Department of Transport and Main Roads

Appendices

Road Traffic Air Quality Management

June 2014

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Amendment Register

Issue / Rev no.	Reference section	Description of revision	Authorised by	Date
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Contents

Appendix A – Modelling Example

1 Example 1 – Road emissions

This example shows how to calculate air pollutant emissions for a section of road using the Transport and Main Roads Excel spreadsheet tool *MRD_emfac_scenario.xls* and then calculate the ambient concentration of pollutants using the CALINE4 dispersion model.

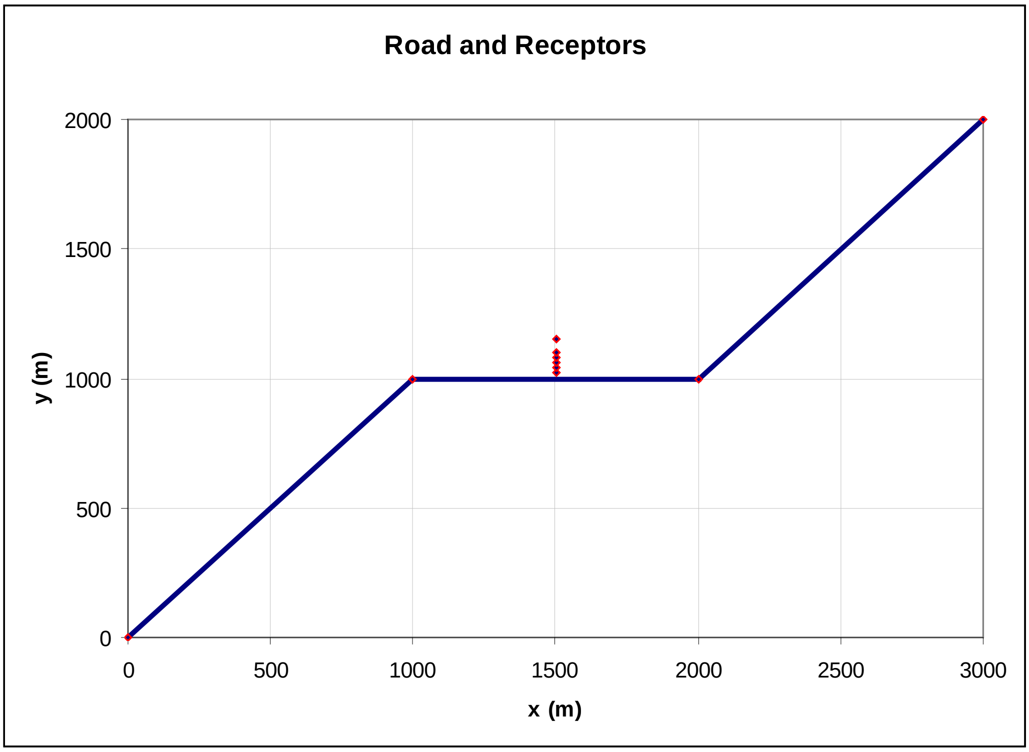
This example considers a new road of four lanes, modelled as three links. On each row of the Table 1 below, the coordinates of one end of each road segmented are tabulated, together with the Annual Average Daily Traffic (AADT), speed limit and percentage heavy vehicles for the link ending at that point. Thus the three values on the last three columns of the first line of data will be ignored.

Table1: Road and traffic input information for modelled scenario

x (m)	y (m)	z (m)	AADT (veh/day)	Speed limit (km/h)	Heavy Vehicles (%)
0	0	0			
1000	1000	50	10000	60	10
2000	1000	120	5000	80	5
3000	2000	130	5000	80	5

The layout of the road and receptors in the example is shown in Figure 1.

Figure 1: Road example layout - plan view, showing receptor locations



1.1 Emissions

Emissions for a section of road comprising several segments are calculated using the Transport and Main Roads Excel spreadsheet tool *MRD_emfac_scenario.xls*.

When the spreadsheet is opened, a grid input area is visible in which the above data can be typed. Data can then be saved as an input scenario for future reference by clicking on the button labelled *Save input file* and then specifying a file name and location.

The spreadsheet has been set up to calculate emission rates for pollutants as *g/vehicle/km* or *g/vehicle/mile*. The *g/vehicle/mile* unit is required for input to CALINE4. Clicking on the Checkbox labelled *Output emissions per mile* selects the appropriate unit.

Clicking on the button labelled *Save output file* calculates emissions for each link and stores them in an Excel Comma Separated Variable (CSV) file which can be opened in Excel to display the results. An example of such output (formatted slightly) appears in Table 2 below.

Table 2: Calculated vehicle emissions using spreadsheet tool

Conditions	**NO_x g/veh/ mile**	**CO g/veh/ mile**	**HC g/veh/ mile**	**PM_{10} g/veh/ mile**	**SO_2 g/veh/ mile**	**Fuel L/veh/ mile**	**CO_2e kg/veh/ mile**
AADT = 10 000 Speed = 60 Heavy_Veh = 10	6.66	30.54	1.84	0.25	0.22	0.26	0.65
Speed = 80 AADT = 5000	7.12	33.78	1.71	0.28	0.26	0.33	0.81
Heavy_Veh = 5	4.58	28.14	1.36	0.16	0.17	0.19	0.46
Totals	NO_x g/s	CO g/s	HC g/s	PM_{10} g/s	SO_2 g/s	Fuel L/s	CO_2e kg/s
	1473.2	7268.8	413.8	54.2	50.1	62.4	154.1

The emissions spreadsheet tool can also input a road from a file containing a single road centreline string in Autocad DXF format, provided that the centreline is defined as a continuous set of line segments or a single polyline (an Autocad entity that defines a set of end-to-end line segments).

1.2 CALINE4 line source dispersion model

The CALINE4 model is freely available from the Internet. It models a road as a number of straight segments, each associated with a constant air pollutant emission rate in units of g/vehicle/mile. It also requires data on traffic volumes and meteorological conditions.

CALINE4 is a DOS style program that requires a fairly rigid input format and is not very user-friendly. A Windows style front end program called CL4 can be downloaded with CALINE4. After installation, it can be used to produce input files for CALINE4 and to run the program.

CL4 is somewhat limited in that it only allows a limited range of inputs – for example, only allowing calculation of the concentration of carbon monoxide (CO).

However, the input file produced by CL4 can be edited manually using a program such as *WordPad* to calculate concentrations of other pollutants.

Alternatively, the concentration of pollutants other than CO can be calculated by scaling the output in CO ppm units produced for the emission rate of the other pollutant by a density scale factor (28 g/mol x 1000 L/m^3 / 22.4 L/mol = 1250 g/m^3) that converts ppm of CO to µg/m^3.

For example, if an emission rate of 10 g/vehicle/mile of CO produces 3.1 ppm of CO, then 2 g/vehicle/mile of NO_x (reported as NO_2) will result in a concentration of
2 / 10 x 3.1 x 1250 = 775 µg/m^3 of NO_x.

For the data generated by the spreadsheet for Summer of 2005, CALINE4 was set up as follows:

- 3 links – A, B and C
- Hourly traffic volume 1000 vehicles/hour
- Pollutant - CO (only pollutant calculated by CL4)
- Wind direction – worst angle
- Wind speed – low wind, worst case recommended by USEPA
- Stability - Stability Class G (worst case, highly stable, low dispersion)
- Mixing height 500m (not critical for receptors near road unless very low, rarely low when traffic volumes are high)
- Surface roughness 100 cm (suburban)
- Sigma theta 10 degrees
- Temperature 15 degrees C
- Receptors at 20, 40, 60, 80, 100 and 150 metres from the road centreline, height 1.8 m
- No ambient background CO

The output was as follows:

- CALINE4: CALIFORNIA LINE SOURCE DISPERSION MODEL
- JUNE 1989 VERSION
- PAGE 1
- JOB: Transport and Main Roads Ex 1
- RUN: Hour 1 (WORST CASE ANGLE)
- POLLUTANT: Carbon Monoxide

I. SITE VARIABLES

U= 1.0 M/S	Z0= 100. CM	ALT= 0. (M)
BRG=WORST CASE	VD= .0 CM/S	
CLAS= 7 (G)	VS= .0 CM/S	
MIXH= 500 M	AM B= .0 PPM	
SIGTH= 10. DEGREES	TEMP= 15.0 DEGREE (C)	

II. LINK VARIABLES

LINK DESCRIPTION	**LINK COORDINATES**				**TYPE**	**EF VPH (G/MI)**	**H (M)**	**W (M)**
A. Link A	0	0	1000	1000	AG	1000 28.2	.0	20.0
B. Link B	1000	1000	2000	1000	AG	1000 33.8	.0	20.0
C. Link C	2000	1000	3000	2000	AG	1000 28.1	.0	20.0

III. RECEPTOR LOCATIONS

RECEPTOR	COORDINATES (M)		
1. Recpt 1	1500	1020	1.8
2. Recpt 2	1500	1040	1.8
3. Recpt 3	1500	1060	1.8
4. Recpt 4	1500	1080	1.8
5. Recpt 5	1500	1100	1.8
6. Recpt 6	1500	1150	1.8

CALINE4: CALIFORNIA LINE SOURCE DISPERSION MODEL

JUNE 1989 VERSION

PAGE 2

OB: Transport and Main Roads Ex 1

RUN: Hour 1 (WORST CASE ANGLE)

POLLUTANT: Carbon Monoxide

IV. MODEL RESULTS (WORST CASE WIND ANGLE)

RECEPT	BRG DEG	PRED CONC PPM	CONC / LINK (PPM)		
			A	B	C
1. Recpt 1	259.	1.9	.2	1.6	.0
2. Recpt 2	254.	1.2	.3	1.0	.0
3. Recpt 3	253.	1.0	.3	.8	.0
4. Recpt 4	250.	.9	.3	.3	.0
5. Recpt 5	248	.9	.3	.5	.0
6. Recpt 6	243.	.8	.4	.4	.0

The direction of wind is reported as the direction from which the wind blows toward the road, ranging from 0° (north), clockwise through 90° (east), 180° (south) and so on. It can be seen from the results above that the worst case wind direction for receptor 1, which is 20 m from the centre of the road, is 259° or 11° south of west. This produces a maximum concentration of 1.9 ppm, with 0.2 ppm coming from Link A and 1.6 ppm from Link B. As the distance from the road increases, the worst case wind angle swings further to the south and the concentration drops to 0.8 ppm at a distance of 150 m.

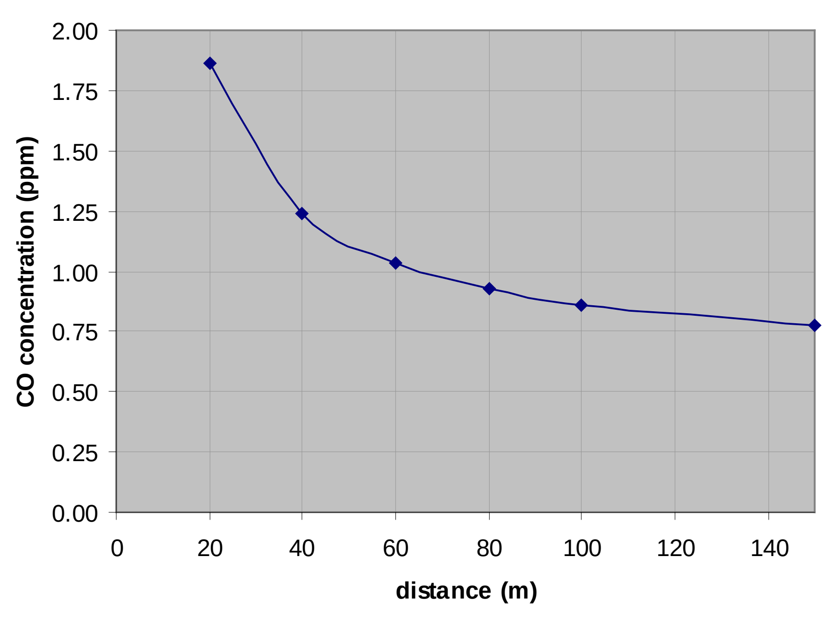
Because there is no way to change the format of the output, the accuracy of displayed results is limited. To produce a more precise output, it is possible to increase the input emission rates by a factor of say 50 or 100, and then divide the results by the same factor as shown below.

IV. MODEL RESULTS (WORST CASE WIND ANGLE)

RECEPT	BRG DEG	PRED CONC PPM	CONC/LINK (PPM)		
			A	B	C
1. Recpt 1	259.	1.864	.250	1.614	.0
2. Recpt 2	254.	1.236	.274	0.962	.0
3. Recpt 3	253.	1.032	.280	.752	.0
4. Recpt 4	250.	.924	.302	.622	.0
5. Recpt 5	248.	.860	.316	.546	.0
6. Recpt 6	243.	.778	.350	.426	.0

A plot of the results showing the variation of worst case hourly CO concentration with distance from the road is provided in Figure 2.

Figure 2: Plot of predicted concentration vs distance from road centreline



As previously stated, the worst hourly concentration of NO_x can be calculated by multiplying the predicted concentration of CO by the ratio of emissions of NO_x compared to CO and by the conversion factor 1250. In this case, the predicted concentration of NO_x reported as NO_2 at 20 m is 1.864 x 7.12 / 33.78 x 1250 = 491.1 µg/m^3 of NO_x.

Chapter 4 of the Air Quality Manual notes the finding of Cox et al (2005) that 10% of NO_x is in the form of NO_2 at distances to 20 m. Hence the maximum hourly NO_2 concentration at 20 m should be 491.1 x 10% = 49 µg/m^3.

For freeways, the NO_2/NO_x ratio is assumed to increase linearly to 30% at 60 m for the evening peak periods. However, the predicted concentration of CO has dropped from 1.864 ppm at 20 m to 1.032 ppm at 60 m, and the corresponding NO_x concentration from 491.1 µg/m^3 to 271.9 µg/m^3. Hence the worst case hourly concentration of NO_2 at 60 m is predicted to be 81.6 µg/m^3. It can be seen from Table 3 that the highest concentration of NO_2 may occur at a significant distance from the road.

