	25480	26940	-1%	-1%	-1%
Rode Rd E Gympie	22480	22300	25180	1%	0%	1%
Newmarket Rd	29050	30680	35510	1%	1%	0%
Herston Rd	17030	18460	20460	0%	1%	0%
Markwell Tce	21200	23430	27140	5%	4%	6%
Breakfast Ck Rd	36340	37450	44340	0%	0%	0%
Gateway MWY S KS	75840	84380	101970	0%	0%	-1%
Gateway MWY N KS	67640	75540	89990	0%	1%	-1%
Gateway MWY N Arterial	48580	52890	69840	0%	-1%	-1%
Gateway MWY N Toombul	25970	26180	35330	1%	-1%	-2%
EW Arterial	70100	73930	79360	0%	0%	0%
Airport Dr E MWY	71240	80320	108340	0%	0%	-1%
Airport DrS E Gateway Ext	29480	38880	54470	0%	0%	0%
Airport DrN E Gateway Ext	62990	79870	126730	0%	0%	0%
Toombul Rd	29970	35930	43010	0%	0%	0%
Lutwyche Rd N Maygar	42340	44190	44260	-15%	-17%	-25%

From examination of these data the CALPUFF results for the Project with the NB would be expected to be similar to the Project without the NB. Some very localised differences would however be predicted on some road sections and a more detailed assessment of the air quality impacts of the NB will be prepared as part of the Northern Busway EIS. Also, as discussed in **Section 8.3**, near roadside air quality impacts for the AL with the NB are predicted to be very similar to impacts of the AL without the NB.

9.2 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 emissions have been taken from the National Pollutant Inventory (NPI) database (**NPI, 2000**).

Table 19 provides information required to determine different air toxic emissions from motor vehicles.

Table 19 : 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 20**.

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 20 : Predicted air toxics concentrations at selected locations

SITE	2004 DM	2012 DM	2012 DS	NEPM investigation level
Bowen Hills air quality monitoring site				
Annual average 1,3 Butadiene (mg/m^3)	2.54E-05	3.44E-05	3.15E-05	-
Annual average Acetaldehyde (mg/m^3)	5.51E-05	7.48E-05	6.84E-05	-
Annual average Benzene (mg/m^3)	2.57E-04	3.48E-04	3.19E-04	9.35E-03
Annual average Benzo(a)pyrene (mg/m^3)	1.80E-08	2.44E-08	2.23E-08	3.00E-07
Annual average Formaldehyde (mg/m^3)	8.06E-05	1.09E-04	1.00E-04	-
Annual average Toluene (mg/m^3)	4.09E-04	5.55E-04	5.08E-04	3.84E-01
Annual average Xylene (mg/m^3)	2.96E-04	4.02E-04	3.68E-04	8.44E-01
Maximum 24-hour average Toluene (mg/m^3)	1.85E-03	2.44E-03	2.21E-03	3.84E+00
Maximum 24-hour average Xylene (mg/m^3)	1.34E-03	1.76E-03	1.60E-03	1.06E+00
Eagle Farm air quality monitoring site				
Annual average 1,3 Butadiene (mg/m^3)	1.41E-05	1.65E-05	1.66E-05	-
Annual average Acetaldehyde (mg/m^3)	3.05E-05	3.58E-05	3.60E-05	-
Annual average Benzene (mg/m^3)	1.42E-04	1.67E-04	1.68E-04	9.35E-03
Annual average Benzo(a)pyrene (mg/m^3)	9.96E-09	1.17E-08	1.17E-08	3.00E-07
Annual average Formaldehyde (mg/m^3)	4.47E-05	5.24E-05	5.27E-05	-
Annual average Toluene (mg/m^3)	2.27E-04	2.66E-04	2.68E-04	3.84E-01
Annual average Xylene (mg/m^3)	1.64E-04	1.93E-04	1.94E-04	8.44E-01
Maximum 24-hour average Toluene (mg/m^3)	9.99E-04	1.18E-03	1.22E-03	3.84E+00
Maximum 24-hour average Xylene (mg/m^3)	7.23E-04	8.57E-04	8.84E-04	1.06E+00
Kedron air quality monitoring site				
Annual average 1,3 Butadiene (mg/m^3)	1.22E-05	1.50E-05	1.80E-05	-
Annual average Acetaldehyde (mg/m^3)	2.64E-05	3.27E-05	3.90E-05	-
Annual average Benzene (mg/m^3)	1.23E-04	1.52E-04	1.82E-04	9.35E-03
Annual average Benzo(a)pyrene (mg/m^3)	8.61E-09	1.06E-08	1.27E-08	3.00E-07
Annual average Formaldehyde (mg/m^3)	3.87E-05	4.78E-05	5.71E-05	-
Annual average Toluene (mg/m^3)	1.96E-04	2.43E-04	2.90E-04	3.84E-01
Annual average Xylene (mg/m^3)	1.42E-04	1.75E-04	2.10E-04	8.44E-01
Maximum 24-hour average Toluene (mg/m^3)	1.04E-03	1.26E-03	1.24E-03	3.84E+00
Maximum 24-hour average Xylene (mg/m^3)	7.50E-04	9.08E-04	8.94E-04	1.06E+00

9.3 Network Analysis

Network traffic statistics for the Greater Brisbane area have been reviewed in order to examine emissions both with and without the AL. 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 2012. The details of these calculations are provided below in **Table 21**. Emission factors for 2011 have been used for the calculations.

Table 21 : Network traffic and emission statistics

Traffic	2012	
	Without tunnel	With tunnel
Total VKT per AAWT	55,754,160	55,832,875
Total MVKT per year	18,399	18,425
Estimated emissions of criteria pollutants		
VOC (t/y) Emission factor = 0.26 g/km	4,784	4,790
NO_x (t/y) Emission factor = 0.98 g/km	18,031	18,056
CO (t/y) Emission factor = 3.44 g/km	63,292	63,381
PM_{10} (t/y) Emission factor = 0.0405 g/km	745	746

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.

9.4 Tunnel Filtration Analysis

An analysis of the effect on local air quality due the AL 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 AL 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 AL 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 2012. 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 suggest 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 six kilometres (approximately) of tunnels associated with the Project would result in very similar ambient air quality implications to the Project without emissions treatment.

9.5 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} (μg/m^3) to particle numbers (with units of particles/cm^3). **Table 22** provides details of the calculations.

Table 22 : Particle number emission factors and calculations

Average PM_{10} emission factor from surface roads (by PIARC for 2012)	0.117 g/v-mi (0.072 g/km)
Sub-micrometre particle emission factor (**Morawska *et al*, 2004**)	5.15 x 10^{13} particles/VKT
Therefore, 1 μg/m^3 PM_{10} is equivalent to:	711 particles/cm^3

Therefore, in terms of emissions factors from the fleet using surface roads, 1 μg/m^3 of PM_{10} is determined to be equivalent to 711 sub-micrometre particles/cm^3. Annual average PM_{10} concentrations, as measured at Bowen Hills, are of the order of 21 μg/m^3 which would be equivalent to 14,931 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 Bowen Hills will 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.

10. CONCLUSIONS

This report has assessed the effects on air quality of the proposed Airport 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 (2012+) arising from motor vehicles would be expected to be similar to existing (2004) 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.
- 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.
- 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.
- 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.
- Air quality impacts arising from the Project with the proposed Northern Busway would be expected to be very similar to the Project without the Northern Busway.

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 function although the evidence concerning effects has been mixed and conflicting. 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 4×10^{-6} for a lifetime exposure to 1 μg/m^3. The United Kingdom has an annual average ambient benzene goal of 5 parts per billion (ppb) or 16 μg/m^3 to be achieved by 2005. The 5 ppb goal is based on the "No Observable Adverse Effect Level" from the findings of the UK Expert Panel on Air Quality Standards that the risk of leukaemia in workers would not be detectable when the average working lifetime exposure to benzene was less than 500 ppb. Two safety factors of 10 were then applied to derive the goal of 5 ppb. The NEPM (Air Toxics) air quality goal for benzene is 3 ppb.

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 2004 were not a complete dataset for the purposes of the CALMET modelling. The missing periods are listed below.

Gap between soundings is greater than 14 hours before: 13 Jan 2004 hour 11 GMT
Gap between soundings is greater than 14 hours before: 10 Feb 2004 Hour 11 GMT
Gap between soundings is greater than 14 hours before: 23 Feb 2004 Hour 23 GMT

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\BACNPR\calmet\prtmet\bap2004.aus (Brisbane Airport 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	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
NE	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
ENE	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
E	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
ESE	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
SE	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
SSE	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
S	0.000114	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000114
SSW	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
SW	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
WSW	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
W	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
WNW	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
NW	0.000000	0.000114	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000114
NNW	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
N	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
CALM									0.000000
TOTAL	0.000114	0.000114	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000228

MEAN WIND SPEED (m/s) = 1.70
NUMBER OF OBSERVATIONS = 2

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	0.000114	0.001370	0.004567	0.001713	0.000000	0.000000	0.000000	0.000000	0.007763
NE	0.000114	0.000571	0.001827	0.002512	0.000000	0.000000	0.000000	0.000000	0.005023
ENE	0.000114	0.000114	0.001370	0.000685	0.000000	0.000000	0.000000	0.000000	0.002283
E	0.000228	0.000799	0.001941	0.000457	0.000000	0.000000	0.000000	0.000000	0.003425
ESE	0.000114	0.001142	0.001598	0.000457	0.000000	0.000000	0.000000	0.000000	0.003311
SE	0.000000	0.000913	0.000457	0.000000	0.000000	0.000000	0.000000	0.000000	0.001370
SSE	0.000114	0.000457	0.000685	0.000000	0.000000	0.000000	0.000000	0.000000	0.001256
S	0.000000	0.001256	0.000913	0.000000	0.000000	0.000000	0.000000	0.000000	0.002169
SSW	0.000457	0.001028	0.001941	0.000114	0.000000	0.000000	0.000000	0.000000	0.003539
SW	0.000457	0.001598	0.001256	0.000000	0.000000	0.000000	0.000000	0.000000	0.003311
WSW	0.000571	0.000571	0.000228	0.000000	0.000000	0.000000	0.000000	0.000000	0.001370
W	0.000457	0.000114	0.000114	0.000000	0.000000	0.000000	0.000000	0.000000	0.000685
WNW	0.000228	0.000457	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000685
NW	0.000228	0.000114	0.000000	0.000114	0.000000	0.000000	0.000000	0.000000	0.000457
NNW	0.000228	0.000685	0.000228	0.000000	0.000000	0.000000	0.000000	0.000000	0.001142
N	0.000114	0.002968	0.002740	0.000457	0.000000	0.000000	0.000000	0.000000	0.006279
CALM									0.000114
TOTAL	0.003539	0.014157	0.019865	0.006508	0.000000	0.000000	0.000000	0.000000	0.044183

MEAN WIND SPEED (m/s) = 3.26
NUMBER OF OBSERVATIONS = 387

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	0.000000	0.000457	0.007421	0.009248	0.002854	0.004453	0.001713	0.000343	0.026487
NE	0.000343	0.000571	0.004453	0.008220	0.000685	0.000000	0.000000	0.000000	0.014271
ENE	0.000114	0.000913	0.002740	0.003882	0.000228	0.000000	0.000000	0.000000	0.007878
E	0.000228	0.000685	0.004224	0.003768	0.000000	0.000000	0.000000	0.000000	0.008905
ESE	0.000114	0.000913	0.005708	0.011874	0.001941	0.001142	0.000000	0.000000	0.021692
SE	0.000114	0.000571	0.002854	0.002968	0.000571	0.000228	0.000000	0.000000	0.007307
SSE	0.000114	0.000457	0.000343	0.001370	0.000000	0.000114	0.000000	0.000000	0.002398
S	0.000457	0.000913	0.003539	0.001827	0.000000	0.000000	0.000000	0.000000	0.006736
SSW	0.000571	0.002626	0.005594	0.004795	0.000000	0.000000	0.000000	0.000000	0.013586
SW	0.001484	0.003083	0.003539	0.004338	0.000000	0.000114	0.000000	0.000000	0.012559
WSW	0.000343	0.001256	0.001142	0.001484	0.000228	0.000228	0.000000	0.000000	0.004681
W	0.000685	0.001484	0.000457	0.001827	0.000228	0.000114	0.000114	0.000000	0.004909
WNW	0.000228	0.000571	0.000228	0.000228	0.000114	0.000000	0.000000	0.000000	0.001370
NW	0.000343	0.000228	0.000571	0.000114	0.000000	0.000000	0.000000	0.000000	0.001256
NNW	0.000343	0.000913	0.001713	0.000343	0.000000	0.000000	0.000000	0.000000	0.003311
N	0.000571	0.001028	0.007193	0.004338	0.000457	0.001484	0.000457	0.000000	0.015527
CALM									0.000343
TOTAL	0.006051	0.016669	0.051718	0.060623	0.007307	0.007878	0.002283	0.000343	0.153214

MEAN WIND SPEED (m/s) = 4.58
NUMBER OF OBSERVATIONS = 1342

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	0.000114	0.002398	0.004909	0.011874	0.009933	0.011188	0.003311	0.000457	0.044183
NE	0.000000	0.002854	0.004681	0.010618	0.002398	0.000457	0.000000	0.000114	0.021121
ENE	0.000114	0.001370	0.004338	0.007078	0.002283	0.000571	0.000000	0.000000	0.015755
E	0.000114	0.003768	0.006736	0.006964	0.000114	0.000228	0.000114	0.000114	0.018153
ESE	0.000343	0.002055	0.010732	0.025574	0.006279	0.003539	0.000114	0.000000	0.048636
SE	0.000457	0.002854	0.009019	0.017468	0.005594	0.002740	0.000114	0.000000	0.038246
SSE	0.000228	0.001941	0.007307	0.008220	0.001598	0.000571	0.000228	0.000000	0.020094
S	0.000343	0.005594	0.011188	0.010846	0.001370	0.000114	0.000000	0.000000	0.029455
SSW	0.000571	0.011531	0.021920	0.013358	0.001256	0.000685	0.000000	0.000000	0.049321
SW	0.000457	0.006964	0.008334	0.006393	0.002055	0.000799	0.000228	0.000114	0.025345
WSW	0.000457	0.002968	0.002398	0.004453	0.003311	0.003996	0.002055	0.000913	0.020550
W	0.000343	0.002626	0.002398	0.005252	0.002169	0.004224	0.001370	0.000228	0.018609
WNW	0.000000	0.002398	0.001142	0.000685	0.000457	0.000114	0.000114	0.000000	0.004909
NW	0.000114	0.001941	0.001370	0.000228	0.000000	0.000228	0.000000	0.000000	0.003882
NNW	0.000000	0.002169	0.003425	0.002169	0.000457	0.000114	0.000000	0.000000	0.008334
N	0.000228	0.004110	0.011874	0.026373	0.021806	0.026830	0.005937	0.001142	0.098299
CALM									0.000343
TOTAL	0.003882	0.057541	0.111771	0.157552	0.061080	0.056399	0.013586	0.003083	0.465236

MEAN WIND SPEED (m/s) = 5.27
NUMBER OF OBSERVATIONS = 4075

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	0.001256	0.002055	0.001598	0.000000	0.000000	0.000000	0.000000	0.004909
NE	0.000000	0.001941	0.002055	0.001028	0.000000	0.000000	0.000000	0.000000	0.005023
ENE	0.000000	0.001370	0.000457	0.000114	0.000000	0.000000	0.000000	0.000000	0.001941
E	0.000000	0.003311	0.000799	0.000000	0.000000	0.000000	0.000000	0.000000	0.004110
ESE	0.000000	0.003311	0.003539	0.001028	0.000000	0.000000	0.000000	0.000000	0.007878
SE	0.000000	0.002398	0.001256	0.001142	0.000000	0.000000	0.000000	0.000000	0.004795
SSE	0.000000	0.003882	0.003197	0.001256	0.000000	0.000000	0.000000	0.000000	0.008334
S	0.000000	0.006279	0.005594	0.002169	0.000000	0.000000	0.000000	0.000000	0.014043
SSW	0.000000	0.010846	0.022034	0.008106	0.000000	0.000000	0.000000	0.000000	0.040986
SW	0.000000	0.009362	0.012559	0.001370	0.000000	0.000000	0.000000	0.000000	0.023290
WSW	0.000000	0.004453	0.004224	0.002055	0.000000	0.000000	0.000000	0.000000	0.010732
W	0.000000	0.002740	0.003083	0.002169	0.000000	0.000000	0.000000	0.000000	0.007992
WNW	0.000000	0.001028	0.001256	0.000114	0.000000	0.000000	0.000000	0.000000	0.002398
NW	0.000000	0.001484	0.001142	0.000114	0.000000	0.000000	0.000000	0.000000	0.002740
NNW	0.000000	0.002854	0.002055	0.000228	0.000000	0.000000	0.000000	0.000000	0.005138
N	0.000000	0.003425	0.010503	0.005594	0.000000	0.000000	0.000000	0.000000	0.019523
CALM									0.000000
TOTAL	0.000000	0.059938	0.075808	0.028085	0.000000	0.000000	0.000000	0.000000	0.163831

MEAN WIND SPEED (m/s) = 3.49
NUMBER OF OBSERVATIONS = 1435

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	0.000799	0.001256	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.002055
NE	0.000571	0.002055	0.000228	0.000000	0.000000	0.000000	0.000000	0.000000	0.002854
ENE	0.000457	0.000913	0.000114	0.000000	0.000000	0.000000	0.000000	0.000000	0.001484
E	0.001713	0.005023	0.000114	0.000000	0.000000	0.000000	0.000000	0.000000	0.006850
ESE	0.002169	0.006279	0.000114	0.000000	0.000000	0.000000	0.000000	0.000000	0.008563
SE	0.001028	0.003768	0.000114	0.000000	0.000000	0.000000	0.000000	0.000000	0.004909
SSE	0.001598	0.003882	0.000114	0.000000	0.000000	0.000000	0.000000	0.000000	0.005594
S	0.001713	0.006051	0.000228	0.000000	0.000000	0.000000	0.000000	0.000000	0.007992
SSW	0.003653	0.021692	0.000114	0.000000	0.000000	0.000000	0.000000	0.000000	0.025460
SW	0.005138	0.030825	0.000913	0.000000	0.000000	0.000000	0.000000	0.000000	0.036876
WSW	0.004110	0.009704	0.000343	0.000000	0.000000	0.000000	0.000000	0.000000	0.014157
W	0.003539	0.006850	0.000343	0.000000	0.000000	0.000000	0.000000	0.000000	0.010732
WNW	0.002512	0.006165	0.000343	0.000000	0.000000	0.000000	0.000000	0.000000	0.009019
NW	0.002055	0.007649	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.009704
NNW	0.002740	0.006051	0.000114	0.000000	0.000000	0.000000	0.000000	0.000000	0.008905
N	0.001598	0.004681	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.006279
CALM									0.011874
TOTAL	0.035392	0.122845	0.003197	0.000000	0.000000	0.000000	0.000000	0.000000	0.173307

MEAN WIND SPEED (m/s) = 2.07
NUMBER OF OBSERVATIONS = 1518

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	0.001028	0.006736	0.018952	0.024432	0.012787	0.015641	0.005023	0.000799	0.085398
NE	0.001028	0.007992	0.013244	0.022377	0.003083	0.000457	0.000000	0.000114	0.048293
ENE	0.000799	0.004681	0.009019	0.011759	0.002512	0.000571	0.000000	0.000000	0.029341
E	0.002283	0.013586	0.013814	0.011188	0.000114	0.000228	0.000114	0.000114	0.041443
ESE	0.002740	0.013700	0.021692	0.038931	0.008220	0.004681	0.000114	0.000000	0.090079
SE	0.001598	0.010503	0.013700	0.021578	0.006165	0.002968	0.000114	0.000000	0.056627
SSE	0.002055	0.010618	0.011645	0.010846	0.001598	0.000685	0.000228	0.000000	0.037676
S	0.002626	0.020094	0.021464	0.014842	0.001370	0.000114	0.000000	0.000000	0.060509
SSW	0.005252	0.047722	0.051604	0.026373	0.001256	0.000685	0.000000	0.000000	0.132892
SW	0.007535	0.051832	0.026601	0.012102	0.002055	0.000913	0.000228	0.000114	0.101381
WSW	0.005480	0.018952	0.008334	0.007992	0.003539	0.004224	0.002055	0.000913	0.051490
W	0.005023	0.013814	0.006393	0.009248	0.002398	0.004338	0.001484	0.000228	0.042927
WNW	0.002968	0.010618	0.002968	0.001028	0.000571	0.000114	0.000114	0.000000	0.018381
NW	0.002740	0.011531	0.003083	0.000571	0.000000	0.000228	0.000000	0.000000	0.018153
NNW	0.003311	0.012673	0.007535	0.002740	0.000457	0.000114	0.000000	0.000000	0.026830
N	0.002512	0.016212	0.032310	0.036762	0.022263	0.028314	0.006393	0.001142	0.145907
CALM									0.012673
TOTAL	0.048978	0.271264	0.262359	0.252769	0.068387	0.064277	0.015869	0.003425	1.000000

MEAN WIND SPEED (m/s) = 4.23
NUMBER OF OBSERVATIONS = 8759

FREQUENCY OF OCCURENCE OF STABILITY CLASSES

A : 0.0%
B : 4.4%
C : 15.3%
D : 46.5%
E : 16.4%
F : 17.3%

STABILITY CLASS BY HOUR OF DAY

Hour	A	B	C	D	E	F
01	0000	0000	0000	0114	0119	0132
02	0000	0000	0000	0111	0119	0135
03	0000	0000	0000	0107	0115	0143
04	0000	0000	0000	0097	0134	0134
05	0000	0000	0000	0096	0125	0144
06	0000	0000	0012	0166	0109	0078
07	0000	0002	0057	0247	0036	0023
08	0000	0016	0124	0225	0000	0000
09	0000	0047	0141	0177	0000	0000
10	0001	0071	0130	0163	0000	0000
11	0000	0098	0145	0122	0000	0000
12	0000	0078	0171	0116	0000	0000
13	0001	0052	0176	0136	0000	0000
14	0000	0019	0165	0181	0000	0000
15	0000	0003	0098	0264	0000	0000
16	0000	0001	0096	0268	0000	0000
17	0000	0000	0027	0338	0000	0000
18	0000	0000	0000	0251	0057	0057
19	0000	0000	0000	0189	0093	0083
20	0000	0000	0000	0157	0109	0099
21	0000	0000	0000	0154	0104	0107
22	0000	0000	0000	0141	0103	0121
23	0000	0000	0000	0132	0109	0124
24	0000	0000	0000	0123	0103	0138

STABILITY CLASS BY MIXING HEIGHT

Mixing height	A	B	C	D	E	F
<=500 m	0000	0013	0083	0553	1023	1516
<=1000 m	0001	0207	0484	1431	0405	0002
<=1500 m	0001	0146	0658	1398	0007	0000
<=2000 m	0000	0019	0103	0620	0000	0000
<=3000 m	0000	0002	0014	0073	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	0038	0072	0106	0092	0053	0004	0000
02	0044	0073	0100	0109	0037	0002	0000
03	0051	0073	0104	0098	0035	0004	0000
04	0037	0080	0112	0100	0031	0005	0000
05	0046	0069	0117	0106	0025	0002	0000
06	0032	0053	0115	0122	0040	0003	0000
07	0014	0024	0070	0160	0094	0003	0000
08	0001	0005	0037	0162	0154	0006	0000
09	0000	0000	0007	0087	0240	0031	0000
10	0000	0000	0001	0077	0261	0026	0000
11	0000	0000	0000	0062	0276	0027	0000
12	0000	0000	0000	0057	0274	0034	0000
13	0000	0000	0000	0034	0285	0046	0000
14	0000	0000	0000	0032	0284	0049	0000
15	0000	0000	0000	0030	0275	0060	0000
16	0000	0000	0000	0044	0266	0055	0000
17	0003	0002	0017	0064	0237	0042	0000
18	0011	0024	0052	0087	0148	0043	0000
19	0028	0028	0074	0101	0110	0024	0000
20	0036	0045	0080	0099	0095	0010	0000
21	0021	0054	0079	0112	0089	0010	0000
22	0038	0056	0090	0106	0069	0006	0000
23	0026	0076	0098	0097	0065	0003	0000
24	0037	0069	0094	0101	0058	0005	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, 10.5 years old compared with 9.5 years old in NSW. **Table C1** summarises the Queensland vehicle distribution by age.

Table C1 : Queensland vehicle distribution by age category

Year of manufacture	Total vehicles
To 1985	502580
1986-1990	427817
1991-1995	557281
1996-2000	715594
2001-2003	345277
Not stated	3512
TOTAL	2552061

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 : Comparison of SEQ emissions and PIARC

Hour of day	Percentage of all vehicles in the day	Percentage of heavy vehicles in the day
1	0.4%	0.3%
2	0.3%	0.3%
3	0.3%	0.4%
4	0.3%	0.5%
5	0.6%	0.9%
6	2.1%	2.6%
7	4.8%	6.4%
8	7.2%	9.0%
9	7.2%	9.0%
10	5.9%	7.7%
11	5.6%	7.5%
12	5.6%	7.3%
13	5.8%	7.2%
14	5.8%	7.1%
15	6.5%	7.4%
16	7.4%	7.1%
17	7.8%	4.7%
18	7.8%	4.7%
19	6.1%	3.2%
20	4.0%	2.0%
21	3.0%	1.6%
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 : Comparison of SEQ emissions and PIARC

Main tunnel (south to north)				Main tunnel (north to south)			
Chainage (m)		Length (m)	Grade %	Chainage (m)		Length (m)	Grade %
Start	End			Start	End		
732	1200	468	-3.5	6700	6400	300	3.5
1200	2100	900	-3	6400	6110	290	0
2100	3200	1100	3	6110	5763	347	5
3200	3689	489	5	5763	5200	563	3.5
3689	4200	511	-0.3	5200	4678	522	-3.5
4200	4678	478	-5	4678	4200	478	-5
4678	5200	522	-3.5	4200	3689	511	-0.3
5200	5763	563	3.5	3689	3200	489	5
5763	6110	347	5	3200	2100	1100	3
6110	6400	290	0	2100	1200	900	-3
6400	6700	300	3.5	1200	732	468	-3.5
		5968				5968	

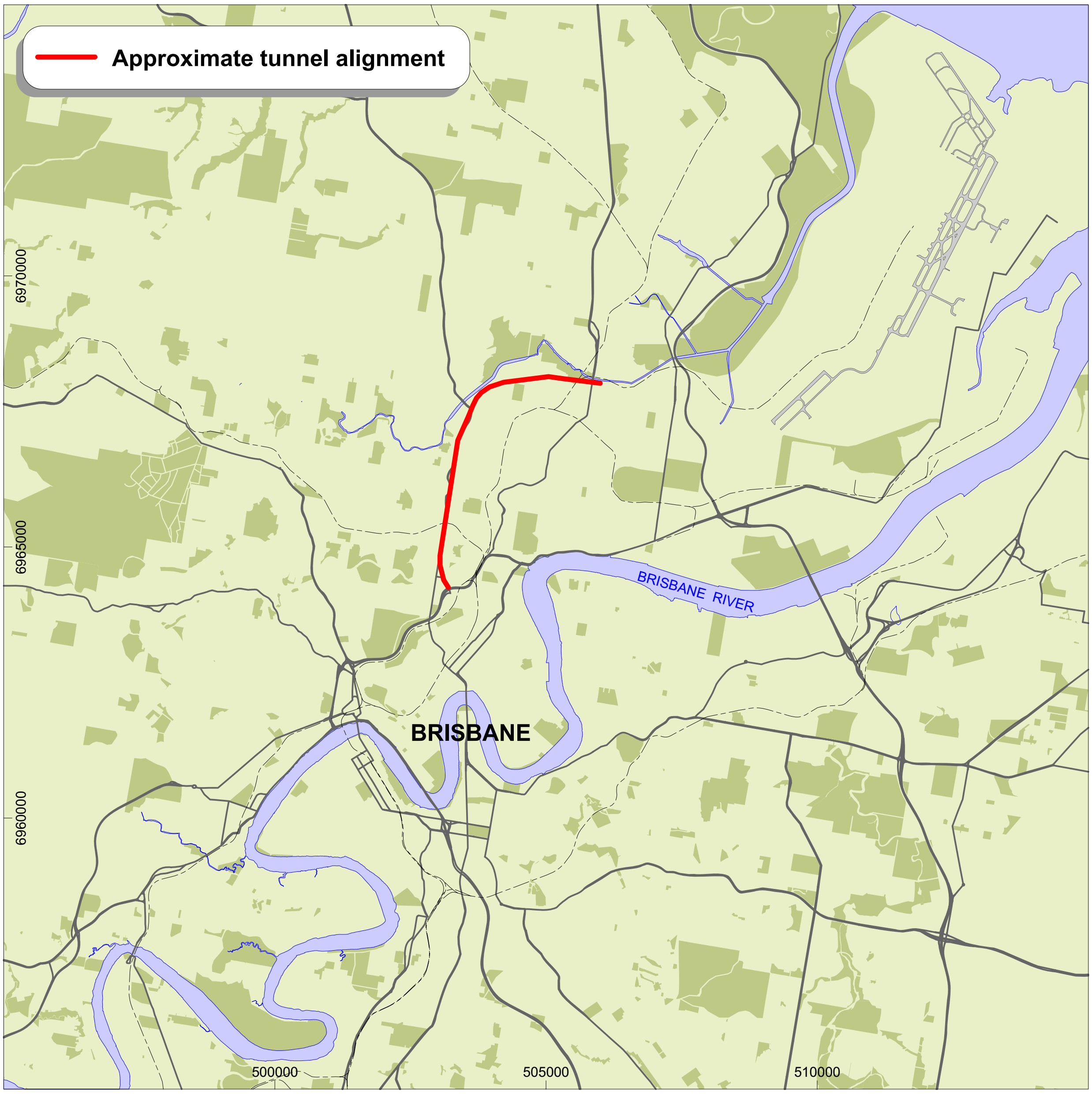
Table C5 shows the sources associated to each road section (also refer to **Figure 17** of main report).

Table C5 : Surface road source allocation for the CALPUFF modelling

Section name	Sources associated with this section (refer **Figure 17**)
Bradfield HWY	68 69 70 71 72 73
Brunswick St	73 74
Bowen Br Rd	67 154 155
Lutwyche Rd/Gympie Road	159 160 161
Gympie Rd	161 162 163 164 165
Pacific MWY	1 2 3 4 5
Hale St	5 6 7 8
ICB	8 9 10 11
ICB Nth	12 13 14
Abbotsford Rd N ICB	14 150 151 152 153
Sandgate Rd S	146 147 148 149
Sandgate Rd N	142 143 144 145
Kingsford Smith DR W	14 15 16 17 18 19
Kingsford Smith DR M	19 20 21 22
Kingsford Smith DR E	22 23 24
Gateway MWY S Lytton	92 99 100 101
Gateway MWY N Lytton	92 104 105 106 107
Gateway MWY N Curtin	24 107 108
Gateway MWY N KingsSmth	24 127 128 129
Gateway MWY N Airport Dr	122 123 124 125 126
Junction / Lytton Rd	81 82 83 84 85 86 87 88 89 90 91 92
Lytton Rd E MWY	92 93 94 95
Port of Bris MWY	101 102 103
Creek Rd	96 97 98
Grey St	5 25 26 27
Countess / Petrie	5 8 28 29
Kelvin Gr Rd	8 61 62 63
Kelvin Gr Rd S Newmarket	59 60 61

Section name	Sources associated with this section (refer **Figure 17**)
Enoggera	56 57 58
Samford Rd E Wardell	42 55 56
Samford Rd W Wardell	42 51 52 53 54
MiltonRd	194 195 196
Waterworks / Musgrave	30 31 32 33 34 35 36 37
Wardell S Samford	35 38 39 40 41 42
Wardell N Samford	42 43 44 45
South Pine	45 46 47 48 49 50
Stafford Rd E Sth Pine	45 184 185 186 187
Stafford Rd E Webster	161 182 183 184
Webster S Stafford	184 188 189 190
Webster N Stafford	177 184 191 192 193
Rode Rd W Webster	177 178 179 180 181
Rode Rd E Webster	165 176 177
Rode Rd E Gympie	143 165 172 173 174 175
Newmarket Rd	155 166 167 168 169
Herston Rd	61 64 65 66 67
Markwell Tce	73 75 76 77
Breakfast Ck St	76 78 79 80
Gateway MWY S KS	22 107 109 110
Gateway MWY N KS	22 111 112 113 114 115
Gateway MWY N Arterial	115 116 117 118
Gateway MWY N Toombul	118 119 120 121
EW Arterial	115 139 140 141
Airport Dr E MWY	115 137 138
Airport DrS E Gateway Ext	130 131 132 133
Airport DrN E Gateway Ext	125 134 135 136
Toombul Rd	118 170 171
Lutwyche Rd N Maygar	155 156 157 158 159

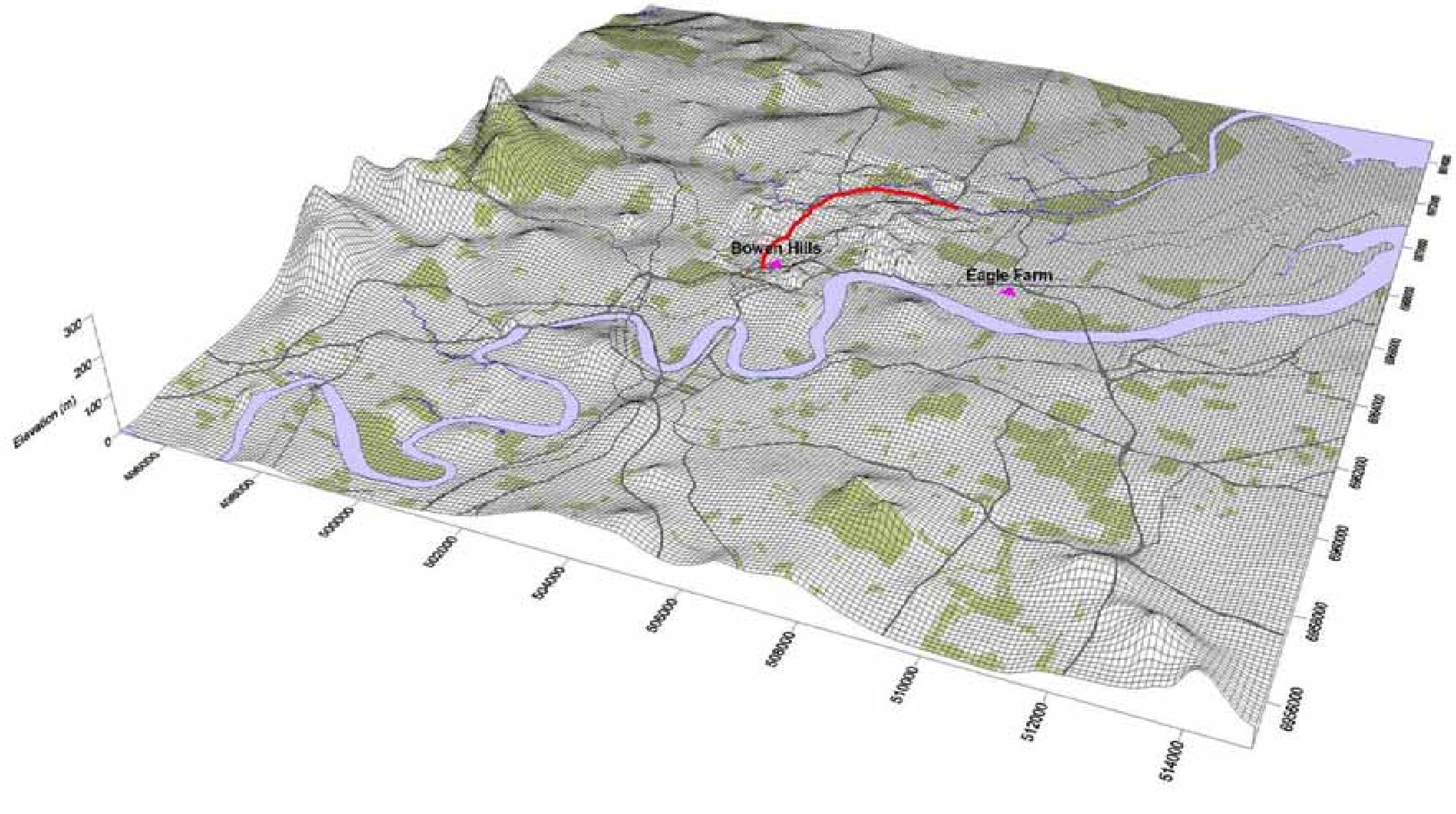
FIGURES



MGA Zone 56 (GDA84)