Table 3: Calculation of nitrogen dioxide concentrations using Cox (2005) freeway conversion factors

Distance (m)	CO (ppm)	NO_x as NO_2 ($\mu g/m^3$)	Conversion Factor	NO_2 ($\mu g/m^3$)
20	1.864	491.1	10%	49.1
40	1.236	325.6	20%	65.1
60	1.032	271.9	30%	81.6
80	0.924	243.4	65%	158.2
100	0.86	226.6	100%	226.6
150	0.778	205.0	100%	205.0

This worst case analysis assumes that the worst case meteorological conditions occur at the same time as the worst case traffic and the highest NO_2 conversion rates. If predicted concentrations are significant in relationship to recommended air quality guidelines, a more detailed analysis of the occurrence of worst case wind speed, direction and stability parameters is warranted.

Chapter 4 of the Air Quality Manual notes the findings of a central Brisbane study that for periods of 8 hours, 24 hours, 90 days and 12 months, the maximum concentrations can be obtained from peak one hour concentrations by using multiplicative concentration ratios (persistence factors) of 0.4, 0.24, 0.14 and 0.06 respectively. Table 4 shows results for other averaging times using these procedures as well as the guideline values.

Table 4: Pollutant concentrations calculated using EPA Brisbane persistence factors and guideline levels

Distance (m)	CO (ppm) 8 hr	NO_2 ($\mu g/m^3$) 1 hr	PM_{10} 24 hr	SO_2 24 hr
20	0.75	49.1	4.6	4.3
40	0.49	65.1	3.1	2.9
60	0.41	81.6	2.6	2.4
80	0.37	158.2	2.3	2.1
100	0.34	226.6	2.1	2.0
150	0.31	205.0	1.9	1.8
Guideline	9	246	50	100

If pollutant concentrations are significant in relation to guideline levels, it would be preferable to undertake modelling of each hour of the year to compile statistics for the relevant averaging times.

If air pollutant concentrations (including a 90th percentile background) for a new road are predicted to exceed 80% of guidelines at sensitive locations within 10 years of construction, control or design measures should be adopted with the aim of reducing pollutant levels below 80% of guidelines as discussed in Chapter 3 of the manual.

2 Example 2 - Construction emissions

In this example, emissions from a road construction activity are calculated using emission factors from the NPI and EPA AP-42 handbooks. These emissions are then input, together with meteorological data derived from the TAPM model, into the Ausplume dispersion model to calculate dust concentrations and deposition rates.

- Activities modelled
- Emissions are assumed to arise from the following activities:
- Soil/subsoil excavation and loading to haul trucks
- Spoil transport by truck on unpaved haul roads
- Spoil dumping
- Dozer ripping and pushing activities
- Grading
- Movement of trucks carrying gravel
- Dumping of gravel
- Movement of light vehicles on unpaved roads
- Wind-blown dust from unpaved areas
- Wind-blown dust from stockpile loading/unloading

Scenarios such as this will typically be constructed to model emissions at the peak of activities, or when activities are close to some sensitive location.

2.1 Input parameters

The parameters assumed are as follows:

Road length	500 m
Road width	25 m
Depth excavated	2 m
Soil/subsoil density	2.12 t/m^3
Haul truck capacity	50 t
Haul truck gross mass	55 t
Haul distance round trip	1.5 km
Days hauling	60 days
Silt[1] content	5%
Road moisture content	0.5%
Average wind speed	3 m/s
Small vehicle trips	100 per day
Average s.v. trip length	0.5 km
Average s.v. speed	60 kph
Bulldozing activity	10 h/day
Grading activity	10 h/day

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[1] Silt comprises particles smaller than 75 micrometers (µm) in diameter in the road surface materials. The silt fraction is determined by measuring the proportion of loose dry surface dust that passes a 200-mesh screen, using the ASTM-C-136 method.

Grading speed	11.4 km/h
Open area	2.5 ha
Gravel deliveries	100 t/day
Gravel truck capacity	20 t
Proportion to stockpile	50%

2.2 Pollutants modelled

This example considers only particulate emissions in the form of TSP and PM_{10}. Emission factors are also available for gaseous pollutants from various types of equipment for example, Table 4 of the NPI Emission Estimation Technique Manual for Mining, but these are not considered in this example as they are modelled in the same manner.

2.3 Emission factors used

The emission factors used in this example scenario are summarised in Table 5 and Table 6 for TSP and PM_{10} respectively.

Table 5: Emission factor estimates for TSP

Source	Emission Factor Equation	Units	Assumed control efficiency
Loading spoil	$0.74 * 0.0016 * (U/2.2)^{1.3} * (M/2)^{-1.4}$	kg/t	-
Hauling spoil	$2.82 * (S/12)^{A} * (W/3)^{B} / (M/0.2)^{C}$	kg/VKT	75%
Dumping spoil	0.012	kg/t	70%
Small vehicle movements	$(6*(S/12)^{1}*(KPH/1.6/30)^{0.3} / (M/0.5)^{0.3}-0.00047)*281.9$	g/VKT	75%
Bulldozing	$2.6*S^{1.2}*M^{-1.3}$	kg/h	-
Grading	$0.0034*S^{2.5}$	kg/VKT	-
Gravel dumping to stockpile	0.004	kg/t	50%
Loading from stockpile	0.03	kg/t	50%
Open area wind	0.4	kg/ha/h	75%

U = mean wind speed (m/s)

M = Moisture content in %

S = silt content in %

W = vehicle gross mass in tonnes

A = 0.8

B = 0.5

C = 0.4

VKT = vehicle kilometres travelled

KPH = vehicle speed in kph

Table 6: Emission factor estimates for PM$_{10}$

Source	Emission Factor Equation	Units	Assumed control efficiency
Loading spoil	$0.74 * 0.0016 * (U/2.2)^{1.3} * (M/2)^{-1.4}$	kg/t	-
Hauling spoil	$2.82 * (S/12)A * (W/3)B / (M/0.2)C$	kg/VKT	75%
Dumping spoil	0.012	kg/t	70%
Small vehicle movements	$(6*(S/12)^{1}*(KPH/1.6/30)^{0.3} / (M/0.5)^{0.3}-0.00047)*281.9$	g/VKT	75%
Bulldozing	$2.6*S^{1.2}*M^{-1.3}$	kg/h	-
Grading	$0.0034*S^{2.5}$	kg/VKT	-
Gravel loading to stockpile	0.004	kg/t	50%
Loading from stockpile	0.03	kg/t	50%
Open area wind	0.4	kg/ha/h	75%

Abbreviations as below Table 5, except:

B = 0.4

C = 0.3

References: Small vehicle movements AP42 Ch 13.2.2-4 (11/06) Eq 1b and Table 13.2.2-2

Other sources: Emission Estimation Technique Manual for Mining Version 2.3, 5 December 2001

2.4 Source estimates

The above emission factor data and equations are typically entered into an Excel spreadsheet and calculated emissions are converted into units of g/s (for point sources) or g/m^2/s (for area sources). Summaries of the above for the various activities and sources are provided in Table 7 and Table 8.

Table 7: Estimated emission rates for various activities

Activity	Assigned source	TSP (g/s)	PM_{10} (g/s)
Loading spoil	1	0.126	0.0597
Hauling spoil	3	0.184	0.0478
Dumping spoil	5	0.0368	0.0132
Small vehicle movements	3	0.109	0.0342
Bulldozing	1, 4, 5	2.08	0.440
Grading	1, 4, 5	0.251	0.112
Gravel hauling	3	0.0347	0.00902
Gravel dumping	4	0.00417	0.00149
Gravel loading to stockpile	2	0.00116	0.000492
Gravel loading from stockpile	2	0.0347	0.00376
Open area wind	2	0.0458	0.0229

Table 8: Estimated emission rates for various sources

Source	Source area (m^2)	TSP (g/s)	TSP ($g/m^2/s$)	PM_{10} (g/s)	PM_{10} ($g/m^2/s$)
1	1 250	0.903	7.215E-04[1]	0.244	1.950E-04
2	2 500	0.0209	8.380E-06	0.00901	3.924E-06
3	12 500	0.362	2.899E-05	0.108	8.670E-06
4	1 250	0.780	6.238E-04	0.186	1.484E-04
5	1 250	0.812	6.499E-04	0.197	1.578E-04

Note 1: Number format notation 7.215E-04 is equivalent to 7.215×10^{-4} or 0.0007215

In this example of a long, straight road, the number of sources is small and the geometry is simple. In real life, more sources with more complex geometry and emission behaviour may need to be considered.

If annual averages are being calculated for a long term project and activities move with time, the results of the modelling of several scenarios may need to be combined.

In the example, emissions have been assumed constant over all hours. If winds have a diurnal variation or if some sources operate at particular times, an hourly emission profile could be used to provide more accurate predictions.

2.5 Dispersion modelling

Programs such as Ausplume, TAPM, Calpuff, Aermod and ISCST can be used to model dispersion from roads. Models such as TAPM and Calpuff are designed to model dispersion from large industrial sources, are probably over-complex and have insufficient resolution of dust dispersion near construction sites. Given the likely accuracy of the emissions data, simple, fast-running models such as Ausplume and ISCST are considered more appropriate. In this example, Ausplume is used to calculate concentrations of dust from the above sources.

When running Ausplume, it is usually best to select the menu item *Edit* and then the menu item *Sequential Inputs*. This will prompt the user to enter all the appropriate data in sequence and select appropriate input options through a series of input forms. A context-sensitive help file is accessible from each form to explain the meaning of the various options presented.

A suitable meteorological file for any particular location can generally be constructed from measured wind and solar radiation data obtained at the site. If limited site-specific information is available, a file such as that used in this example can be constructed. However, it should be validated where possible against measured wind speed and direction measurements and adjusted where necessary if systematic differences are noted. Frequency analysis of several years of data can demonstrate that a particular year's data chosen for modelling is representative of typical long-term conditions. For this example, a meteorological input file was constructed for each hour of year using the TAPM meteorological model with synoptic data for 2005 and local terrain data for Brisbane.

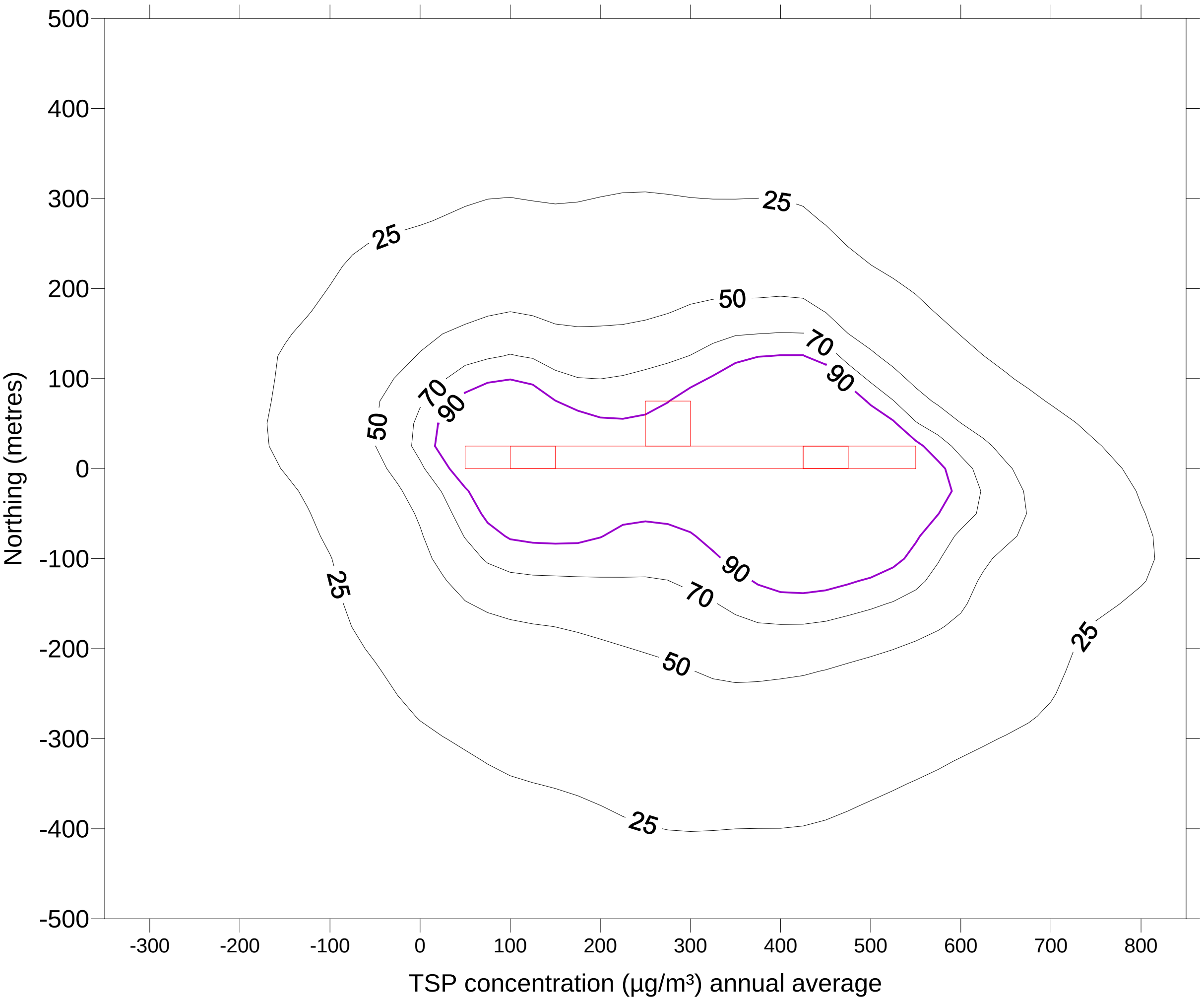
Terrain does not generally affect dust dispersion from surface sources greatly as the air in the surface layer tends to follow the terrain contours at a fairly constant height. During stable conditions, there is some tendency for vertical air motions to be suppressed and for the wind to flow around obstacles, but most standard models do not handle such situations well. However, emissions during such conditions are generally low because they tend to occur at night when dew is present, wind speeds are low and dust-generating equipment is not operating.

The averaging times relevant to dust concentration are generally annual for TSP and 24 hour and annual for PM_{10}. For dust deposition, the long term average TSP deposition rate is required. Three month and/or annual averages would be appropriate.

Table 11-9.1 of AP42 Chapter 11.9 (Final Section, Supplement E, October 1998) provides estimates of the proportions of particles in the size ranges less than 30, 15, 10 and 2.5 µm in diameter. Representative diameters in these size ranges can be used in the dry depletion section to model dust fallout if site-specific information is not available.

Output from the model will be in the form of a report of predicted levels at discrete locations or a contour plot of predicted levels over a region. Ausplume interfaces directly with the Surfer graphical package and so can present high-quality graphical representations of the predicted impact of emissions from the project. To enable use of Surfer, calculations are made over a suitably spaced grid of receptor points. Surfer interpolates contour lines representing equal concentrations or deposition rates over the area modelled. Interface of Ausplume with Surfer is managed automatically by Ausplume, although the user can adjust titles, axes labels, background images and so on. A contour plot of modelled emissions for sources with one year of constant emissions and no depletion appears below.

Figure 3: Ausplume plot of TSP annual average concentration



More realistic modelling would result from the inclusion of depletion due to fallout, attention to the effects of source height and the use of a variable source input file that would allow for different emissions for each hour of the year from each source.

Modelling of dust dispersion is a difficult subject, with emissions expected to vary markedly with meteorological and operational conditions (wind, watering, revegetation, re-entrainment, particle capture, mechanical breakdown of soil particles, vehicle operations etc). Hence modelling will normally be indicative only of those areas on which control and monitoring activities will need to focus. A detailed and comprehensive environmental management plan incorporating monitoring and appropriate control strategies will be of prime importance to maintain environmental values in the surrounding area and minimise the likelihood of nuisance or health impacts.

Appendix B – Tunnels

1 Tunnels

Covered roadways in excess of 90 m in length should be considered as tunnels. Details about various aspects of tunnel design can be found in Chapter 23 of Transport and Main Roads' *Road Planning and Design Manual (RPDM)*.

This Manual covers aspects of air pollution relating to the emission of pollutants emitted from vehicle exhausts, engines, fuel systems, tyres and braking systems during normal operation or in congested situations. Sources such as external combustion and leaks of transported materials are beyond the scope of the document.

Dangerous goods carried through tunnels can provide a risk of fire, explosion or toxic exposure. These risks are a safety issue that should be covered in a separate risk assessment. They are not covered in this guideline. Occupational health and safety issues for persons working in tunnels should also be considered separately.

2 Internal air quality guidelines

Pollutant guideline levels provided by the World Road Association (PIARC) are summarised in Table 3.3.1 of Chapter 3 of this Manual for the indicators carbon monoxide, nitrogen dioxide and visibility (extinction coefficient K).

A new tunnel should be designed with predicted internal concentration levels of carbon monoxide and nitrogen dioxide for normal operations of no more than 60% of the guideline levels for normal operations and up to 100% of the guidelines for congested conditions.

It should be designed with an extinction coefficient K of no more than 0.005/m for normal operations and 0.009/m for congested conditions.

The traffic levels used for assessment against the above criteria should be those predicted for up to 10 years from the opening of the tunnel.

3 Parameters relevant to emission rates

3.1 Gradient

For a number of reasons, RPDM recommends that gradients in road tunnels be limited to 3.5% in general. For long two lane tunnels with two-way traffic, a maximum grade of 3% is desirable to maintain reasonable truck speed.

In underwater tunnels or tunnels with low points, grades should preferably not be less than 0.5%.

3.2 Speed

The maximum allowable speed in two-way tunnels throughout the world is 60 to 80 km/h. In one-way tunnels, the speed limits are between 80 and 110 km/h.

3.3 Emissions estimation

For the current vehicle fleet, 10 to 20% of emitted nitrogen oxides are assumed to be in the form of nitrogen dioxide. For purposes of prediction, it may generally be assumed that 20% of NO_x within the tunnel is in the form of nitrogen dioxide unless measured ratios from similar projects are available.

Emissions may be calculated using measured local data or emission factors such as the spreadsheet described in Section 4.3.2.1 of Chapter 4 of this Manual.

3.4 Dispersion modelling

Internal pollutant concentrations are expected to be almost uniform across the tunnel cross section because of vehicle induced turbulence.

Average concentrations of pollutants may be calculated by dividing the above emission rates by the designed ventilation rate. A 90 percentile regional background concentration should also be included in the gas concentration predictions.

Of course, it is quite possible that the ventilation rate will be varied based on data from real time monitors to ensure that internal air quality criteria are met.

For tunnels without stacks and ventilation inlets, or those with widely separated stacks, the pollutant concentration will increase with distance along the tunnel. It is generally possible to calculate the maximum concentration along the tunnel as follows:

- Consider a 1 metre long plug of air moving along a tunnel of cross-sectional area A m^2.
- The time t taken for the plug to move along a distance d at the average ventilation velocity v m/s is given by $t = d/v$.
- If n vehicles per second travel through the tunnel and their average emission rate is E g/m/veh, then the concentration of the pollutant will reach a maximum of
- $C_{max} = 10^6\ n\ E\ t\ /\ A$ [μg/m^3]

For example, consider 1800 vehicles per hour each emitting CO at a rate of 20 g/km/veh travelling through a 100 m long tunnel of area 50 m^2 for which the longitudinal tunnel ventilation velocity is 2.5 m/s.

n = 1800 veh/h / 3600 s/h = 0.5 veh/s

t = 100 m / 2.5 m/s = 40 s

E = 20 g/km/veh / 1000 m/km = 2 x 10-*2* g/m/veh

C_{max} = 10*6* x 0.5 x 2 x 10-*2* x 40 / 50 = 8 000 μg/m^3

This may be compared with the PIARC guideline of 112 500 μg/m^3

If the slope within the tunnel varies, the emission rate will also be variable and the calculation may be broken into several steps, each with their own t and E values.

For short tunnels without fans, the ventilation rate will depend to some extent on various factors including:

- tunnel configuration (one-way, two-way)
- tunnel orientation to prevailing winds and wind speed
- tunnel cross section
- tunnel inlet geometry
- tunnel slope
- proportion of heavy vehicles, and

- vehicle speed.

Modelling such situations may be quite difficult and it may be appropriate to instead use measured data obtained from similar tunnels elsewhere.

Tunnel portals and stacks can in some cases be modelled as volume or point sources using models such as Ausplume or Calpuff. If the geometry is complex, it may be necessary to use numerical CFD models. CFD models should be better able to represent the actual flow behaviour around a source with complex geometry, but each run can only treat a single wind speed / wind direction / emission velocity / atmospheric stability scenario. Representative or worst case scenarios need to be chosen with care as the results of large numbers of model runs can be difficult to interpret meaningfully.

Appendix C – Climate Change Impact Assessment

1 Assessment – GHG emissions and mitigation measures

An assessment of greenhouse gas emissions and and mitigation measures associated with a project will generally include:

- An estimate of generated GHG emissions in tonnes of CO_2e
- A description of the proposed GHG mitigation measures and an estimate of the emissions reduction due to the measures, focussing on the hierarchy of actions
  - Avoid
  - Reduce
  - Switch
  - Offset
- A reassessment of net GHG emissions after mitigation measures are applied
- A description of how the net GHG will affect the State's GHG profile (% change to the latest Queensland GHG emissions inventory).

2 Assessment – Climate change risks and adaptation measures

Briefly describe the key risks/vulnerabilities to the proposal from projected climate change impacts based on an analysis of increased risk of flood/storm tide inundation, increased vulnerability to more intense bushfires, threat from sea level rise.

Provide an overview of the adaptation measures adopted or proposed and their expected benefits, emphasising measures relevant to minimising climate change impacts to health, safety and/or property.

3 Calculation methods

The Commonwealth Department of Climate Change has provided guidelines for assessing GHG emissions:

- *National Greenhouse and Energy Reporting System: Technical Guidelines for the Estimation of Greenhouse Emissions and Energy at Facility Level (December 2007)*
- *National Greenhouse Accounts Factors (January 2008)*

A spreadsheet tool has been developed by the Net Balance Management Group of VicRoads and was available on the VicRoads website at the time of writing. The RTA had also developed a trial version of a construction greenhouse emissions estimation tool.

Appendix D – Assessment of Potential Air Quality Impacts of Busway Projects

1 Objectives

This document consolidates the learnings from a number of air quality studies that were prepared during the Concept Design and Impact Management Plan phase of various busway projects in Queensland. The air quality studies were commissioned by Queensland Transport (now the Department of Transport and Main Roads, TMR) to ensure that air quality, amongst other things, was a central consideration in the design of the busways.

The studies were commissioned to quantify the potential impacts of the projects on air quality and to provide a basis to optimise the busway alignment and busway station locations and to implement mitigation measures. The studies were prepared to support the approvals of:

- The Boggo Road Busway
- The Eastern Busway
- The South East Busway
- The Inner Northern and Northern Busways.

Early studies were undertaken at a time when there was no specific technical guidance available from industry or regulatory agencies. As a consequence, inconsistent methodologies were applied that resulted in significant challenges when attempting to interpret results under a unified perspective. The source of discrepancies between some studies was not always able to be resolved and investigations into why those discrepancies occurred did not always come to a satisfactory conclusion. To avoid such problems in later busway projects, a consistent methodology was developed and used by the study participants for the Eastern, Inner Northern and Northern Busways. This document represents a formalisation and extension of the methodologies adopted for these projects.

Additionally, this document establishes a consistent and transparent framework for air quality assessment that will provide answers to the questions that are most frequently raised by the community.

The information contained within this document has been compiled for use by both the technical specialist and the non-technical reader.

Ultimately, it is anticipated that this document will form the basis of the framework by which air quality impacts of busway infrastructure projects will be assessed and will provide the basis for the implementation of mitigation measures.

1.1 Document overview

This document covers the following topics:

- air quality impact assessment philosophy
- air pollutants of concern and air quality objectives used in Queensland
- techniques to quantify air pollutant emissions from the motor vehicle fleet
- design standards to manage potential air quality impacts
- existing air quality and defining background levels of air pollutants
- data required to characterise the busway within a dispersion model

- the choice and suitability of modelling tools
- the development of representative meteorological fields
- level 1 and level 2 assessment requirements
- reporting of dispersion model results both at sensitive receptor locations and as contour plots
- detailed study limitations, and
- gaps in our current knowledge and future investigations to be undertaken.

2 Assessment philosophy

The quality of the air can have a direct impact on our health and wellbeing. As a consequence, it is important to ensure that the potential impact of new activities is appropriately quantified during the design stage and that provision is made to ensure that an activity can be conducted in a manner that minimises the emission of air pollutants and avoids adverse impacts on the community.

An air quality impact assessment study is conducted to quantify the potential change in concentrations of air pollutants that may occur as a result of a change to an existing activity or the construction and operation of a new facility. Where the activity is likely to increase the concentrations of air pollutants, the assessment must:

- determine the baseline or existing air quality
- ensure that the activity is designed so as to minimise the emission rate of air pollutants to the extent that is reasonably achievable
- quantify the magnitude of the increase in air pollutant concentrations associated with the changed activity or new activity
- determine whether the magnitude of the increase is acceptable having regard to the existing air quality, human health and air quality objectives.

The complexity, level of refinement or level of detail required in an air quality impact assessment will depend on the nature and scale of a given project and its proximity to sensitive land-uses. For example, a major development of a high capacity busway in close proximity to sensitive land-uses will require a more intensive assessment than a lower capacity busway in a sparsely populated area. In general, one of two levels of assessment will be applicable:

- Level 1 (screening level assessment): for which worst-case impacts are assessed utilising gross conservative assumptions based on project-specific information.
- Level 2 (detailed assessment): involves a refinement of the Level 1 assessment in order to improve the accuracy of the assessment and will typically include the development of project-specific inputs. A Level 2 assessment may involve (for example) the collection of study area specific data (such as local road network vehicle fleet details, air quality and meteorological data).

It is not intended that an assessment should routinely progress through the two levels of assessment. If the air quality impact is considered to be a significant issue, there is no impediment to immediately conducting a Level 2 assessment. Equally, if a Level 1 assessment conclusively demonstrates that adverse impacts will not occur, there is no need to progress to Level 2.

The requirements and methodology of Level 1 and Level 2 assessments are addressed in detail in Section 9.2 and Section 9.3, respectively.

3 Air pollutants of concern

3.1 General

Motor vehicles are one of the most important anthropogenic sources of air pollutants in Australian state capitals and are responsible for a large proportion of the air pollutants that people are exposed to in their everyday lives. Research into the health implications for pollution-sensitive people living in close proximity (less than 500 metres) of very major road corridors (daily traffic flow rates of 100,000 vehicles) suggests a strong correlation between proximity and adverse health outcomes. Many studies have shown that traffic air pollution can adversely affect human health and amenity, especially for pollution-sensitive people such as young children and elderly or health-compromised adults (e.g. Balmes 2003, Brunekreef 2003, Jalaludin 2003, World Health Organisation (WHO) (2004a, b).

The major air pollutants associated with motor vehicles are summarised in Table 1. The main pollutants of concern are nitrogen dioxide and benzene, but with particulate matter probably of more importance than shown (because of the underestimation in current inventories due to the neglect of wheel-generated dust and the lack of a “no-effects” threshold). The importance of benzene is likely to decrease in the next few years as the benzene content of fuel is reduced nationally.

Table 1 Ranking of air pollutants of concern in South east Queensland

Air pollutant	Health criteria as 1 hour average (μg/m^3) [3]	Emission rate[1] (tonnes per annum)	Hazard Index[2]	Ranking
Nitrogen dioxide	250	60,579	86.5	1
$PM_{2.5}$	47	2,249	79.7	2
PM_{10}	94	2,249	42.1	3
Benzene	61	2,277	38.1	4
1,3 Butadiene	15	415	28.6	5
CO	16673	417,317	28.2	6
Sulphur dioxide	570	1,871	3.5	7
Toluene	7742	3,583	0.5	8

Note

[1] Emission rate from SEQ Inventory.

[2] Hazard index calculated by dividing emission rate by health criteria. Ratio NO_2:NO_x = 0.3. Background concentrations as 1 hour averages assumed to be: NO_2 = 40 μg/m³; PM_{10} = 41 μg/m³; $PM_{2.5}$ = 19 μg/m³; Benzene = 1.7 μg/m³; 1-3 Butadiene = 0.2 μg/m³; SO_2 = 31.3 μg/m³; and CO = 1,875 μg/m³.

[3] Criteria are based on the Air EPP

In the Southeast Queensland (SEQ) Region, motor vehicles have been estimated to contribute 62% of oxides of nitrogen, 68% of carbon monoxide and 67% of volatile organic compounds from anthropogenic sources (EPA & BCC, 2003). Motor vehicles also contribute 27% of all anthropogenic particles (as PM_{10}) with a disproportionately high contribution (75%) being due to heavy diesel vehicles.