Location of study area and proposed airport link tunnel

FIGURE 1

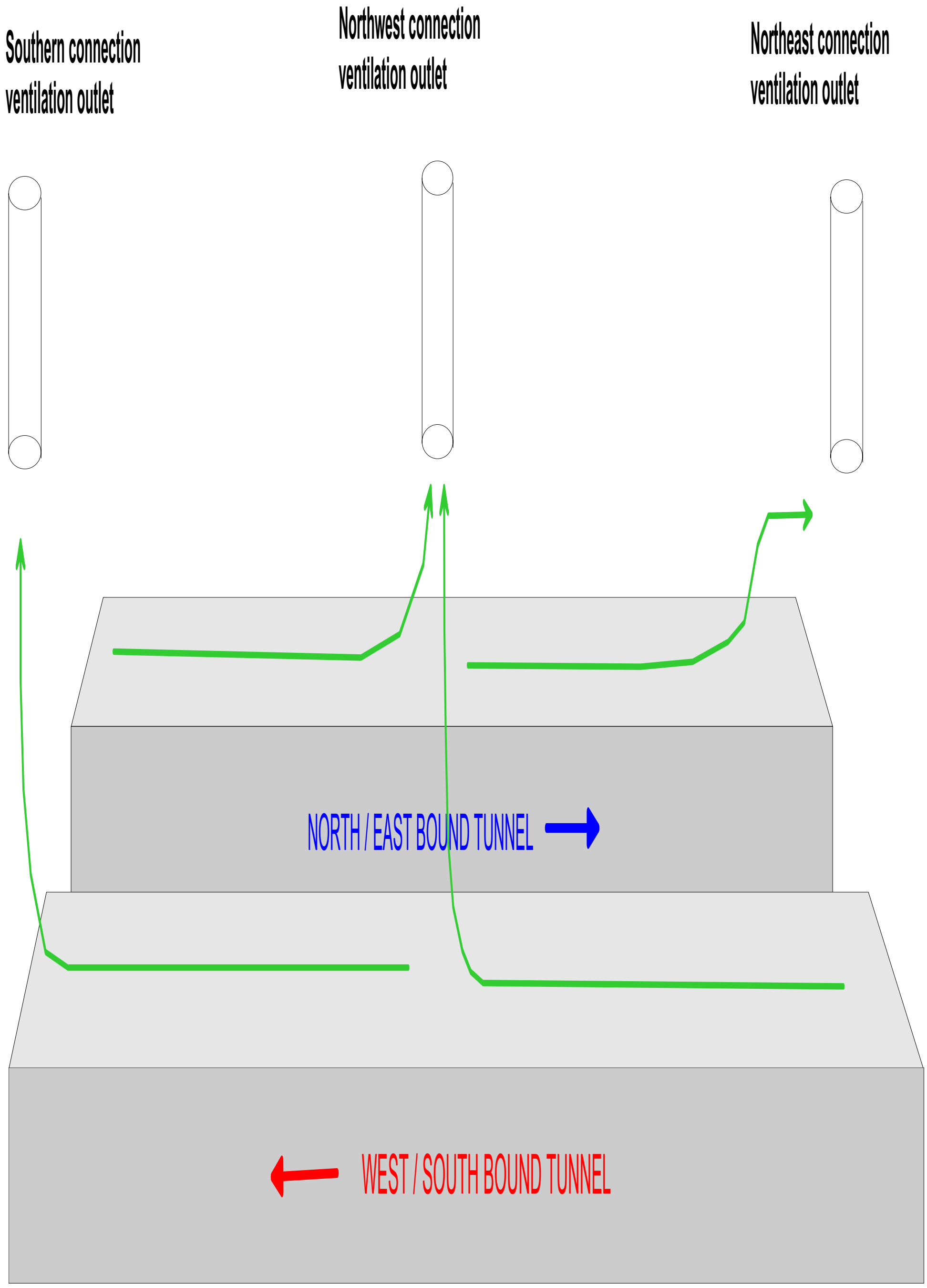


Pseudo three-dimensional representation of the study area

FIGURE 2

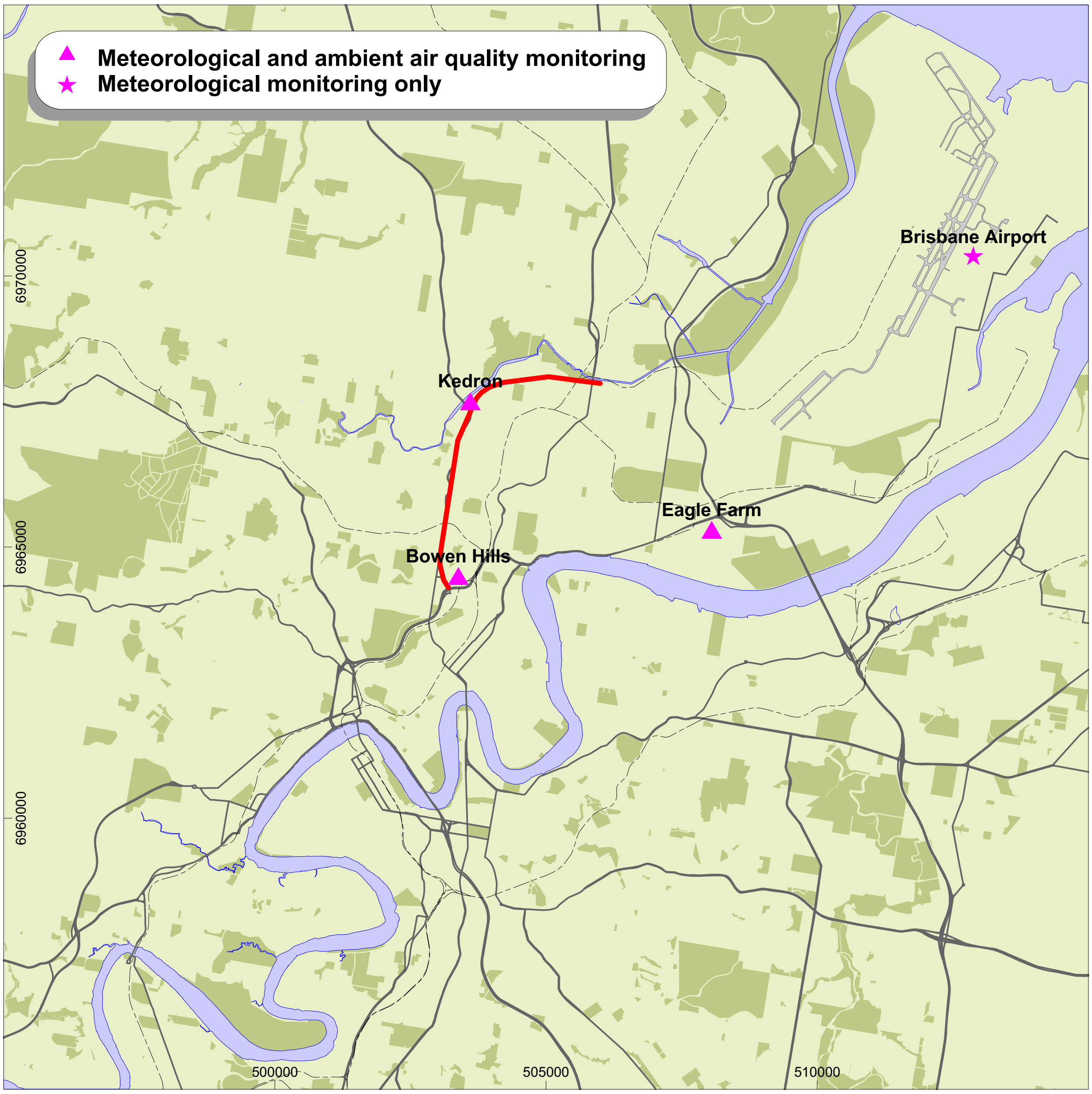
MGA Zone 56 (GDA84)

Location of preferred tunnel ventilation outlets



Schematic of air movements in the tunnel

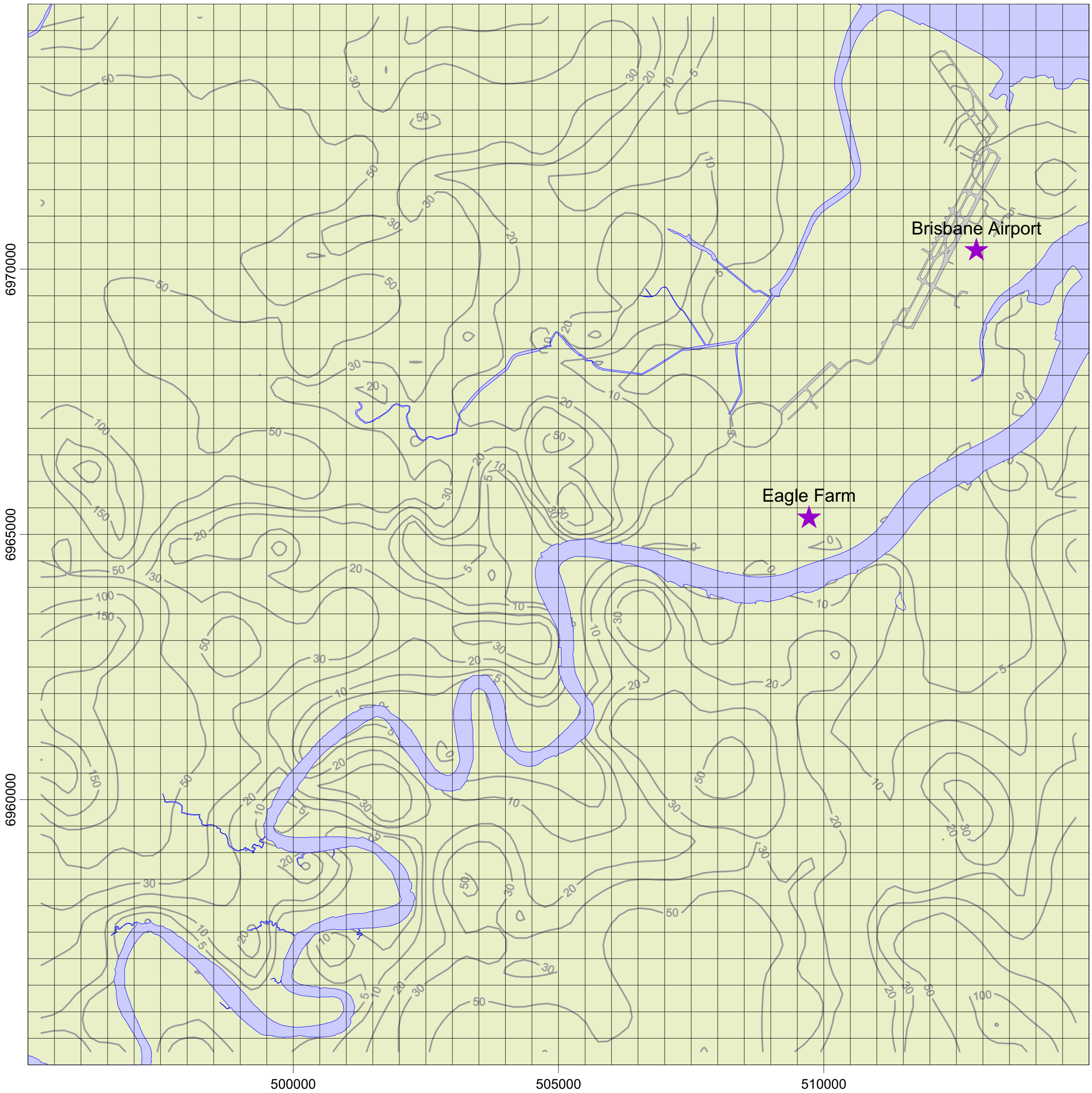
FIGURE 4



MGA Zone 56 (GDA84)

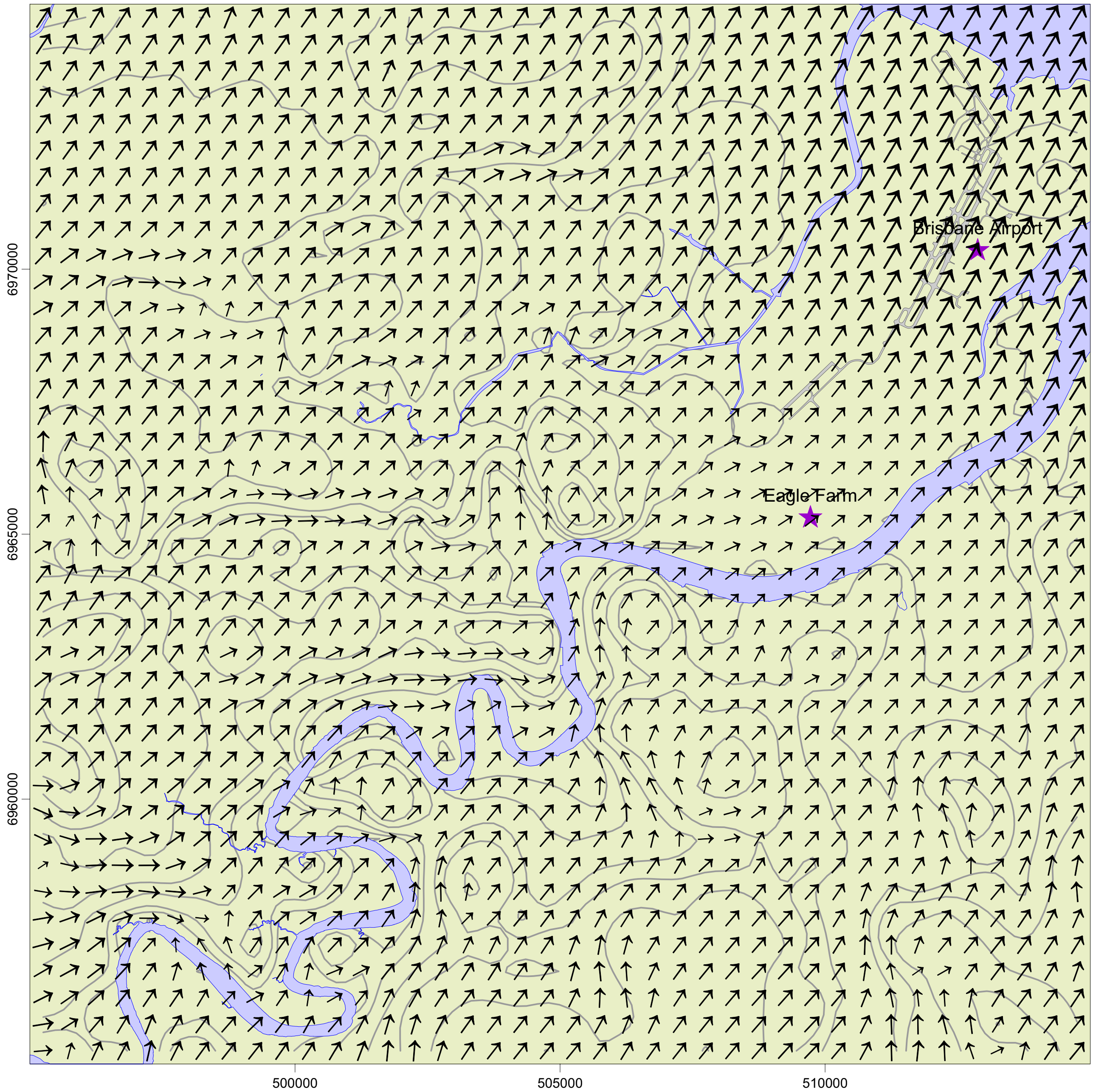
Meteorological and ambient air quality monitoring locations

FIGURE 5



CALMET model grid, meteorological stations and terrain information

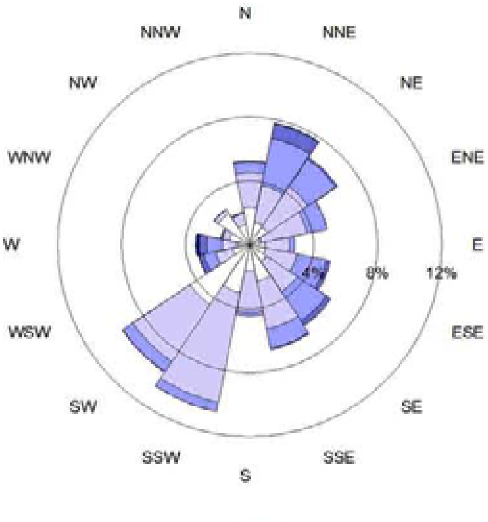
FIGURE 6



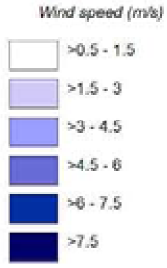
Ground-level wind patterns in the study area as simulated by CALMET (1-Jul-2004 Hour 3)

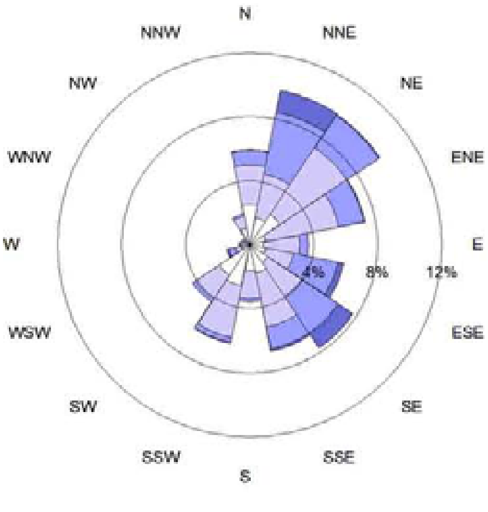
FIGURE 7

Annual and seasonal windroses for Bowen Hills (2004/2005)

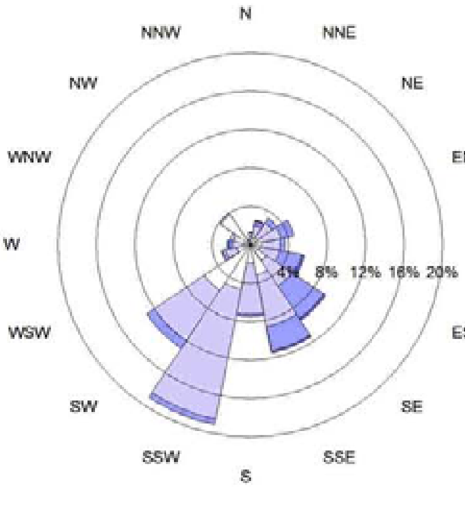


Annual
Calms = 16.9%

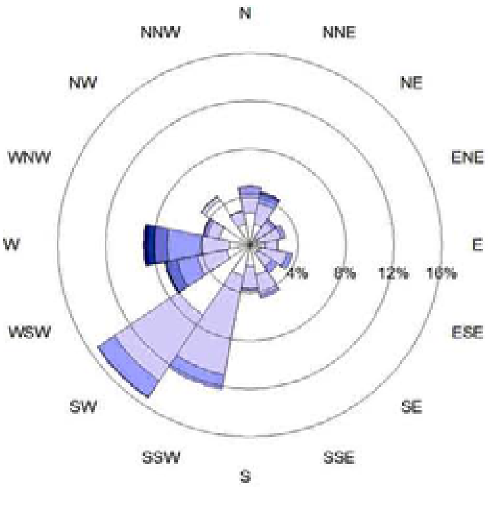




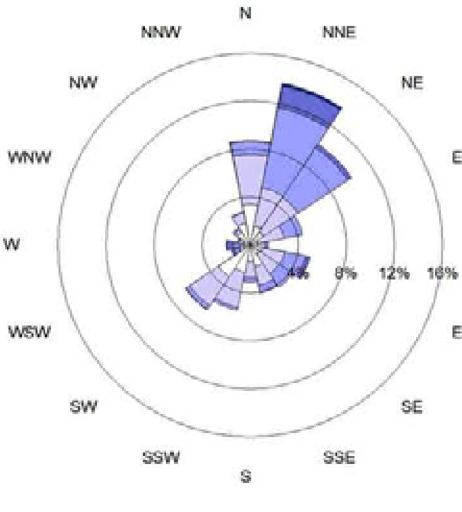
Summer
Calms = 23.8%



Autumn
Calms = 6.4%



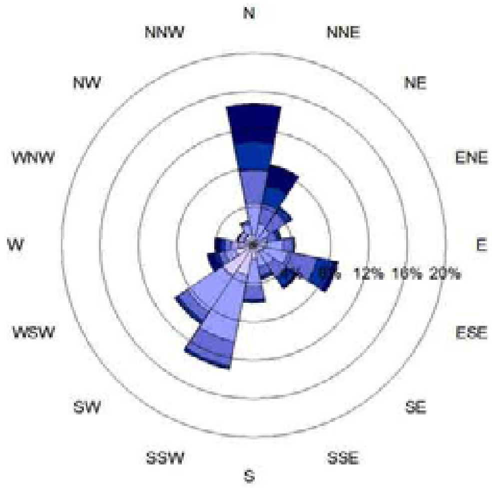
Winter
Calms = 12.6%



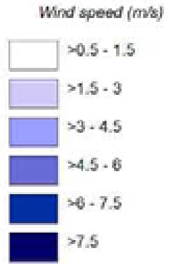
Spring
Calms = 23.8%

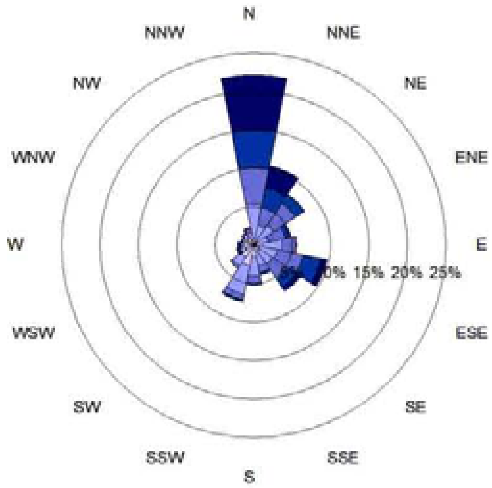
FIGURE 8

Annual and seasonal windroses for Brisbane Airport (BoM 2004 data)

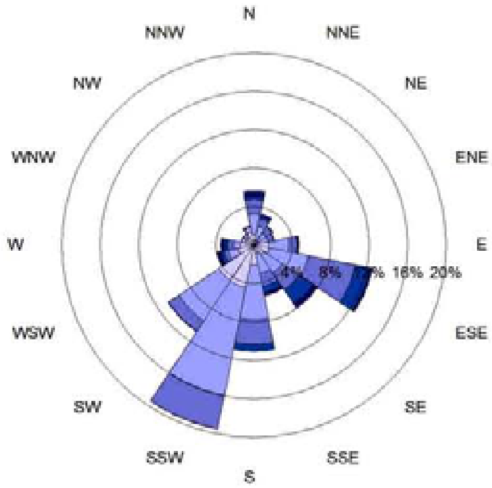


Annual
Calms = 2.2%

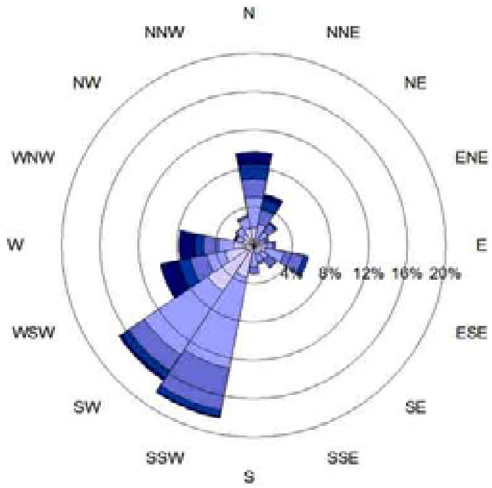




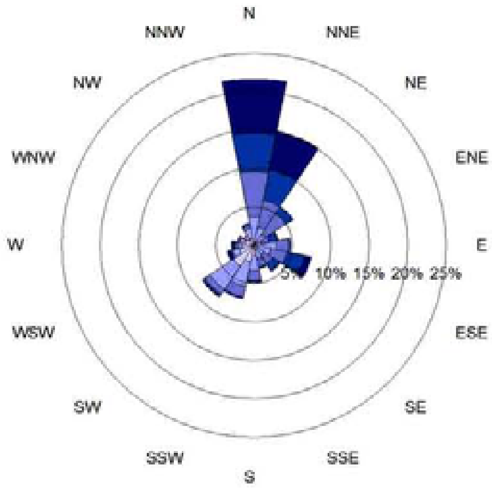
Summer
Calms = 1.4%



Autumn
Calms = 2.6%



Winter
Calms = 3.8%



Spring
Calms = 1.0%

FIGURE 9

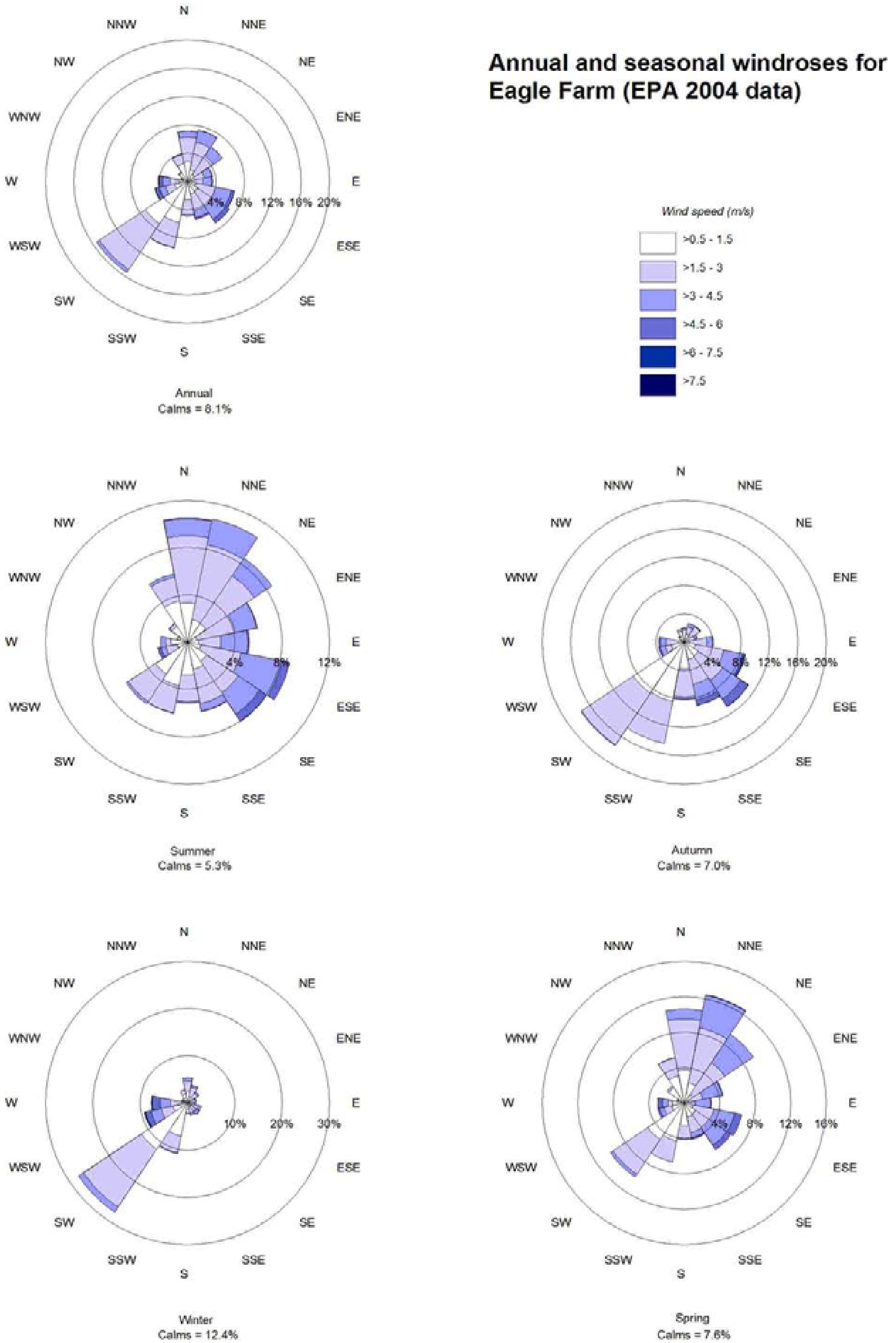
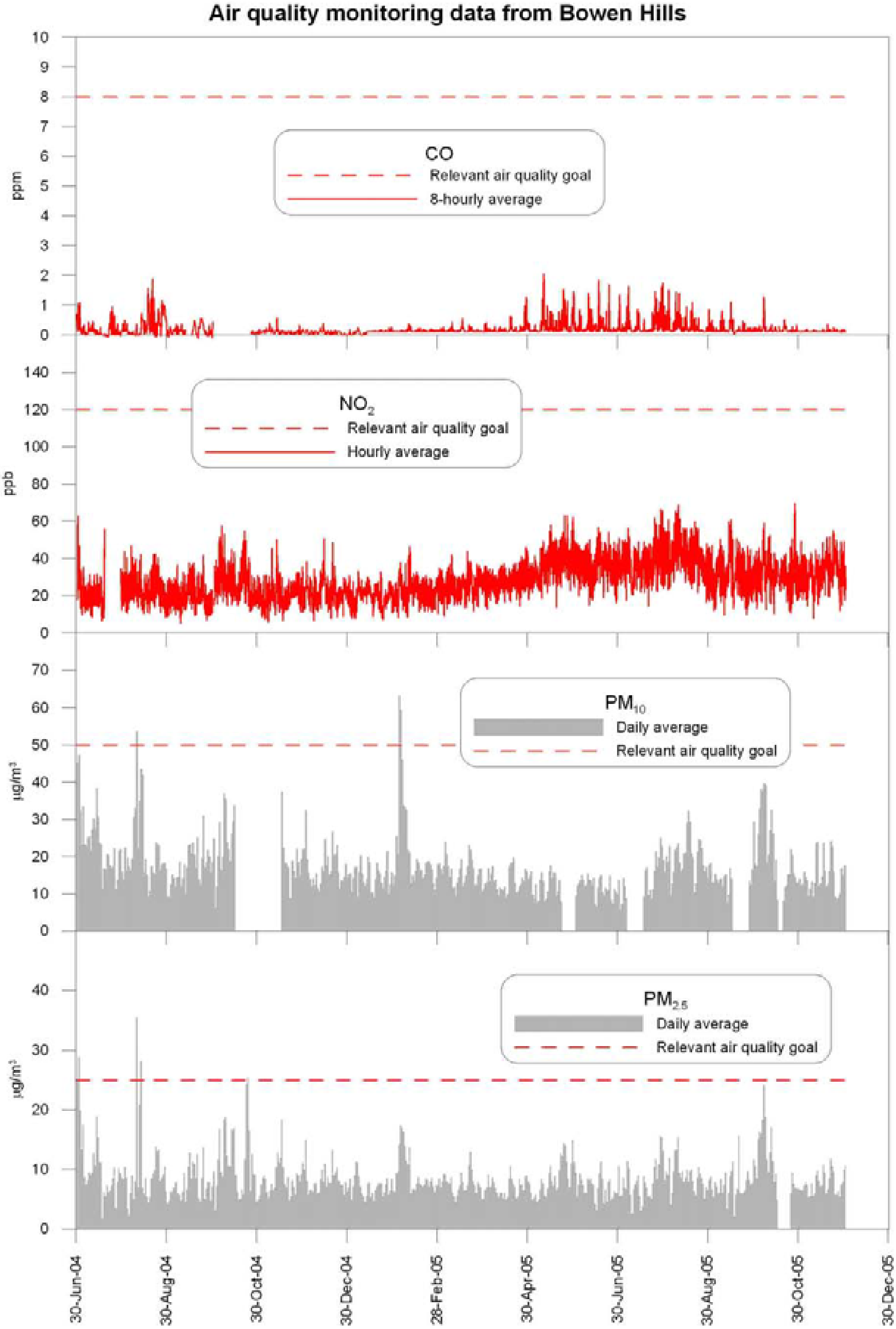
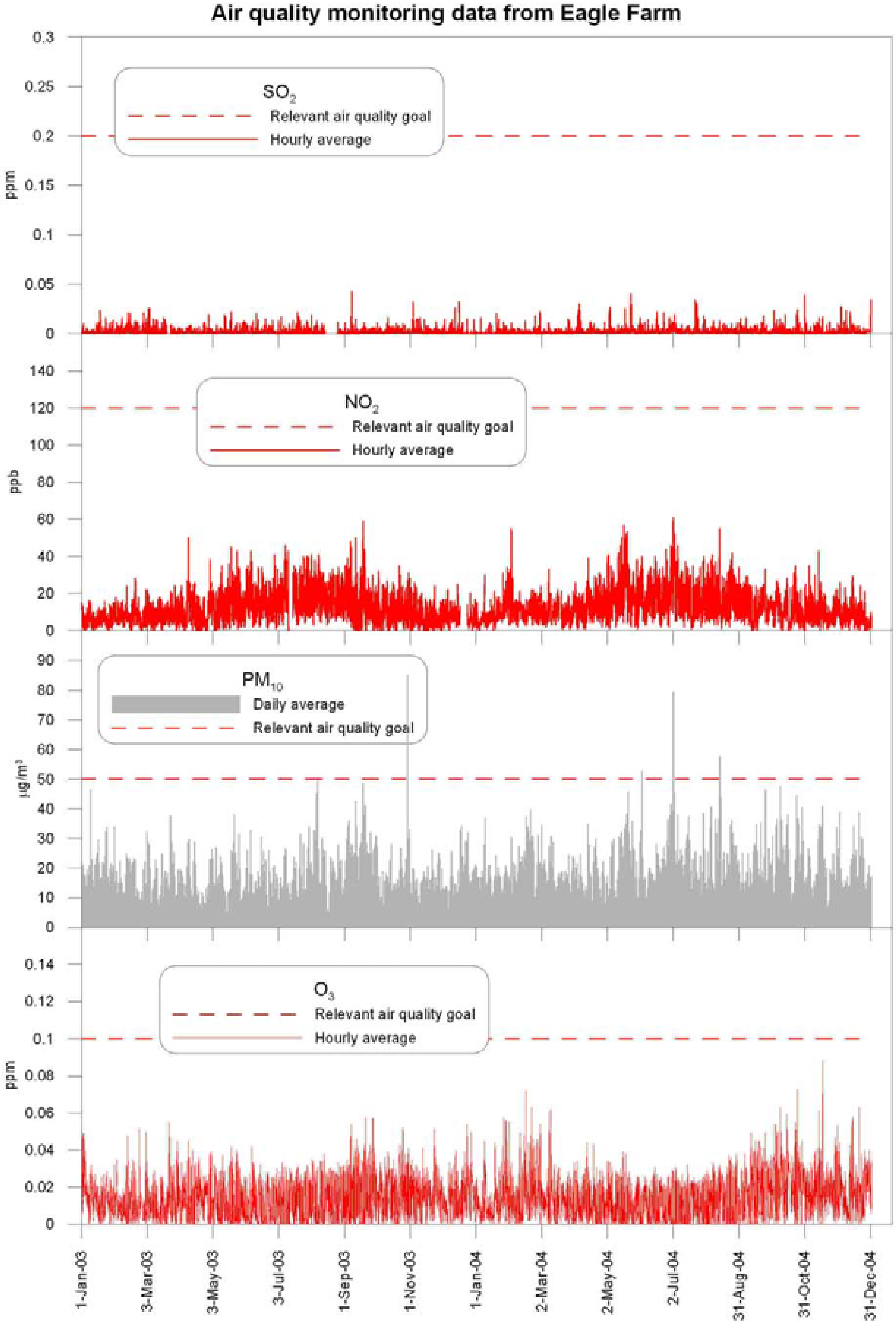

Annual and seasonal windroses for Eagle Farm (EPA 2004 data)
Wind speed (m/s)
>0.5 - 1.5
>1.5 - 3
>3 - 4.5
>4.5 - 6
>6 - 7.5
>7.5
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
4% 8% 12% 16% 20%
Annual
Calms = 8.1%
4% 8% 12%
Summer
Calms = 5.3%
4% 8% 12% 16% 20%
Autumn
Calms = 7.0%
10% 20% 30%
Winter
Calms = 12.4%
4% 8% 12% 16%
Spring
Calms = 7.6%

FIGURE 10



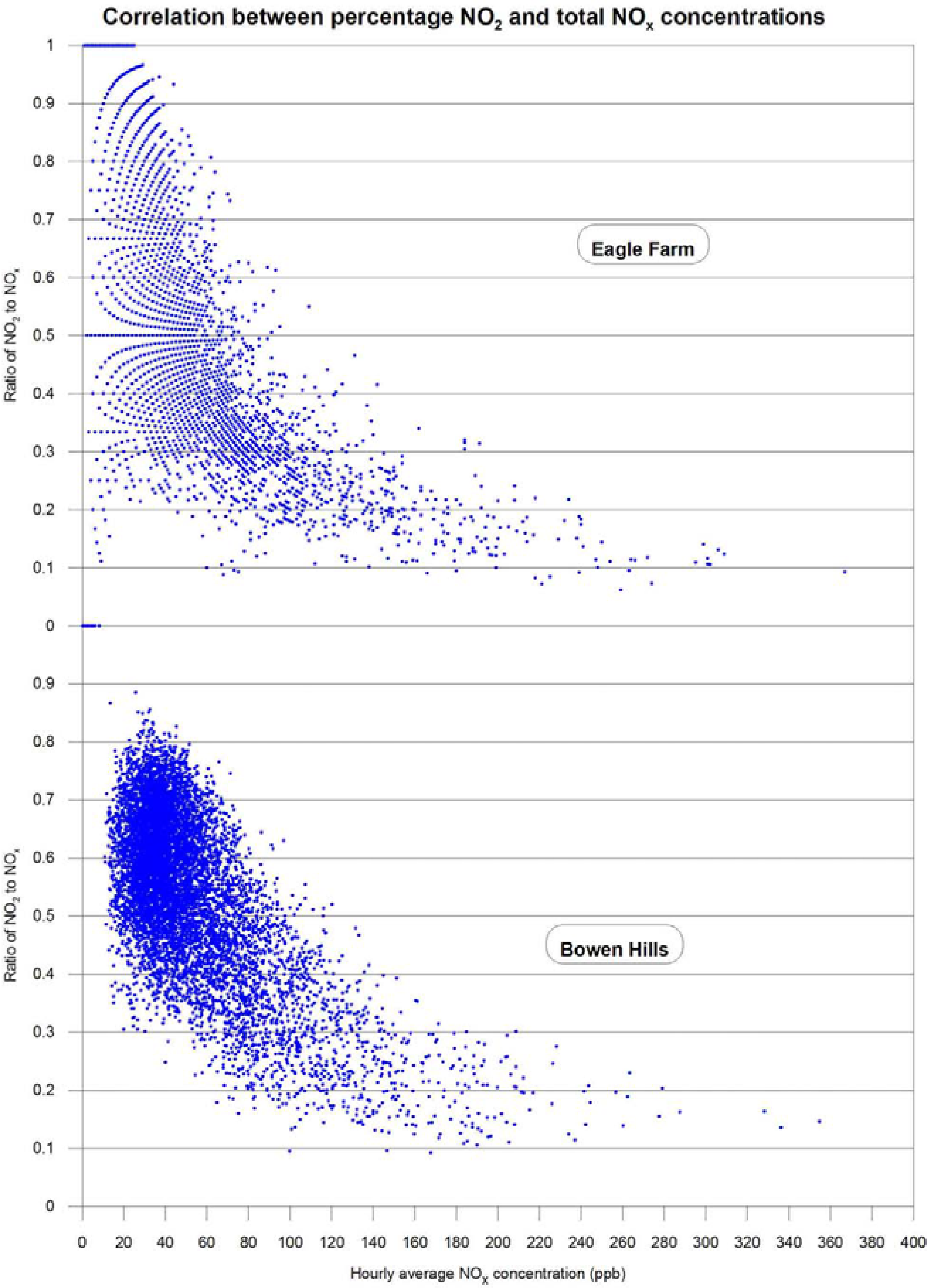
Air quality monitoring data from Bowen Hills
CO
Relevant air quality goal
8-hourly average
ppm
NO_2
Relevant air quality goal
Hourly average
ppb
PM_{10}
Daily average
Relevant air quality goal
µg/m³
$PM_{2.5}$
Daily average
Relevant air quality goal
µg/m³
30-Jun-04
30-Aug-04
30-Oct-04
30-Dec-04
28-Feb-05
30-Apr-05
30-Jun-05
30-Aug-05
30-Oct-05
30-Dec-05

FIGURE 11



Air quality monitoring data from Eagle Farm
SO2
Relevant air quality goal
Hourly average
ppm
NO2
Relevant air quality goal
Hourly average
ppb
PM10
Daily average
Relevant air quality goal
µg/m3
O3
Relevant air quality goal
Hourly average
ppm
1-Jan-03
3-Mar-03
3-May-03
3-Jul-03
1-Sep-03
1-Nov-03
1-Jan-04
2-Mar-04
2-May-04
2-Jul-04
31-Aug-04
31-Oct-04
31-Dec-04

FIGURE 12



Correlation between percentage NO_2 and total NO_x concentrations
Eagle Farm
Bowen Hills
Ratio of NO_2 to NO_x
Ratio of NO_2 to NO_x
Hourly average NO_X concentration (ppb)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400

FIGURE 13

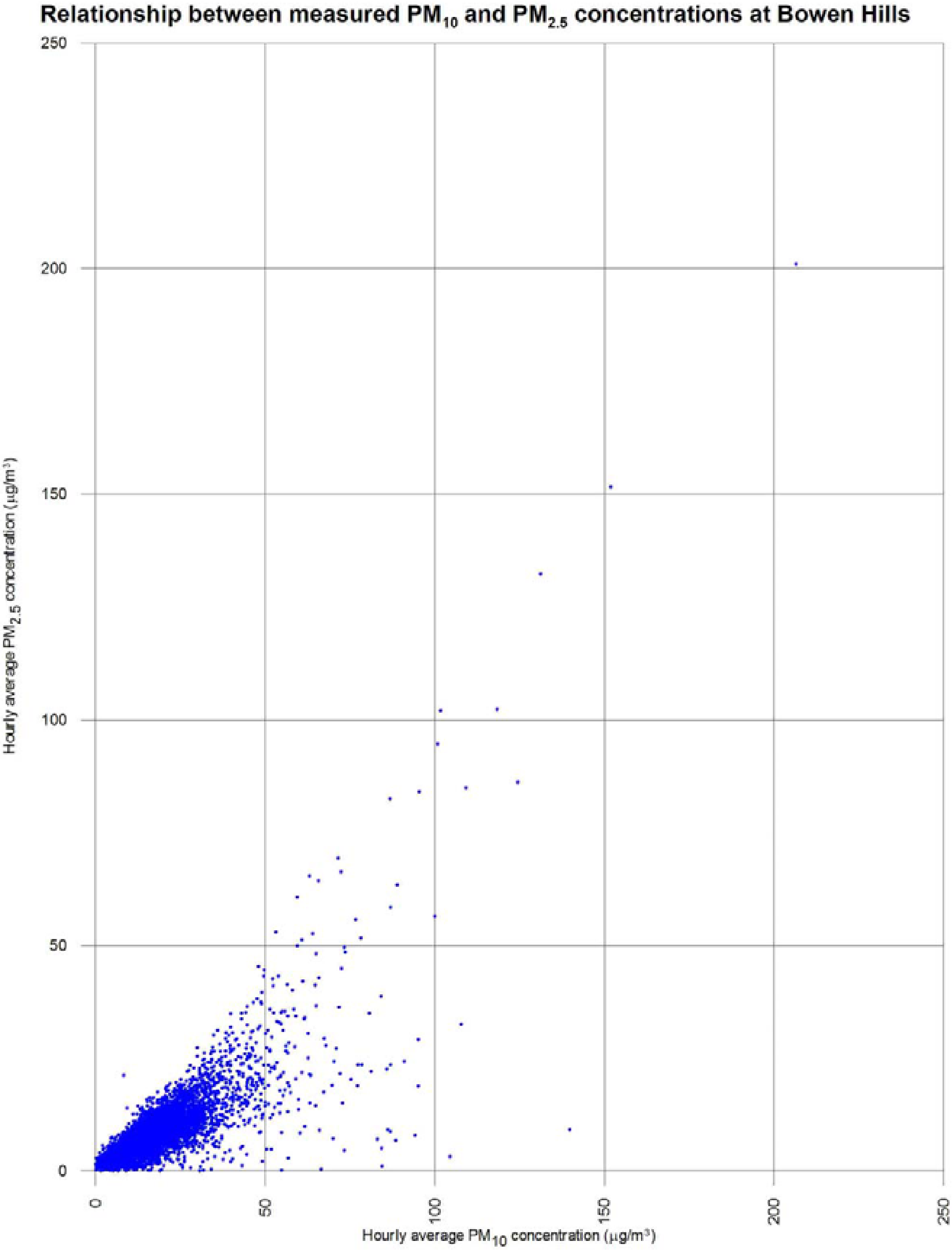
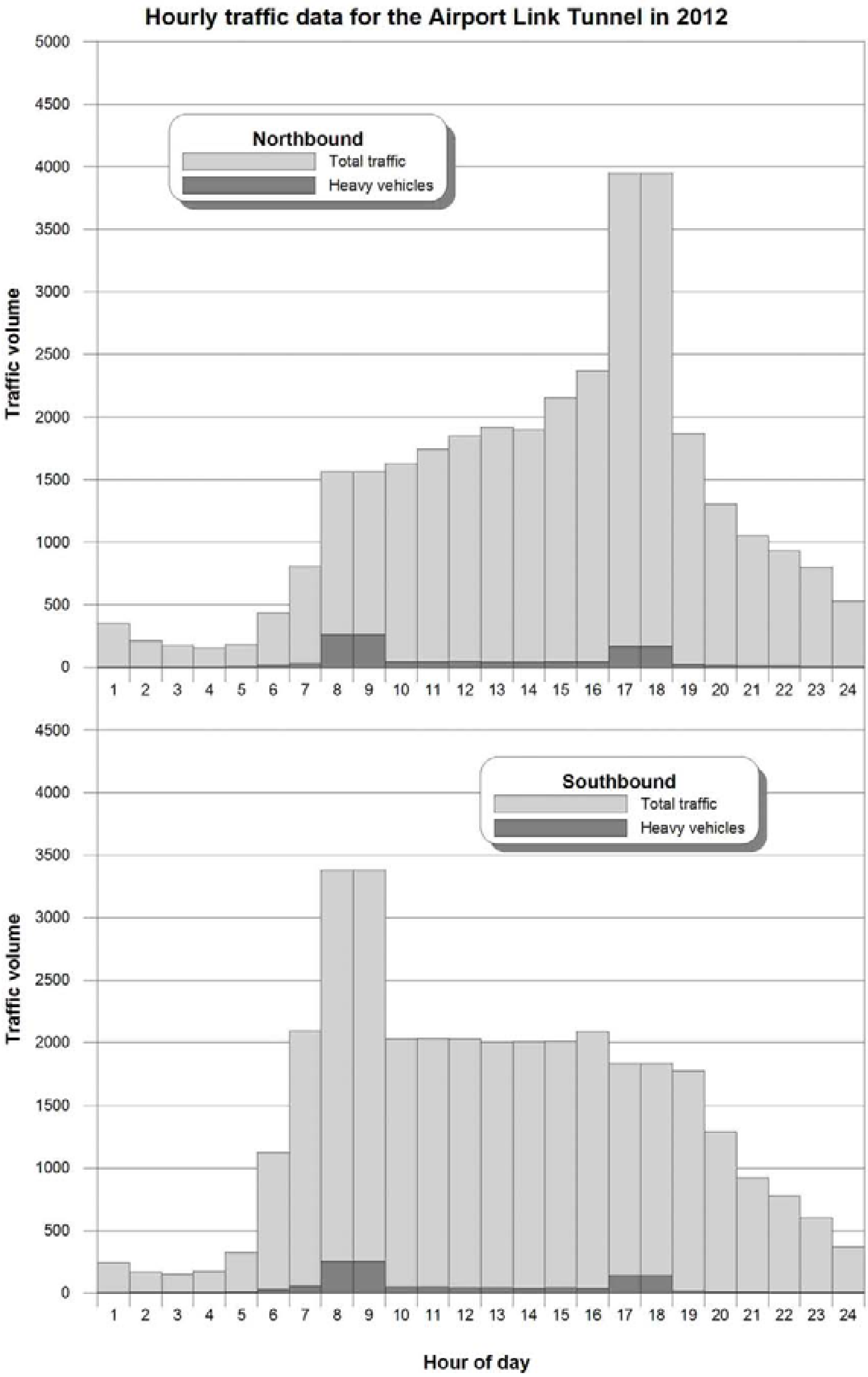
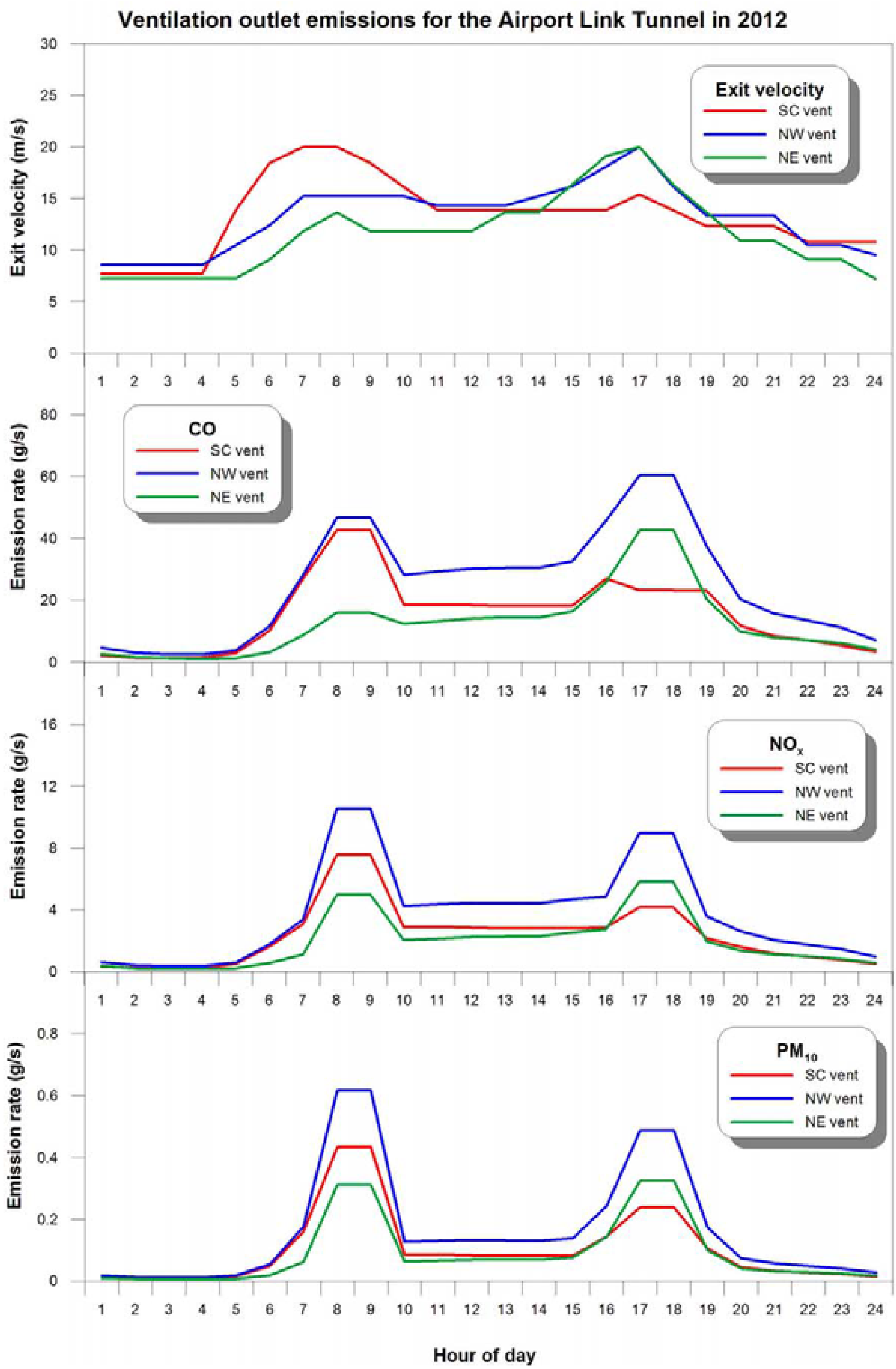

Relationship between measured PM_{10} and $PM_{2.5}$ concentrations at Bowen Hills
Hourly average $PM_{2.5}$ concentration ($\mu g/m^3$)
Hourly average PM_{10} concentration ($\mu g/m^3$)
0
50
100
150
200
250

FIGURE 14

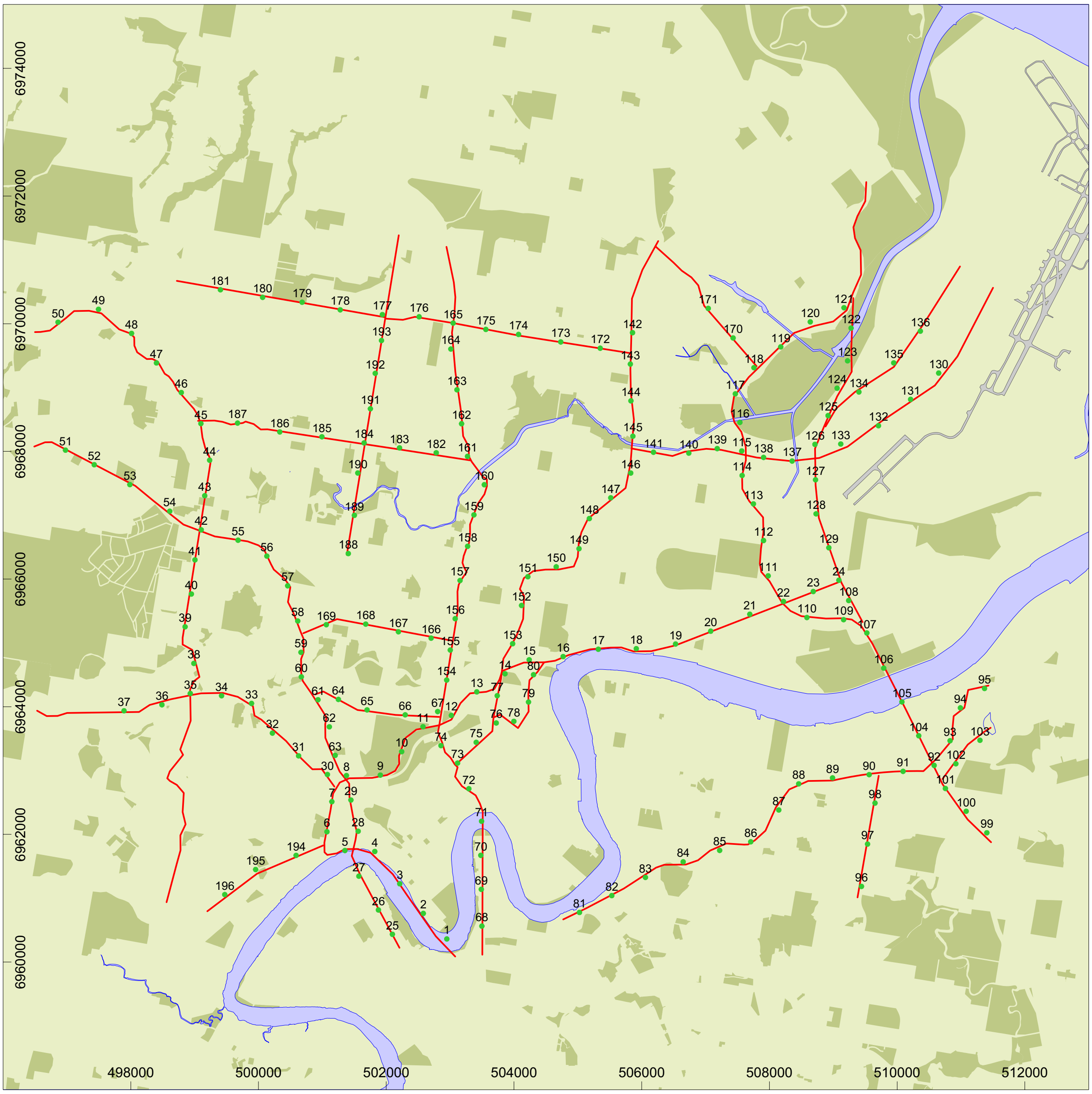


Hourly traffic data for the Airport Link Tunnel in 2012
Northbound
Total traffic
Heavy vehicles
Southbound
Total traffic
Heavy vehicles
Traffic volume
Hour of day

FIGURE 15


Ventilation outlet emissions for the Airport Link Tunnel in 2012
Exit velocity
SC vent
NW vent
NE vent
Exit velocity (m/s)
CO
Emission rate (g/s)
NOx
PM10
Hour of day

FIGURE



MGA Zone 56 (GDA84)

Sources used to represent roadways in the CALPUFF dispersion model

FIGURE 17

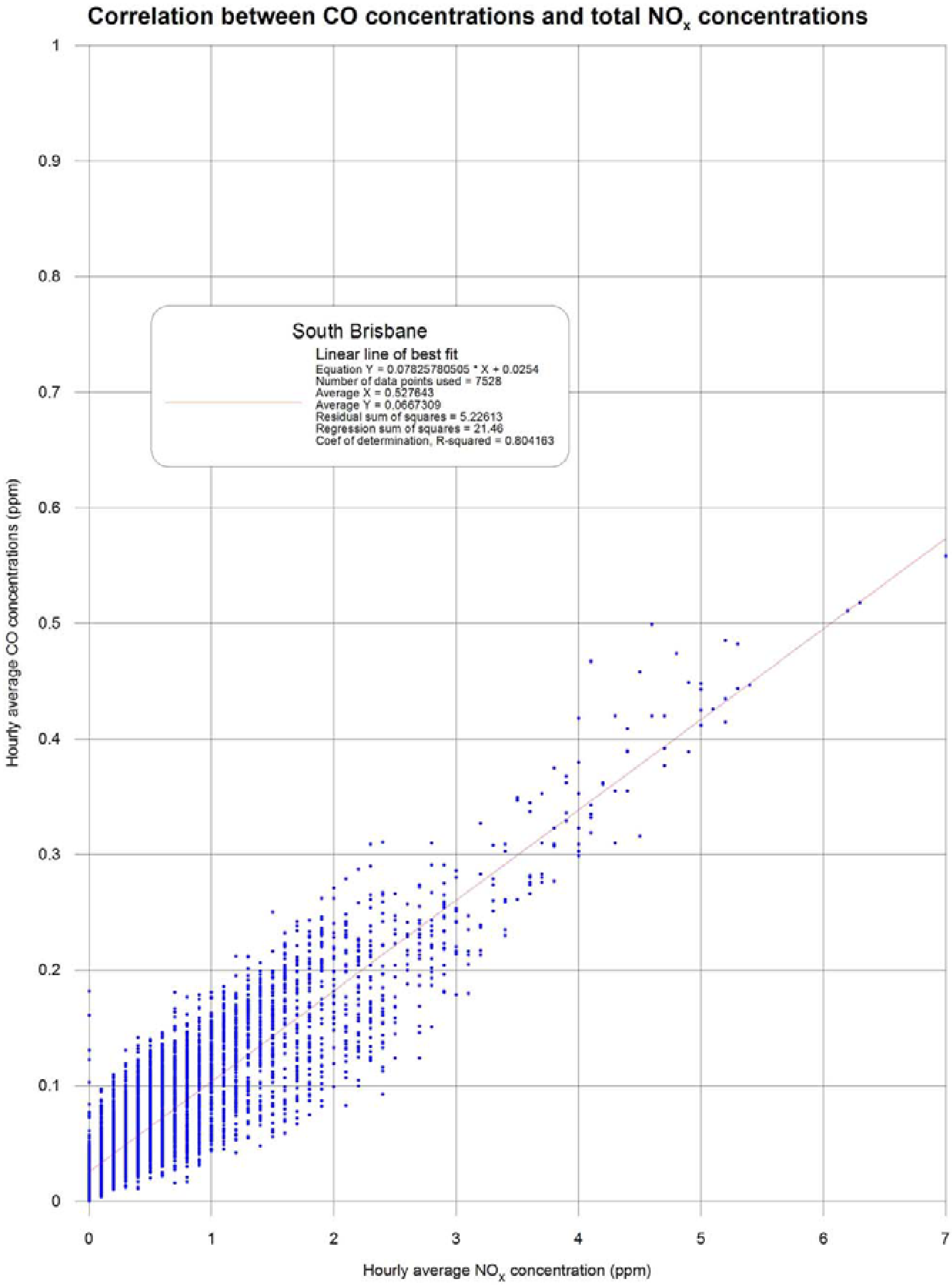
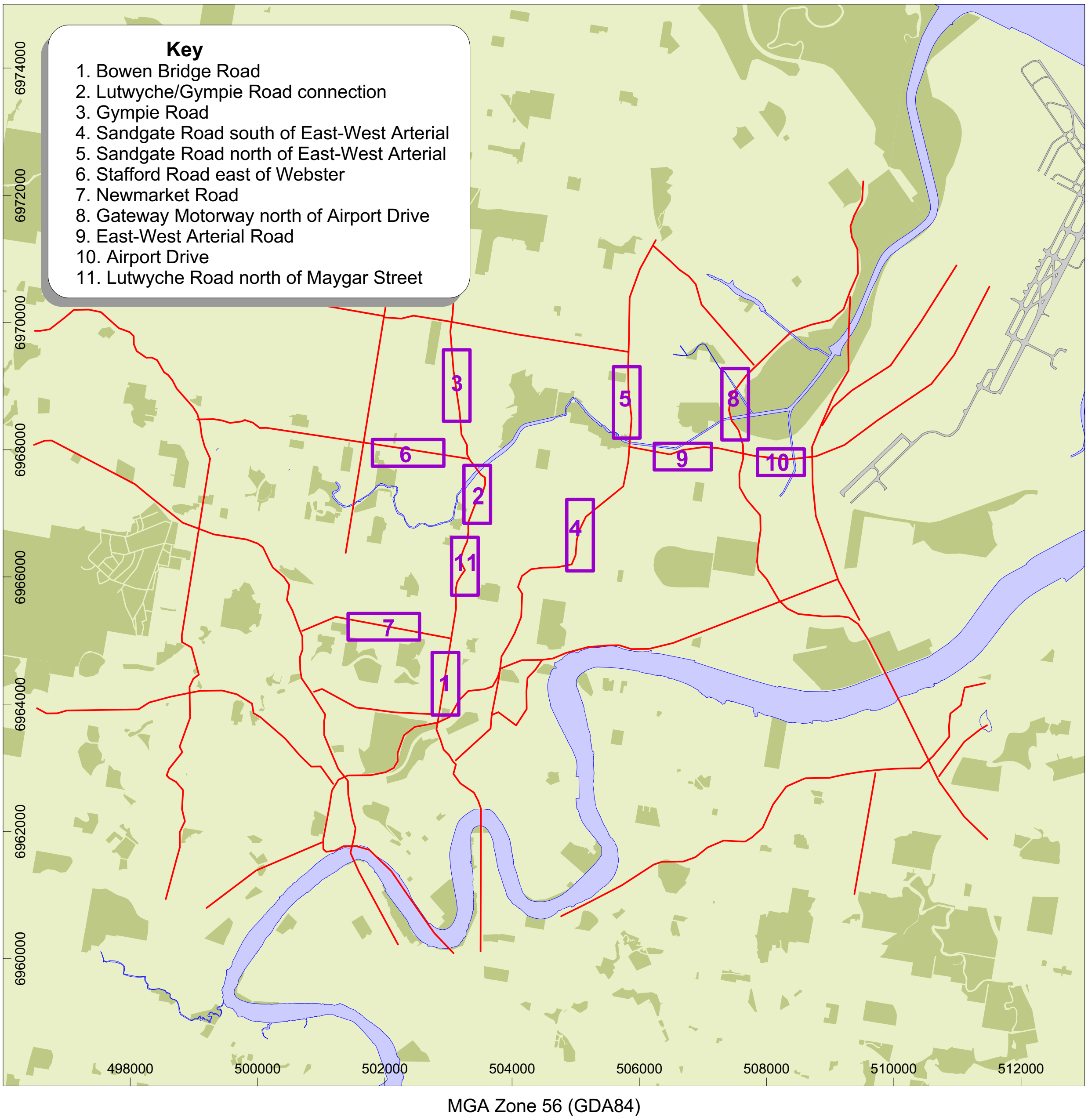
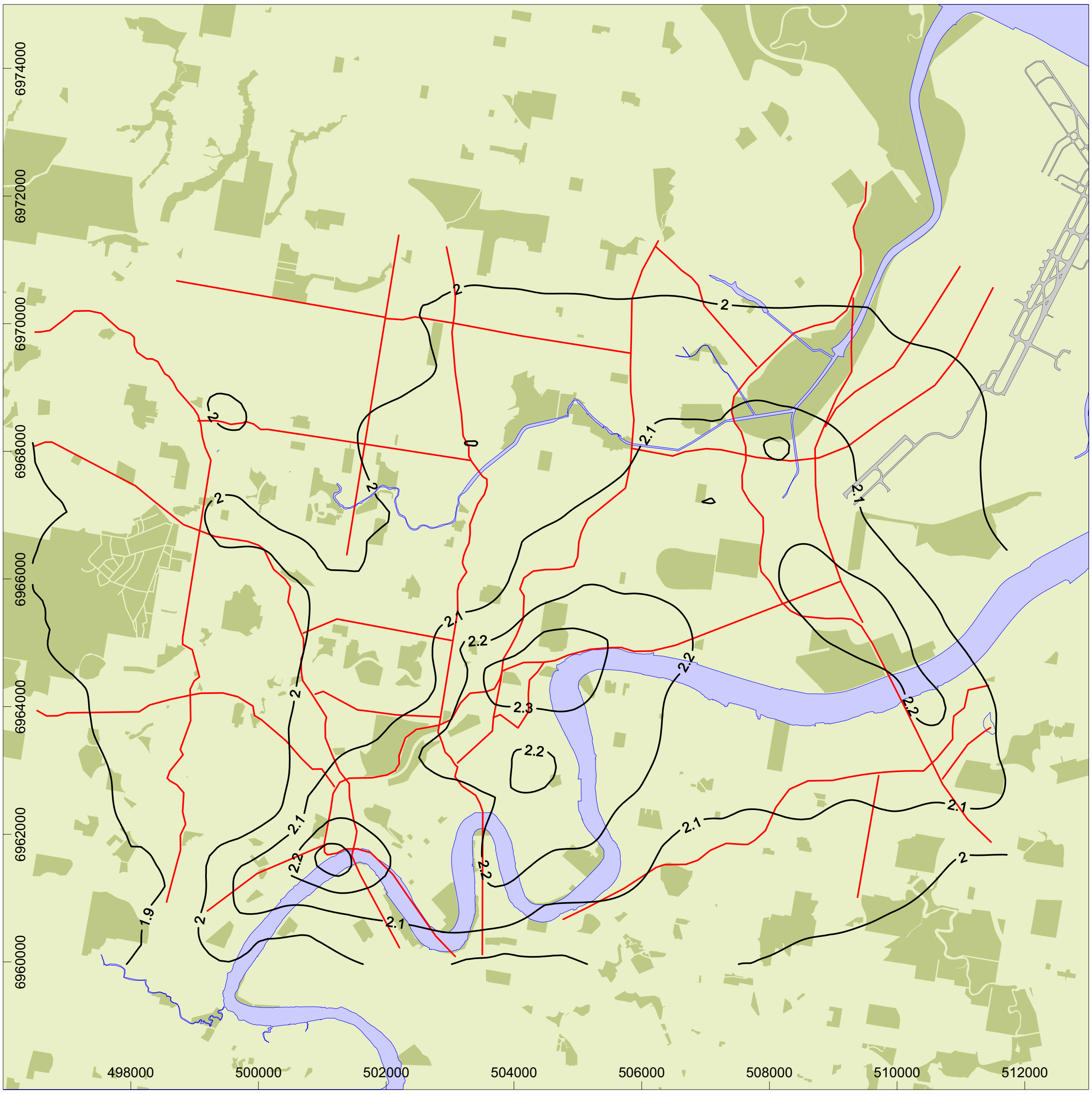

Correlation between CO concentrations and total NOx concentrations
South Brisbane
Linear line of best fit
Equation Y = 0.07825780505 * X + 0.0254
Number of data points used = 7528
Average X = 0.527843
Average Y = 0.0667309
Residual sum of squares = 5.22613
Regression sum of squares = 21.46
Coef of determination, R-squared = 0.804163
Hourly average CO concentrations (ppm)
Hourly average NOx concentration (ppm)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
1
2
3
4
5
6
7

FIGURE 18



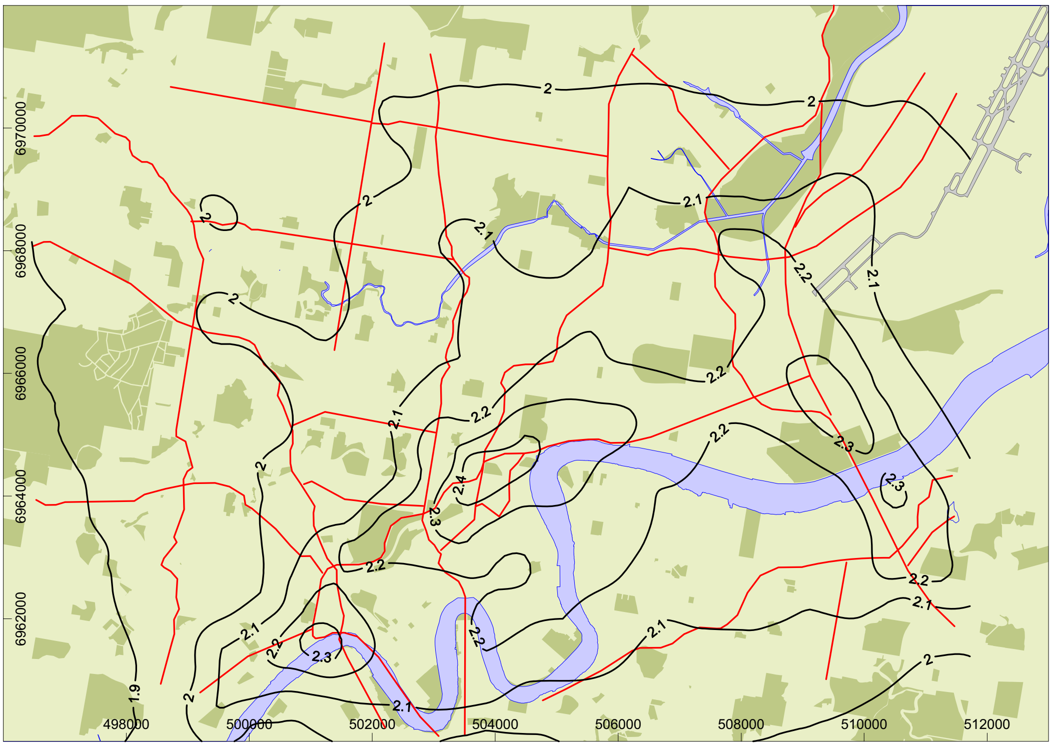
Road sections selected for the CALINE modelling



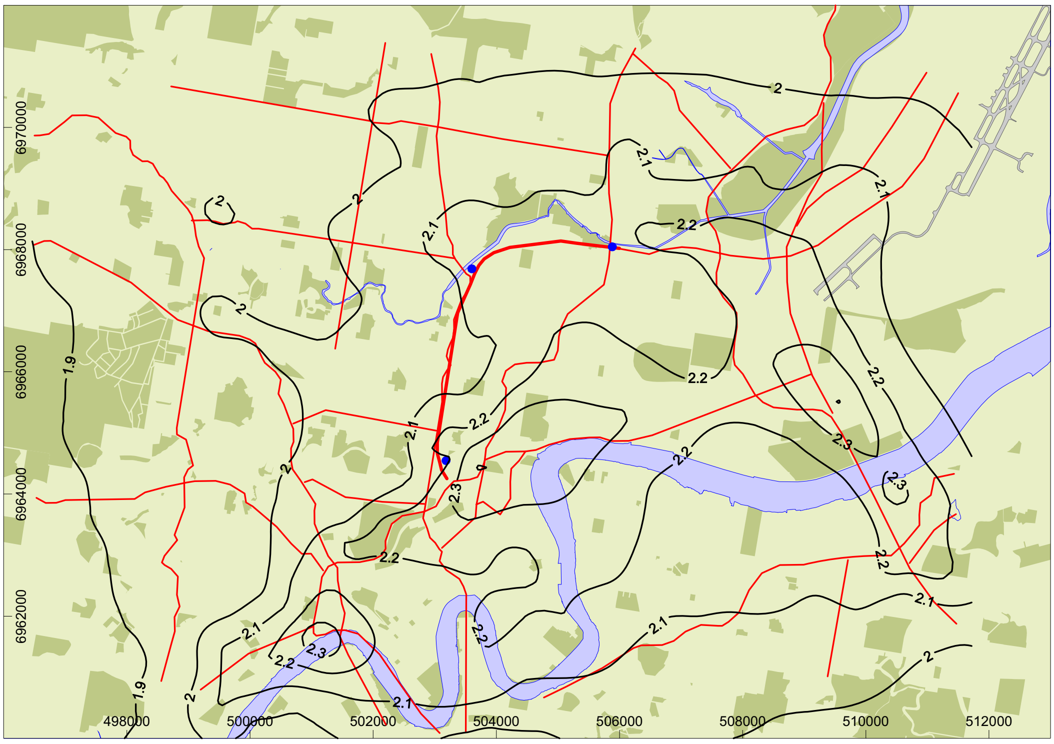
Existing

Predicted maximum 8-hour average CO concentrations in 2004 (mg/m^3)

FIGURE



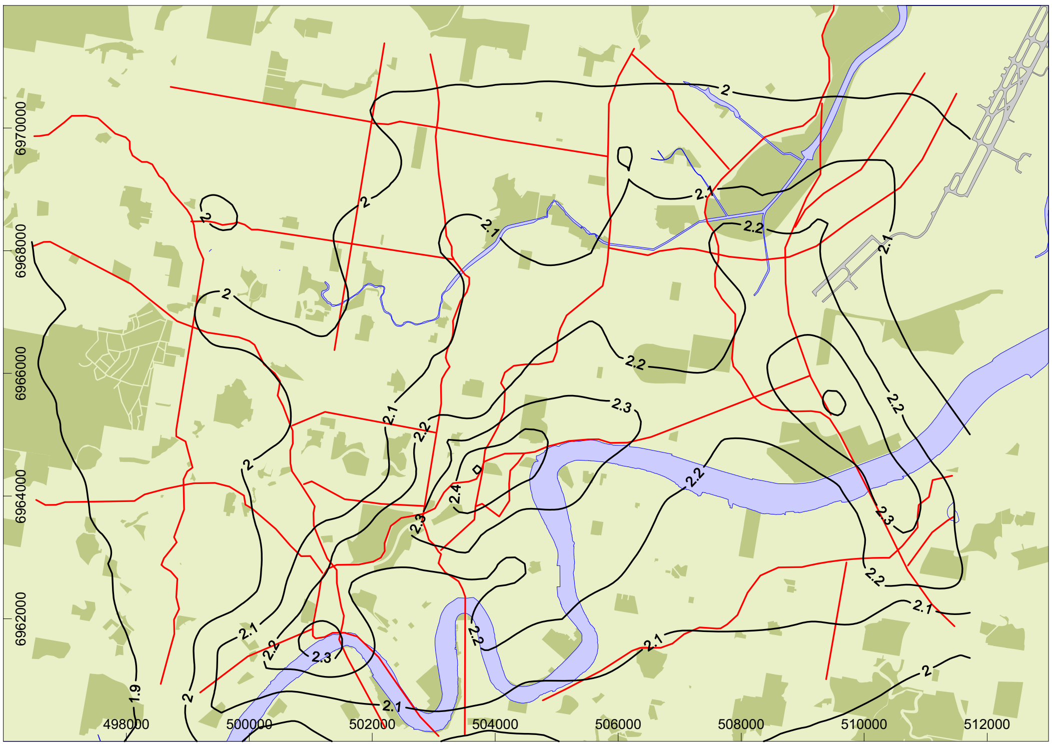
Without Airport Link



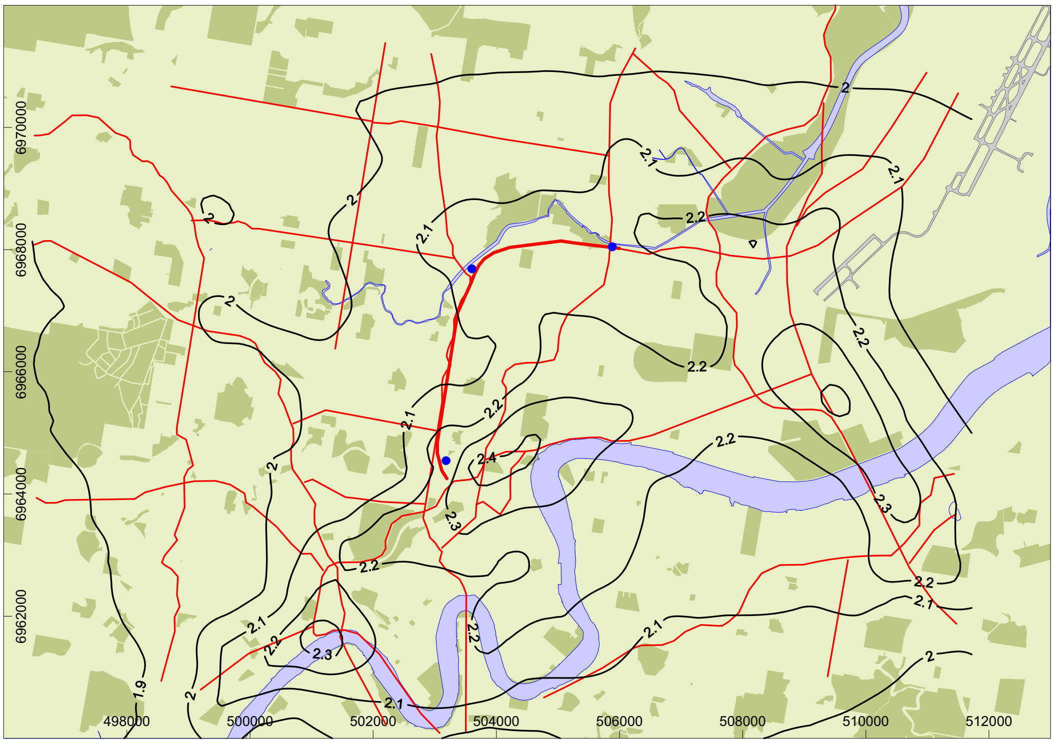
With Airport Link

Predicted maximum 8-hour average CO concentrations in 2012 (mg/m^3)

FIGURE 21



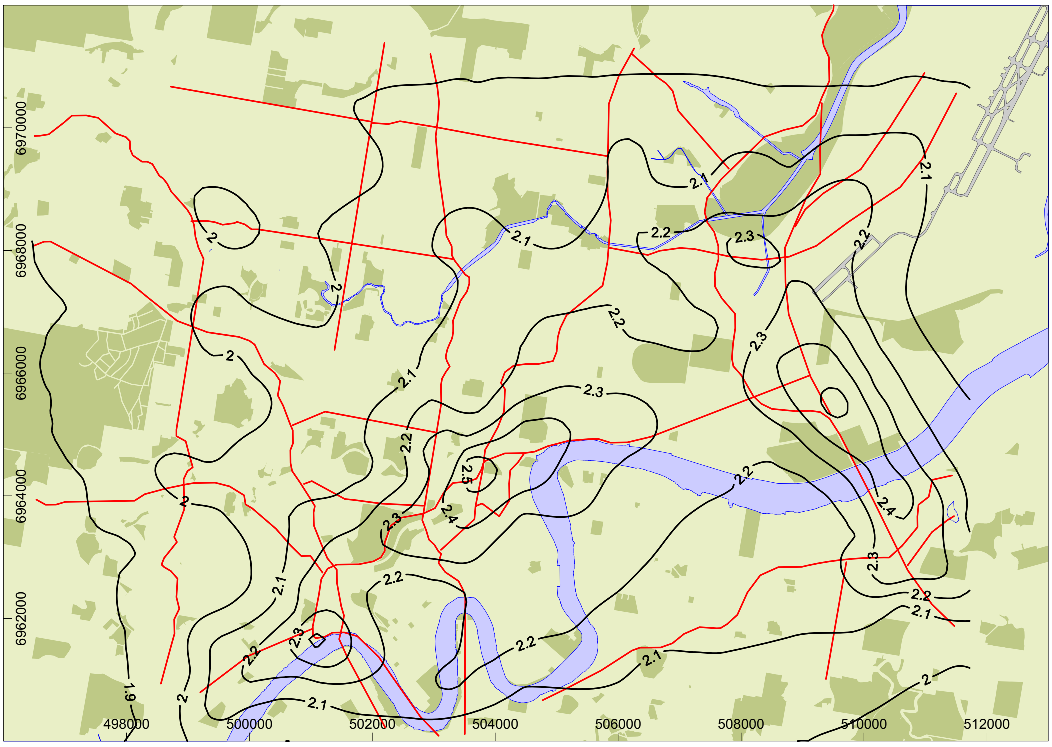
Without Airport Link



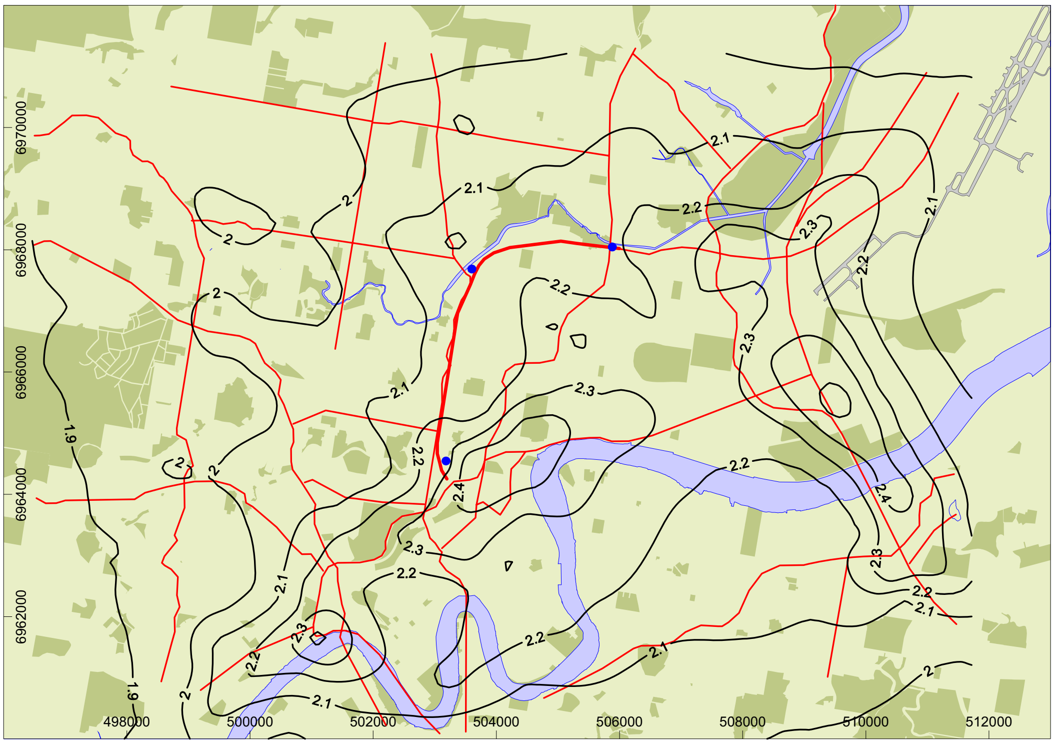
With Airport Link

Predicted maximum 8-hour average CO concentrations in 2016 (mg/m^3)