The total amount of air pollutants emitted in the SEQ Region depends on the total number of kilometres travelled by motor vehicles (vehicle kilometres travelled, VKT) and the amount of pollutants that each vehicle emits per kilometre travelled. VKT in the SEQ Region is estimated to increase by between 10% and 17% in the years from 2000 to 2005 and by 30% to 60% by 2011.

Tighter emission standards for new motor vehicles will substantially reduce emissions compared with older vehicles. However, it is possible that the reductions in total vehicle emissions achieved will be matched and perhaps overtaken by the increase in total vehicle emissions associated with a growing VKT. From a public health perspective, regional air quality monitoring in Brisbane indicates that the last ten years have seen a small improvement or stabilisation in air quality, with fewer regional events likely to affect pollution-sensitive people (Katestone Environmental, 2004).

High pollution events tend to occur on days with particular meteorological conditions, the frequency of which can change dramatically from year to year. The air quality monitoring data from Brisbane suggest that meteorological variability and particularly the inland penetration of sea-breezes is very important to the occurrence of pollution-conducive days.

On a local level within 100 metres of busy roads, air pollution hotspots may exist particularly during the morning and afternoon peak hours and are more likely for locations in close proximity to congested intersections with queuing traffic or where a significant proportion of the traffic are heavy diesel vehicles. In the mid 1990’s, Neale and Wainwright (2001) found high concentrations of carbon monoxide and PM_{10} at monitoring points between 1 metre and 20 metres from the edge of various roads and intersections in Brisbane.

3.2 Pollutants of interest to the Department of Transport and Main Roads

TMR has identified the following pollutants of concern in relation to potential air quality impacts associated with emissions from busways:

- oxides on nitrogen
- carbon monoxide
- particulate matter as PM_{10}
- particulate matter as $PM_{2.5}$
- ultrafine particles
- volatile organic compounds including (but not necessarily limited to): benzene, toluene, xylene, 1,3-butadiene
- pollutants included in Schedule 1 of the Queensland Environmental Protection (Air) Policy 2008 (Air EPP).

Note that due to uncertainties in the nature and level of impact associated with ultrafine particles, TMR requires that consideration be given to estimating ground-level impacts of emissions of ultrafine particles associated with the busways.

For the purposes of conducting an air quality assessment of the impacts of emissions from busways on ambient air quality, consideration will necessarily be given to all identified pollutants.

As additional information becomes available in relation to the characterisation of the emission sources (i.e. buses and our general vehicle fleet), TMR may choose to update the list of pollutants of interest which may include the addition and/or removal of pollutant species form this list.

4 Transport emission 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, grams per kilowatt-hour (kWh) 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 assessing air quality impacts from busway studies have included:

- bus emissions data collected by the International Laboratory for Air Quality and Health (ILAQH) of Queensland University of Technology (QUT) and is considered to be representative of the current Brisbane bus fleet
- the New South Wales EPA Motor Vehicle Emissions Projection System (MVEPS)
- World Road Association, referred to as PIARC (formerly the Permanent International Association of Road Congresses)
- the South-East Queensland Region Air Emissions Inventory.

In the context of busway air quality studies, emission factors are needed to quantify emissions from the fleet of buses that will use the busway and projected to some future year or years. If traffic on the road network surrounding the busway is to be included in the dispersion modelling, emission factors would also be required to quantify emissions from the non-busway traffic (urban vehicle fleet).

To provide an accurate characterisation of the emission rates of air pollutants from a busway and surrounding road network, the emission factors need to account for:

- road gradient
- vehicle speed and idling
- vehicle type (e.g. passenger car, bus, truck)
- vehicle design (Australian Design Rule (ADR) emissions regulations) and fuel type
- age of vehicles in the fleet.

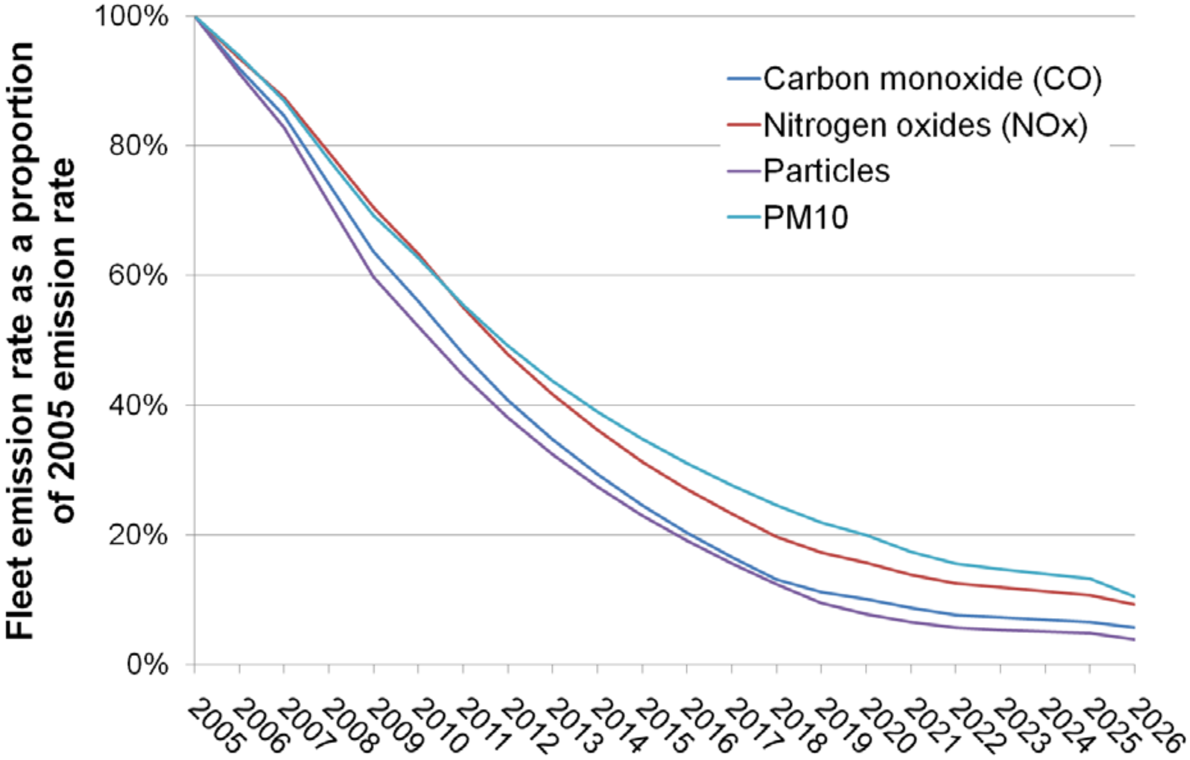
4.1 South-east Queensland bus fleet

4.1.1 Background

For recent air quality assessments, emissions data has been primarily derived from work undertaken by the International Laboratory for Air Quality and Health (ILAQH) on behalf of TMR supplemented by MVEPS data from New South Wales. The data is based on buses that are currently in service. However, the bus fleet will continue to evolve as stricter limits are adopted into Australian Design Rules (ADR) and as operators adopt economical and environmentally friendly technologies.

Gradual uptake of Euro 4 buses up to 2010 and then uptake of Euro 5 buses from 2010 is expected to result in fleet emissions falling to less 20% of 2005 emissions by 2020, based on current assumptions about uptake of new vehicles (Figure 1).

Figure 1: South-east Queensland bus fleet emissions as a proportion of 2005 emissions, projected annually to 2026 (data provided to Katestone Environmental by Bill Duncan)



4.1.2 Options

4.1.2.1 QUT emissions data

Queensland Transport commissioned a study undertaken by the International Laboratory for Air Quality and Health (ILAQH) in 2006 which involved the measurement of emissions of oxides of nitrogen, particulate matter, ultrafine particles, carbon monoxide and benzene from diesel and CNG buses.

It is important to note that the sampling of emissions from the Brisbane City Council bus fleet was limited to a small number of buses and that measurement values were not reproducible and were inconsistent between sample days. Limitations of the data set notwithstanding, this fleet-specific information has been used in preference to other sources of bus emission information for busway studies undertaken on behalf of Queensland Transport.

Additional information relating to the emissions testing study may be found in QUT (2006).

Table 2: QUT Emission factors for diesel and CNG buses (Source: Katestone Environmental, 2008)

Load	**Units**	**Emission rate**	
		Diesel buses	**CNG buses**
Oxides of nitrogen			
Idling	g/hr	34.8	28.8
25%	g/km	9.5	3.2
50%	g/km	14.0	4.1
100%	g/km	24.0	8.2
Carbon monoxide			
Idling	g/hr	14.4	-
25%	g/km	1.6	-
50%	g/km	2.6	-
100%	g/km	6.9	-
Particle mass			
Idling	g/hr	1.2	0.0
25%	g/km	0.2	1.0E-4
50%	g/km	0.38	3.0E-4
100%	g/km	0.84	1.0E-3
Particle number			
Idling	Number of particles/hr	5.4E14	1.2E14
25%	Number of particles/km	2.5E14	6.9E12
50%	Number of particles /km	3.3E14	1.8E13
100%	Number of particles /km	6.7E14	6.5E14
Benzene			
Idling	g/hr	2.5E-3	4.5E-3
25%	g/km	2.8E-4	4.7E-4
50%	g/km	4.5E-4	7.8E-4
100%	g/km	9.6E-4	1.0E-3

4.1.2.2 MVEPS emissions data

The database of vehicle emissions in Australia is limited and most of the emission inventories developed by state agencies draws from the same database. The data compiled in NSW is in a convenient format and has been drawn upon for this assessment. It identifies vehicle types and distinguishes emissions from buses fuelled with CNG from those fuelled with diesel for selected years in the future. The CNG data have been used for this assessment and it has been assumed that the CNG buses would be affected by grade in the same way as the diesel buses identified in the QUT study.

Table 3 summarises the MVEPS data for diesel and CNG buses for different roadway types for 2006 and 2016 (Holmes, 2006). This data has been used in various busway studies to fill the gap in the QUT data with respect to carbon monoxide emissions from CNG buses.

Table 3: Summary of MVEPS data, 2006 and 2016 (Source: Holmes, 2006)

Vehicle Category	Arterials	Highway	Commercial/Arterial	Commercial Highway	Residential Minor	Congested Conditions
2006						
HC emissions						
Diesel	1.259	0.914	1.259	0.914	1.153	2.023
CNG Bus	4.026	3.564	4.026	3.564	4.628	5.183
CO emissions						
Diesel	4.136	2.540	4.136	2.540	2.877	5.019
CNG Bus	1.812	1.113	1.812	1.113	1.261	2.199
NO_x emissions						
Diesel	10.237	7.704	10.237	7.704	8.381	12.427
CNG Bus	7.427	5.590	7.427	5.590	6.081	9.016
PM_{10} emissions						
Diesel	0.374	0.260	0.374	0.260	0.241	0.384
CNG Bus	0.042	0.029	0.042	0.029	0.027	0.043
2016						
HC emissions						
Diesel	0.826	0.599	0.826	0.599	0.756	1.327
CNG Bus	2.641	2.338	2.641	2.338	3.036	3.400
CO emissions						
Diesel	1.673	1.027	1.673	1.027	1.164	2.030
CNG Bus	0.733	0.450	0.733	0.450	0.510	0.889
NO_x emissions						
Diesel	5.096	3.835	5.096	3.835	4.172	6.186
CNG Bus	3.697	2.783	3.697	2.783	3.027	4.488
PM_{10} emissions						
Diesel	0.085	0.059	0.085	0.059	0.055	0.087
CNG Bus	0.042	0.029	0.042	0.029	0.027	0.043

4.1.2.3 Comparison of methodologies

Table 4 compares the QUT, MVEPS (2005 fleet) and MVEPS (2011 fleet) emissions data assuming at grade emissions for QUT data and congested conditions for MVEPS.

The three data sets are reasonably consistent for the critical pollutants, NO_x and PM_{10}. The emissions from the QUT database are lower but they are representative of the newer vehicles in the fleet. They are similar to the MVEPS 2011 fleet estimates which are also included in the table.

Table 4 Comparison of diesel bus emissions data (Source: Holmes, 2006)

Data Source	Emissions (g/km)	
	NO_x	PM_{10}
QUT (new buses)	9.5	0.2
MVEPS (2005 fleet)	13.5	0.47
MVEPS (2011 fleet)	9.3	0.23

4.2 Urban vehicle fleet

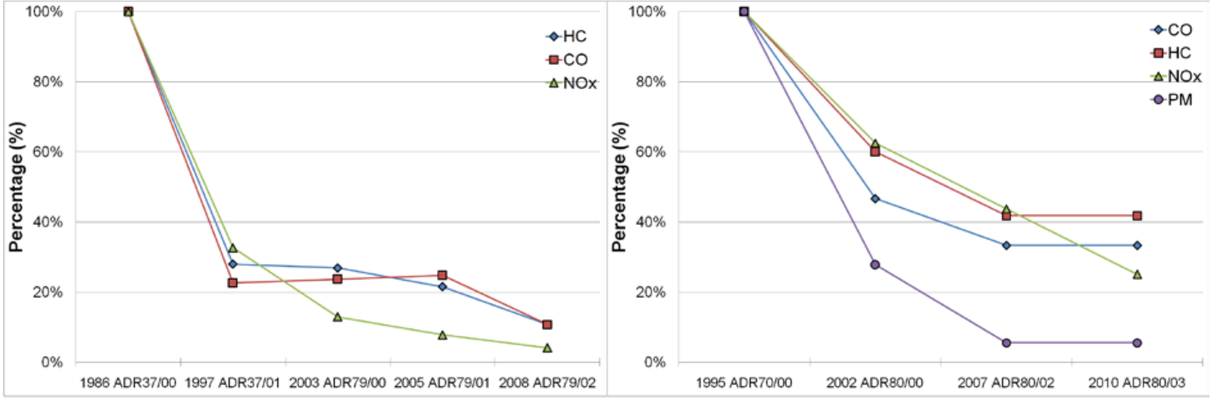
4.2.1 Background

Within Australia as a whole, it is anticipated that there will be significant long-term changes between current and future motor vehicle emissions; in particular the offsetting trends between increased VKT and tighter emissions standards brought about by changes to Australian Design Rule (ADR) regulations.