FIGURE



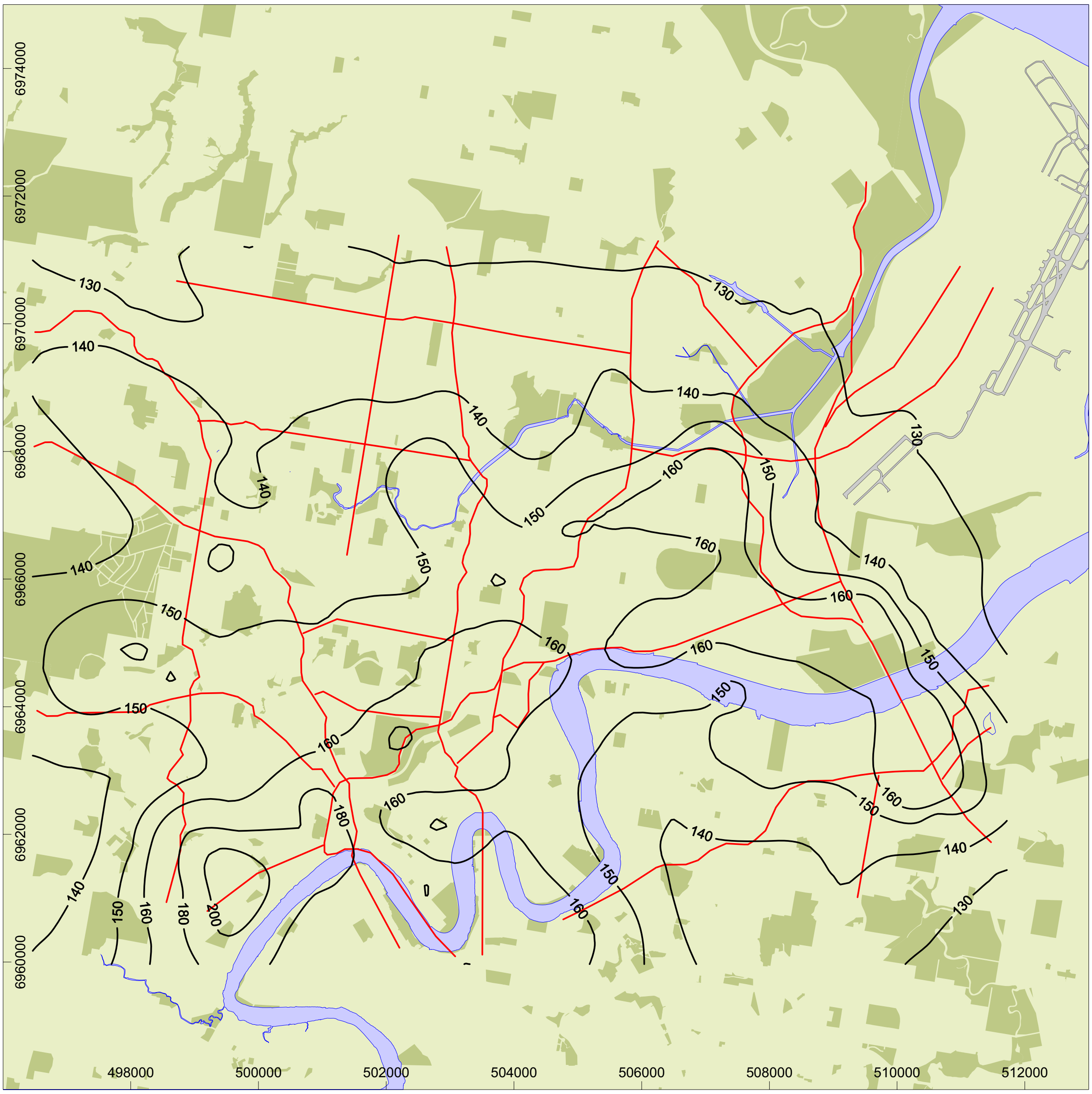
Without Airport Link



With Airport Link

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

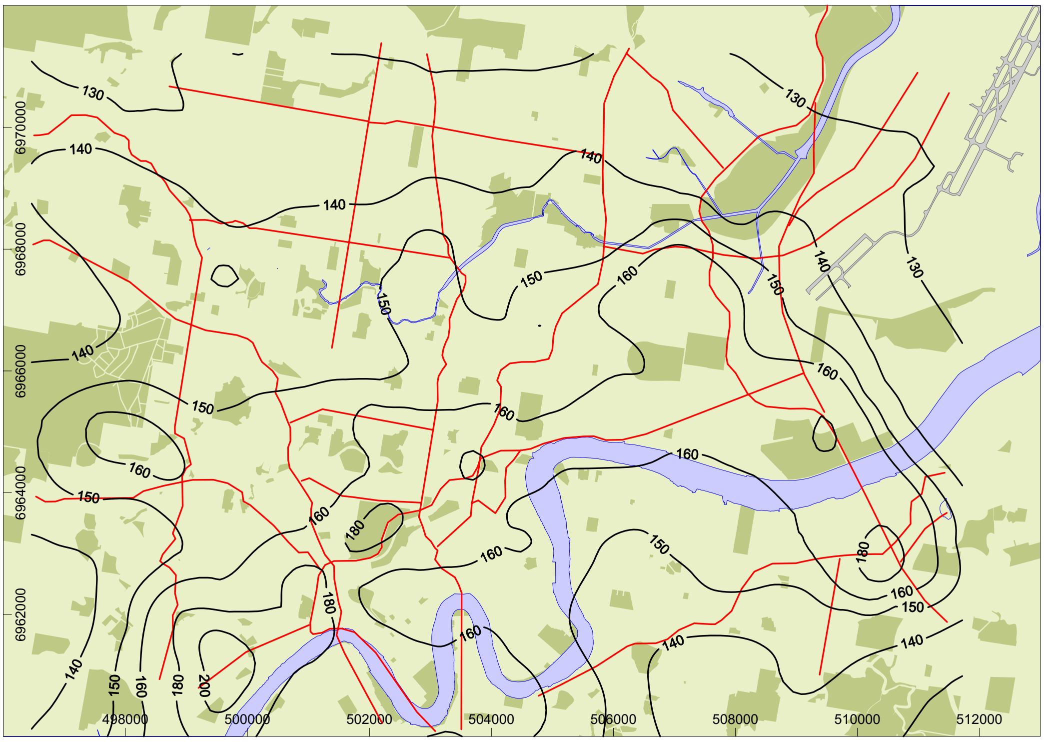
FIGURE 23



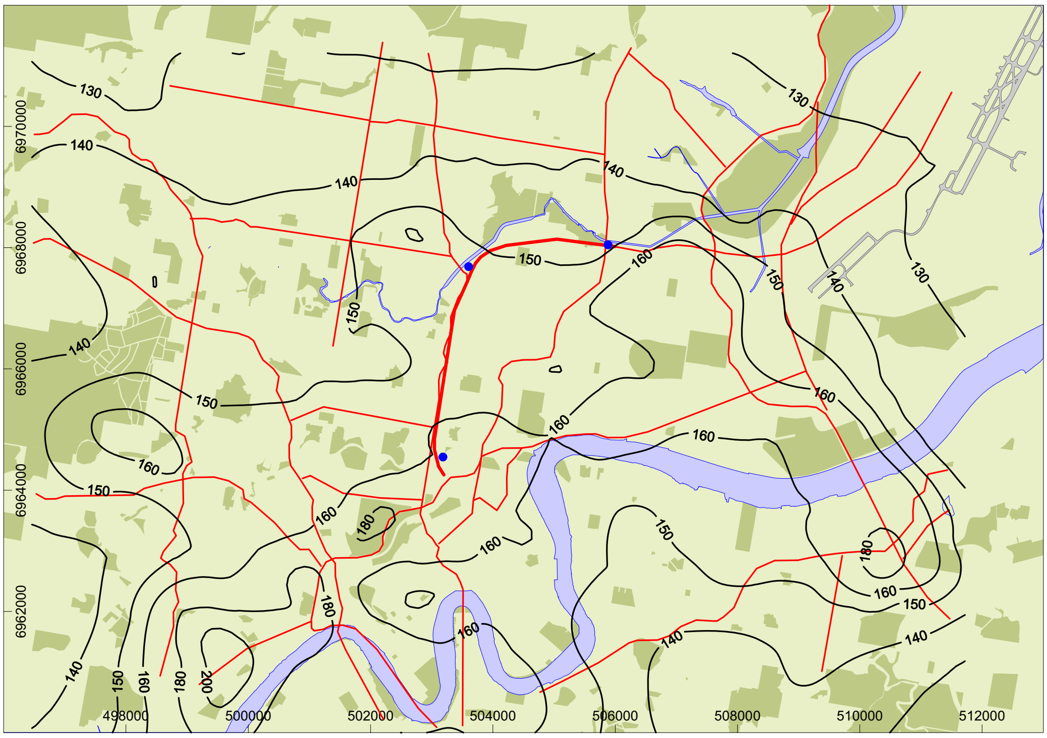
Existing

Predicted maximum 1-hour average NO_2 concentrations in 2004 (µg/m^3)

FIGURE 24



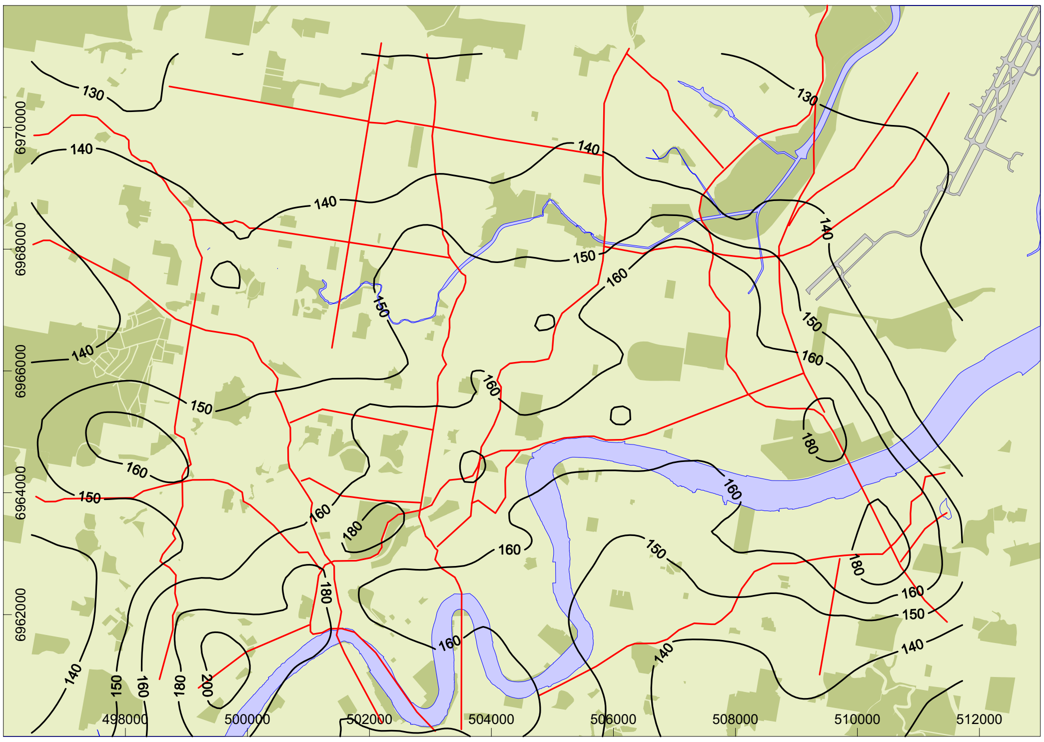
Without Airport Link



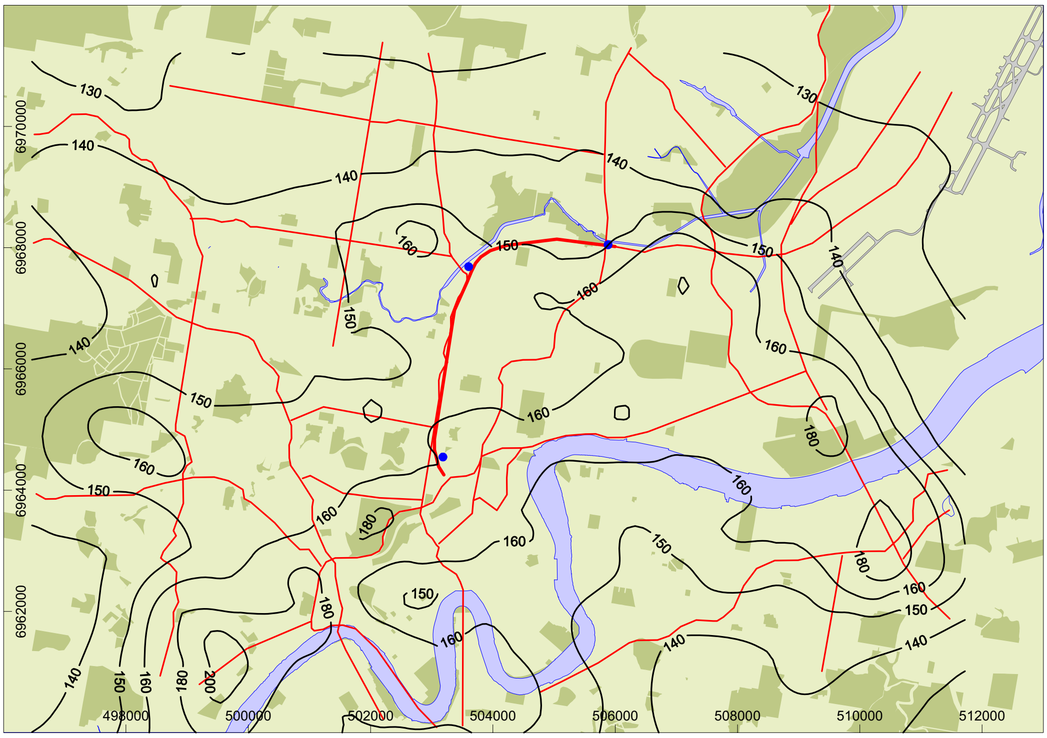
With Airport Link

Predicted maximum 1-hour average NO_2 concentrations in 2012 (µg/m^3)

FIGURE 25

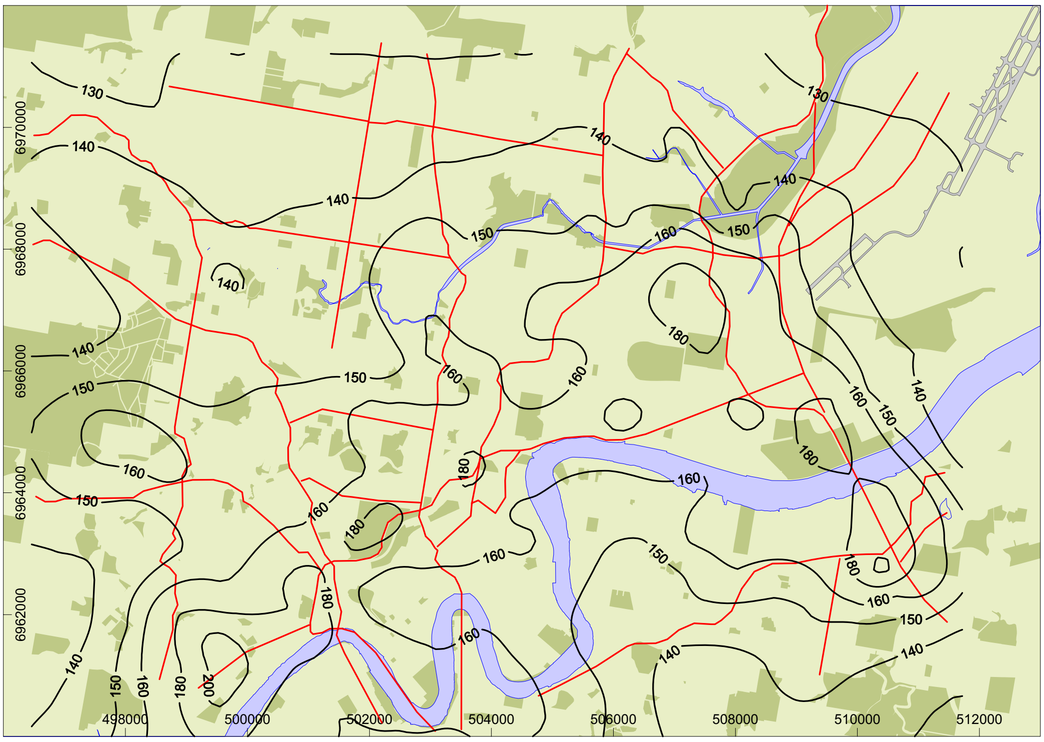


Without Airport Link

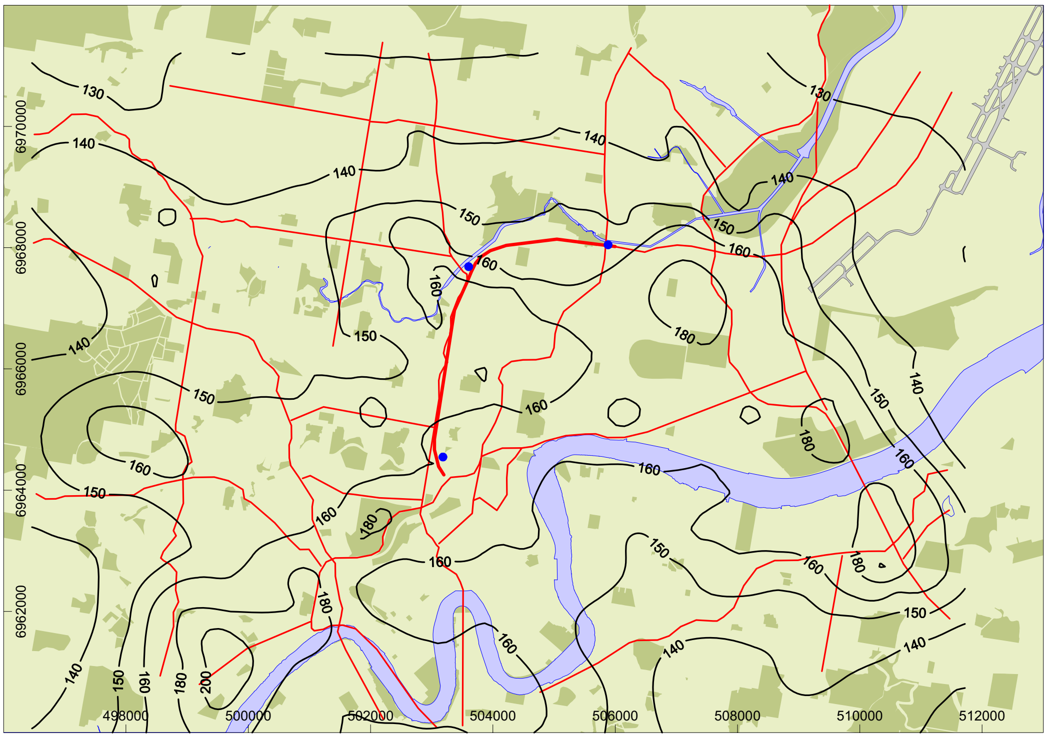


With Airport Link

Predicted maximum 1-hour average NO_2 concentrations in 2016 (µg/m^3)

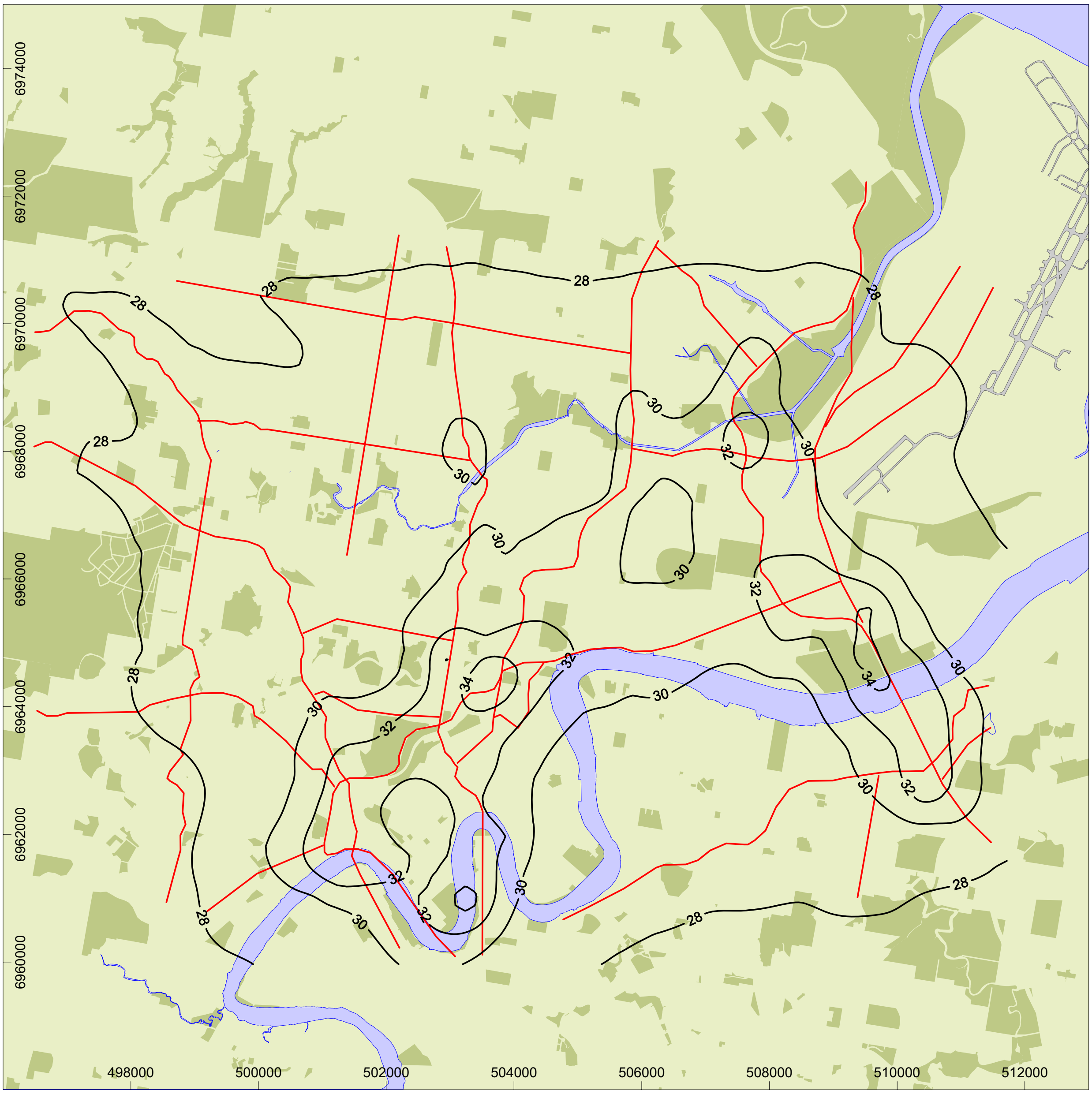


Without Airport Link



With Airport Link

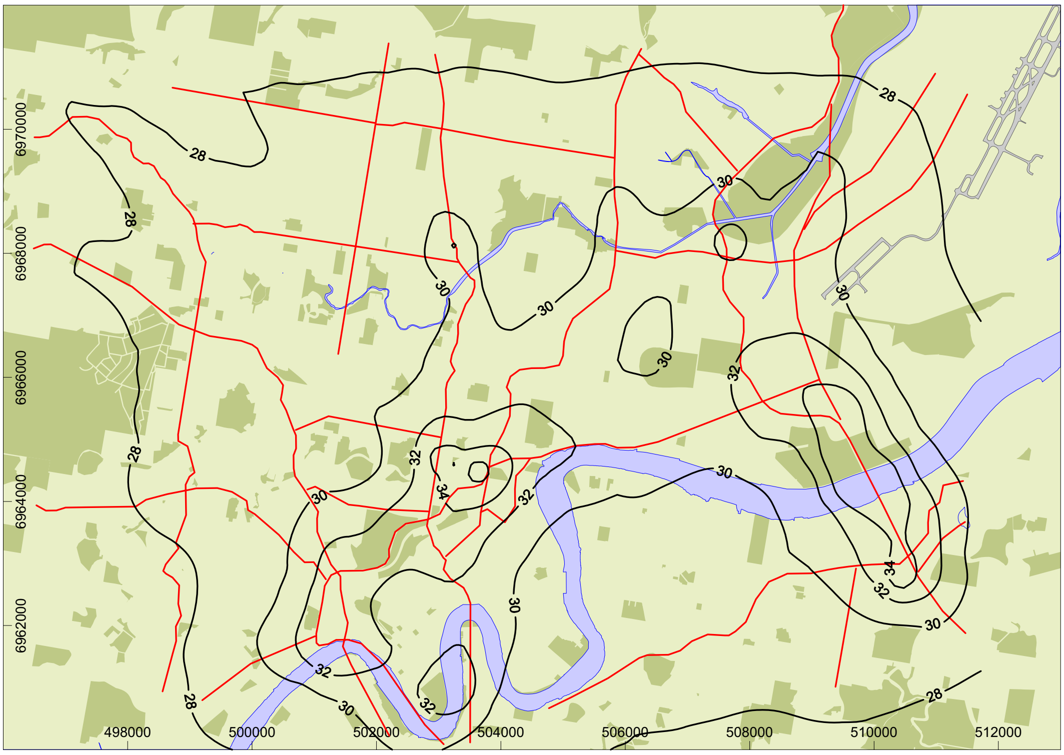
Predicted maximum 1-hour average NO_2 concentrations in 2026 (µg/m^3)



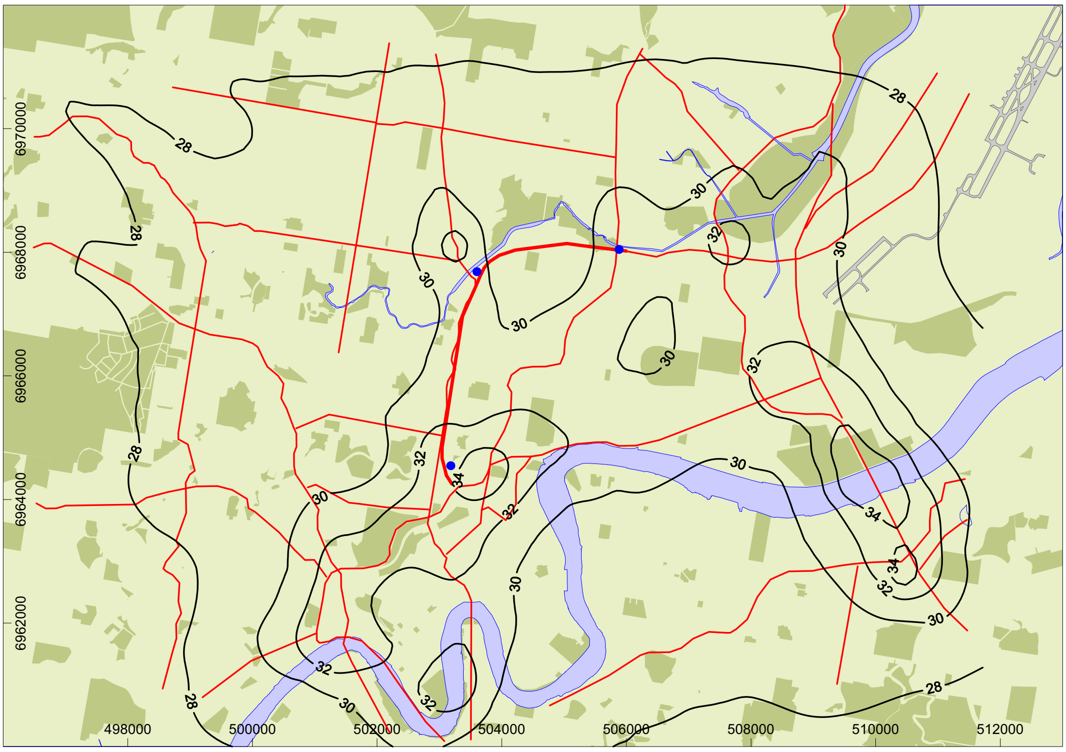
Existing

Predicted annual average NO_2 concentrations in 2004 ($\mu g/m^3$)

FIGURE 28

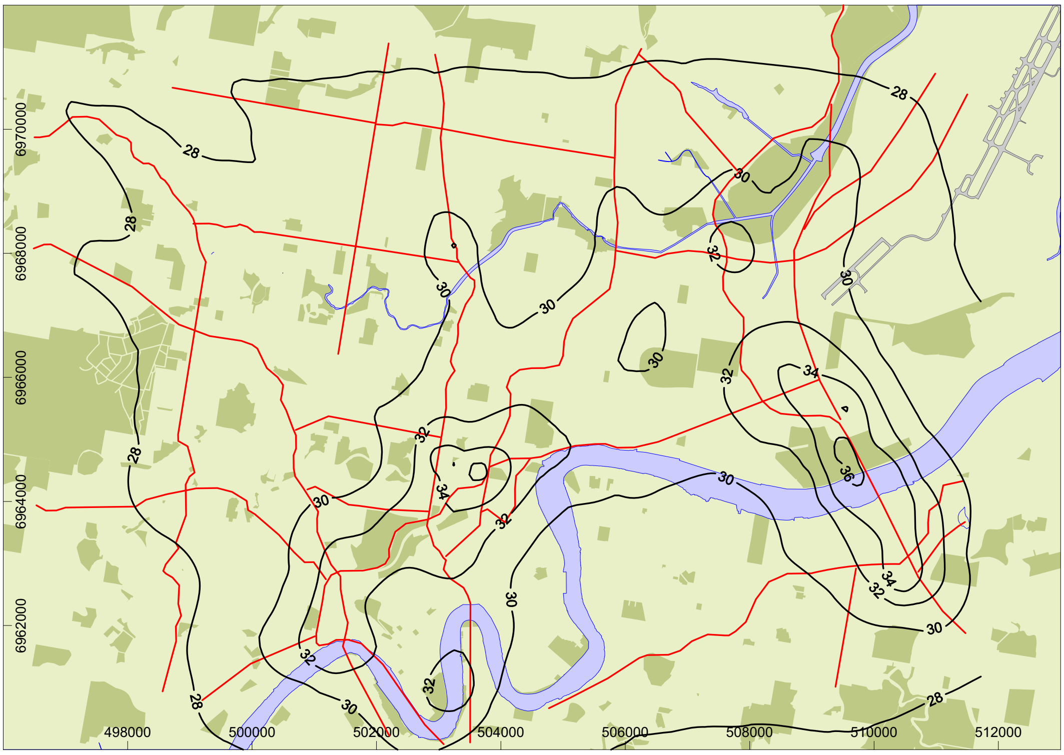


Without Airport Link

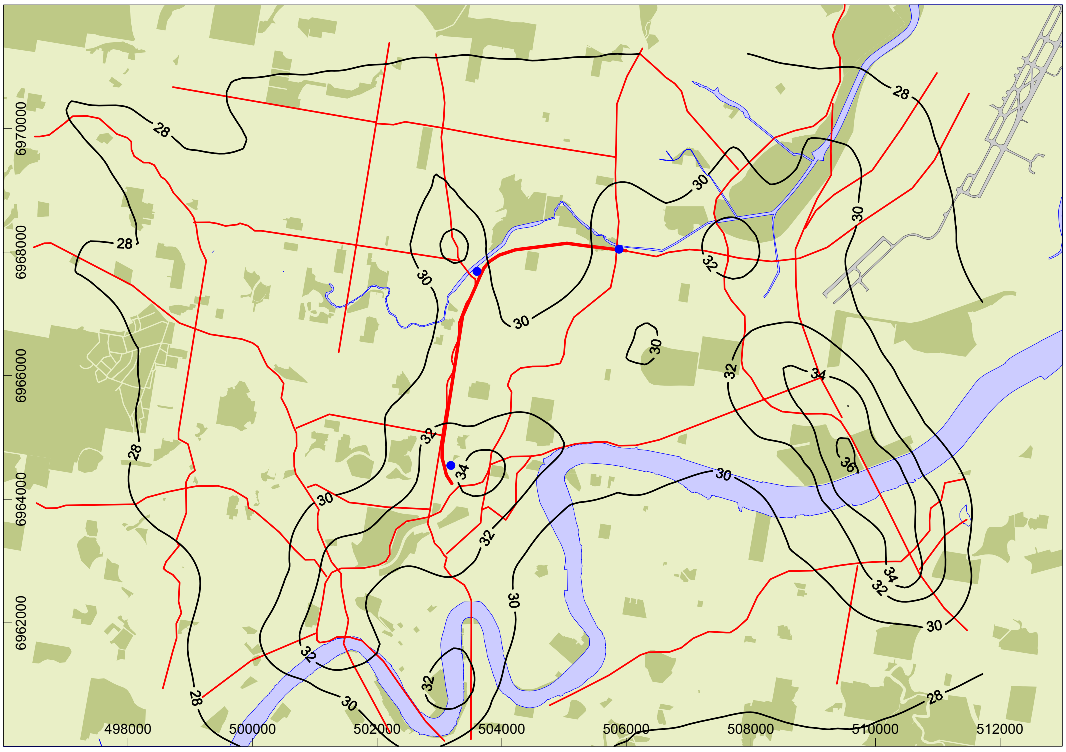


With Airport Link

Predicted annual average NO_2 concentrations in 2012 (µg/m^3)



Without Airport Link

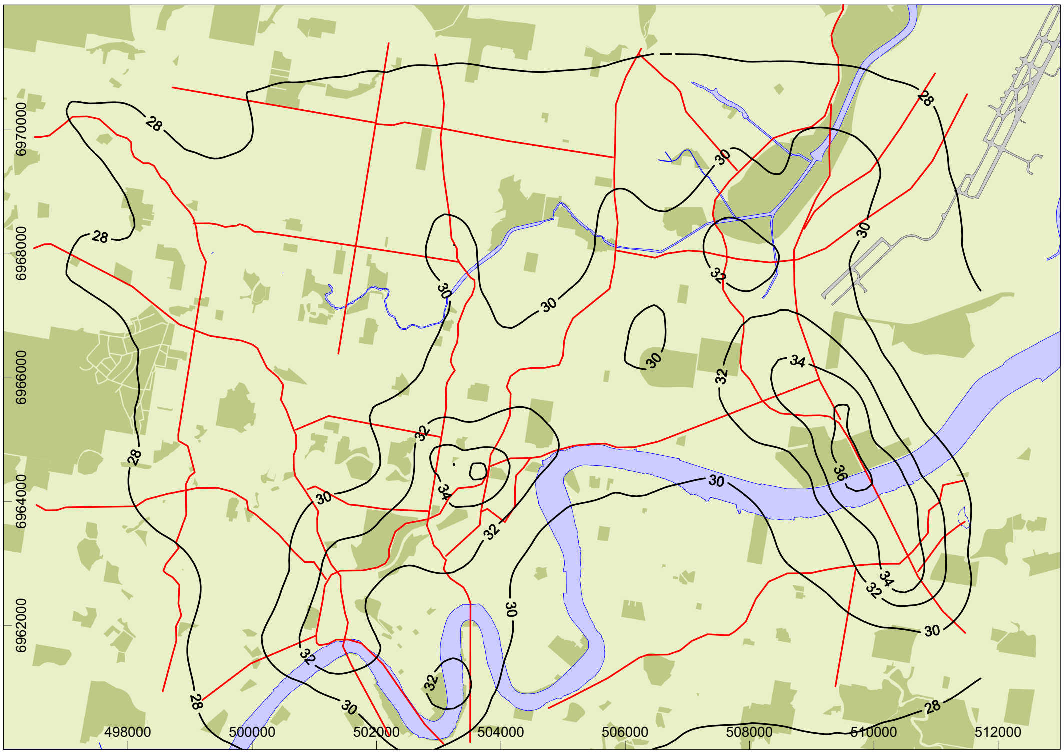


With Airport Link

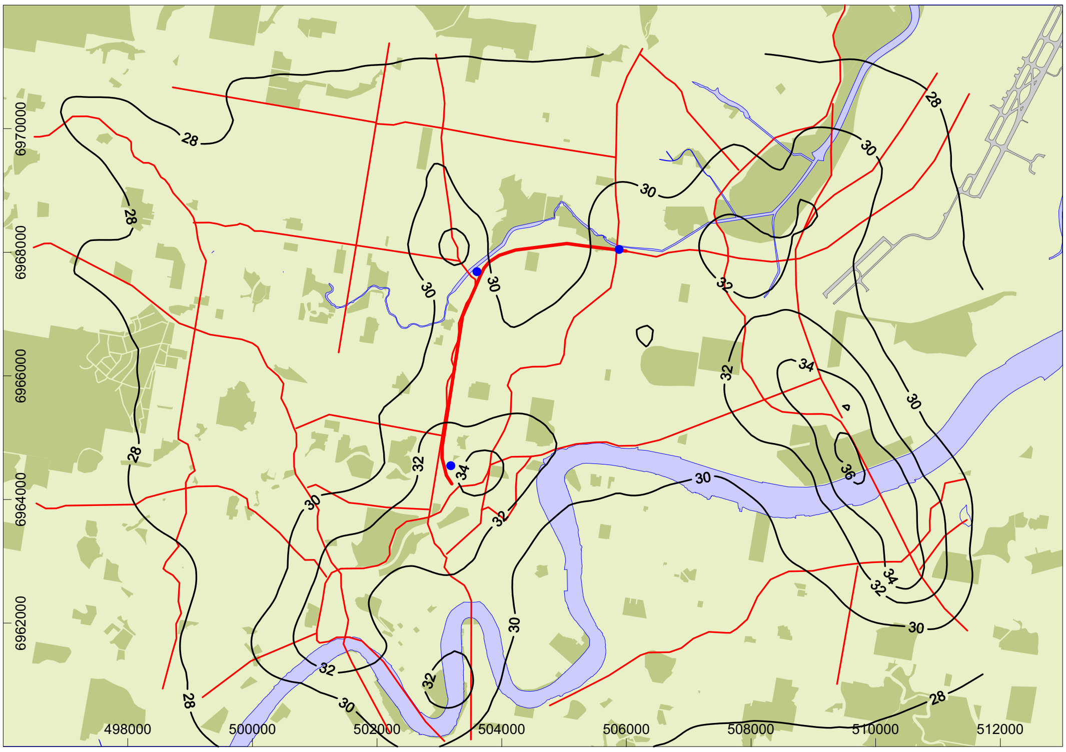
Predicted annual average NO_2 concentrations in 2016 (μg/m^3)