Currently, ADR 37/01 covers CO, NO_x and VOC emissions from new light-duty passenger vehicles, and ADR 70/00 covers the above pollutants, plus particulates, from new diesel vehicles.

Historical changes in the ADR for passenger vehicles are shown in Figure 2.

Figure 2 Australian Design Rules percentage reduction in emissions (g/km)



It can be seen that end-of-pipe emissions of PM_{10} from new heavy diesels are predicted to be one tenth of those from a pre-1995 vehicle. ADR 70/00 are equivalent to the adoption of Euro 1 emission standards. ADR80/00, ADR80/02 and ADR80/03 are equivalent to Euro 3, Euro 4 and Euro 5 emission standards, respectively. These trends are reflected in the emission factors used for the air quality modelling scenarios.

New standards for cleaner fuels came into effect in Queensland on 1 July 2000 including low sulphur diesel (less than 500 ppm of sulphur) which provided immediate benefits including an average improvement of about 25% in particulate emissions from existing engines. In addition the reduction enables the use of new technology engines using catalytic converters and particle traps. These technologies cannot operate with high sulphur fuels, and result in cleaner performance with lower emissions of fine particles, nitrogen oxides, carbon monoxide and hydrocarbons.

4.2.2 Options

4.2.2.1 PIARC

The World Road Association - PIARC is a European-based organisation focused on road transport related issues.

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 include factors that can be used to take account of the age, vehicle mix, vehicle speed, gradient of road and emissions control technology.

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 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.

4.2.2.2 South-east Queensland Region Air Emissions Inventory

A partnership between the 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. Whilst the proportion of heavy diesel vehicles can be varied using the database, other aspects of the fleet mix cannot be varied because the database was intended to provide fleet average emission rates.

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.

In most busway studies, the South-east Queensland Region Air Emissions Inventory has not been used to characterise emissions from the urban vehicle fleet, but has been used to ground-truth estimates made using the PIARC methodology.

4.2.2.3 Comparison of Methodologies

Table 5 provides a comparison of emissions generated using the PIARC methodology with those generated as part of the South-east Queensland Region Air Emissions Inventory. It can be seen that PIARC estimates of CO emissions are lower than the SEQ Air Emissions Inventory projections for the years 2000 and 2005, but are slightly higher for 2011. Both the NO_x and PM_{10} emission estimates are similar for 2000 and 2005 with the PIARC methodology yielding higher estimates in 2011.

Table 5: Comparison of SEQ emissions and PIARC (Source: Holmes, 2006)

SEQ Emissions inventory **Vehicle running mode at average speed of 50 km/h**				**Calculated emissions using PIARC**			
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

5 Air Quality Design standards

5.1 Ambient Air Quality

The Environmental Protection Act 1994 (EP Act) provides for the management of the air environment in Queensland. The legislation applies to government, industry and individuals and provides a mechanism for the delegation of responsibility to other government departments and local government and provides all government departments with a mechanism to incorporate environmental factors into decision-making.

The EP Act gives the Environment Minister the power to create Environmental Protection Policies that identify and aim to protect environmental values of the atmosphere that are conducive to the health and well-being of humans and biological integrity. The Environmental Protection (Air) Policy (Air EPP) was gazetted in 2008. The administering authority must consider the requirements of the Air EPP when it decides an application for an environmental authority, amendment of a licence or approval of a draft environmental management plan. Schedule 1 of the Air EPP specifies air quality indicators and goals for Queensland. Objectives that are relevant to these projects are summarised in Table 6.

The National Environment Protection Council defines national ambient air quality standards and goals in consultation, and with agreement from, all state governments. These were first published in 1997 in the National Environment Protection (Ambient Air Quality) Measure (NEPM(Air)). Compliance with the NEPM(Air) standards is assessed via ambient air quality monitoring undertaken at locations prescribed by the NEPM(Air) and that are representative of large urban populations. The goal of the NEPM(Air) is for the ambient air quality standards to be achieved at these monitoring stations within ten years of commencement in 2008.

The applicable standards and goals are summarised in Table 6.

Table 6: Air EPP ambient air quality objectives

Pollutant	Averaging period	Maximum concentration ($\mu g/m^3$)	Allowable exceedances
Nitrogen dioxide	1 hour Annual Annual	250 62 33[1]	1 day per year - -
Carbon monoxide	8 hour	11,000	1 day each year
Particles (as PM_{10})	24 hour	50	5 days a year
Particles (as $PM_{2.5}$)	24 hour Annual	25 8	- -
Benzene	Annual	10	-
Formaldehyde	24 hours	54	-
	30 minute	110[2]	-
Toluene	24 hours	4100	-
	Annual	410	-
Xylenes	24 hours	1200	-
	Annual	950	-
1,3-Butadiene	Annual	2.4	-

Notes:

[1] EPP (Air) 2008 health and biodiversity of ecosystems

[2] EPP (Air) 2008 aesthetics of the environment

5.2 In-tunnel air quality

In Australia, regulatory and design requirements for in-tunnel air quality have generally been based on the recommendations of the PIARC Technical Committee on Road Tunnels Operation. Current recommendations are detailed in PIARC (2004). The North-South Bypass Tunnel (CLEM7) in Queensland and the Lane Cove Tunnel and the Cross City Tunnel in Sydney have all been designed and are regulated to meet the PIARC requirements that were current at the time of approval.

In Queensland, the management of emissions associated with ventilation outlets are covered under an Environmental Relevant Activity (ERA) – ERA51 (Road tunnel ventilation stack operation). This activity can only be conducted under the terms of the development approval and Registration Certificate issued by DERM.

The Coordinator General’s requirements for in-tunnel air quality in the CLEM 7 Tunnel are reproduced below:

> *7.2 Internal Air Quality*
>
> a) *The tunnel ventilation system must be designed to control in-tunnel air pollution to the following maximum allowable levels:*
>
> i. *a maximum carbon monoxide (CO) concentration of 70 ppm at any point in the tunnel under all traffic conditions from a congested case where the average travel speed is less than 20 kph up to at least 80 kph or posted speed whichever is greater*

  ii. *a maximum CO concentration of 90 ppm at any point in the tunnel under an extreme congestion case where the average travel speed is less than 10 kph*

  iii. *an average concentration of nitrogen dioxide (NO_2) along the tunnel of 1 ppm at any one time assuming that NO_2 is no less than 10% of the total oxides of nitrogen (NO_x) present in the airstream*

  iv. *an extinction coefficient of 0.005 $^{m-1}$, averaged over 15 minutes, at any point in tunnel for traffic travelling at a speed equal to or greater than 60 kph, and*

  v. *Workplace Health and Safety Queensland exposure standards during maintenance activities.*

b) *Pollution level measurements used in the control of the ventilation system may be time averaged but only over a period that does not exceed 15 minutes.*

The Conditions of Approval for the Lane Cove Tunnel require that an individual is not exposed to a concentration of carbon monoxide in the tunnel that exceeds the limits specified in Table 7.

Table 7: In-tunnel exposure limits for carbon monoxide in the Lane Cove Tunnel

Pollutant	Units of measure	Averaging period	Limit
Carbon monoxide	ppm	Rolling 15 minute	70
		Rolling 30 minute	50

6 Existing air quality

6.1 Ambient air monitoring

6.1.1 When is monitoring necessary?

6.1.1.1 For the purposes of characterising the existing environment

Ambient air monitoring is required when there exists insufficient representative information available to adequately characterise the existing air quality environment in the vicinity of key sensitive receptors. Sources of ambient air data include (but may not be limited to):

- Regulatory operated monitoring sites (such as Department of Environment and Resource Management, and Bureau of Meteorology)
- published information (such as DERM annual summary reports, EIS, CDIMP, etc)
- data collected by TMR for other projects.

The need to collect ambient monitoring data for a specific project will be assessed in consultation with TMR and regulatory authorities as required.

6.1.1.2 Compliance monitoring during construction

During construction, the main pollutant of concern is typically dust associated with land clearing, earthworks, stockpiles and vehicle movements.

The requirement for monitoring during construction will be assessed on a project by project basis and may involve the continuous monitoring of particulate matter and/or the monthly collection of dust fallout samples.

6.1.1.3 Compliance monitoring during ongoing operation

During the operational phase of the project, the minimum requirements relating to ongoing ambient air monitoring are typically specified in the Coordinator General's Report and the applicable ERA if there is a ventilation outlet associated with the project.

6.1.2 How much monitoring is required?

6.1.2.1 For the purposes of characterising the existing environment

As impacts at receptor locations are in general highly dependent on meteorological conditions, it is important that sampling is conducted over the full range of meteorological conditions that may occur within the study region. The data set should be representative of the temporal and spatial variability that could be reasonably expected and sampling during worst-case meteorological conditions is required.

Targeted site-specific sampling over a minimum of three months may be sufficient to characterise the existing environment if it can be demonstrated that worst-case conditions have been encountered through correlation with a longer-term site representative dataset. However, it is preferable that at least one year of site-specific monitoring is conducted where possible, particularly where a longer-term site representative dataset is not available.

Meteorological information is to be collected concurrently with the ambient air monitoring data.

Should an existing monitoring site be proposed as being representative for the purposes of characterising the ambient environment, consideration should be given to conducting short-term site-specific monitoring to demonstrate a high degree of correlation between the data obtained from the site-specific and the proposed representative monitoring location.

6.1.2.2 During construction

Monitoring of dust emissions during the construction phase of the project may involve continuous monitoring of dust as well as the collection of monthly sample of dust deposition.

6.1.2.3 Ongoing operational monitoring

The establishment of project-specific ambient air monitoring sites from which to assess the success of the management of emissions from tunnel outlets (in particular) in achieving project-specific air quality objectives is becoming increasingly common and will possibly become a standard regulatory requirement.

6.1.3 What methods should be used for monitoring?

In general, it is assumed that if required, all data will be collected in accordance with the requirements of the most recent version of the Queensland Government Air Quality Sampling Manual. Deviations from the requirements outlined in this document will necessarily be approved by TMR.

This document addresses issues such as the siting of instrumentation, quality assurance requirements as well as the accepted methodologies for the monitoring of:

- carbon monoxide
- lead
- oxides of nitrogen
- ozone

- sulphates
- sulphur dioxide
- dust deposition
- total suspended particulates
- fine particles
- visibility.

The Queensland Government document Air Quality Sampling Manual also addresses emissions testing requirements which would apply to tunnel ventilation outlets.

Where the Air Quality Sampling Manual does not include a relevant method or in the case where the method that is cited is out-of-date, an appropriate alternative method should be identified from the following and approval sought from TMR:

- Australian Standards
- Sampling manuals from other Australian jurisdictions e.g. Approved Methods for the Sampling and Analysis of Air Pollutants in NSW (DEC, 2007)
- US EPA methods (http://www.epa.gov/ttn/amtic/methods.html).

6.2 Characterisation of background levels

For the purposes of conducting an air quality assessment, an ‘estimate of background levels’ typically implies developing an estimate of the ground-level concentration of a pollutant that would be measured at a given location in the absence of all emission sources that are explicitly accounted for in the dispersion modelling.

When characterising the background level of pollutants it is important to consider the following:

- What is the nature of the emissions sources within the local area?
- Are emission sources in the regional air shed likely to have a significant contribution to background levels?
- Which emission sources are explicitly accounted for in the dispersion modelling?
- Are complicated meteorological flows such as recirculation, land or sea breezes likely to have a significant impact on pollutant levels?
- Which primary pollutants are of concern?
- Are secondary pollutants such as ozone, of concern?
- How much ambient monitoring data is available?

In general, ‘background levels’ (as the term is used here) may be highly spatially and temporally varying. The estimation of background levels have utilised the following approaches:

- Adoption of a constant background value based on measurements from a representative site. The maximum or 90th percentile concentrations are commonly used for pollutants with short averaging periods (1 hour, 8 hour or 24 hour) or the annual average value is used for pollutants with an annual averaging period

- Adoption of a constant background value based on an appropriate percentile for measurements (see for example VIC EPA) from a representative site
- Explicitly modelling key emission sources and adopting a constant value to represent emission sources not explicitly modelled
- Consideration of project-only (i.e. incremental contribution to) predicted ground-level impacts.

The adoption of an approach for the estimation of background levels will be project-specific and will depend on the level of assessment required (see also Section 9). Typically, estimates of background levels of oxides of nitrogen, carbon monoxide and particulate matter have been derived from monitoring sites operated by DERM or TMR at ‘representative’ locations. A constant background value has typically been applied based on the 95th percentile[1] or average value depending on the averaging period of the assessment criteria (i.e. short-term or long-term respectively).

When assessing impacts associated with infrastructure projects, the key emission sources are typically associated with those parts of the road network that are not explicitly accounted for in the air quality assessment. When quantifying the potential impacts associated with busways, there has been a combination of approaches adopted, some studies excluding the explicit modelling of vehicle roads from the assessment and some that have explicitly modelled the surrounding road network. Although the surrounding road network necessarily requires consideration, whether or not contribution to ground level impacts are included within the ‘background’ estimate or are explicitly modelled requires consideration of the following:

- Is the proposed busway isolated or primarily isolated from the surrounding road network? That is, is the busway dedicated to busway traffic only with limited access points to the vehicle road network?
- Is the proposed busway integrated into the existing road network via (for example) dedicated busway lanes or shared lanes?

A dedicated busway with limited road network access points is likely to have less of an impact on traffic movement when compared to shared lanes. In the former case, explicit modelling of the road network may not be warranted. However, in the latter case, if significant changes to vehicle patterns are likely, then in general the explicit modelling of both the busway and the road network may be warranted.

7 Project information requirements

7.1 Alignment information

7.1.1 Busway and road alignments

Depending on the details of the project, the alignment may include segments of roads associated with some or all of the following:

- dedicated busway

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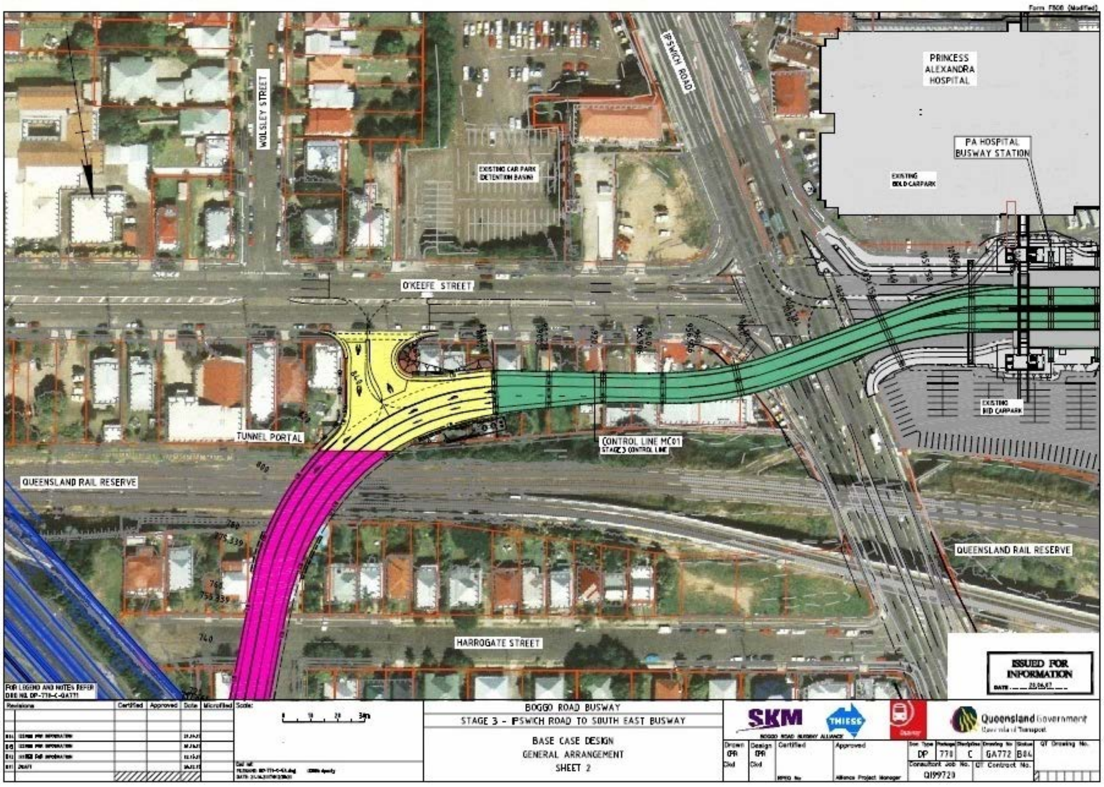
[1] Since Queensland commenced air quality monitoring in 1996, pollutants that are monitored on a continuous basis have been reported using the 95th percentile concentration over the year as an indicator of air quality trends (p. 56, EPA 2005).

- shared lanes
- common use roads
- tunnels
- cut and cover
- elevated sections.

Presented in Figure 3 is an example of project specific alignment information for Stage 3 of the Boggo Road Busway (Katestone Environmental, 2007d).

Figure 3: Example of project specific alignment information (Source: Boggo Road Busway, Queensland Transport)



Illustrated in the Figure 4 are examples of modelled alignment segments (Heggies, 2007).

Figure 4: Examples of modelled roadway (left) and busway (right) segments (Source: Heggies, 2007)

7.1.2 Gradients

Gradient information for all road segments will be required in order to ensure that the appropriate emission factors are used on each road segment.

7.1.3 Intersections

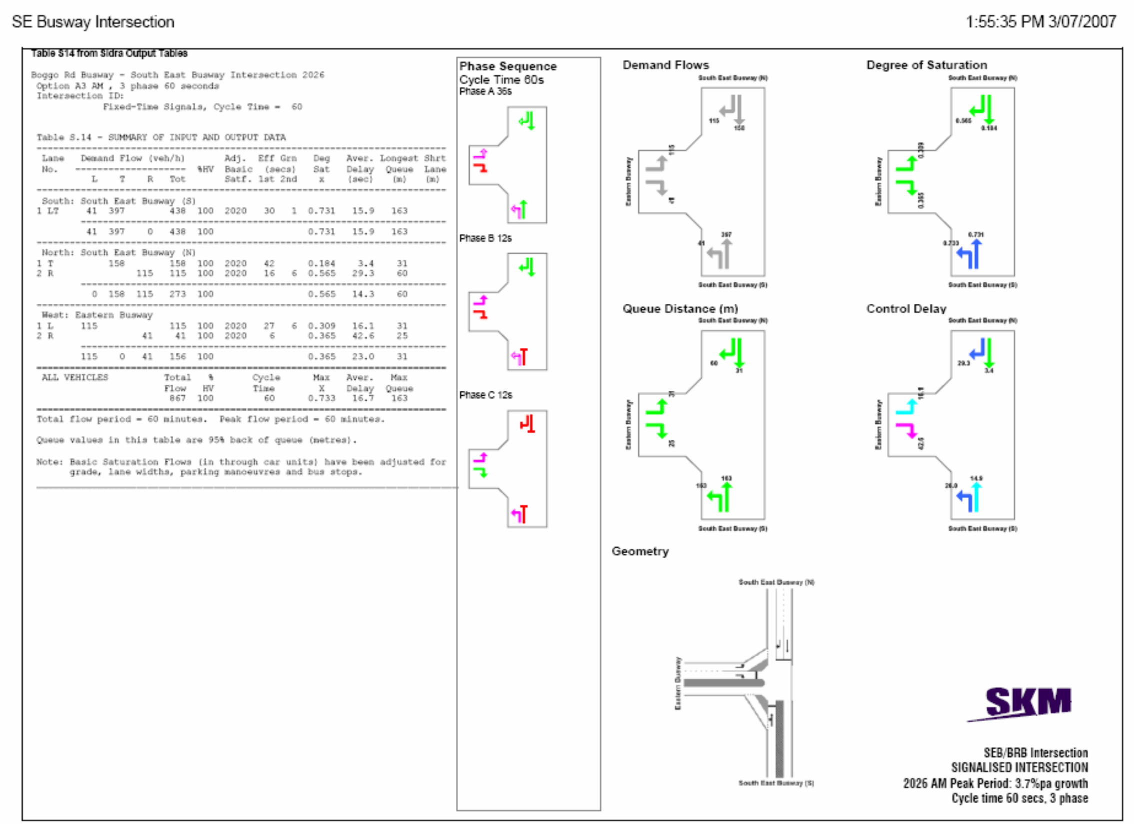
For intersections associated with dedicated busways, a modelling methodology that accounts for the idling at and acceleration away from the intersection is required.

For major intersections associated with road segments involving shared lanes, it is recommended that a modelling tool be utilised that explicitly accounts for the impact of emissions associated with vehicles both idling at and/or accelerating away from intersections be adopted.

7.1.4 Signalling information

The duration of the signal pattern will have an impact on the queuing length and the duration of idling vehicles and will necessarily be considered as part of the assessment (Figure 5).

Figure 5: Example of project specific traffic signal information



SE Busway Intersection

1:55:35 PM 3/07/2007

Table S14 from Sidra Output Tables

```
Boggo Rd Busway - South East Busway Intersection 2026
 Option A3 AM , 3 phase 60 seconds
 Intersection ID:
             Fixed-Time Signals, Cycle Time =  60


 Table S.14 - SUMMARY OF INPUT AND OUTPUT DATA
 ---------------------------------------------------------------------------
  Lane   Demand Flow (veh/h)       Adj.  Eff Grn    Deg   Aver. Longest Shrt
  No.   -------------------  %HV  Basic  (secs)    Sat   Delay  Queue  Lane
           L    T    R   Tot      Satf. 1st 2nd     x    (sec)   (m)    (m)
 ---------------------------------------------------------------------------
  South: South East Busway (S)
 1 LT     41  397        438  100  2020   30   1  0.731   15.9   163
         ------------------------------------------------------------------
          41  397    0   438  100                 0.731   15.9   163
 ---------------------------------------------------------------------------
  North: South East Busway (N)
 1 T          158        158  100  2020   42      0.184    3.4    31
 2 R               115   115  100  2020   16   6  0.565   29.3    60
         ------------------------------------------------------------------
           0  158  115   273  100                 0.565   14.3    60
 ---------------------------------------------------------------------------
  West: Eastern Busway
 1 L     115             115  100  2020   27   6  0.309   16.1    31
 2 R                41    41  100  2020    6      0.365   42.6    25
         ------------------------------------------------------------------
         115    0   41   156  100                 0.365   23.0    31
 ===========================================================================
  ALL VEHICLES            Total    %        Cycle        Max   Aver.   Max
                           Flow   HV         Time         X    Delay  Queue
                            867  100           60     0.733    16.7   163
 ===========================================================================
 Total flow period = 60 minutes.  Peak flow period = 60 minutes.

 Queue values in this table are 95% back of queue (metres).

 Note: Basic Saturation Flows (in through car units) have been adjusted for
       grade, lane widths, parking manoeuvres and bus stops.
 ---------------------------------------------------------------------------
```

SEB/BRB Intersection
SIGNALISED INTERSECTION
2026 AM Peak Period: 3.7%pa growth
Cycle time 60 secs, 3 phase

7.1.5 Acceleration of buses away from intersections and/or traffic lights

The acceleration of buses is to be included on links associated with either turning buses, buses stopped at lights or those leaving the bus station.

During the period of acceleration, the buses are to be assumed to be operating at 100% load. In practice the acceleration distance will vary with a number of factors including the ultimate cruising speed. For typical top speeds of between 45 kph and 50 kph, buses are assumed to reach their peak velocity over a distance of 60 metres.

7.2 Tunnels

7.2.1 Alignment and gradients

As was required for surface roads, alignment information including gradients associated with any and all tunnels will be required.

Alignment and gradient information will necessarily be used to estimate the volume of pollutants released within the tunnel.

7.2.2 Tunnel length and ventilation options

Ventilation options involve either the natural venting of emissions from the portals, or the extraction of in-tunnel air and release via ventilation outlets (typically located near either end of the tunnel). Tunnels that are considered ‘short’ are typically naturally ventilated. Longer tunnels are required to utilise ventilation outlets in order that the in-tunnel air can be monitored and potentially treated prior to release if required.

Details of the preferred ventilation option(s) will be required in order to assess the potential impacts associated with the release of in-tunnel air to the ambient environment.

7.3 Traffic information

The Department of Transport and Main Roads and/or Brisbane City Council should be consulted for the latest information regarding peak- and off-peak times.

7.3.1 Bus volumes

Unlike surface roads, the volume of buses on any given road is typically well defined due to the scheduling of these activities. When assessing the impact of emissions associated with busway projects it is important that buses both in operation and those in transit (but not in operation) are accounted for in the assessment. Although the latter do not stop at bus stations (for example), they can contribute significantly to the overall project emissions inventory.

Note that:

- Ideally, information relating to bus volumes will be provided for both inbound and outbound directions
- In the absence of a breakdown in hourly bus volumes, it is assumed that these are to be equally distributed between directions.

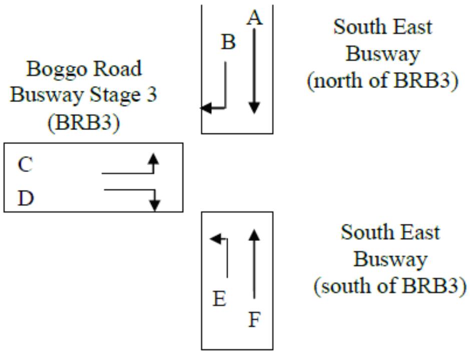
When defining bus volumes for road segments consideration will necessarily need to be given to:

- Bus volumes on the busway
- Bus volumes on common roadways
- Bus volumes at any/all key intersection.

Presented in the following figure is an example of the bus volume data that was provided for the Dutton Park Air Quality Assessment (Katestone Environmental, 2007d).

Figure 6: Bus volume data used in the Eastern Busway assessment (Source: Katestone Environmental, 2007d)

Section	2016			2026		
	peak buses	off peak buses	daily total buses	peak buses	off peak buses	daily total buses
Dutton Park Tunnel	526	931	1457	757	1339	2096
A	1153	1324	2477	1658	1904	3562
B	428	677	1104	615	973	1588
C	428	677	1104	615	973	1588
D	129	292	421	186	420	606
E	129	292	421	186	420	606
F	1153	1324	2477	1658	1904	3562

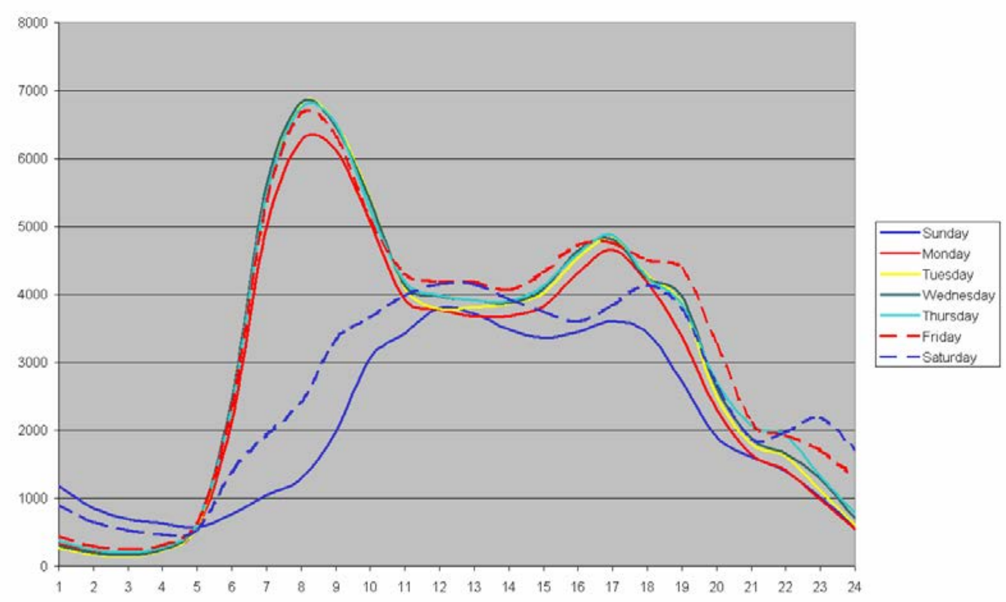


7.3.2 General vehicle traffic volumes

Traffic census data for key roadways can be obtained from the TMR website.

An example of the data available is depicted in Figure 7 (Heggies, 2008).

Figure 7: Average hourly vehicle counts as a function of day of the week (Source: Heggies, 2008)



7.3.3 Traffic speeds

For the purposes of defining traffic speeds, the options include:

- posted speed limits, and

- short-term data available from TMR and/or Brisbane City Council depending on the jurisdiction of the roadway.