FIGURE

30

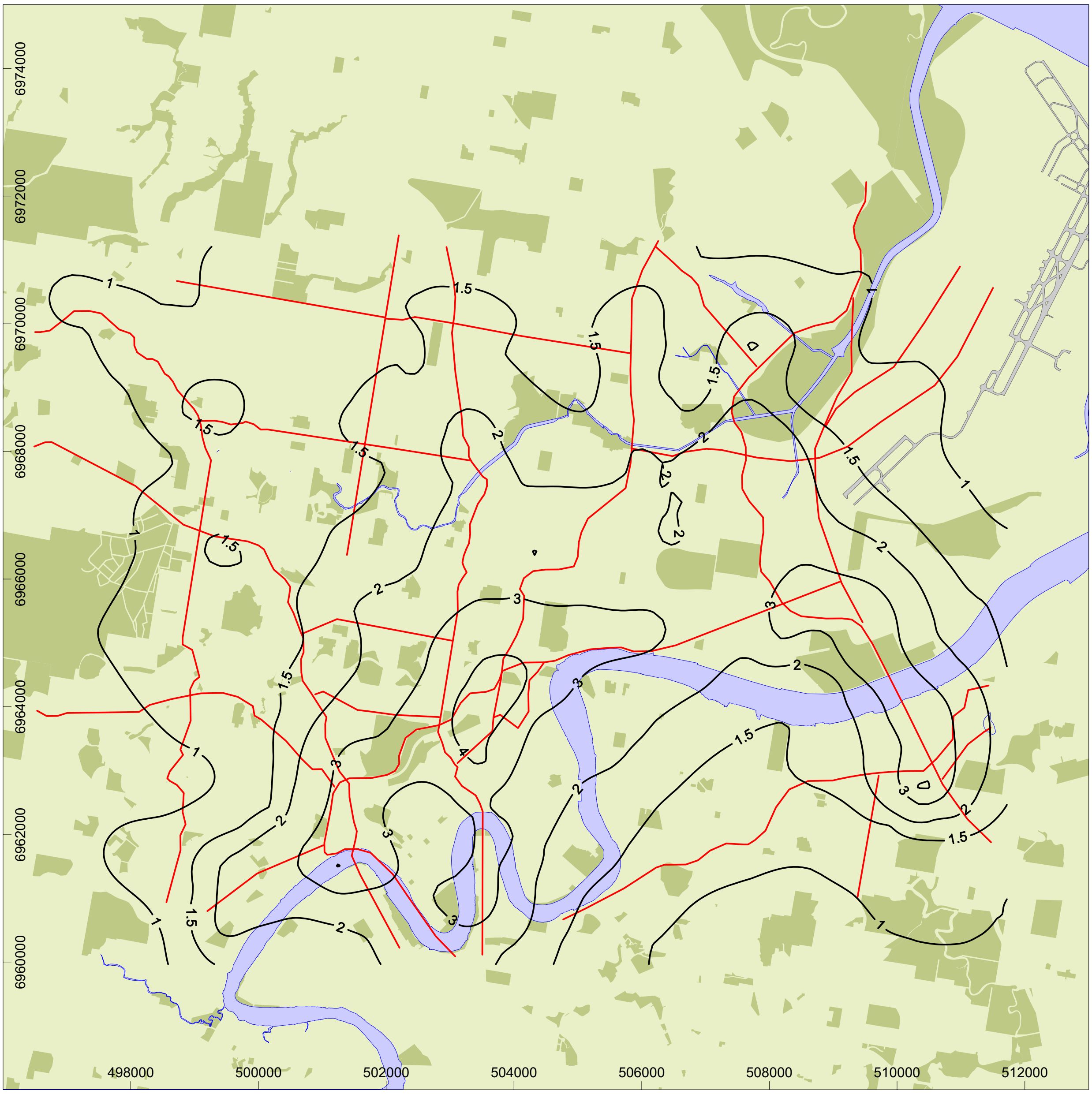


Without Airport Link



With Airport Link

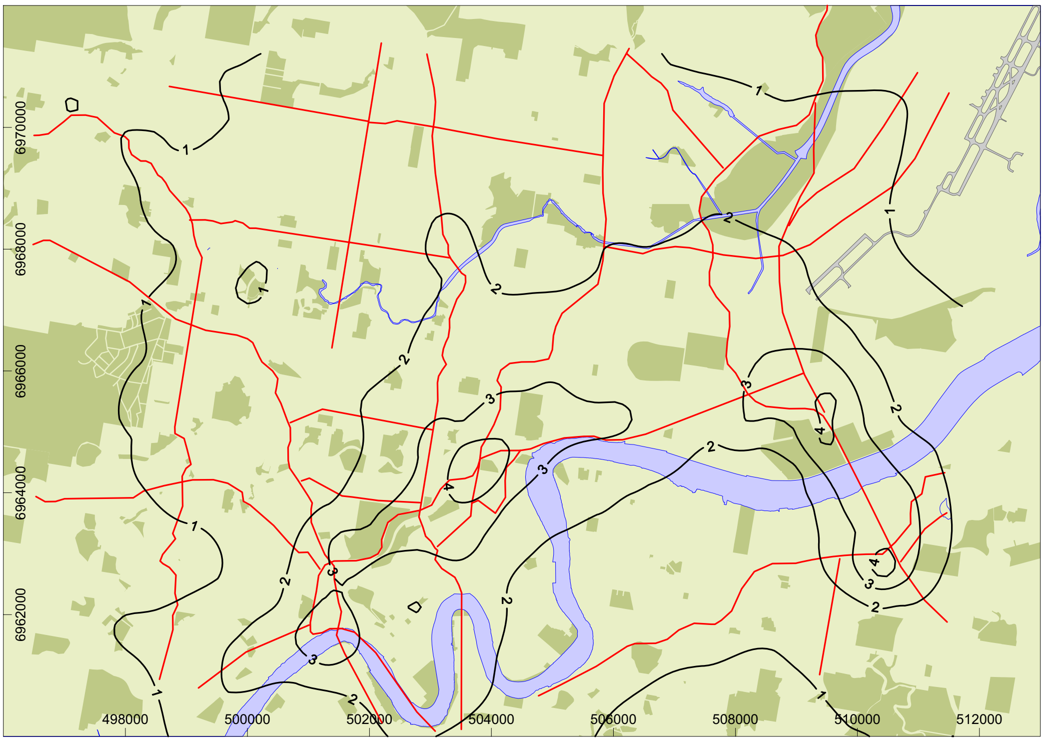
Predicted annual average NO_2 concentrations in 2026 (µg/m^3)



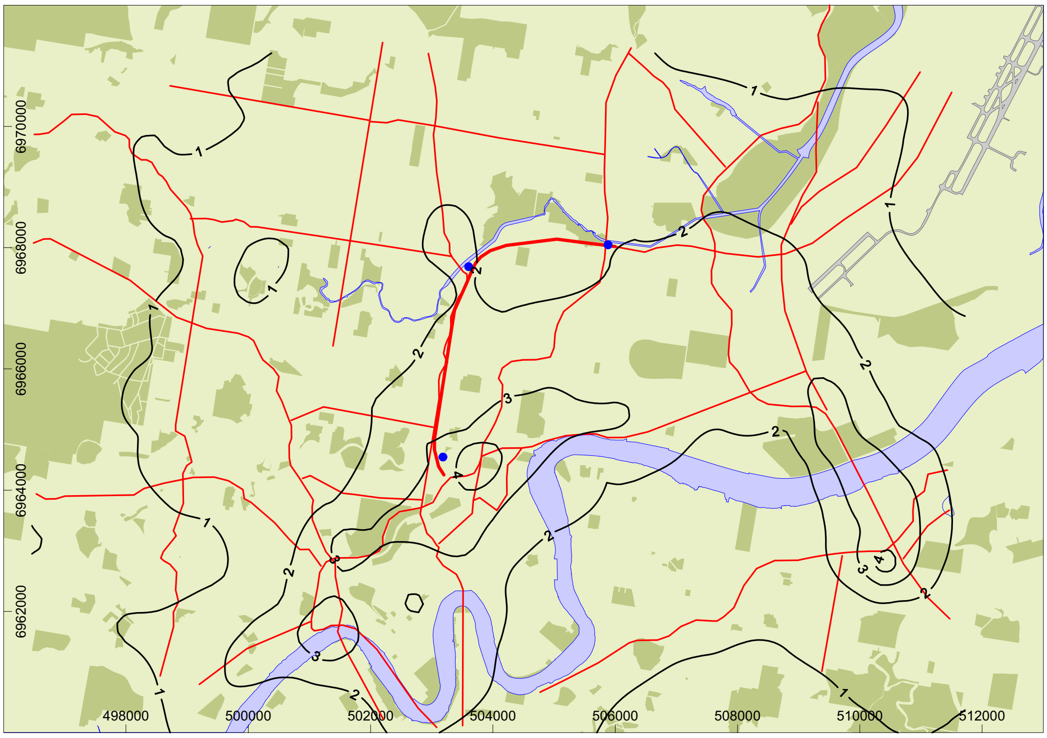
Existing

Predicted maximum 24-hour average PM_{10} concentrations in 2004 (µg/m^3)

FIGURE 32

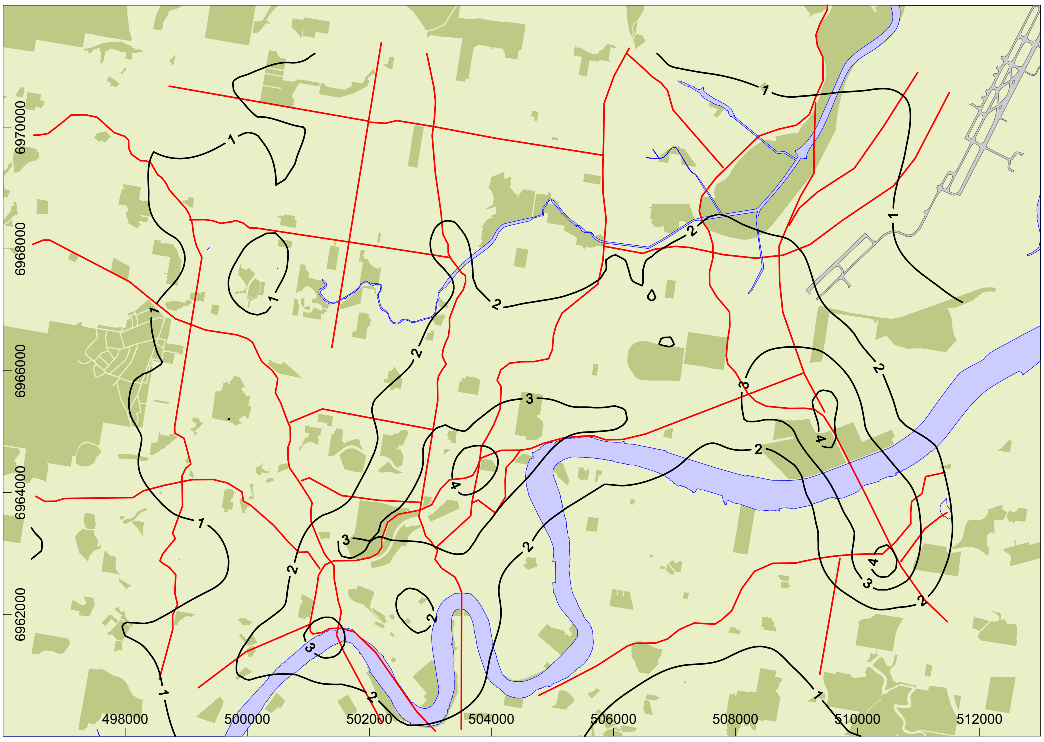


Without Airport Link

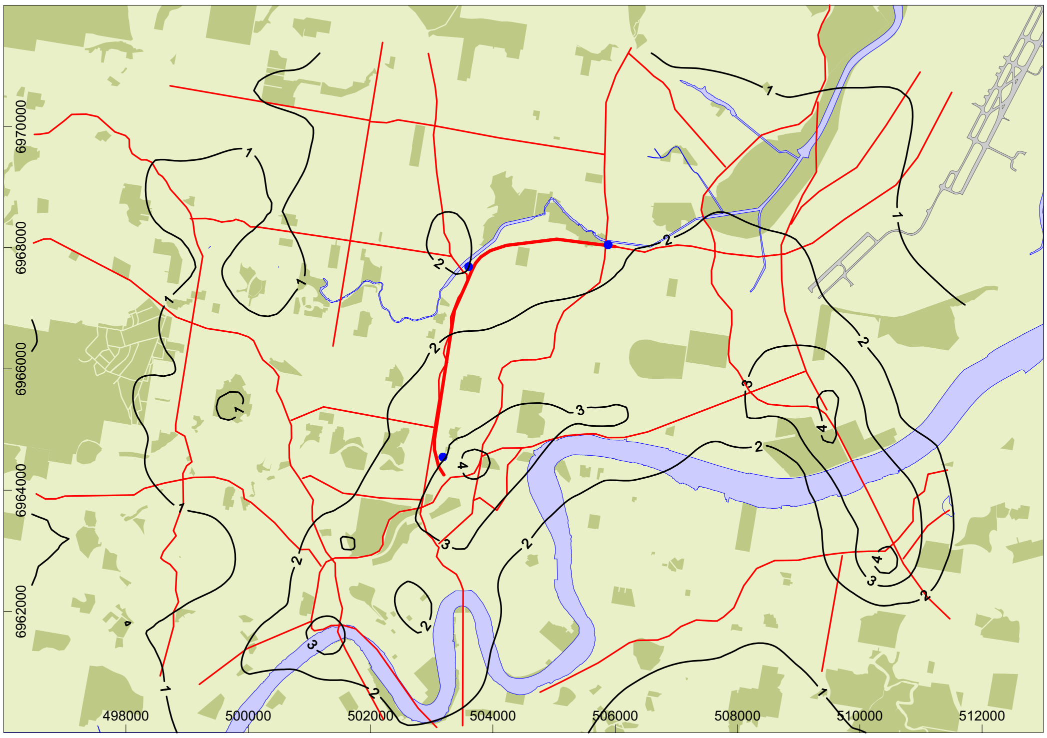


With Airport Link

Predicted maximum 24-hour average PM_{10} concentrations in 2012 ($\mu g/m^3$)



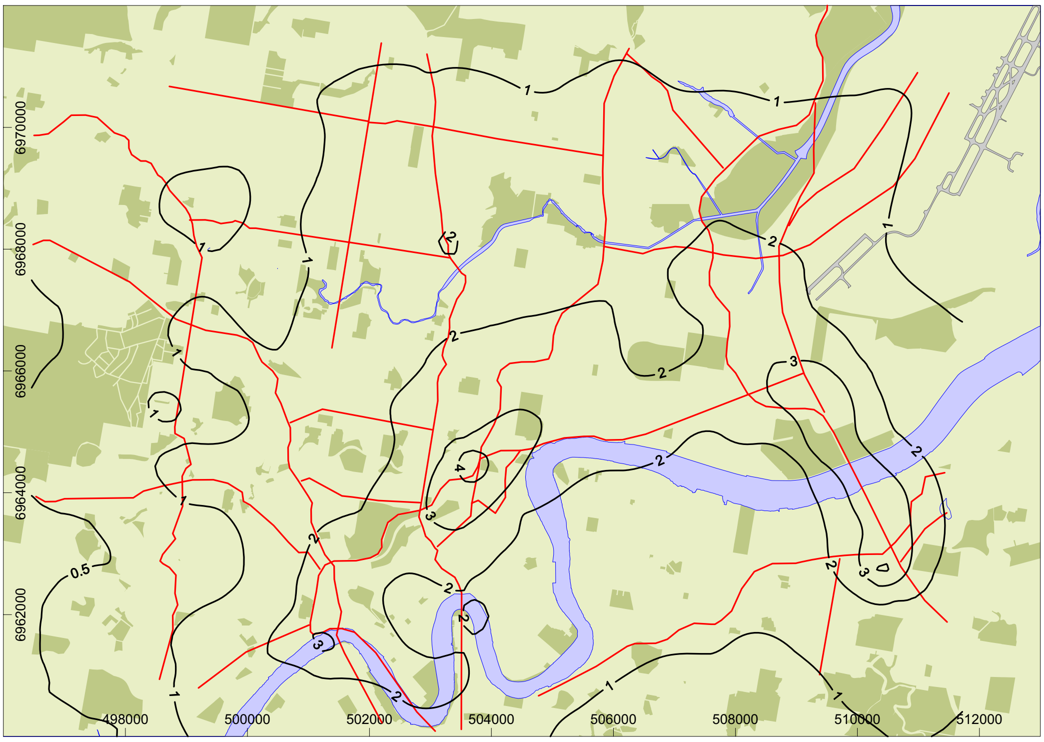
Without Airport Link



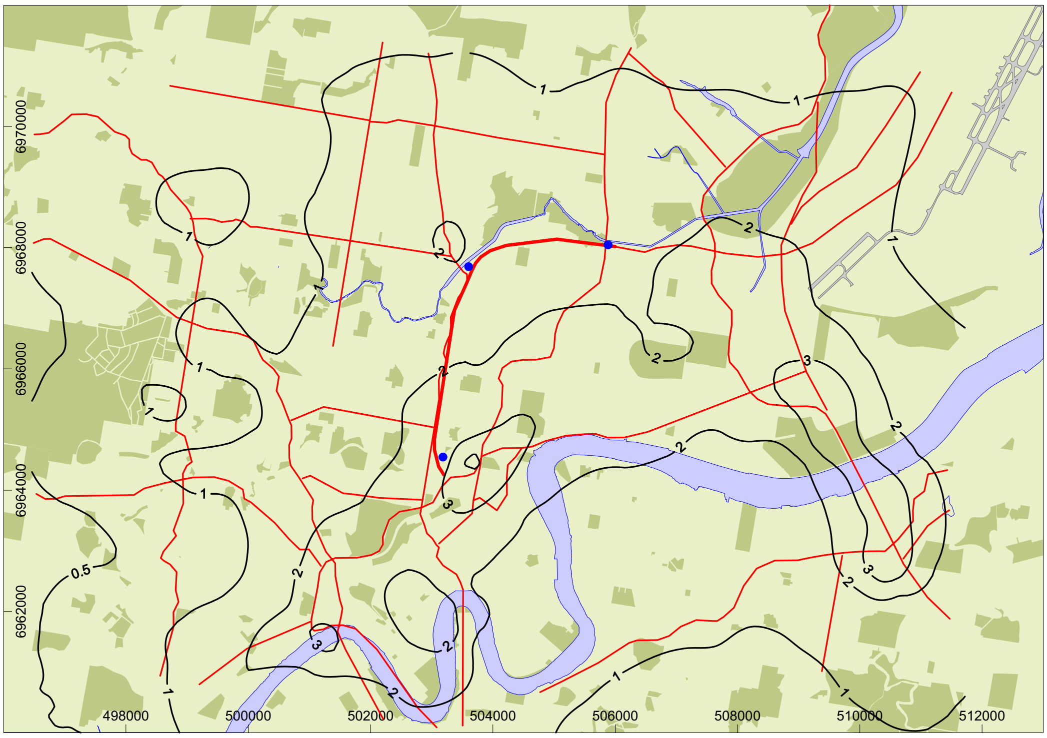
With Airport Link

Predicted maximum 24-hour average PM_{10} concentrations in 2016 ($\mu g/m^3$)

FIGURE 34



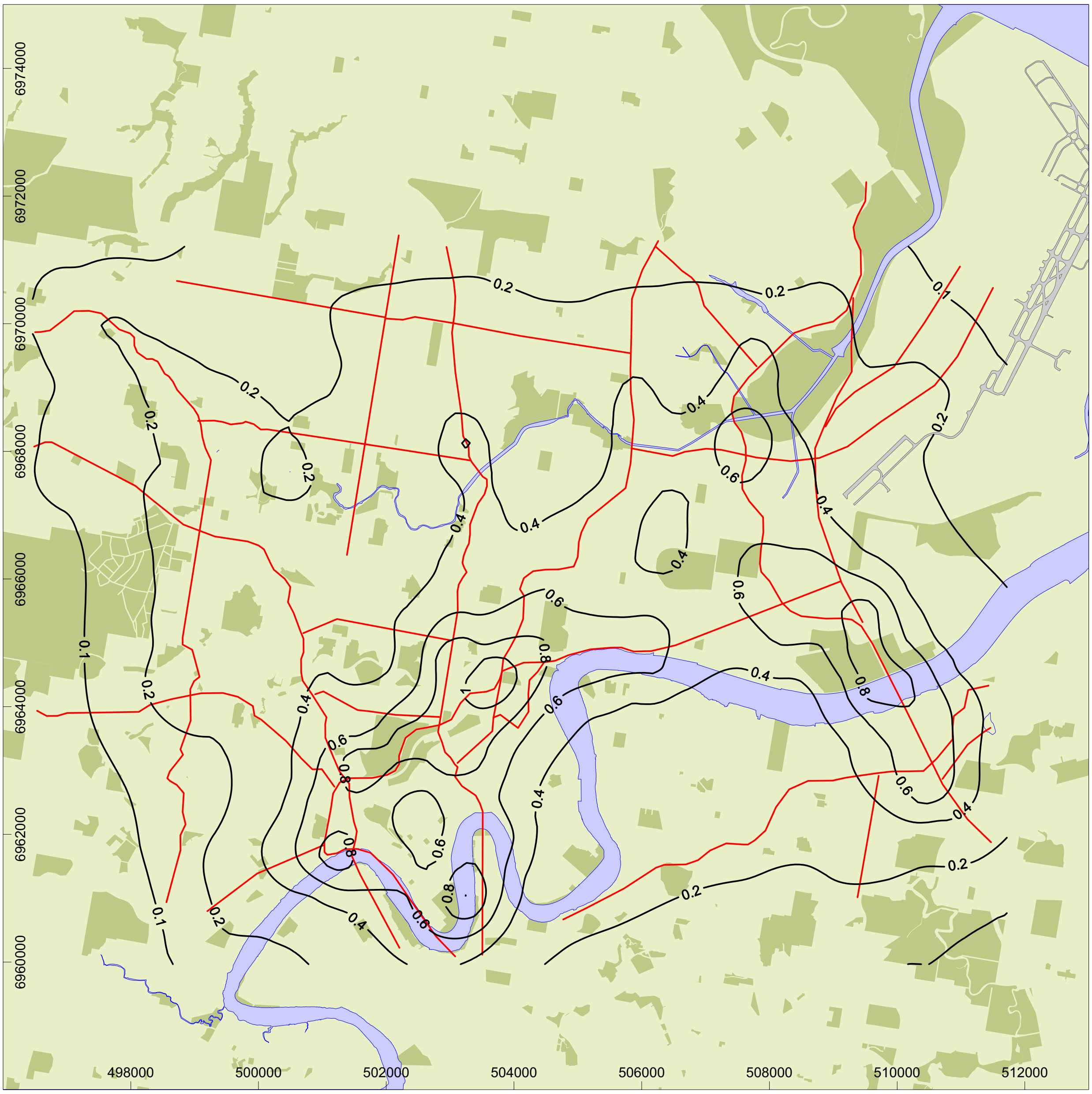
Without Airport Link



With Airport Link

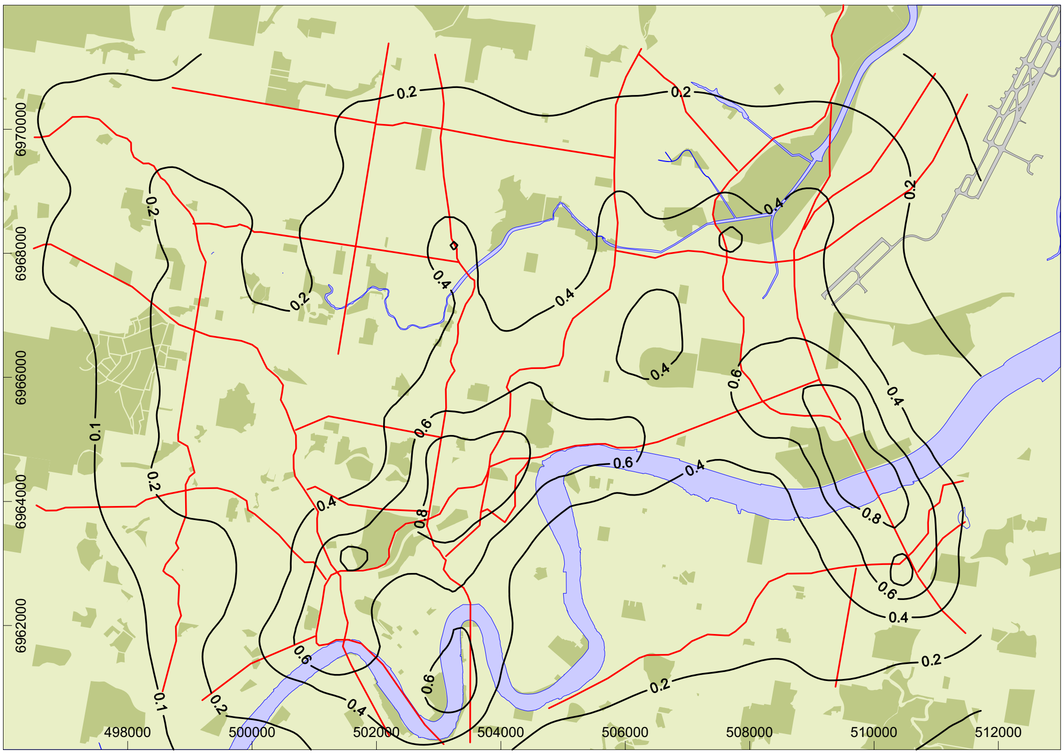
Predicted maximum 24-hour average PM_{10} concentrations in 2026 ($\mu g/m^3$)

FIGURE 35

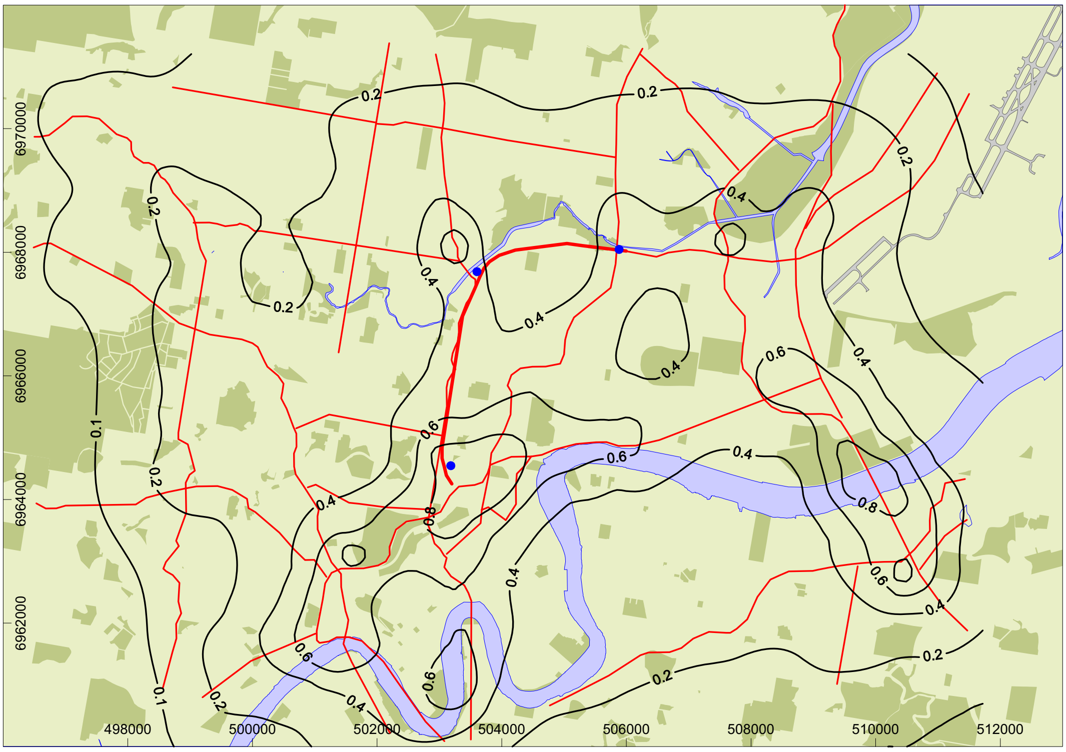


Existing

Predicted annual average PM_{10} concentrations in 2004 ($\mu g/m^3$)

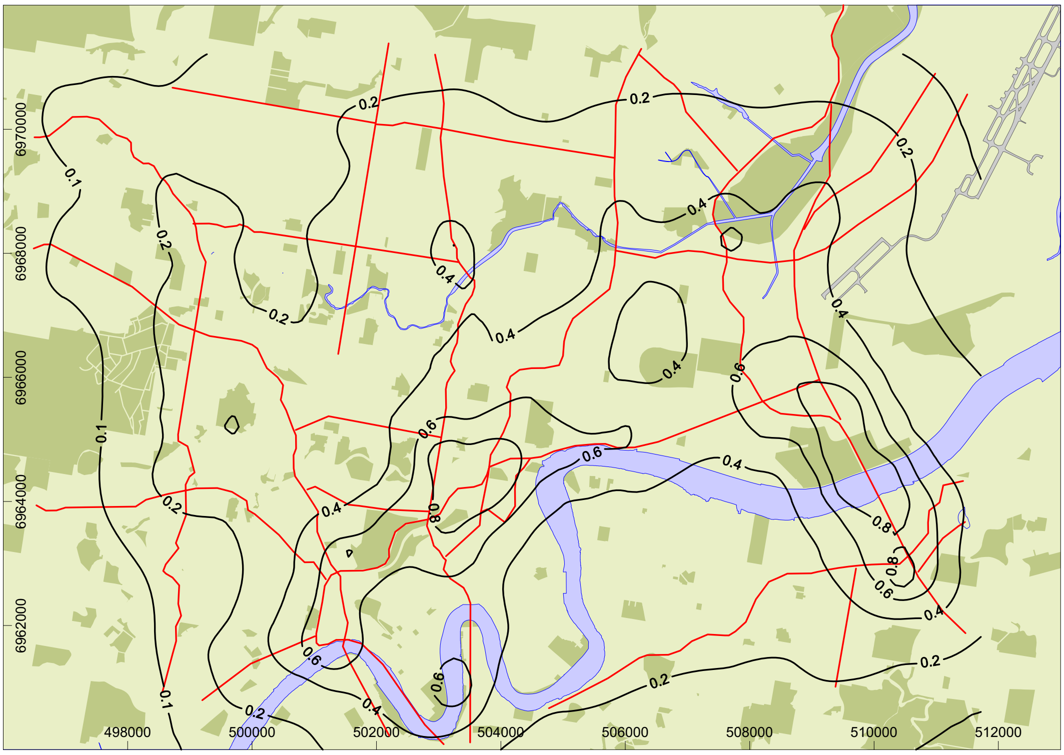


Without Airport Link

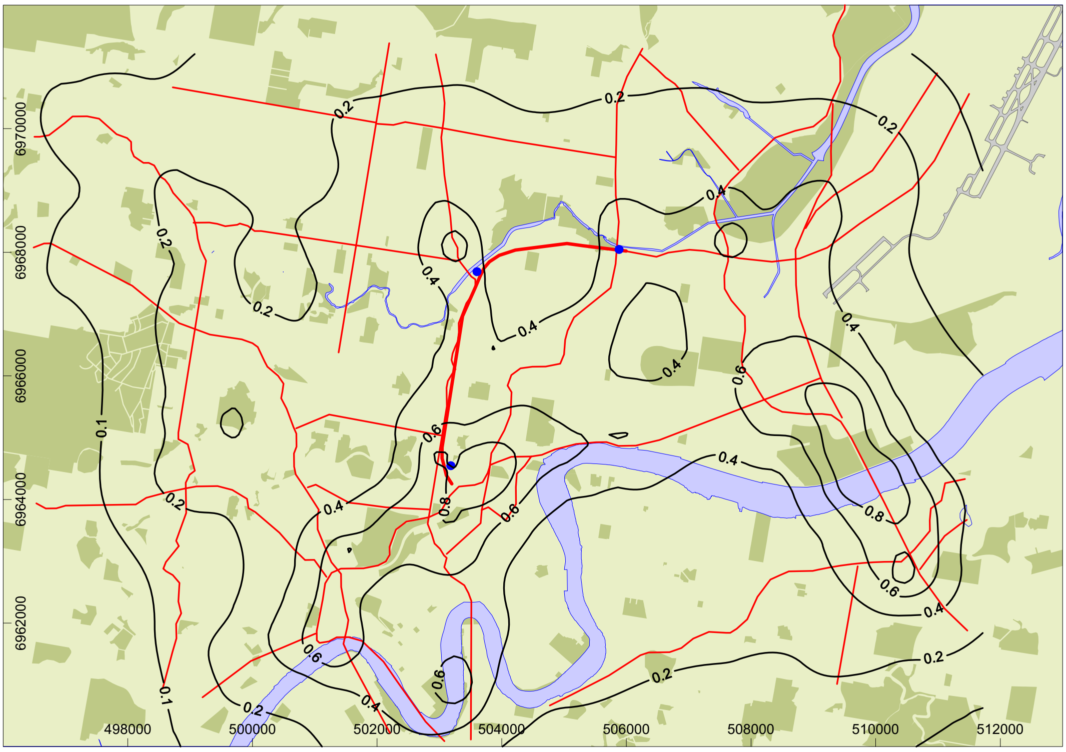


With Airport Link

Predicted annual average PM$_{10}$ concentrations in 2012 (µg/m^3)



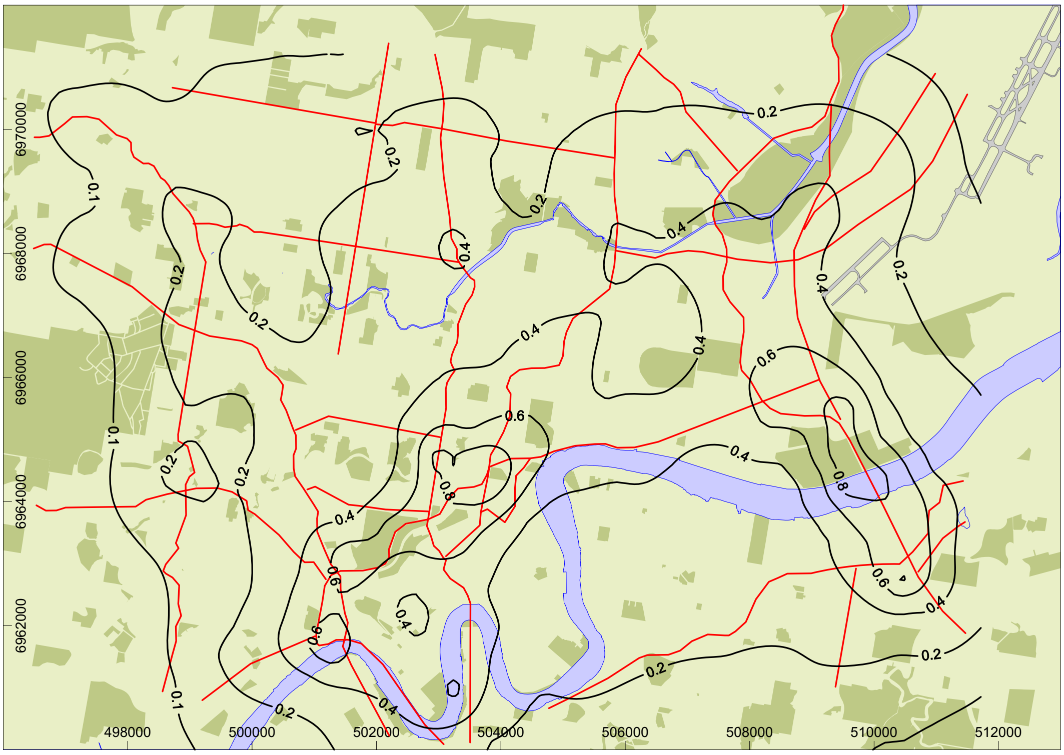
Without Airport Link



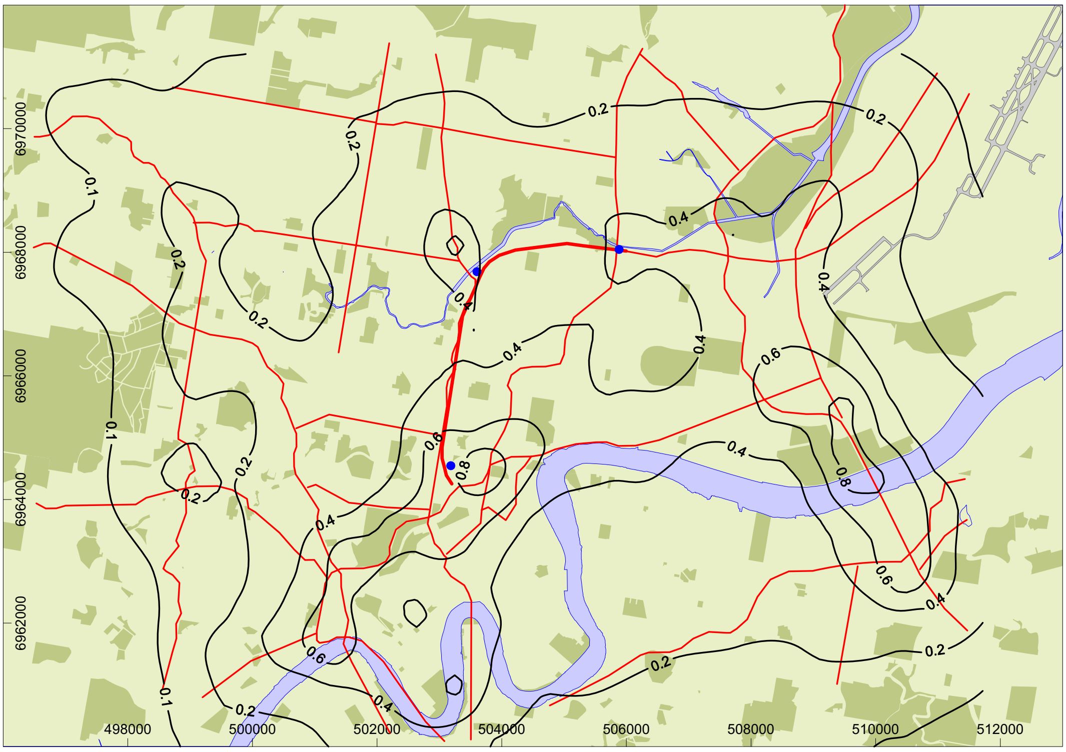
With Airport Link

Predicted annual average PM_{10} concentrations in 2016 ($\mu g/m^3$)