The appropriateness of the use of any of these options (or a combination of options) will need to be assessed on a project by project basis and may vary from road segment to road segment.

7.4 Fleet information

Note that the nature of the proposed busway (i.e. either dedicated or shared) will determine whether or not explicit modelling of the road network is warranted. Thus in the following section the term fleet may refer to either a fleet consisting of buses-only or a combined buses-vehicle fleet.

Also, it is important to note that the assessment of impacts associated with infrastructure projects typically involves consideration of impacts associated with:

- the current situation
- the project at the time of commissioning, and
- the project during operations (for example Operational Year 10).

In order to quantify impacts attributable to the project in isolation of other factors, consideration will typically also need to be given to a project ‘Go’ and project ‘No-Go’ scenario.

7.4.1 Fleet composition

Sources of vehicle fleet information include (but may not be limited to):

- Translink
- Brisbane Transport (www.btbuses.info)
- Department of Transport and Main Roads
- Australian Bureau of Statistics
- Project-specific vehicle surveys and traffic modelling studies

7.4.1.1 Age of fleet

The percentage of vehicles in Queensland falling within each age category should be sourced from the Australian Bureau of Statistics. Queensland vehicles are, on average, 9.5 years old compared with 9.4 years old for Australia as a whole. Table 8 summarises the Queensland vehicle distribution by age (ABS, 2009).

Table 8: Queensland vehicle distribution by age category (Source: ABS, 2009)

Year of manufacture	Total vehicle
≤1993	646,137
1994-1998	600,740
1999-2003	815,789
2004-2008	1,181,282
2009[1]	22,883
Not stated	16,412
Total	3,283,243

Note

[1] To end of March 2009

7.4.1.2 Fuel types

In 2007, the Translink bus fleet consisted of 358 (42%) diesel and 495 (58%) CNG buses.

At that time, it was projected that the 2026 bus fleet would consist of 20% diesel, 80% CNG fleet composition by 2026, a shift in fleet ratio from 42/58 to 20/80 requires a decrease in diesel buses of approximately 1.16% per year.

For intermediate years the fleet ratio can be calculated assuming a linear increase/decrease in the ratio of diesel to CNG buses combined with the corresponding projected increase in bus numbers over the same period.

Information on fuel type for the urban vehicle fleet can be obtained from the Australian Bureau of Statistics.

7.4.2 Fleet emissions inventory

When developing a project specific emissions inventory consideration must necessarily be given to the following:

- fleet composition
- age of fleet
- growth and attrition rates
- fuel type
- vehicle emission standards
- year of introduction of emission standards.

The level of detail to which the project specific emission inventory is developed depends on the level of assessment to be undertaken (see also Section 9).

7.4.2.1 Buses

Presented in Table 9 are the emission factors for diesel and CNG buses that have been adopted for recent busway studies (Katestone Environmental, 2008) (see also Section 4.1).

Table 9: Emission factors for diesel and CNG buses (Source: Katestone Environmental, 2008)

Load	**Emission rate**		
	Units	**Diesel buses[1]**	**CNG buses[1]**
Oxides of nitrogen			
Idling	g/hr	34.8	28.8
25%	g/veh-km	9.5	3.2
50%	g/veh-km	14.0	4.1
100%	g/veh-km	24.0	8.2
Carbon monoxide			
Idling	g/hr	14.4	5.8[2]
25%	g/veh-km	1.6	0.6[2]
50%	g/veh-km	2.6	1.0[2]
100%	g/veh-km	6.9	2.8[2]
Particle mass			
Idling	g/hr	1.2	0.0
25%	g/veh-km	0.2	1.0E-4
50%	g/veh-km	0.38	3.0E-4
100%	g/veh-km	0.84	1.0E-3
Particle number[3]			
Idling	/km	5.4E14	1.2E14
25%	/km	2.5E14	6.9E12
50%	/km	3.3E14	1.8E13
100%	/km	6.7E14	6.5E14
Benzene			
Idling	g/hr	2.5E-3	4.5E-3
25%	g/veh-km	2.8E-4	4.7E-4
50%	g/veh-km	4.5E-4	7.8E-4
100%	g/veh-km	9.6E-4	1.0E-3

[1] QUT data, April 2006

[2] MVEPS data

[3] Note: 1E14 is equivalent to 1 x 1014

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

The relationships between driving conditions and load, road gradients, bus stopping and idling conditions that are to be incorporated into the assessment are summarised in the following table:

Table 10: Relationship between load, road gradients, and bus condition

Situation	**Equivalent emission rate**
Level ground	25% load
2% up-gradient	50% load
6% up-gradient	100% load
All down-gradients	25% load
Stopping at stations/intersections	Idling mode
Accelerating away from stations/intersections	100% load

Using project specific information relating to the VKTs on each road segment, the developed emission factors can be used to determine the emission rate of pollutants which will typically vary for each road segment.

Presented in Table 11 is an example of calculated busway emission rates developed for three stages of the Northern Busway Project (Holmes, 2006).

Table 11: Example of busway emission rates (grams per vehicle kilometre) (Source: Holmes, 2006)

Busway Station	**Time of day**	**Emission rate (g/veh-km)**											
		2012 Interim Case				**2016 Interim Case**				**2026 Ultimate Case**			
		CO	**NO_x**	**PM_{10}**	**Benzene**	**CO**	**NO_x**	**PM_{10}**	**Benzene**	**CO**	**NO_x**	**PM_{10}**	**Benzene**
RBWH	AM Peak	1.47	7.33	0.09	0.024	1.00	5.24	0.07	0.016	0.89	4.49	0.04	0.015
	Day	1.47	7.33	0.09	0.024	1.00	5.24	0.07	0.016	0.89	4.49	0.04	0.015
	PM Peak	1.47	7.33	0.09	0.024	1.00	5.24	0.07	0.016	0.89	4.49	0.04	0.015
	Night	1.47	7.33	0.09	0.024	1.00	5.24	0.07	0.016	0.89	4.49	0.04	0.015
Federation Street	AM Peak	-	-	-	-	-	-	-	-	0.89	4.49	0.04	0.015
	Day	-	-	-	-	-	-	-	-	0.89	4.49	0.04	0.015
	PM Peak	-	-	-	-	-	-	-	-	0.89	4.49	0.04	0.015
	Night	-	-	-	-	-	-	-	-	0.89	4.49	0.04	0.015
Windsor	AM Peak	-	-	-	-	-	-	-	-	0.89	4.49	0.04	0.015
	Day	-	-	-	-	-	-	-	-	0.89	4.49	0.04	0.015
	PM Peak	-	-	-	-	-	-	-	-	0.89	4.49	0.04	0.015
	Night	-	-	-	-	-	-	-	-	0.89	4.49	0.04	0.015
Albion Road	AM Peak	-	-	-	-	-	-	-	-	1.17	5.55	0.06	0.019
	Day	-	-	-	-	-	-	-	-	1.17	5.55	0.06	0.019
	PM Peak	-	-	-	-	-	-	-	-	1.17	5.55	0.06	0.019
	Night	-	-	-	-	-	-	-	-	1.17	5.55	0.06	0.019

Busway Station	Time of day	Emission rate (g/veh-km)											
		2012 Interim Case				2016 Interim Case				2026 Ultimate Case			
		CO	NO$_x$	PM$_{10}$	Benzene	CO	NO$_x$	PM$_{10}$	Benzene	CO	NO$_x$	PM$_{10}$	Benzene
Lutwyche	AM Peak	2.09	9.67	0.15	0.034	1.42	6.92	0.11	0.023	1.26	5.92	0.07	0.021
	Day	2.09	9.67	0.15	0.034	1.42	6.92	0.11	0.023	1.26	5.92	0.07	0.021
	PM Peak	2.09	9.67	0.15	0.034	1.42	6.92	0.11	0.023	1.26	5.92	0.07	0.021
	Night	2.09	9.67	0.15	0.034	1.42	6.92	0.11	0.023	1.26	5.92	0.07	0.021
Kedron Brook	AM Peak	1.82	8.63	0.13	0.030	1.23	6.17	0.09	0.020	1.10	5.29	0.06	0.018
	Day	1.82	8.63	0.13	0.030	1.23	6.17	0.09	0.020	1.10	5.29	0.06	0.018
	PM Peak	1.82	8.63	0.13	0.030	1.23	6.17	0.09	0.020	1.10	5.29	0.06	0.018
	Night	1.82	8.63	0.13	0.030	1.23	6.17	0.09	0.020	1.10	5.29	0.06	0.018

Presented in Table 12 is an example of calculated busway portal emissions for the Northern Busway Project (Holmes, 2006).

Table 12: Busway tunnel portal emissions (grams per vehicle) (Source: Holmes, 2006)

Tunnel	Time of day	Portal Emission Rates (grams per vehicle)							
		2016				2026			
		CO	NO$_x$	PM$_{10}$	Benzene	CO	NO$_x$	PM$_{10}$	Benzene
Lutwyche South	AM Peak	-	-	-	-	0.612	2.868	0.036	0.010
	Day	-	-	-	-	0.598	2.828	0.035	0.010
	PM Peak	-	-	-	-	0.587	2.793	0.034	0.010
	Night	-	-	-	-	0.598	2.828	0.035	0.010
Roblane Street	AM Peak	-	-	-	-	0.608	2.371	0.035	0.010
	Day	-	-	-	-	0.655	2.487	0.037	0.011
	PM Peak	-	-	-	-	0.699	2.595	0.040	0.011
	Night	-	-	-	-	0.655	2.487	0.037	0.011
Truro Street	AM Peak	-	-	-	-	0.213	0.854	0.044	0.004
	Day	-	-	-	-	0.229	0.896	0.050	0.004
	PM Peak	-	-	-	-	0.244	0.935	0.056	0.004
	Night	-	-	-	-	0.229	0.896	0.050	0.004
Pop’s Fig	AM Peak	1.097	3.987	0.049	0.018	0.586	2.406	0.034	0.010
	Day	1.048	3.889	0.047	0.017	0.562	2.352	0.033	0.009
	PM Peak	1.007	3.806	0.045	0.017	0.542	2.308	0.032	0.009
	Night	1.048	3.889	0.047	0.017	0.562	2.352	0.033	0.009

Tunnel	Time of day	Portal Emission Rates (grams per vehicle)							
		2016				2026			
		CO	NO_x	PM_{10}	Benzene	CO	NO_x	PM_{10}	Benzene
Lutwyche North	AM Peak	0.555	2.176	0.025	0.009	0.299	1.325	0.018	0.005
	Day	0.574	2.239	0.026	0.009	0.308	1.354	0.018	0.005
	PM Peak	0.593	2.298	0.027	0.010	0.317	1.381	0.019	0.005
	Night	0.574	2.239	0.026	0.009	0.308	1.354	0.018	0.005

7.4.2.2 Vehicles

The long-term policy of the Australian Design Rules is to fully harmonize Australian regulations with Euro standards.

Using the emission factor databases outlined in Section 4.2.2 and project-specific information an emissions inventory that includes emissions from the general vehicle fleet can be developed if required.

The general approach of using the PIARC data to quantify air pollutant emissions for road segments, combines total traffic volume on the segment with percentages of vehicles in each age bracket and type category (Section 7.4.1). Using these inputs, as well as road grade and speed information, (Section 7.1) total emissions for selected segments of road can be estimated.

A detailed example of how the PIARC emission data can be applied to the Australian vehicle fleet is provided in Heggies (2008).

Emission factors for carbon monoxide developed from PIARC emission factors are presented in Table 13.

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

Table 13: Emission factors for carbon monoxide developed from the PIARC emission factor database (grams/veh-km except where noted) (Source: Heggies, 2008)

Speed (km/hour)	**Road gradient (%)**						
	-6	**-4**	**-2**	**0**	**2**	**4**	**6**
0 (idling/g/hr)	113.3	113.3	113.3	113.3	113.3	113.3	113.3
5	23.5	28.9	34.3	38.8	39.9	41.9	44.7
10	14.3	17.4	20.5	23.3	24.4	25.9	27.4
20	9.9	12.0	14.0	15.9	17.5	18.9	22.0
30	7.7	9.3	10.9	12.4	13.8	16.0	22.2
40	6.1	7.3	8.5	9.7	11.9	15.7	22.4
50	5.1	6.1	7.1	8.1	10.5	15.6	22.7
60	4.5	5.5	6.4	7.3	11.1	18.6	25.9
70	4.2	5.0	5.9	6.7	13.2	22.9	30.1
80	3.9	4.7	5.5	6.3	15.7	26.2	33.8
90	5.0	6.0	7.0	8.0	23.7	39.7	49.9
100	5.4	6.6	9.1	10.4	32.3	53.7	69.8
110	4.8	6.2	11.6	13.2	37.3	60.6	84.5
120	4.6	6.2	12.6	14.4	38.1	60.1	85.6
130	4.3	5.8	11.8	13.6	36.1	56.9	81.8

8 Assessment tools and their application

8.1 Dispersion models

8.1.1 CALINE4

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. Further details on the CALINE models can be found in the user manuals (US EPA website).

CALINE4 is a line source air quality model based on the Gaussian diffusion equation and the mixing zone concept and is used to characterise traffic generated pollutant dispersion near roadways. The model may be used to assess the air quality up to 500 m away from roads, under given source strengths, meteorological conditions and site geometry. The model is typically used to predict levels of CO, NO_2 and suspended particulate concentrations.

CALINE4 is limited in its ability to assess a wide range of meteorological information. It is considered appropriate for the assessment of roadways where interruption to vehicle flow associated with intersections or the stopping at bus stations is not considered to be significant. The ease of model use makes it a useful screening (i.e. Level 1) tool. In general it is not recommended for detailed studies due to its meteorological input limitations.

8.1.2 CAL3QHCR

CAL3QHCR is one of the CALINE series of dispersion models and is an enhancement of the CAL3QHC and CALINE3 roadway models that allows time varying meteorological data to be used. 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 and explicitly models the impact of the interruption to vehicle flow associated with intersections. 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.

The CAL3QHCR model is considered appropriate for the purposes of modelling the transport and fate of emissions from the road network.

8.1.3 AusRoads

AusRoads was developed by the Victorian EPA. The traffic component of AusRoads is based on the same algorithms as CALINE4. It has the advantage over CALINE4 in that it has been adapted to include hourly varying meteorology. Unlike CAL3QHCR however, it does not explicitly include the capability to assess the impact of interruptions in vehicle flow associated with intersections.