FIGURE



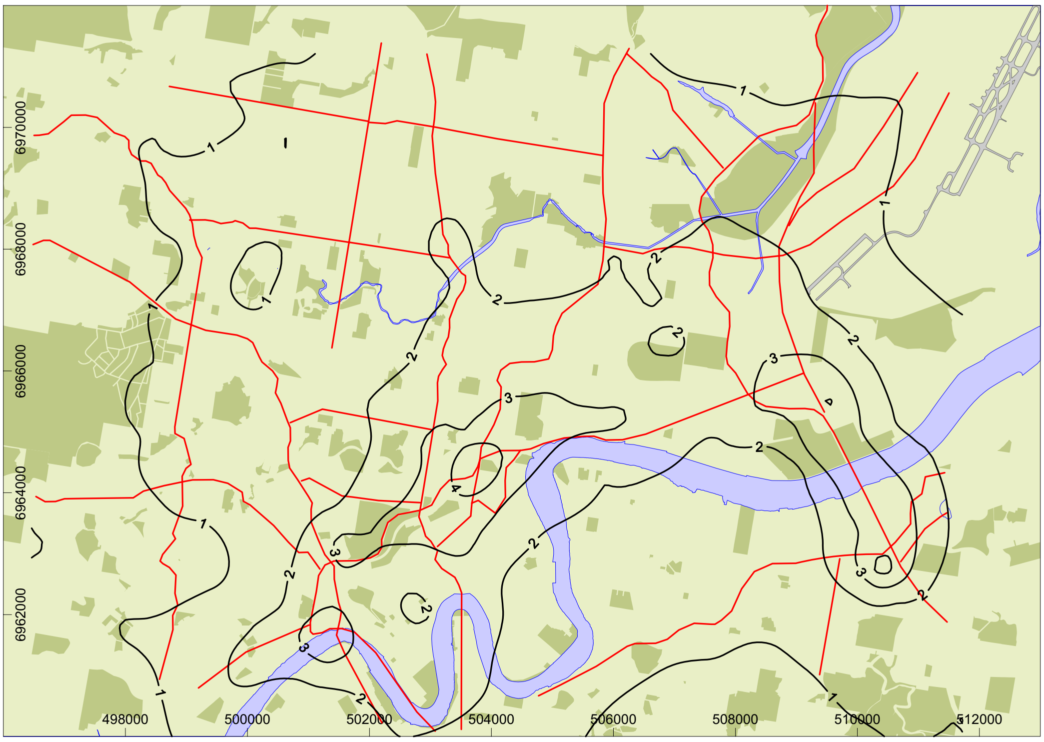
Without Airport Link



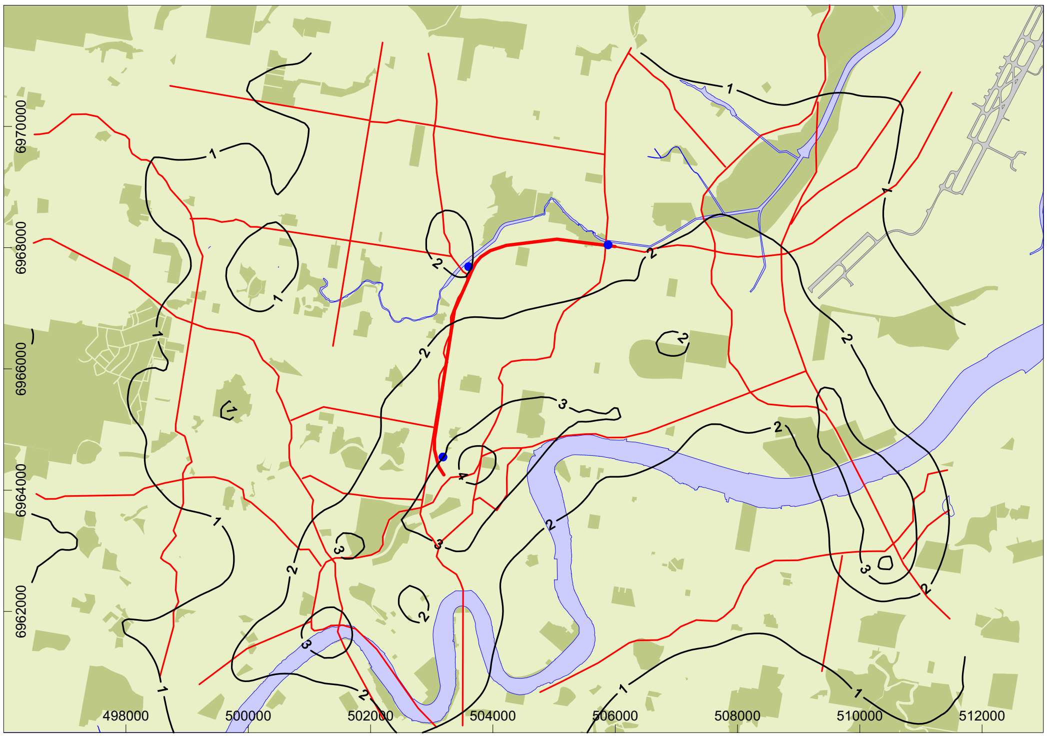
With Airport Link

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

FIGURE 39



Without Airport Link

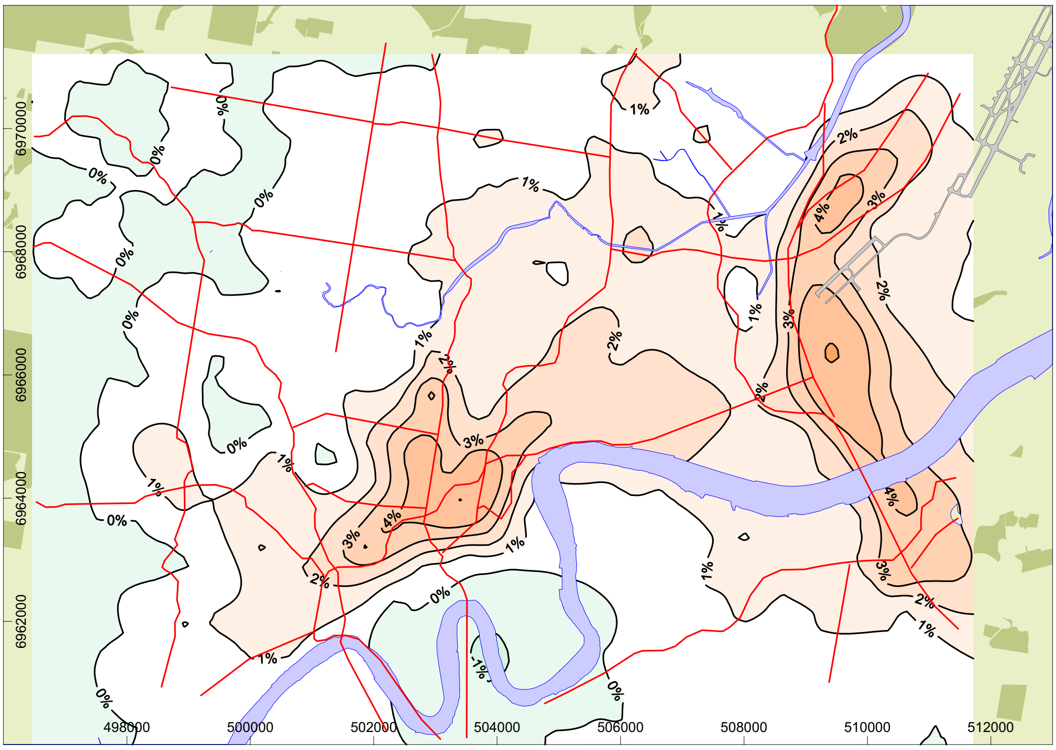


With Airport Link

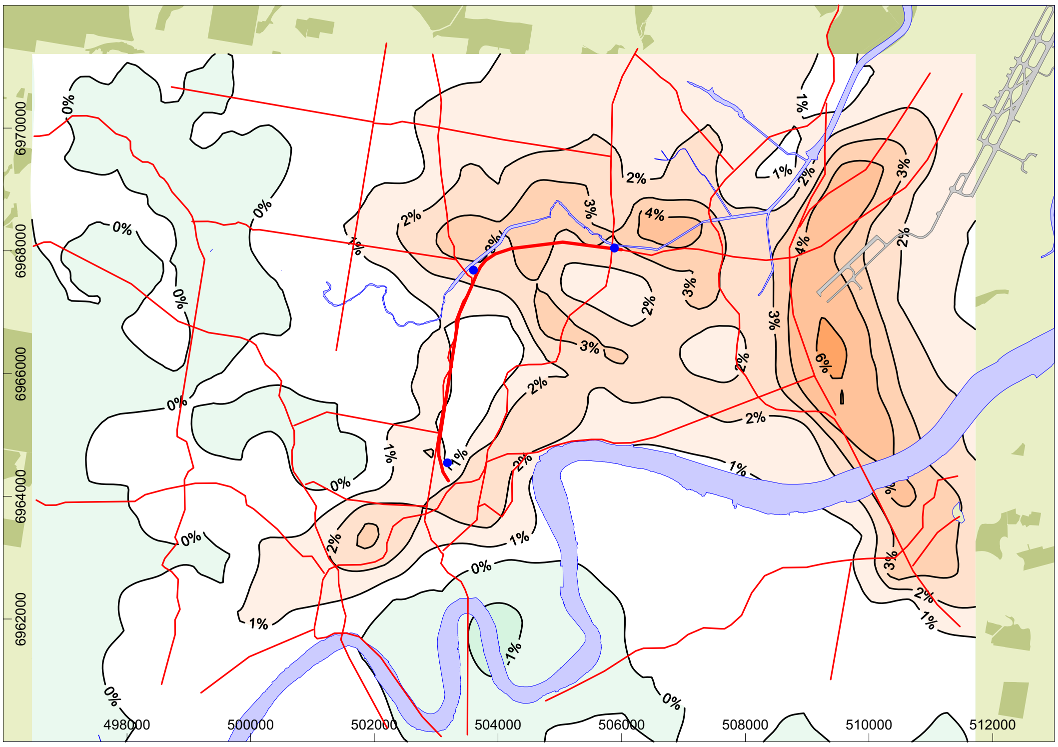
Predicted maximum 24-hour average $PM_{2.5}$ concentrations in 2012 ($\mu g/m^3$)

FIGURE

40

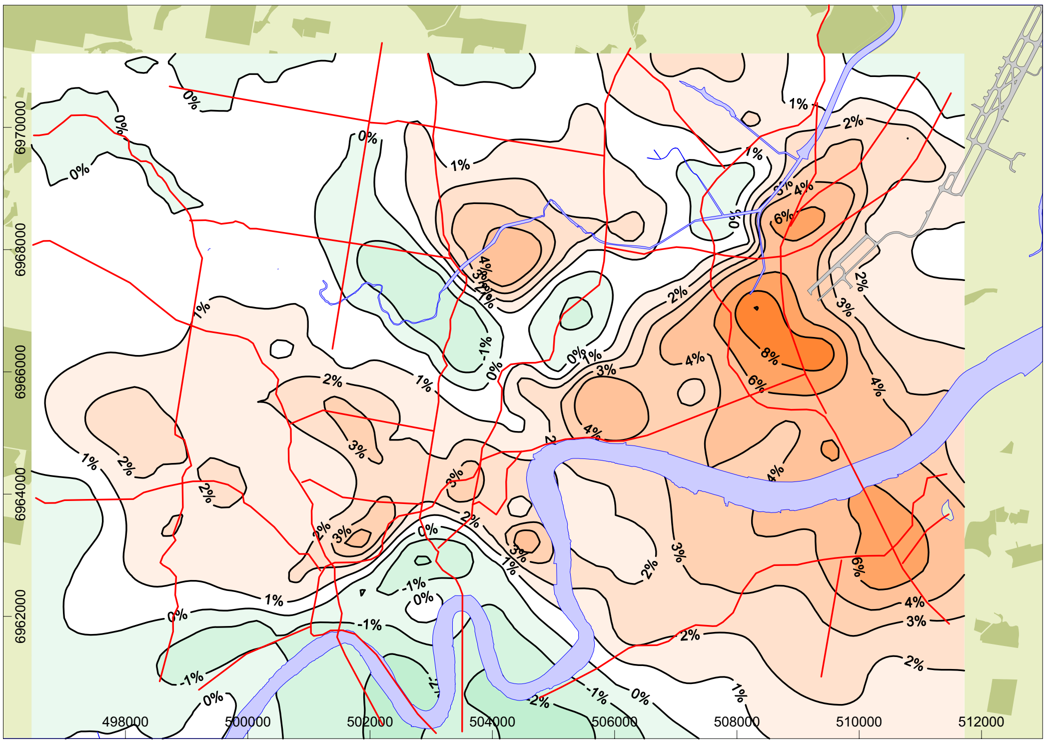


Without Airport Link

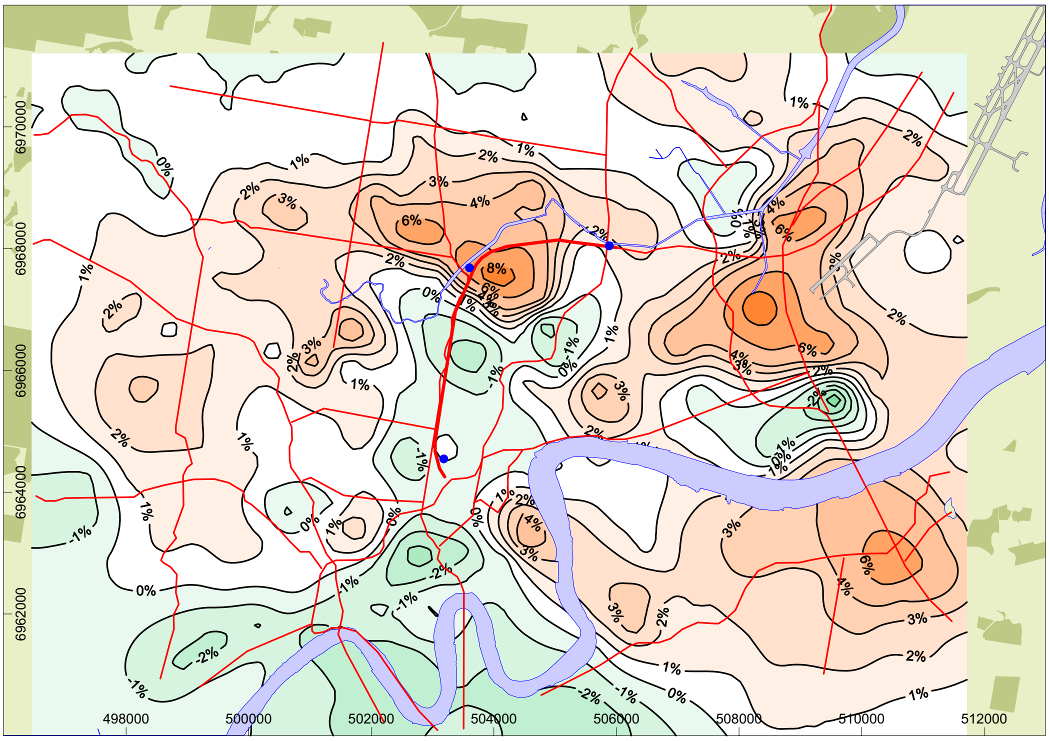


With Airport Link

Percentage change from existing (2004) to 2012 for maximum 8-hour average CO



Without Airport Link

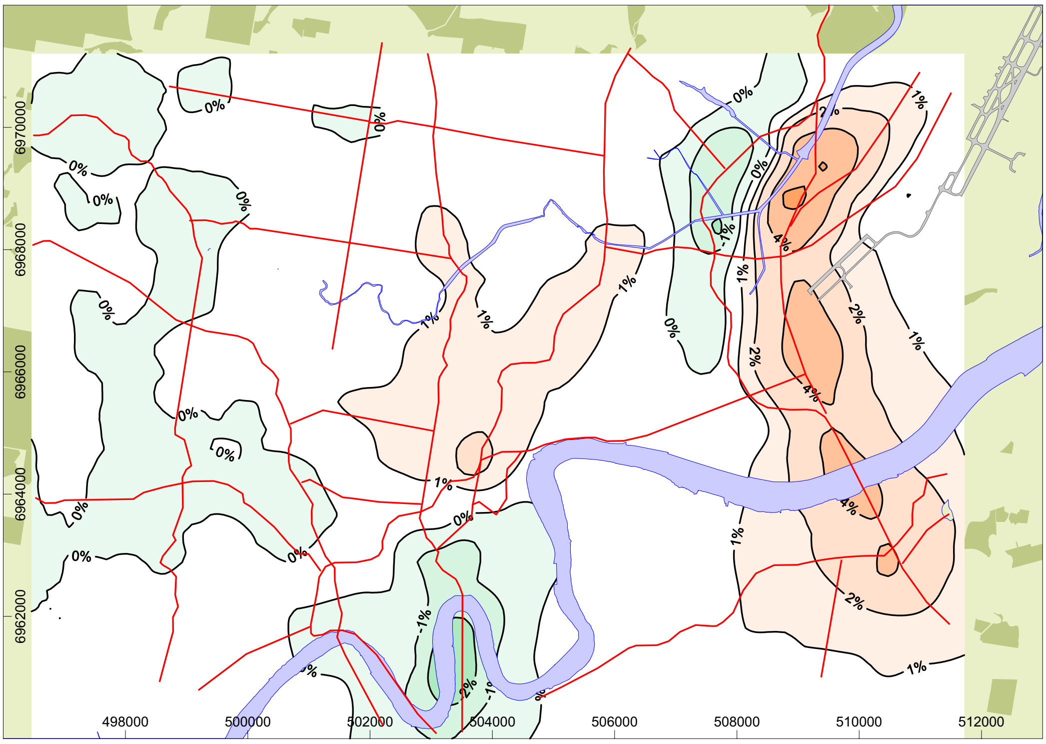


With Airport Link

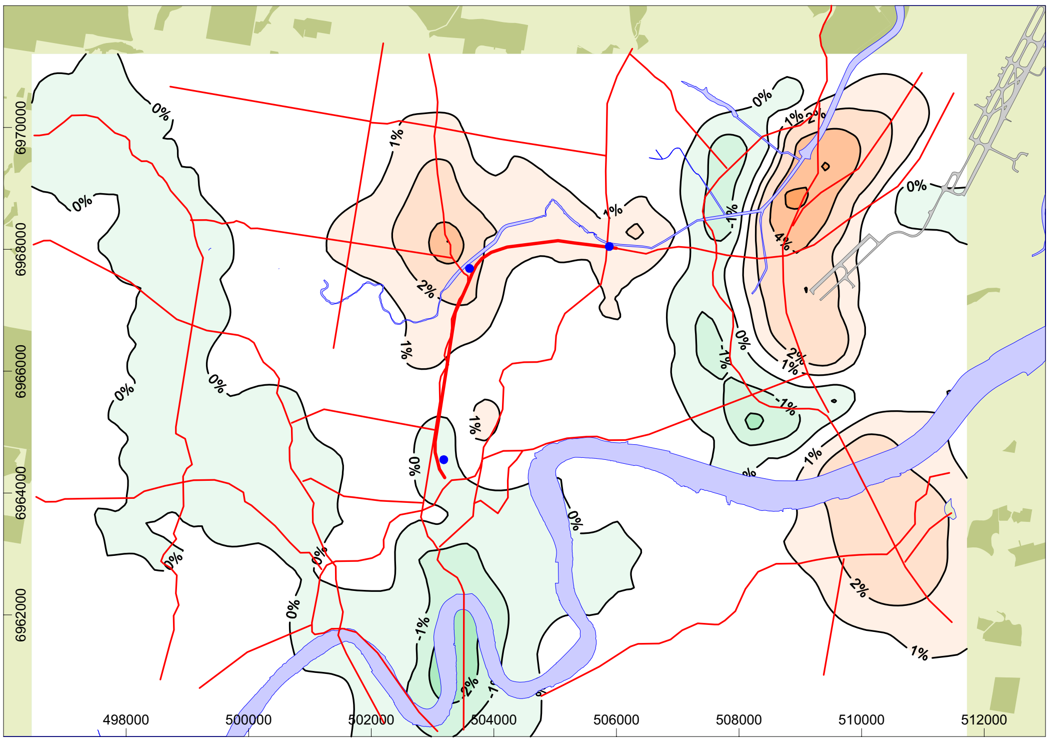
Percentage change from existing (2004) to 2012 for maximum 1-hour average NO_2

FIGURE

42

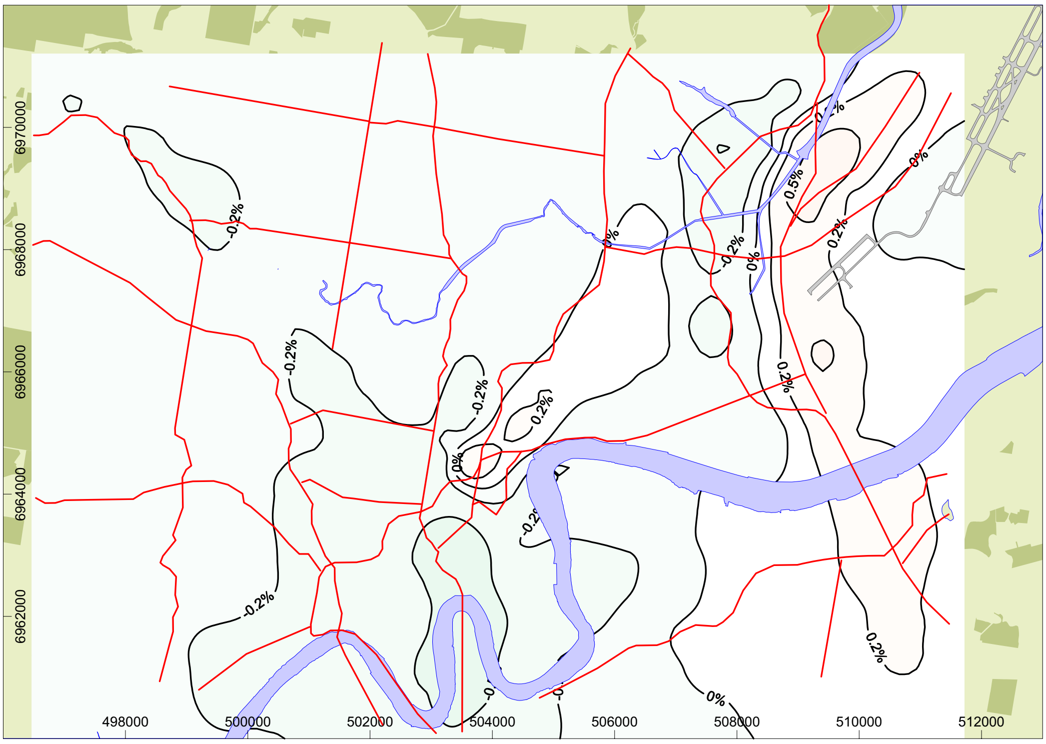


Without Airport Link

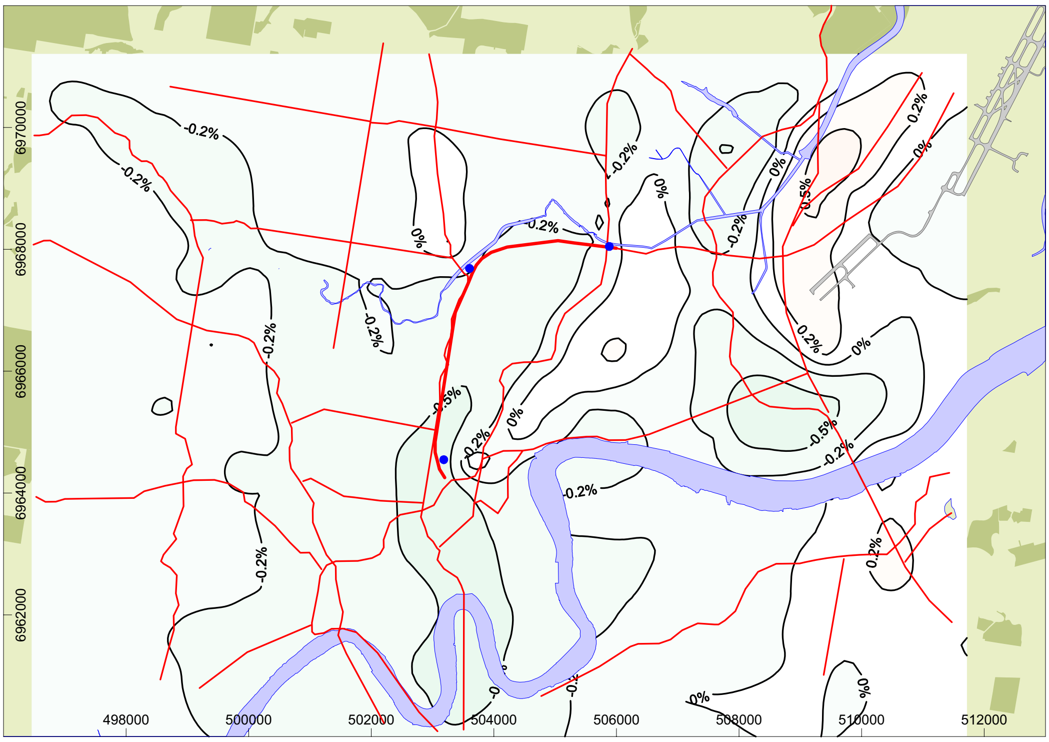


With Airport Link

Percentage change from existing (2004) to 2012 for annual average NO_2



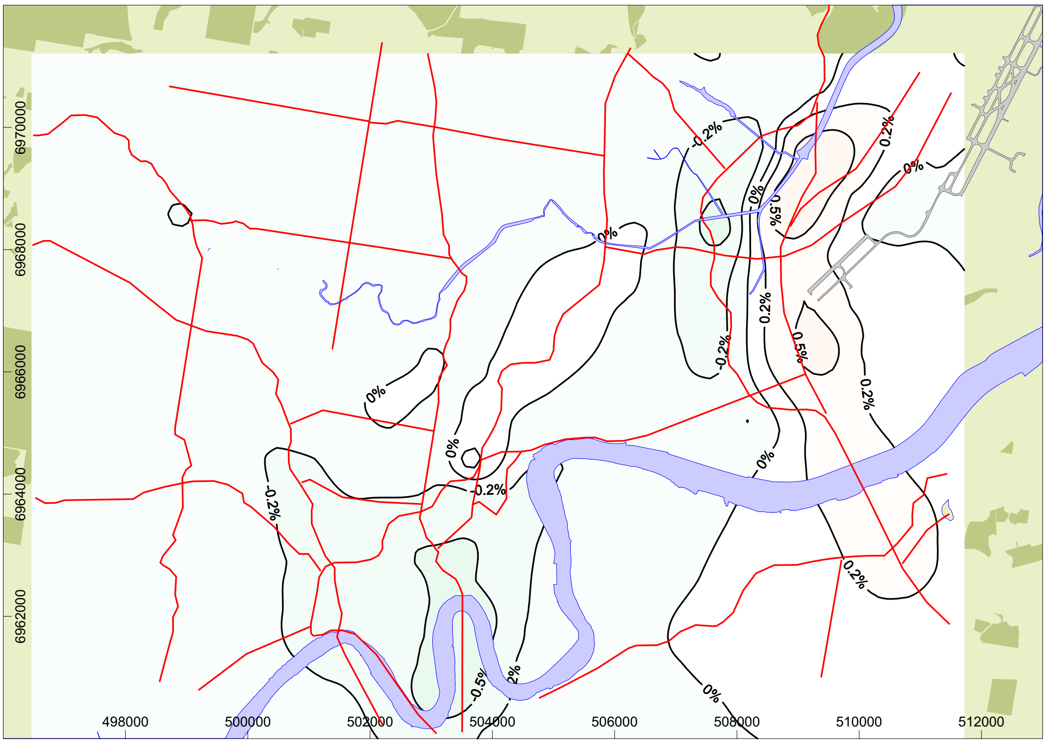
Without Airport Link



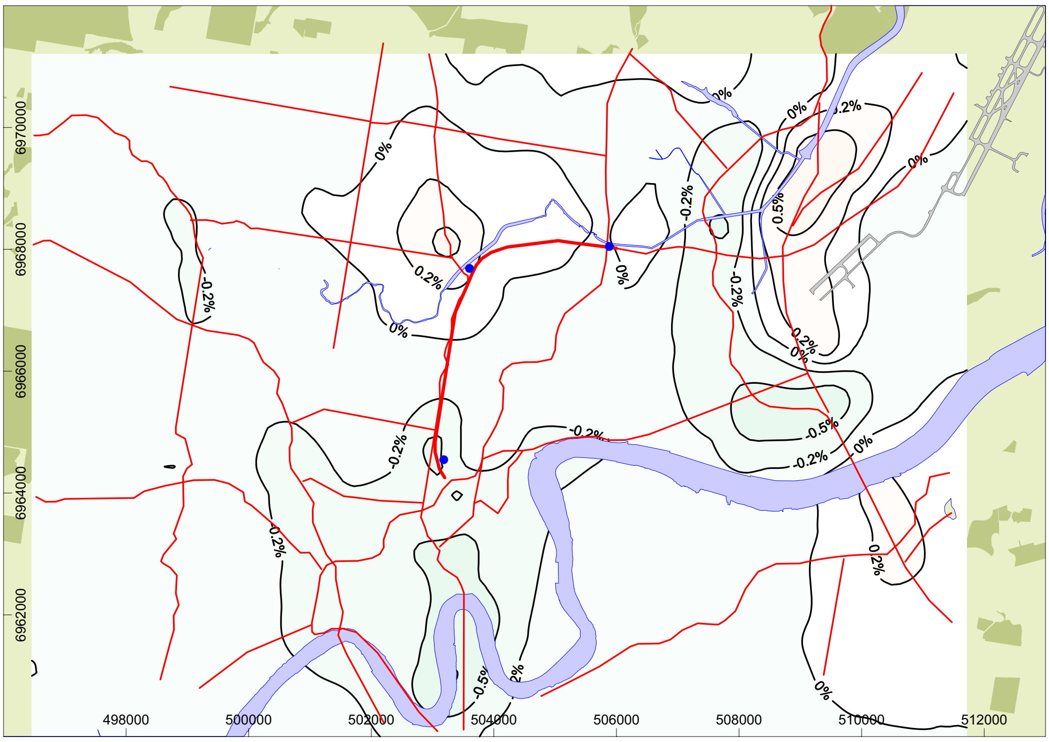
With Airport Link

Percentage change from existing (2004) to 2012 for maximum 24-hour average PM_{10}

FIGURE 44

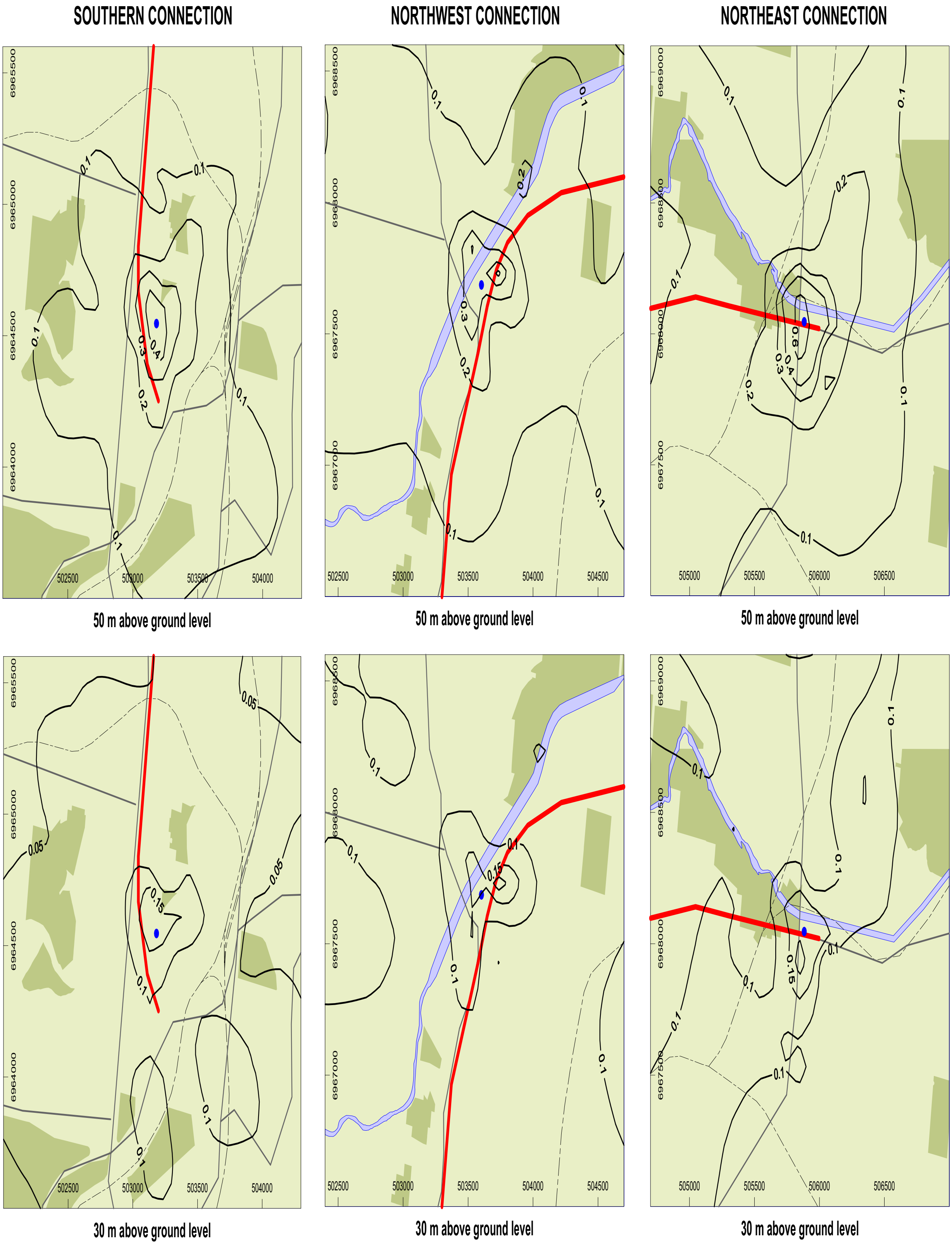


Without Airport Link



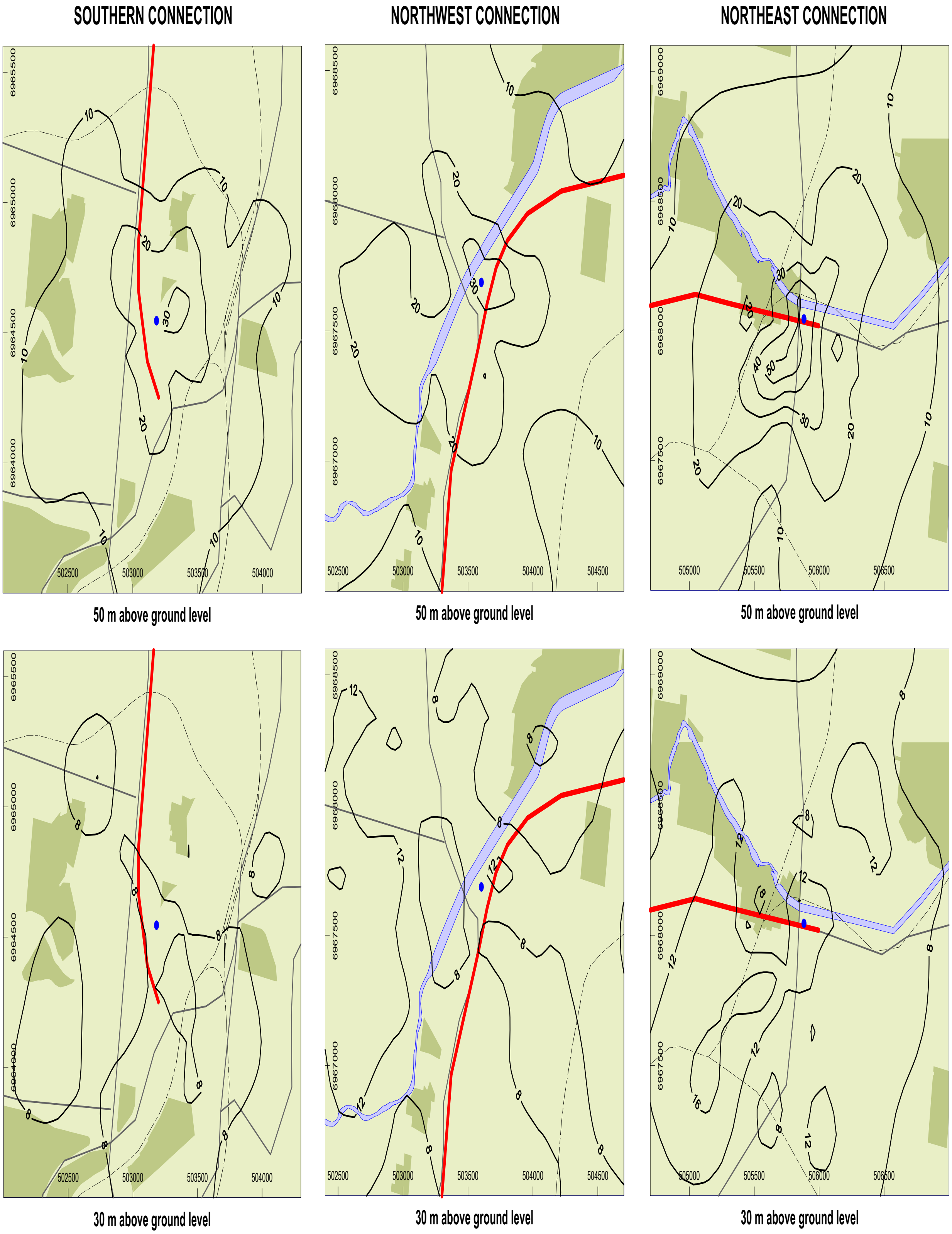
With Airport Link

Percentage change from existing (2004) to 2012 for annual average PM_{10}

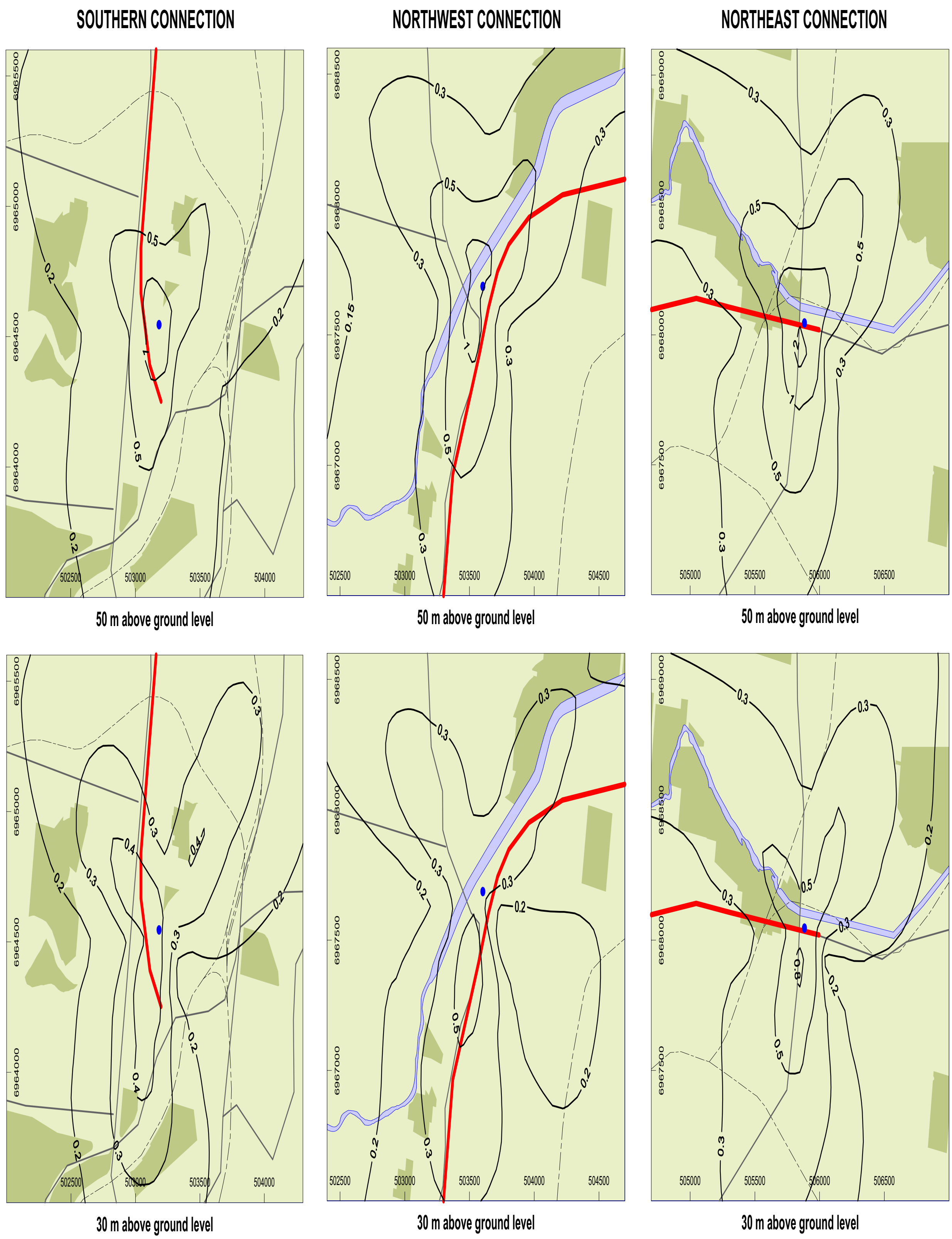


Predicted maximum 8-hour average CO concentrations above ground-level in 2012 (mg/m^3)

FIGURE
46

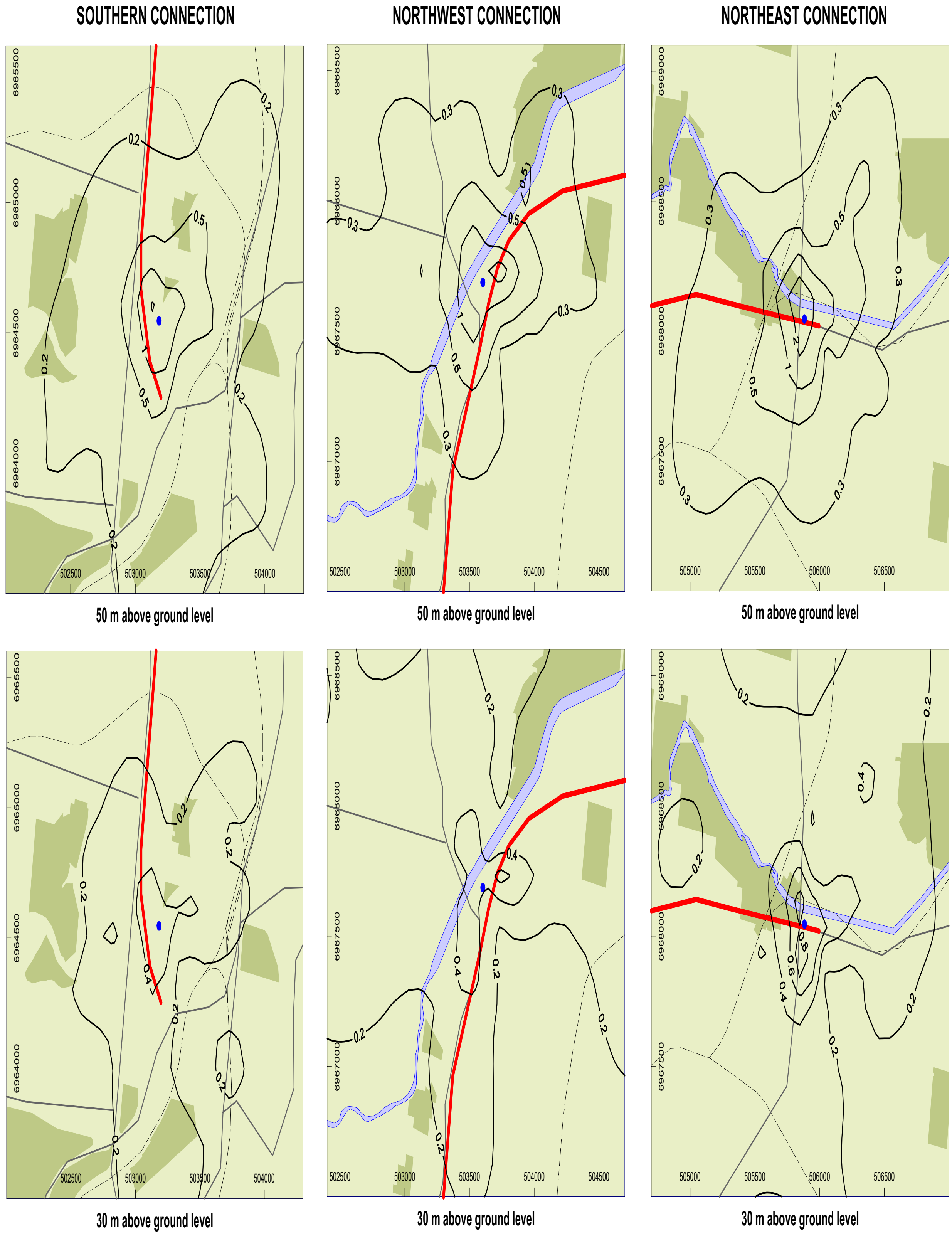


Predicted maximum 1-hour average NO_2 concentrations above ground-level in 2012 ($\mu g/m^3$)

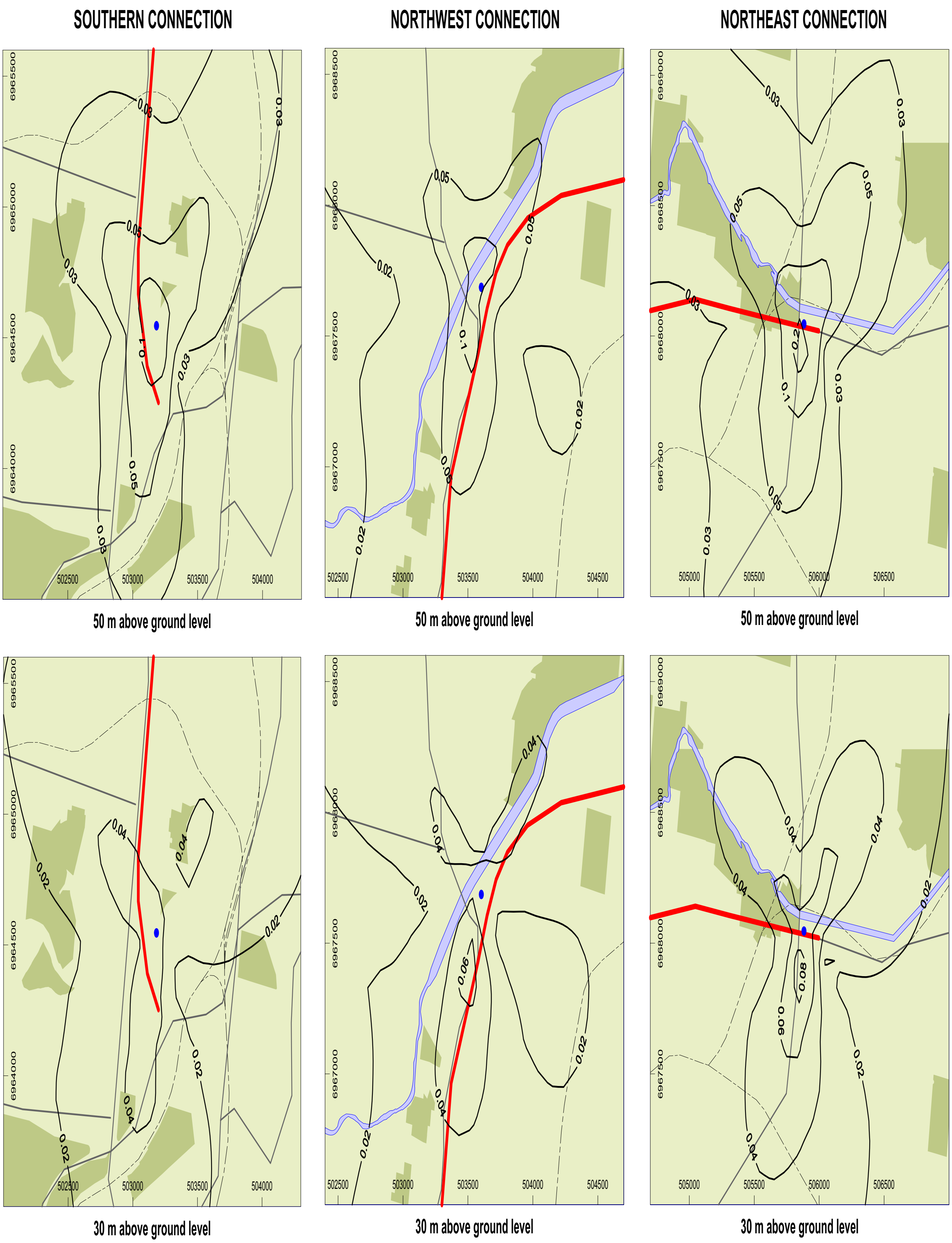


Predicted annual average NO_2 concentrations above ground-level in 2012 ($\mu g/m^3$)

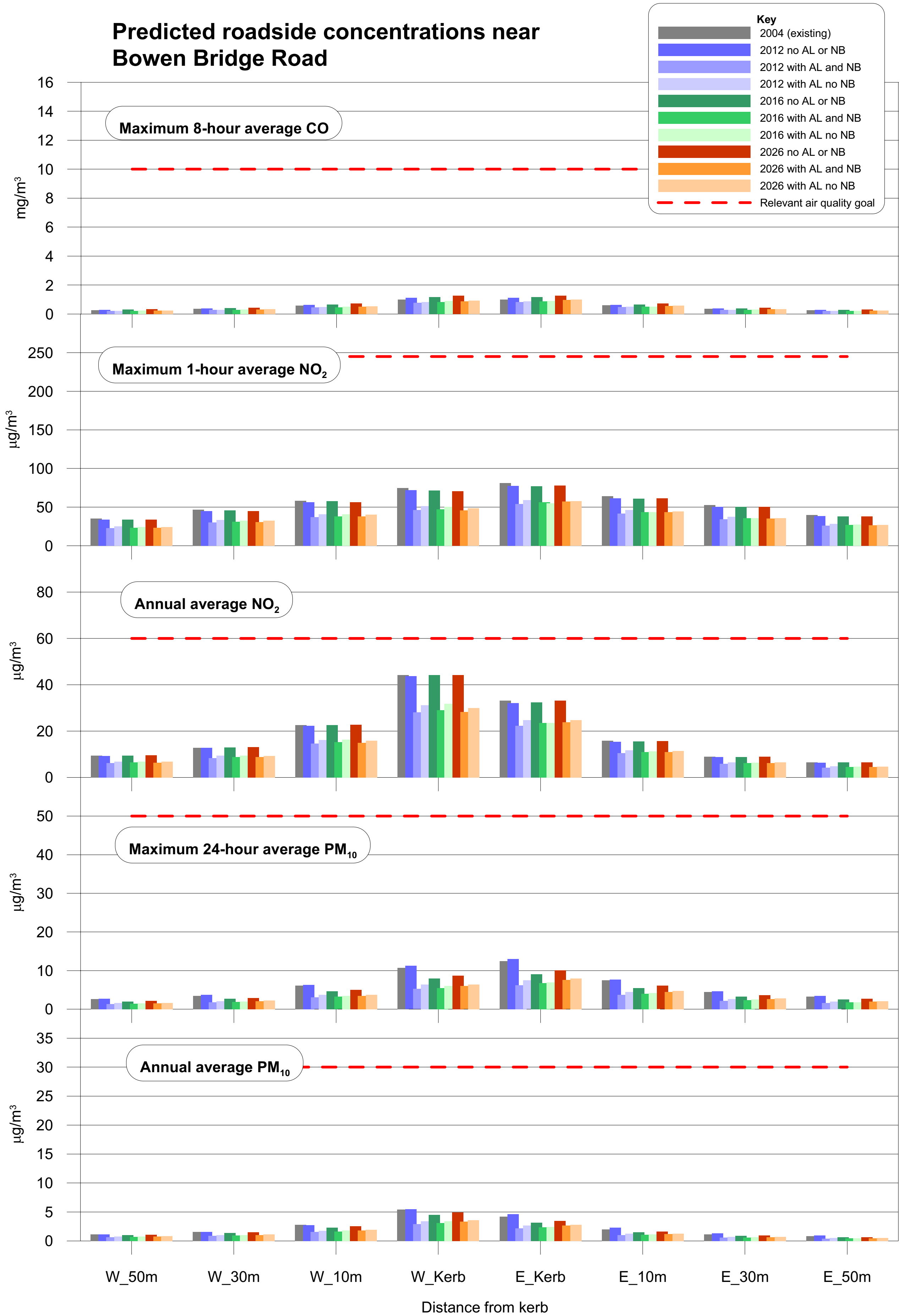
FIGURE 48



Predicted maximum 24-hour average PM_{10} concentrations above ground-level in 2012 ($\mu g/m^3$)

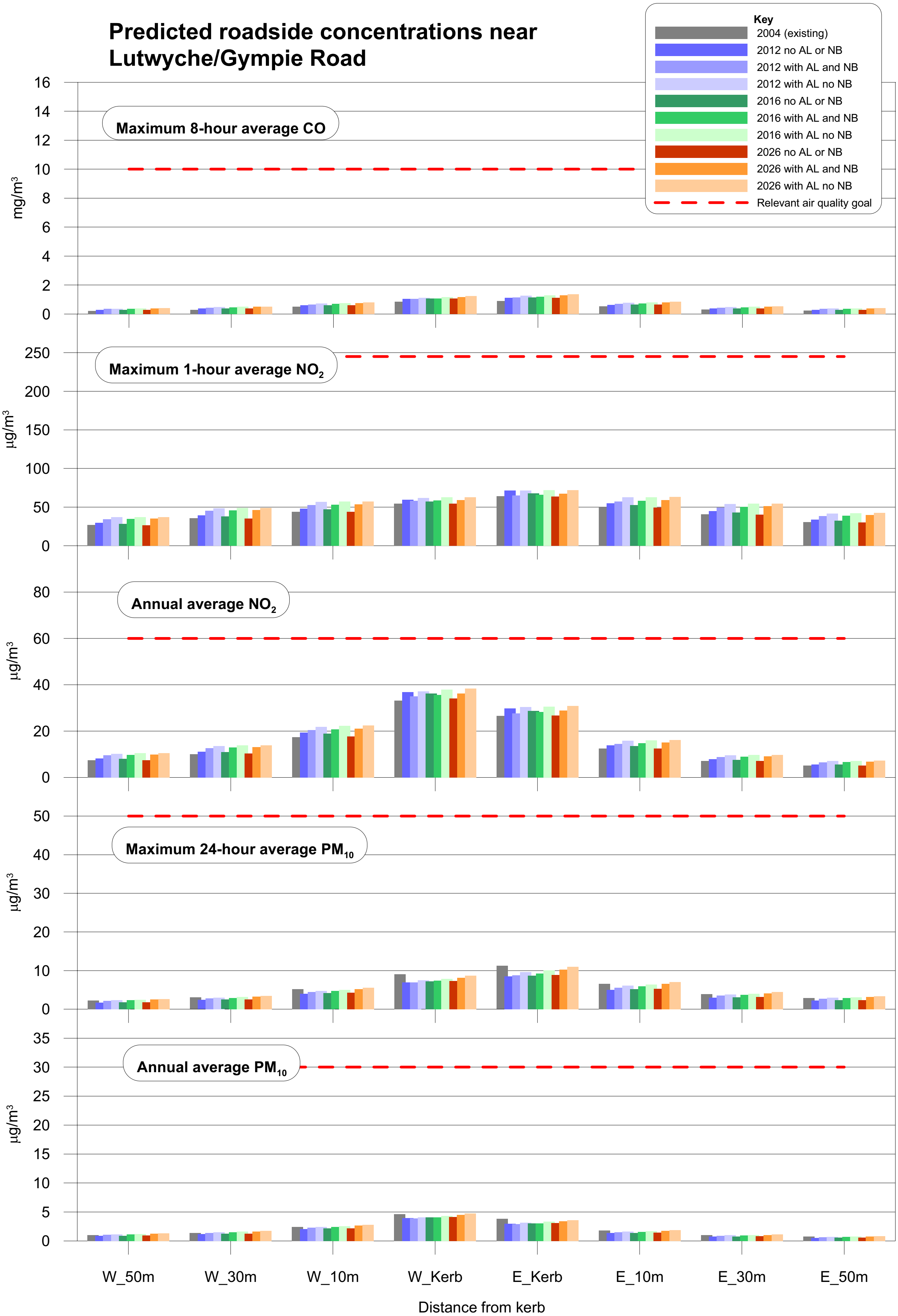


Predicted annual average PM_{10} concentrations above ground-level in 2012 ($\mu g/m^3$)



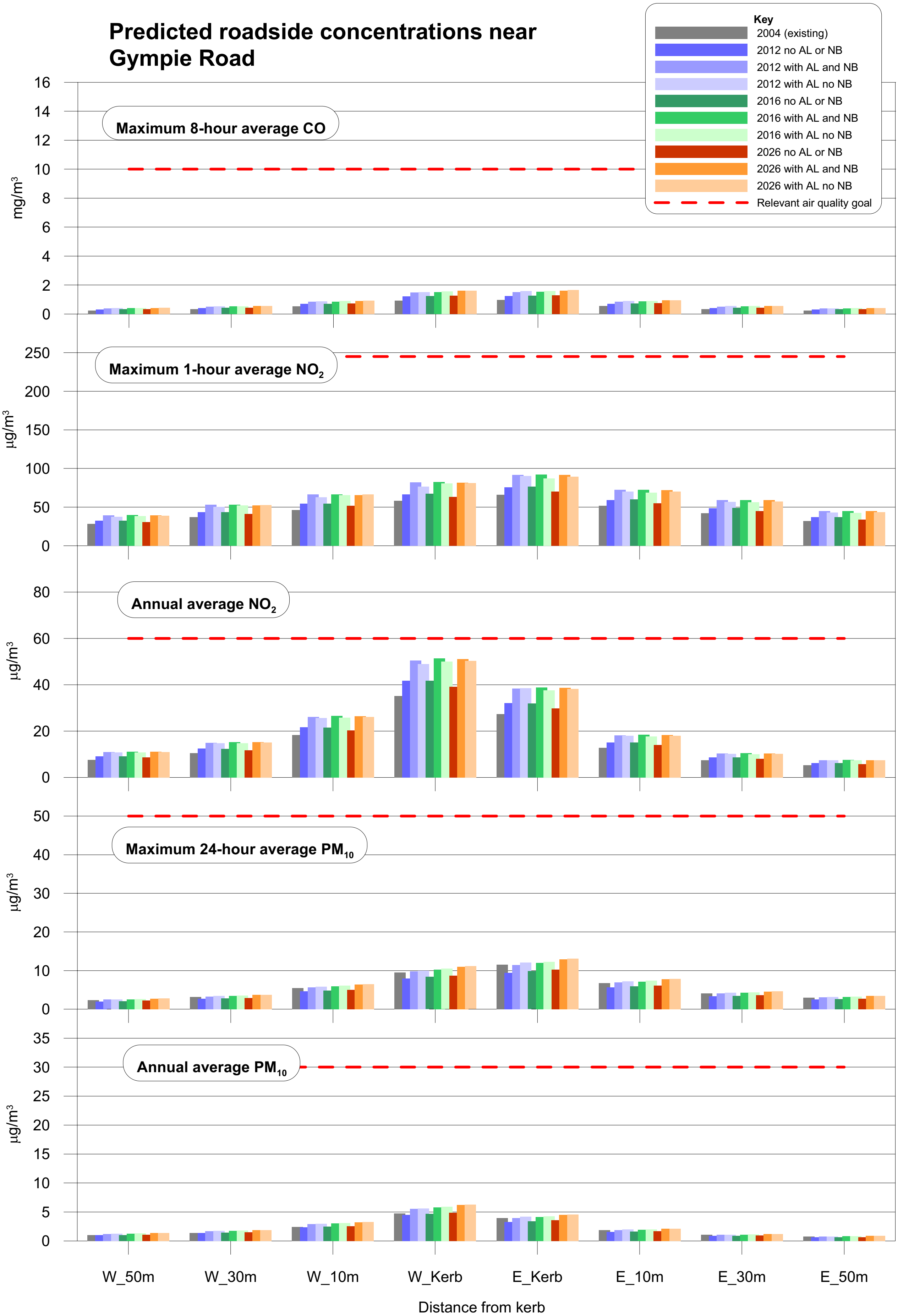
Predicted roadside concentrations near Bowen Bridge Road
Key
2004 (existing)
2012 no AL or NB
2012 with AL and NB
2012 with AL no NB
2016 no AL or NB
2016 with AL and NB
2016 with AL no NB
2026 no AL or NB
2026 with AL and NB
2026 with AL no NB
Relevant air quality goal
Maximum 8-hour average CO
mg/m³
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 51



Predicted roadside concentrations near Lutwyche/Gympie Road
Key
2004 (existing)
2012 no AL or NB
2012 with AL and NB
2012 with AL no NB
2016 no AL or NB
2016 with AL and NB
2016 with AL no NB
2026 no AL or NB
2026 with AL and NB
2026 with AL no NB
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

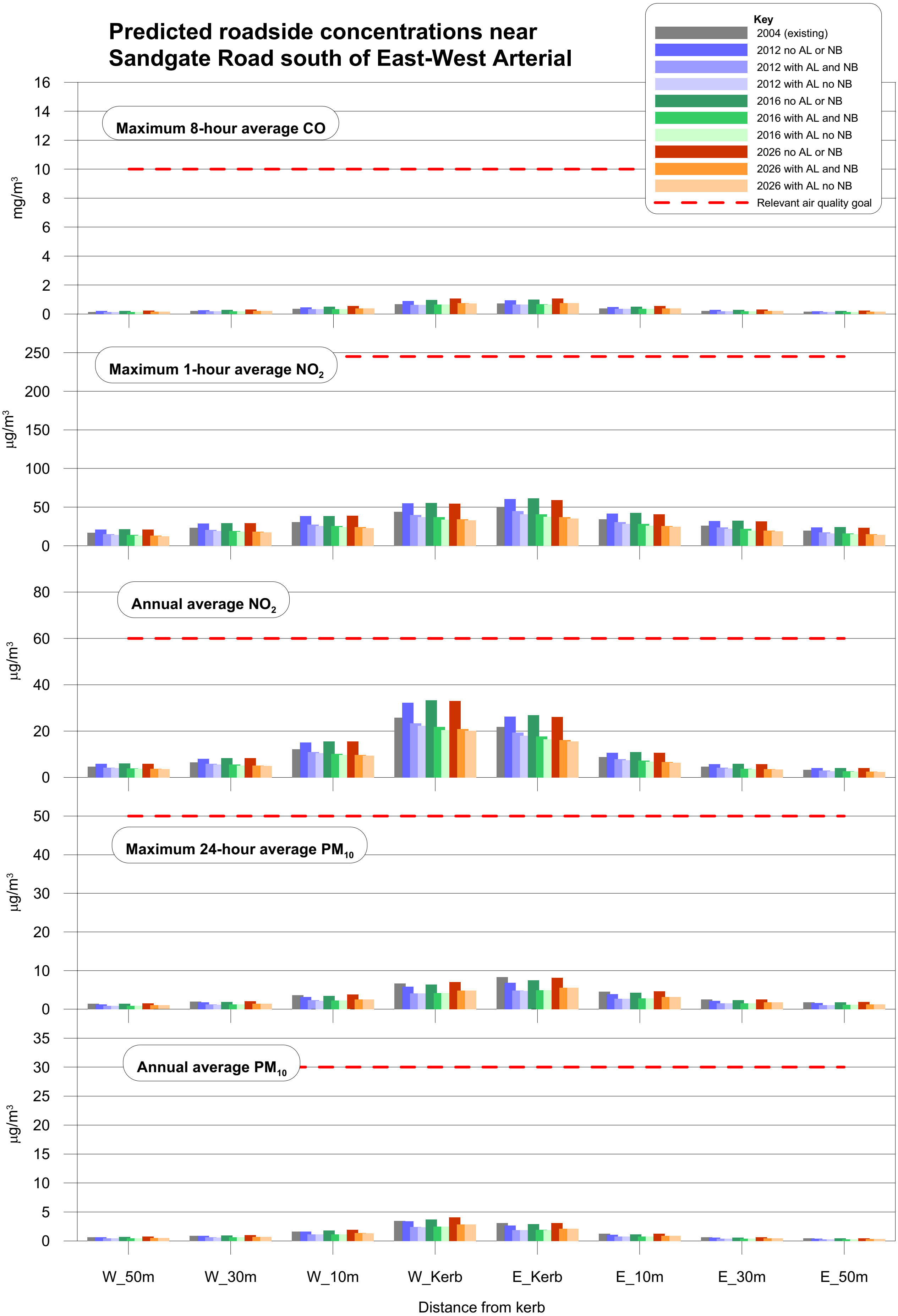
FIGURE



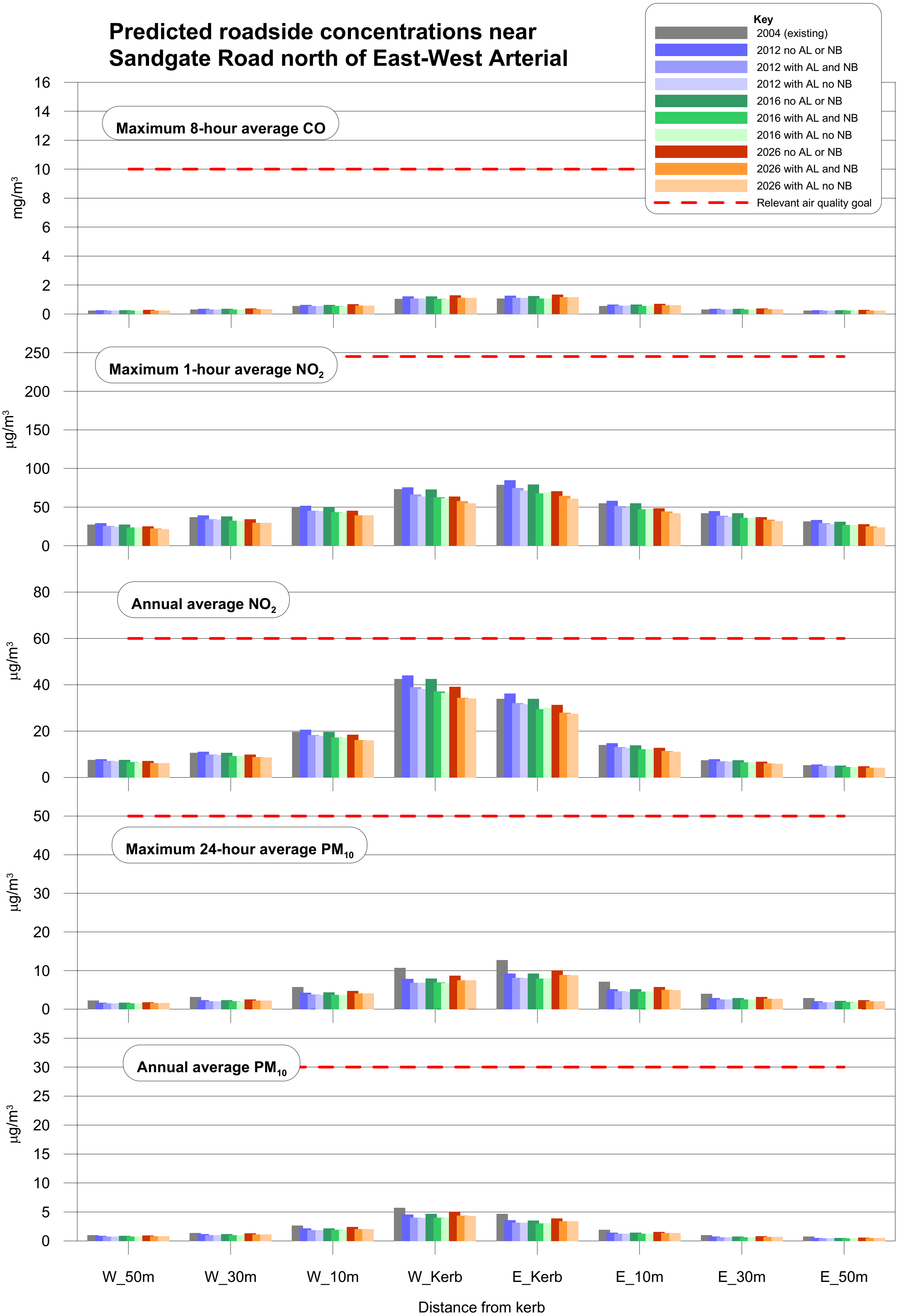
Predicted roadside concentrations near Gympie Road
Key
2004 (existing)
2012 no AL or NB
2012 with AL and NB
2012 with AL no NB
2016 no AL or NB
2016 with AL and NB
2016 with AL no NB
2026 no AL or NB
2026 with AL and NB
2026 with AL no NB
Relevant air quality goal
Maximum 8-hour average CO
mg/m³
Maximum 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

Predicted roadside concentrations near Sandgate Road south of East-West Arterial

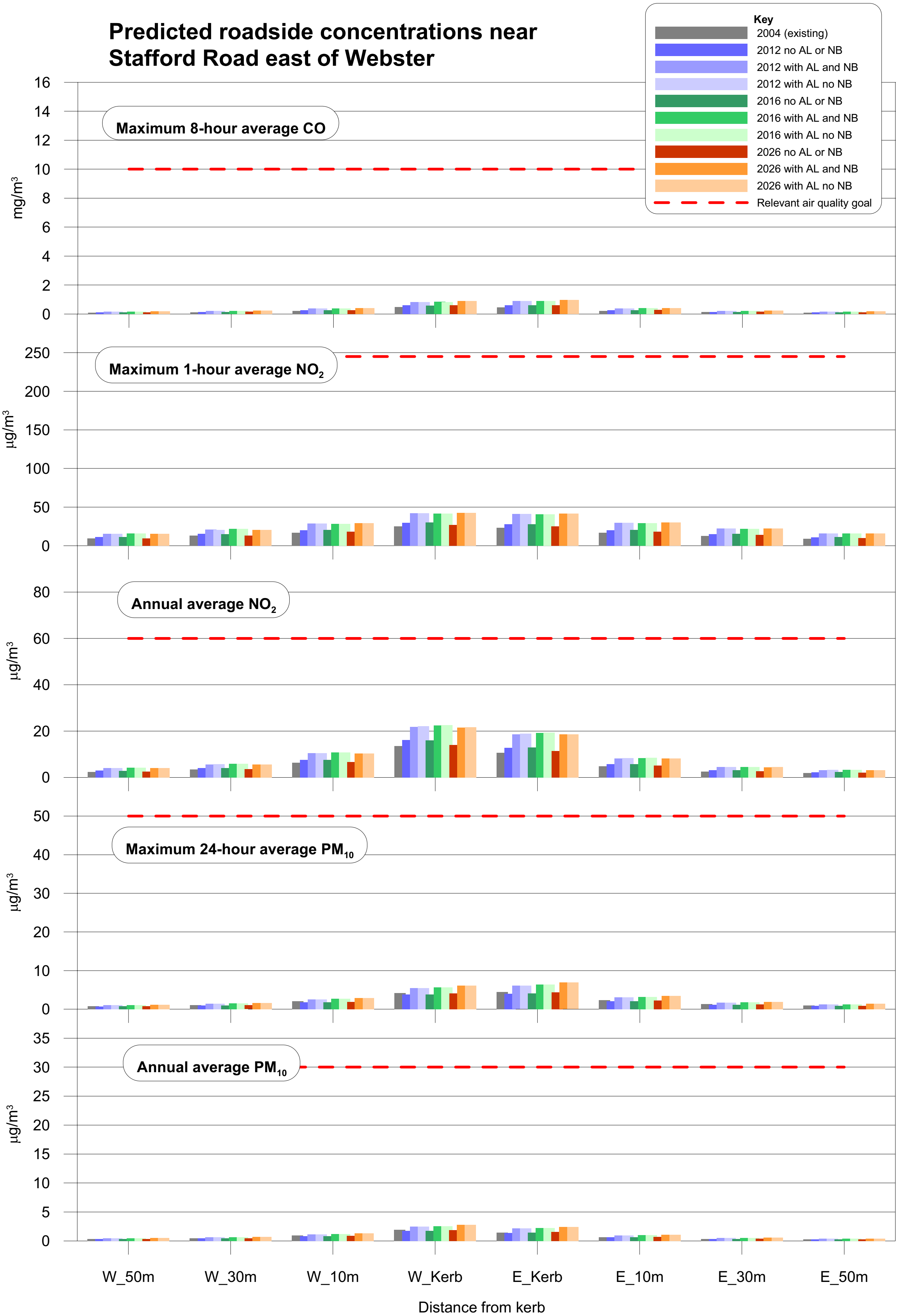


FIGURE

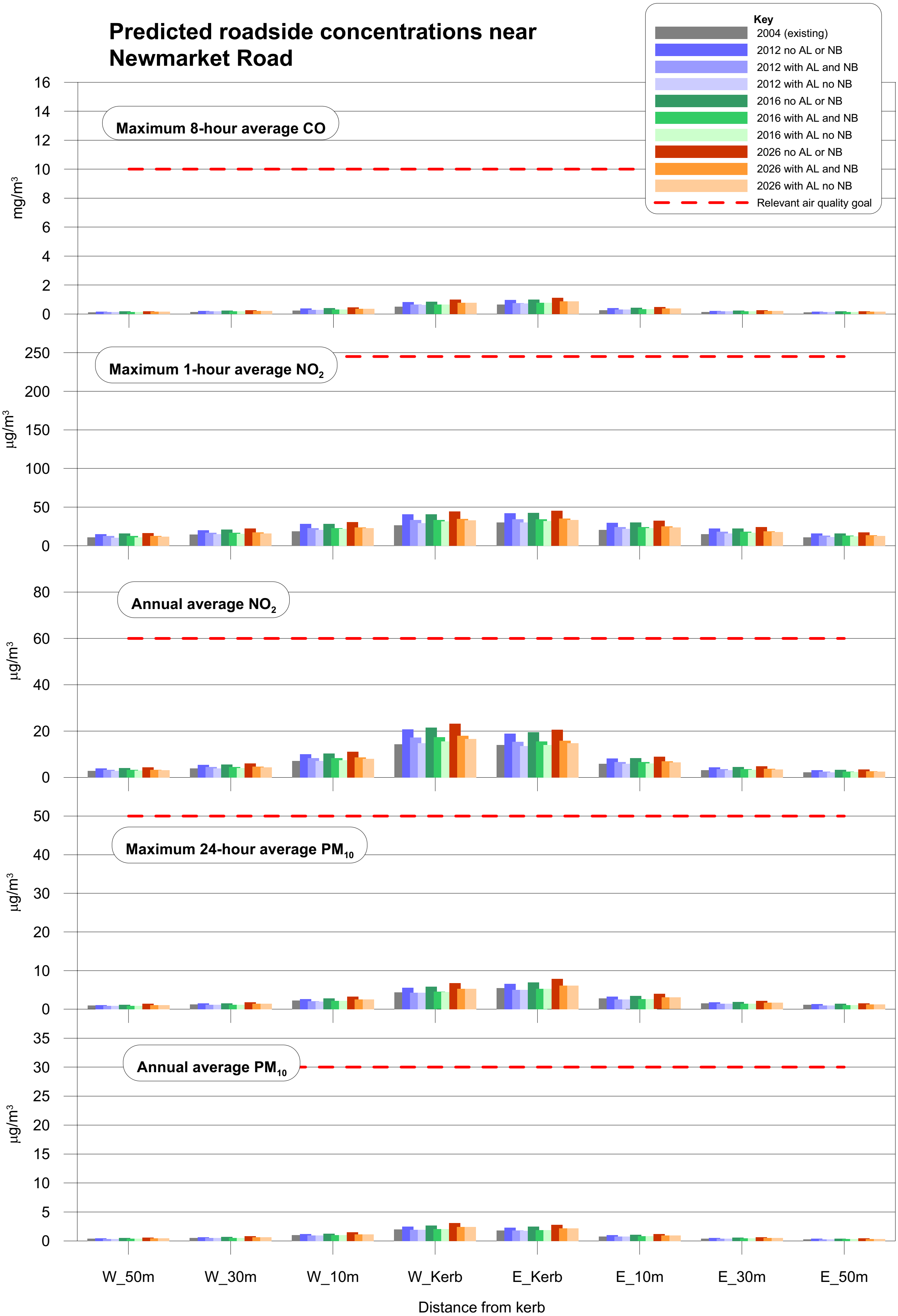

Predicted roadside concentrations near
Sandgate Road north of East-West Arterial
Key
2004 (existing)
2012 no AL or NB
2012 with AL and NB
2012 with AL no NB
2016 no AL or NB
2016 with AL and NB
2016 with AL no NB
2026 no AL or NB
2026 with AL and NB
2026 with AL no NB
Relevant air quality goal
Maximum 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

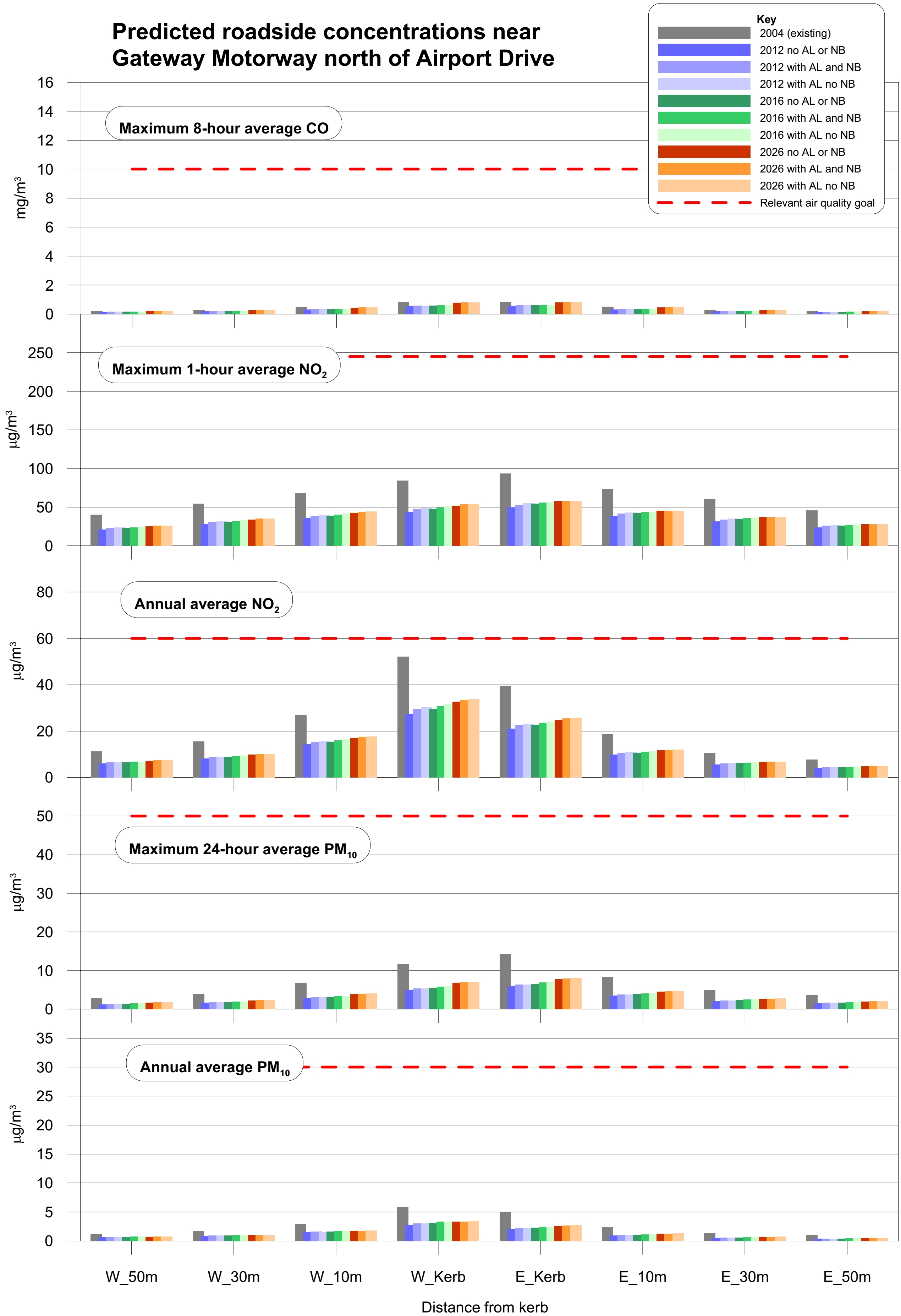
55


Predicted roadside concentrations near
Stafford Road east of Webster
Key
2004 (existing)
2012 no AL or NB
2012 with AL and NB
2012 with AL no NB
2016 no AL or NB
2016 with AL and NB
2016 with AL no NB
2026 no AL or NB
2026 with AL and NB
2026 with AL no NB
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

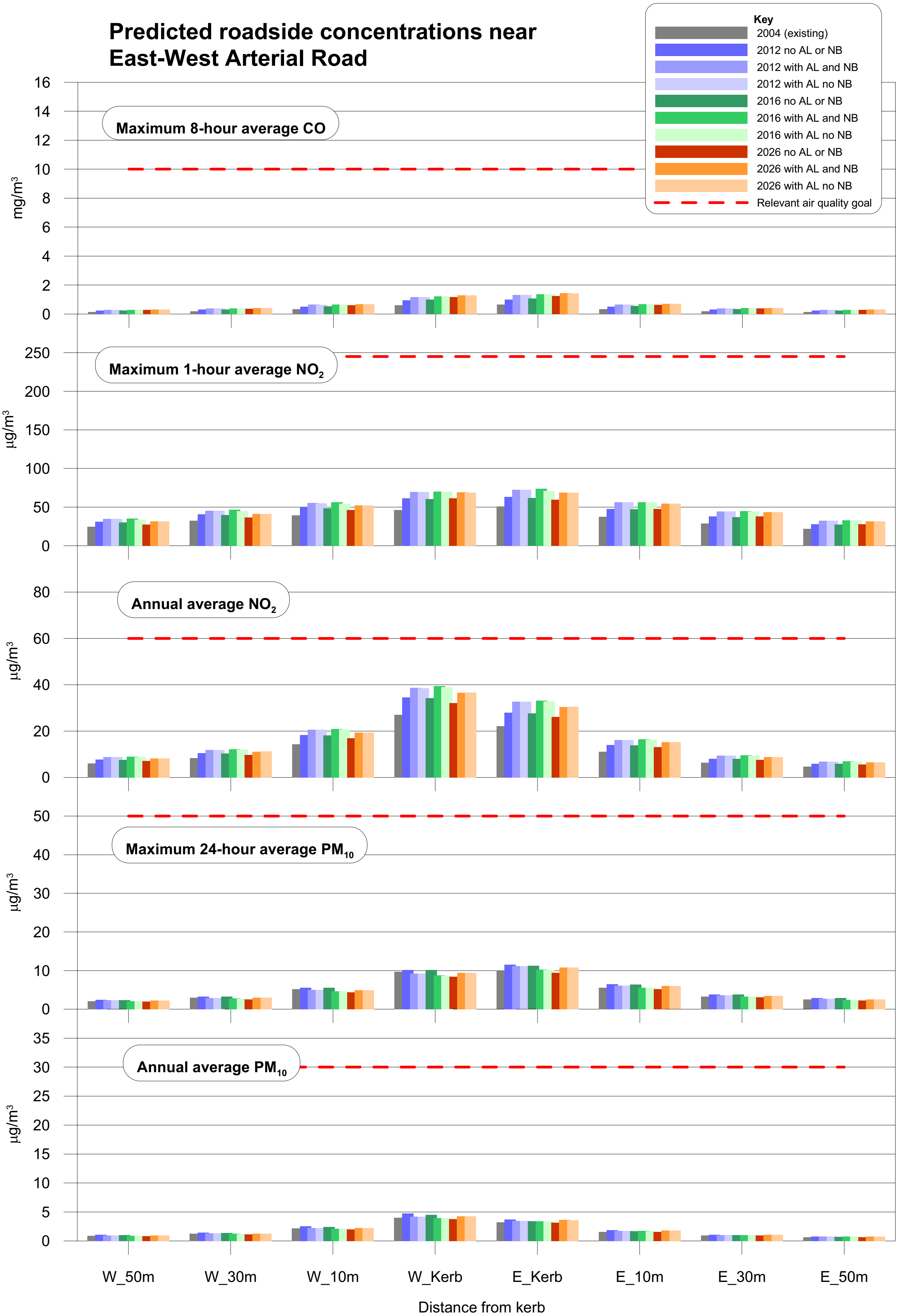

Predicted roadside concentrations near Newmarket Road
Key
2004 (existing)
2012 no AL or NB
2012 with AL and NB
2012 with AL no NB
2016 no AL or NB
2016 with AL and NB
2016 with AL no NB
2026 no AL or NB
2026 with AL and NB
2026 with AL no NB
Relevant air quality goal
Maximum 8-hour average CO
mg/m³
Maximum 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

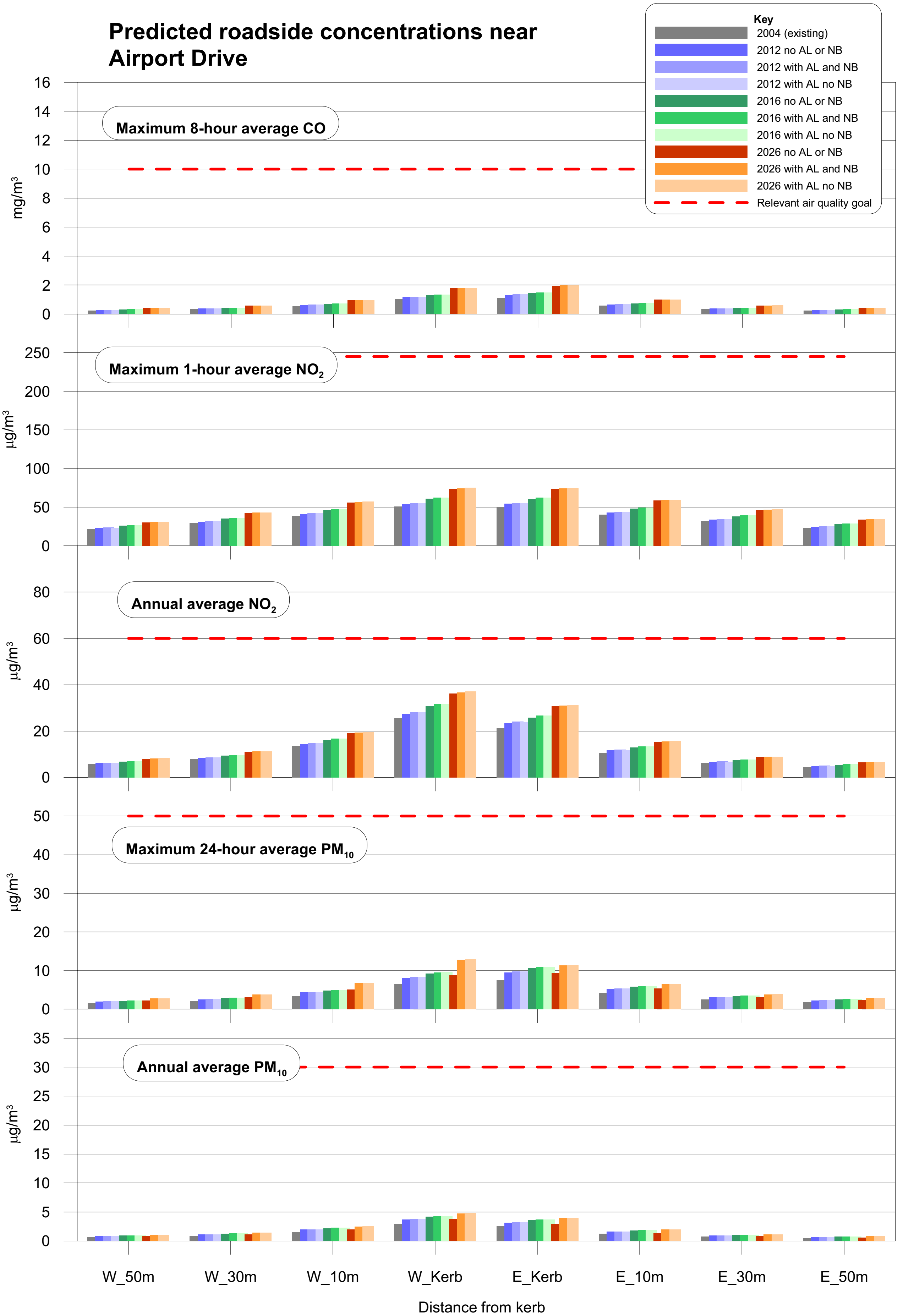


Predicted roadside concentrations near Gateway Motorway north of Airport Drive
Key
2004 (existing)
2012 no AL or NB
2012 with AL and NB
2012 with AL no NB
2016 no AL or NB
2016 with AL and NB
2016 with AL no NB
2026 no AL or NB
2026 with AL and NB
2026 with AL no NB
Relevant air quality goal
Maximum 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

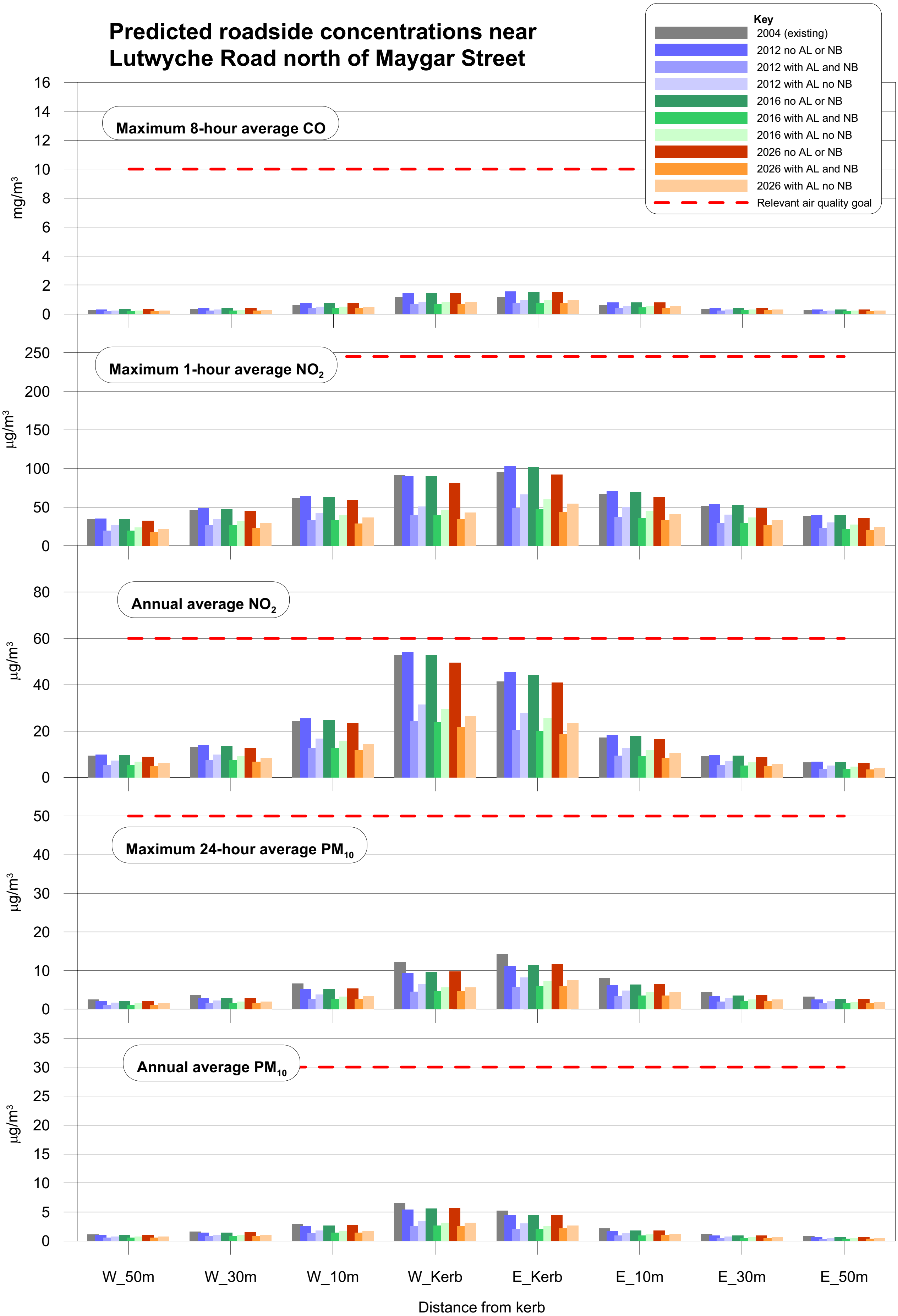

Predicted roadside concentrations near East-West Arterial Road
Key
2004 (existing)
2012 no AL or NB
2012 with AL and NB
2012 with AL no NB
2016 no AL or NB
2016 with AL and NB
2016 with AL no NB
2026 no AL or NB
2026 with AL and NB
2026 with AL no NB
Relevant air quality goal
Maximum 8-hour average CO
mg/m³
16
14
12
10
8
6
4
2
0
Maximum 1-hour average NO_2
µg/m³
250
200
150
100
50
0
Annual average NO_2
µg/m³
80
60
40
20
0
Maximum 24-hour average PM_{10}
µg/m³
50
40
30
20
10
0
Annual average PM_{10}
µg/m³
35
30
25
20
15
10
5
0
W_50m
W_30m
W_10m
W_Kerb
E_Kerb
E_10m
E_30m
E_50m
Distance from kerb

FIGURE

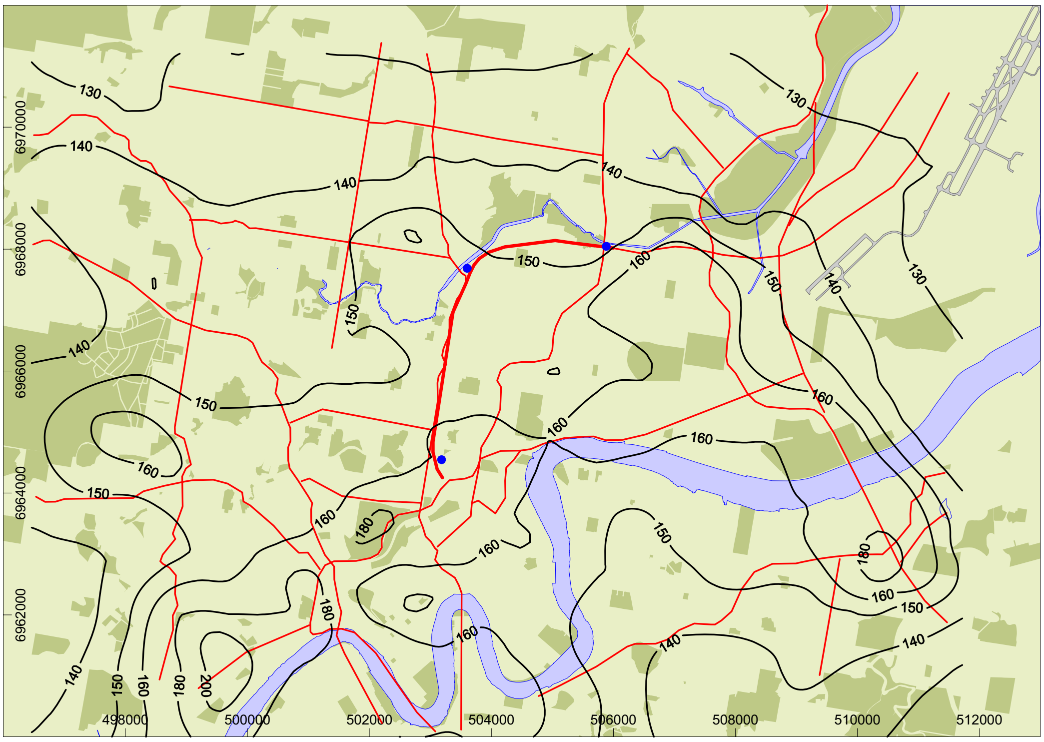


Predicted roadside concentrations near Airport Drive
Key
2004 (existing)
2012 no AL or NB
2012 with AL and NB
2012 with AL no NB
2016 no AL or NB
2016 with AL and NB
2016 with AL no NB
2026 no AL or NB
2026 with AL and NB
2026 with AL no NB
Relevant air quality goal
Maximum 8-hour average CO
mg/m³
Maximum 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

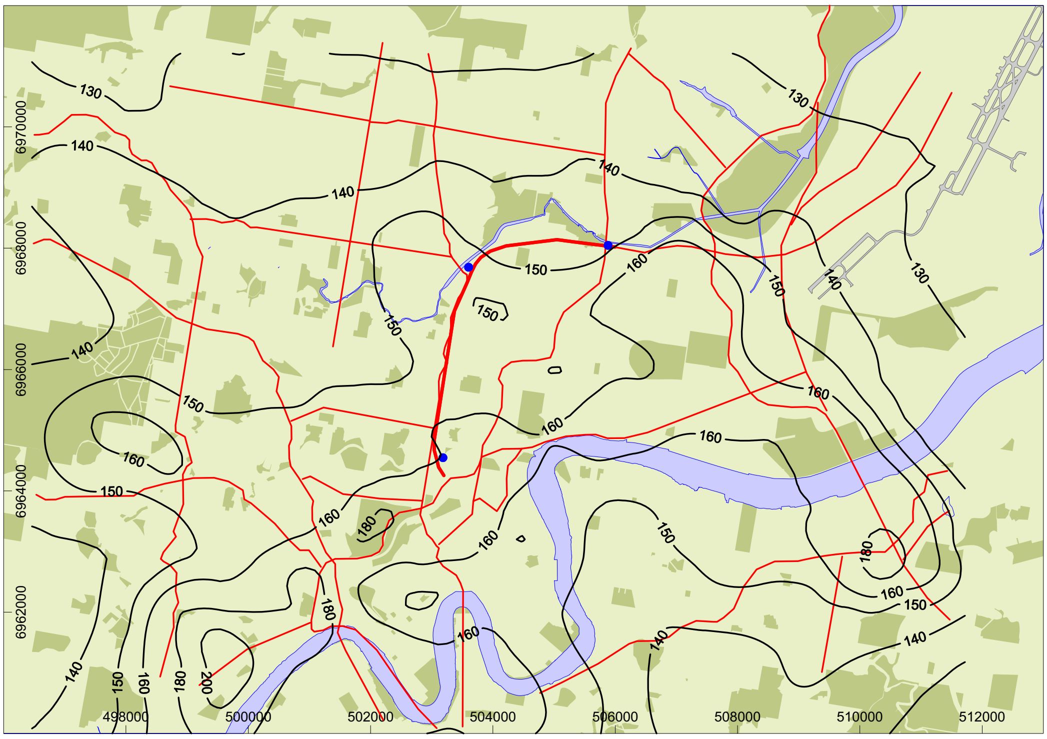
FIGURE


Predicted roadside concentrations near Lutwyche Road north of Maygar Street
Key
2004 (existing)
2012 no AL or NB
2012 with AL and NB
2012 with AL no NB
2016 no AL or NB
2016 with AL and NB
2016 with AL no NB
2026 no AL or NB
2026 with AL and NB
2026 with AL no NB
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

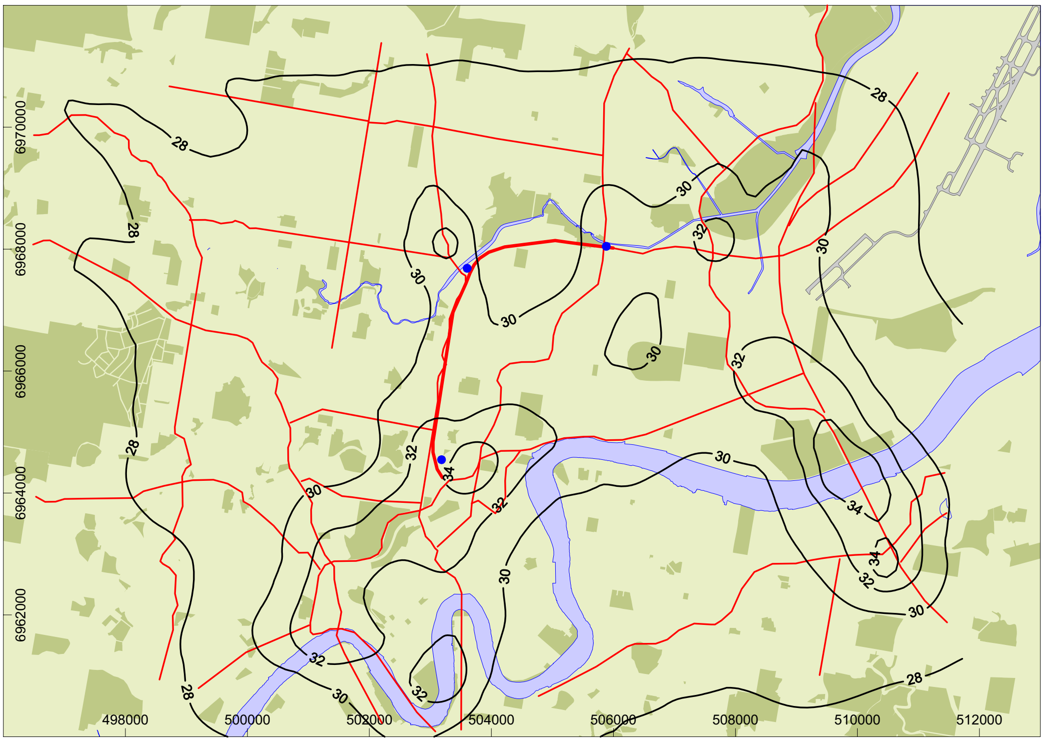


Airport Link tunnel without vent outlet filtration

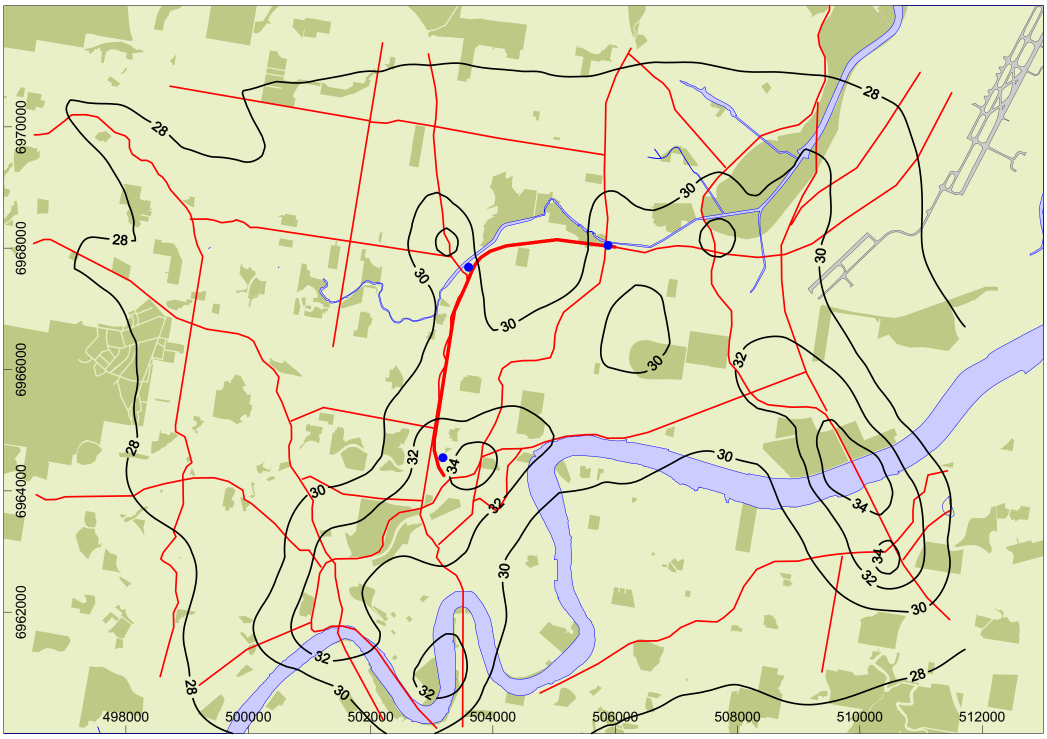


Airport Link tunnel with vent outlet filtration

Comparison of without and with tunnel filtration for maximum 1-hour average NO_2 concentrations in 2012 (μg/m^3)

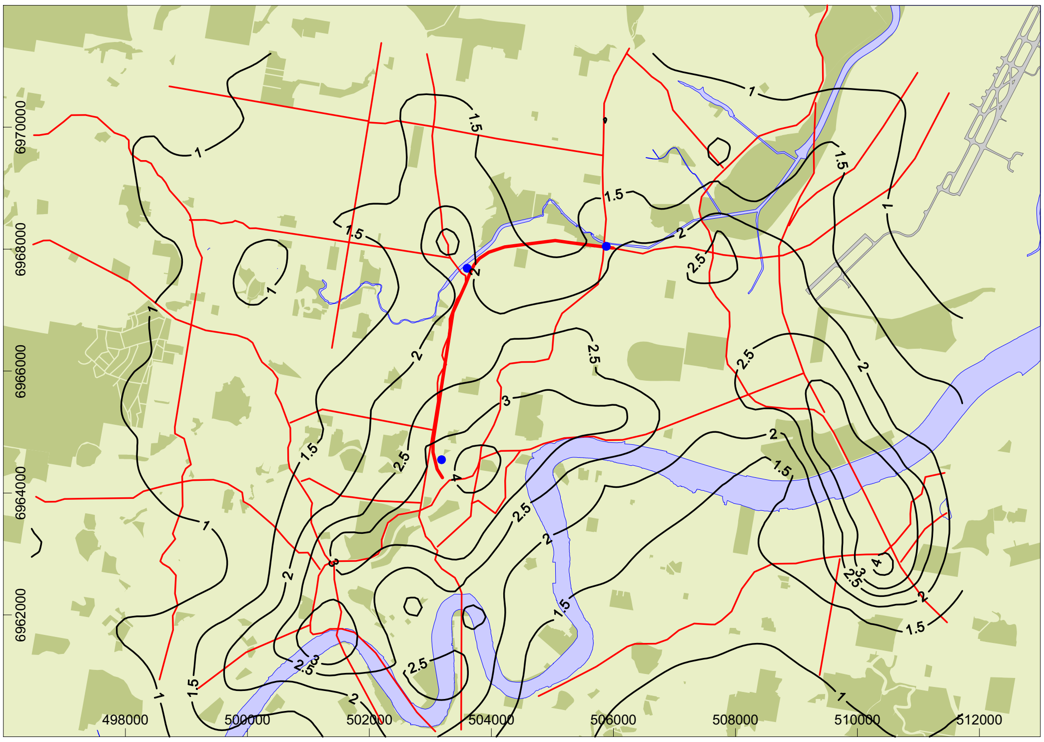


Airport Link tunnel without vent outlet filtration

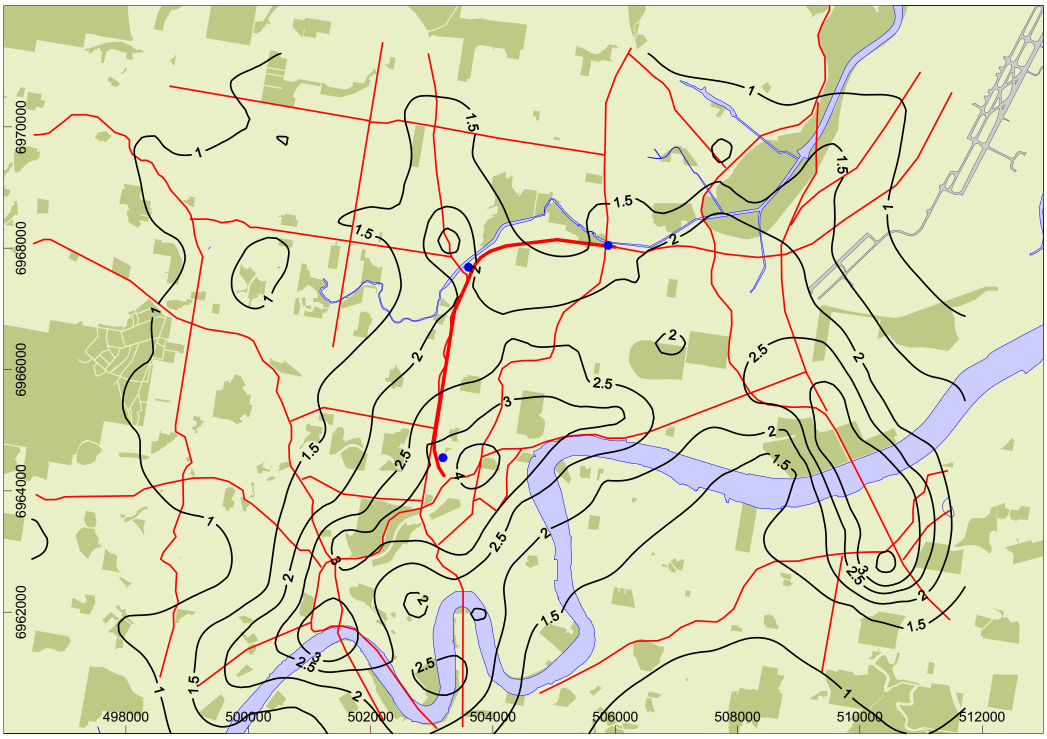


Airport Link tunnel with vent outlet filtration

Comparison of without and with tunnel filtration for annual average NO_2 concentrations in 2012 ($\mu g/m^3$)

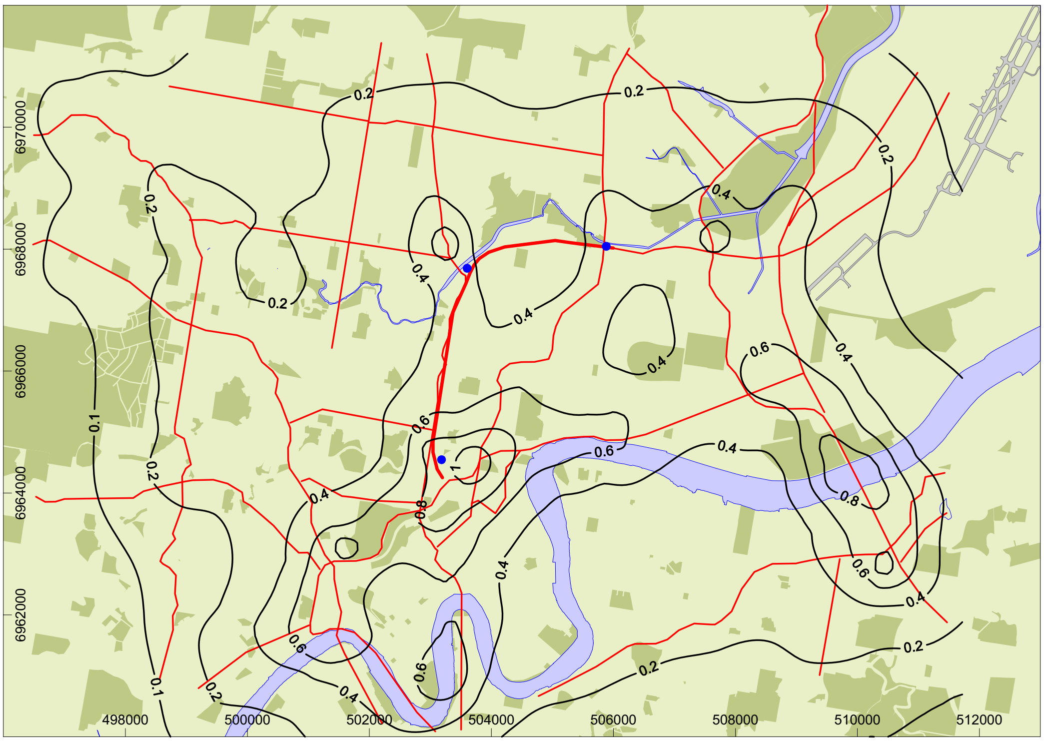


Airport Link tunnel without vent outlet filtration

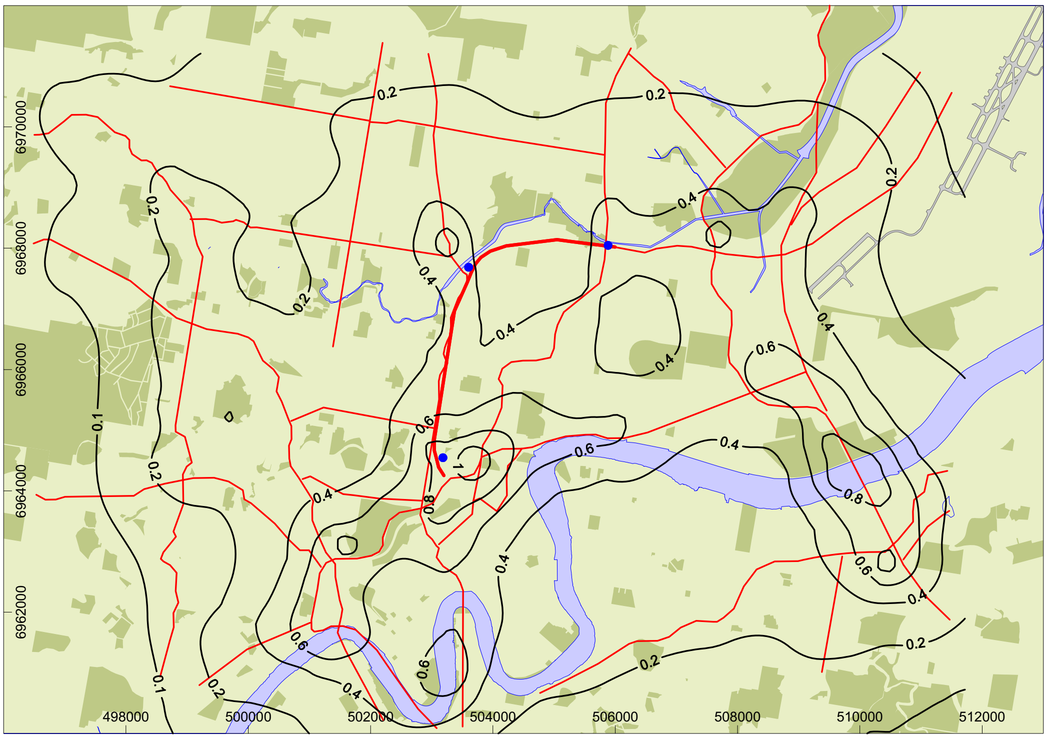


Airport Link tunnel with vent outlet filtration

Comparison of without and with tunnel filtration for maximum 24-hour average PM_{10} concentrations in 2012 ($\mu g/m^3$)

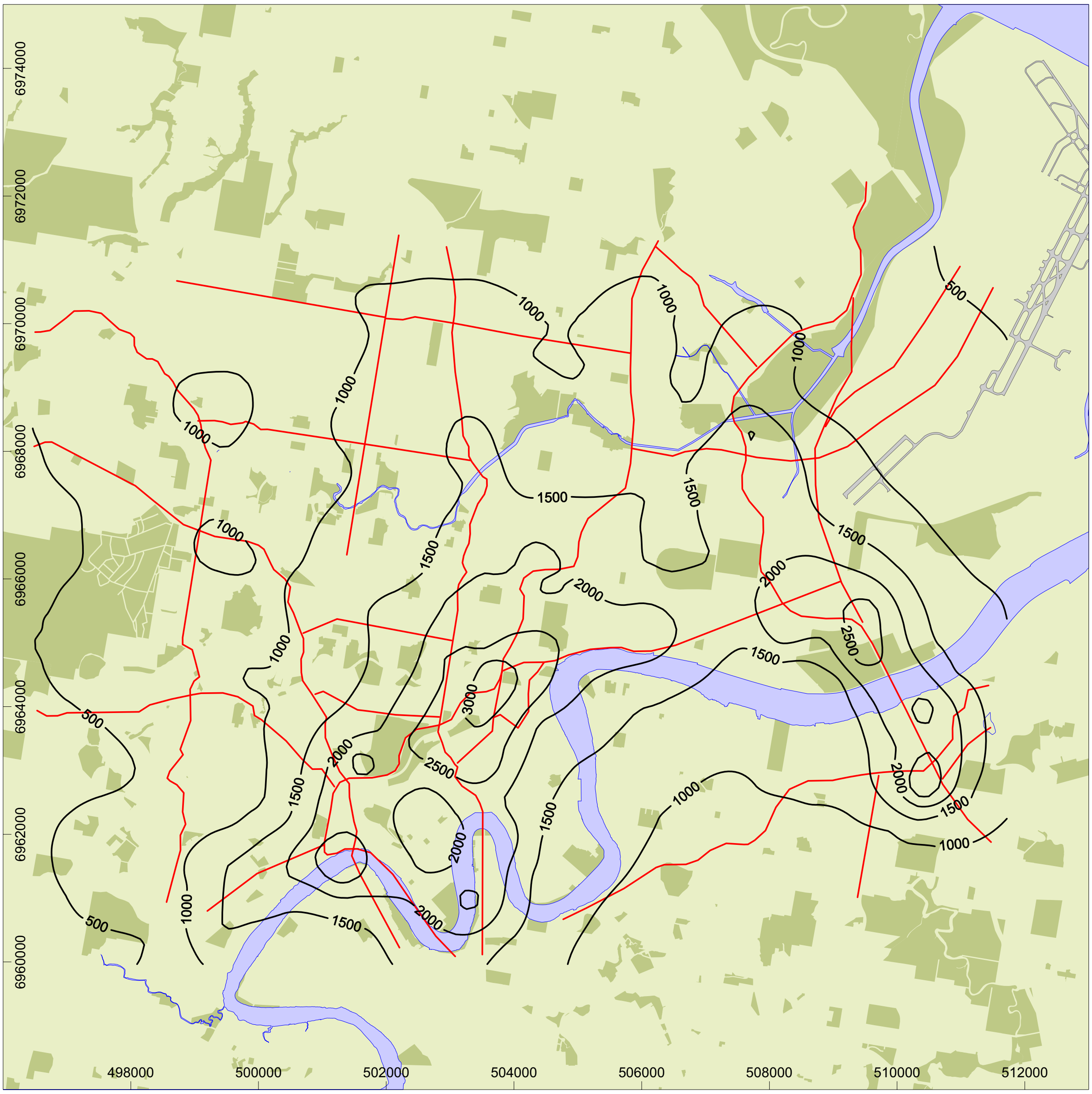


Airport Link tunnel without vent outlet filtration



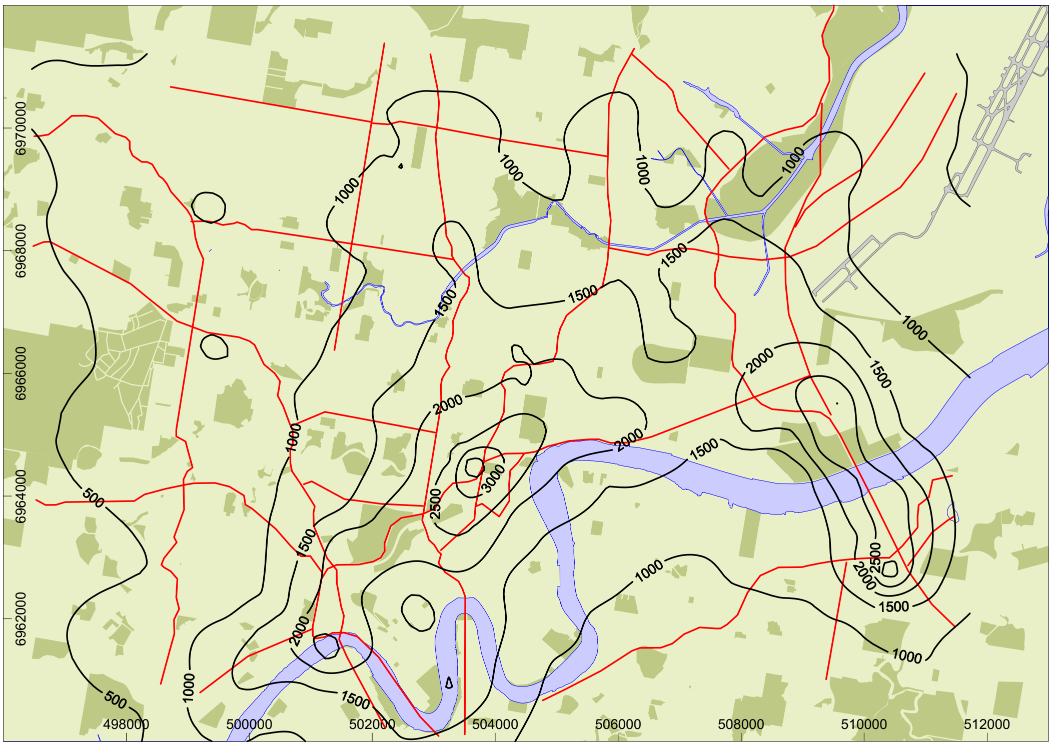
Airport Link tunnel with vent outlet filtration

Comparison of without and with tunnel filtration for annual average PM_{10} concentrations in 2012 (µg/m^3)

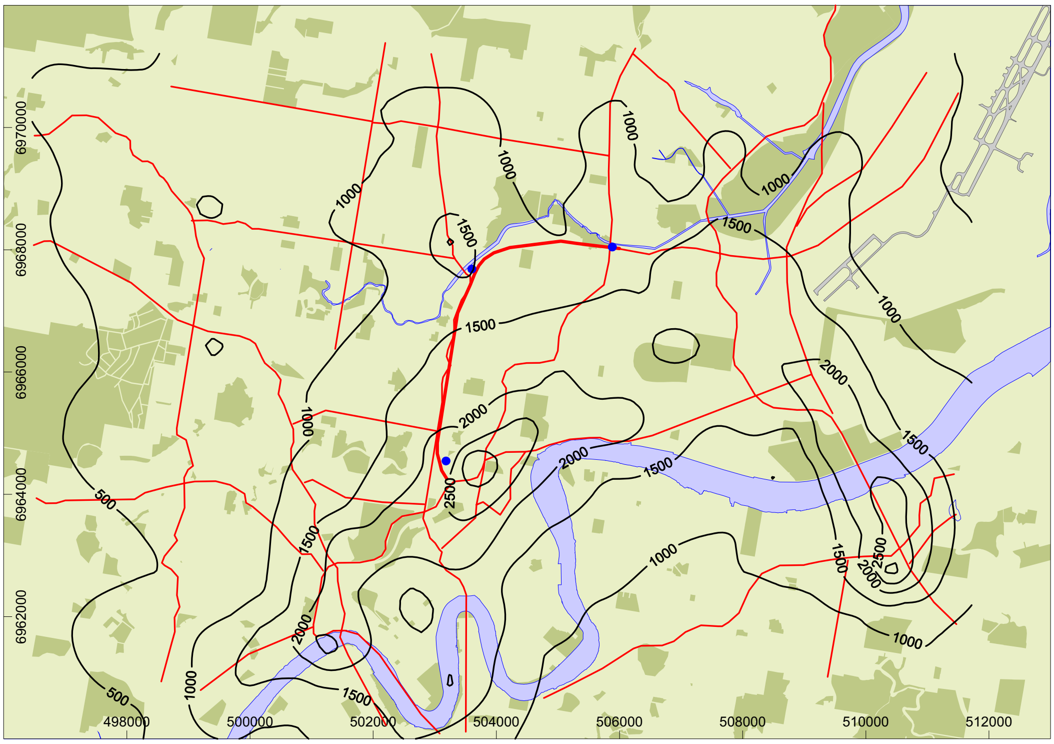


Existing

Predicted maximum 24-hour average sub-micrometre particles in 2004 (particles/m^3)



Without Airport Link



With Airport Link

Predicted maximum 24-hour average sub-micrometre particles in 2012 (particles/m^3)