In general, AusRoads is considered an appropriate tool for the assessment of impacts associated with emissions from busways.

8.1.4 Ausplume

AUSPLUME is a steady-state gaussian plume model that was developed by the Victorian Environmental Protection Agency. It is an extension of the US ISC3 model of Bowers et al (1979) and is widely used across Australian for air quality assessments of point, volume and area sources. Although not designed explicitly to model roadways, a simulated line source methodology is proposed in the AUSPLUME user manual (EPA Victoria, 1999).

Due to the limitations associated with AUSPLUME, the model is considered to be potentially appropriate for the assessment of impacts associated with ventilation outlets in simple terrain. It is not recommended for use when assessing emissions from the road segments associated with either the busway or general use roads.

As yet, its suitability for use in the modelling of the impact of emissions from tunnel portals has not been established.

8.1.5 CALPUFF

CALPUFF is a transport and dispersion model that is used to predict the transport and fate of pollutants emitted from modelled emission sources (Earth Tech 2000a). The CALPUFF model typically uses the wind fields generated by CALMET as input.

CALPUFF is able to simulate emissions from point, area and volume sources. It includes algorithms for buoyant line sources that were designed to represent aluminium smelter emission sources. It does not include emission source characteristics representative of road networks. However, a simulated line source methodology similar to that proposed by AUSPLUME may be feasible. For the busway studies undertaken to date, CALPUFF has not been used to model emissions for the road network.

CALPUFF is considered suitable for the purposes of modelling the impact of emissions from the ventilation outlets.

As yet, its suitability for use in the modelling of the impact of emissions from tunnel portals has not been established.

8.1.6 TAPM

The Air Pollution Model (TAPM) predicts three-dimensional meteorology as well as pollutant concentrations. Technical details of the model equations, parameterisations, and numerical methods are described in the Technical Paper by Hurley (2008).

Due to its spatial resolution, TAPM is considered appropriate for use in larger-scale, regional studies. It is not considered appropriate for assessing impacts in close proximity to roadways.

8.2 Meteorological models

8.2.1 CALMET

CALMET is a meteorological model that develops three-dimensional hourly wind and temperature fields (Earth Tech 2000b). Associated two-dimensional fields such as mixing height and stability class are also included in the CALMET output file. Meteorological fields generated by CALMET can be used as inputs into dispersion models such as CAL3QHCR, CALPUFF, AUSPLUME and AusRoads.

8.2.2 TAPM

The Air Pollution Model (TAPM) predicts three-dimensional meteorology as well as pollutant concentrations. Technical details of the model equations, parameterisations, and numerical methods are described in the Technical Paper by Hurley (2008).

8.3 CFD models

In general the use of a computational fluid dynamics packages is restricted to addressing small-scale problems of the order of metres to tens or hundreds of metres. These type of models are useful in resolving the dynamics of the near-field affects such as plume dilution in close proximity to the emission source.

Although CFD models have the advantages of producing high-resolution three-dimensional pollution concentration fields and are able to resolve finer scale terrain influences compared with (for example) CALPUFF (Section 8.1.5), in general they do not typically allow for the incorporation of detailed meteorological conditions such as atmospheric stratification and hourly varying wind fields.

CFD models more suited to assessing impacts on timescales of minutes when worst-case meteorological conditions have been identified using alternate tools (such as CAL3QHCR, Section 8.1.2).

8.3.1 Fluent

FLUENT (http://www.ansys.com/) is a computational fluid dynamics software package that is commonly used to simulate flow in engineering-type problems of interest.

8.3.2 ARIA

ARIA was used in the study undertaken by Queensland University of Technology (QUT, 2007) to predict pollutant concentrations resulting from busway emissions. ARIA has been used previously for studies of dispersion of vehicle emissions within urban environments (Holmes and Morawska 2006). ARIA uses the CFD code MERCURE, which is a three dimensional atmospheric model designed to include the effect of obstacles, local temperature differences and variable density releases.

8.4 Busway calculator

The Translink ‘busway minimum separation distance calculator’ or BMSDC (beta-version) is a screening level (i.e. Level 1) tool that was developed for Queensland Transport by Katestone Environmental (refer to Katestone Environmental, 2007b for details).

Note that the BMSDC has been developed based on a one-year meteorological data set at a specific location and is therefore applicable only at locations which are well represented by the meteorological dataset utilised within the BMSDC.

8.4.1 Overview of the BMSDC

The BMSDC provides an estimate of the minimum distance from the kerb, that sensitive receptors should be located in order that predicted ground-level concentrations satisfy either:

- The national ambient air quality standards, or
- A maximum incremental change.

BMSDC is able to provide estimates of minimum separation distances based on emissions from:

- Tunnel portals, or
- Free flowing links, or
- Bus stations, or
- Tunnel portals combined with free flowing links, or
- Bus stations combined with free flowing links.

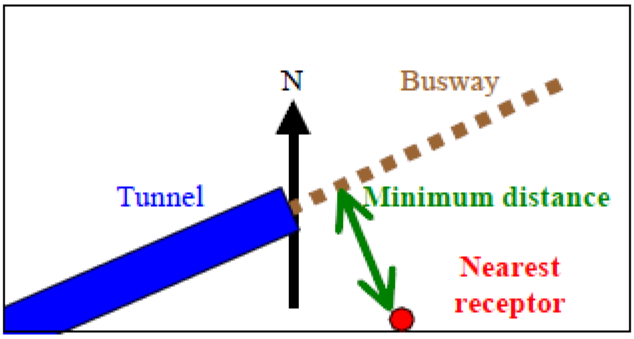
Using a simplified approach, BMSDC is designed to be an aid to the design process by providing a quick and easy means by which to assess the potential impact of a given set of parameters on air quality. Variable parameters include:

- Tunnel length and orientation
- Bus fleet composition
- Bus fleet emission characteristics, and
- Bus volumes.

The dispersion model CAL3QHCR was used to develop the BMSDC. The BMSDC has been designed to be flexible enough to provide an estimate of the minimum separation distance based on the requirement that the relevant air quality objective be satisfied OR that the incremental change in ground-level concentration does not exceed a user specified amount (in µg/m^3). Both of these options are available for estimates of the minimum separation distance based on predictions of the ground-level concentration of nitrogen dioxide and particulate matter as PM$_{10}$.

The minimum separation distance is reported as the minimum perpendicular distance (in metres) to the kerb that satisfies the selection criteria (Figure 8).

Figure 8: Example from the BMSDC: The predicted minimum recommended (perpendicular) distance from the kerb to the nearest receptor (Source: Katestone Environmental, 2007b)



9 Assessment methodology

9.1 Level 1 and Level 2 assessments

Two levels of impact assessment have been defined for busway projects:

- Level 1 – a screening-level dispersion modelling technique using worst-case input data.
- Level 2 – a refined dispersion modelling technique using site-specific input data.

In general, both levels of impact assessment have been designed to cautiously overestimate the potential impact of the project. The Level 2 assessment uses a more detailed methodology and hence should be more accurate than the Level 1 assessment. This means that, for a given busway project, the result of a Level 1 impact assessment would be more conservative and codified and less site-specific than the result of a Level 2 assessment. It is not intended that an assessment should routinely progress through the two levels of assessment. If the air quality impact is considered to be a significant issue, there is no impediment to immediately conducting a Level 2 assessment. Equally, if a Level 1 assessment conclusively demonstrates that adverse impacts will not occur, there is no need to progress to Level 2.

Common elements of Level 1 and Level 2 assessments include:

- establishment of ambient air objectives
- definition and estimation of the background air quality environment
- development of a fleet emissions inventory
- selection of an appropriate model
- conduct of an assessment
- interpretation of the results of the assessment
- assessment of limitations and assumptions
- provision of recommendations, which may lead to a reassessment of the project.

As noted in Section 2, the key difference in the Level 1 and Level 2 assessments is the level of detail which is incorporated into the assessment with Level 1 being indicative of worst-case conditions and the Level 2 assessment providing additional information and accuracy than that obtained by a Level 1 assessment.

9.2 Level 1 assessment

The Level 1 assessment is a simplified screening level assessment procedure using worst-case information. The aim is to produce a conservative quantification of potential impacts that is simple to implement through the codification of input variables.

9.2.1 When to implement?

A Level 1 assessment may be appropriate for all or part of the project when the following apply:

- The project is in the early stages of planning when a high-level comparison and evaluation of the relative impacts of different options is required.
- The nearest sensitive receptors are located at a sufficient distance from the project (greater than 20-40 metres), daily volumes are less than 400 buses per day and peak hourly volumes are less than 80 buses.
- The project involves a dedicated busway and there are no sensitive receptors located in close proximity to the busway (receptors greater than 20 metres from busway).
- Portals are not located in close proximity to receptors (receptors greater than 40 metres from portals).

A Level 1 (screening) assessment is NOT considered appropriate if any of the following applies:

- Exceedances of ambient air objectives are predicted (or anticipated) at sensitive receptor locations based on a Level 1 assessment and the exceedances cannot be eliminated through redesign of the project or through application of mitigation measures.
- The project is located in close proximity to sensitive receptors (receptors less than 20 metres from busway) and the daily volume is greater than 400 buses and the peak hourly volume is more than 80 buses.
- The project involves shared lanes.

9.2.2 Emission inventory

For the purposes of a Level 1 screening assessment the project emissions inventory based on either a bus fleet or a mixed bus and vehicle fleet using representative emission factors (Section 4) will necessarily be developed. As the level of detailed information is typically limited, gross conservative assumptions may necessarily be applied such as the use of posted speed limits. All assumptions that are applied must be justified and documented within the assessment report (Section 10.5).

Potential impacts of nitrogen dioxide and particulate matter (as PM_{10}) need only be assessed in a Level 1 assessment as experience with busways in Southeast Queensland shows that if compliance is achieved for these air pollutants, then compliance will be achieved for all other associated air pollutants.

9.2.3 Assessment tools

Tools that are considered appropriate for a Level 1 assessment include (but may not be limited to):

- Busway Minimum Separation Distance Calculator (Section 8.4): Used for assessing the minimum separation distance required to achieve compliance with project air quality objects for oxides of nitrogen, carbon monoxide and PM_{10} for:
    - Tunnel portals, or

  - Free flowing sections of busway, or
  - Bus stations, or
  - Tunnel portals combined with free flowing sections of busway, or
  - Bus stations combined with free flowing sections of busway

- CALINE4 (Section 8.1.1): For assessing individual (or a limited number) of free-flowing sections of busway without stopping. The following meteorological settings should be used:
  - Wind speed of 1.0 m/s
  - Stability class F
  - Mixing height of 50 metres
  - Worst-case wind angle.

9.2.4 Methodology

The key components of a Level 1 assessment include:

- establishment of ambient air objectives
- definition and estimation of the background air quality environment using at least one year of site representative data. 95th percentile statistics should be used for pollutants with air quality objectives with averaging periods of 1 hour and 24 hours.
- development of a fleet emissions inventory based on Section 4 of this document
- characterisation of busway in terms of location, volume flow and relative proximity to sensitive receptors
- conduct of an assessment
- interpretation of the results of the assessment
- assessment of limitations and assumptions
- provision of recommendations.

9.3 Level 2 assessment

9.3.1 When to implement?

A Level 2 assessment may be required for all or part of the project when the following apply:

- The project is in the impact assessment stage and it has been identified (expressed stakeholder concerns, regulatory requirement, etc.) that detailed modelling is required.
- The nearest sensitive receptors are located in close proximity to the project (‘close’ will depend on traffic volumes and the nature of the receptors).
- Exceedances of ambient air objectives are predicted in a Level 1 assessment or anticipated at sensitive receptor locations.
- The project involves shared lanes.
- Portals and/or ventilation outlets are located in close proximity to sensitive receptors.

A Level 2 (detailed) assessment may NOT be warranted if the following applies:

- The project is in the early planning stages and sufficient information is unavailable for the purpose of conducting a Level 2 assessment.
- A Level 1 assessment does not highlight any potential air quality issues.

Note that in general, the use of CFD models (Section 8.3) should only be considered if there is a need to assess detailed impacts on the timescale of minutes when worst-case meteorological conditions have been identified using alternate tools (such as CAL3QHCR, Section 8.1.2). The areal extent of the study domain used in the CFD model, the representation of the meteorological forcing, and computational run times will necessarily be compromised by the increase in spatial resolution.

9.3.2 Emission inventory

For the purposes of a Level 2 assessment the project emissions inventory based on either a bus fleet or a mixed bus and vehicle fleet using representative emission factors (Section 4) will necessarily be developed.

In developing the project-specific emissions inventory it is expected that detailed fleet information (where available) will be utilised such as: breakdown of fleet composition; the incorporation of hourly varying vehicle volumes and speeds.

All assumptions that are applied must be justified and documented within the assessment report (Section 10.5).

9.3.3 Meteorological data

For a Level 2 assessment, the site-specific meteorological data is required. Key meteorological parameters of interest include: wind speed, wind direction, temperature, mixing height, and stability class. Meteorological monitoring sites typically include the direct sampling of wind speed, wind direction, and temperature (amongst other parameters such as rainfall and solar radiation). However, direct measurement of mixing height and atmospheric stability is in general not undertaken due to the complexity and extent of the instrumentation required.

Thus, a minimum of one year of numerically simulated meteorological fields will necessarily be developed using a suitable modelling tool such as TAPM and/or CALMET. Data assimilation should be utilised if observational data is available.

Based on the scale of the study region, multiple time series of meteorological fields may be required. The assessment must demonstrate that the selection of the number of meteorological fields for the purposes of characterising the existing meteorological environment and/or use in the dispersion modelling is appropriate.

The assessment must also discuss the motivation for, and suitability of, the selected methodology used to develop the meteorological fields for the project.

Presentation of meteorological data should include as a minimum:

- annual and seasonal wind roses
- frequency of stability classes A through F
- mixing height
- temperature statistics.

9.3.4 Assessment tools

Tools that are considered appropriate for a Level 2 assessment include (but may not be limited to):

- CAL3QHCR (Section 8.1.2): For assessing impacts for busways. Has the advantage of explicitly accounting for the impact of intersections
- AUSPLUME (Section 8.1.4): For assessing impacts from ventilation outlet in areas of simple terrain
- CALPUFF (Section 8.1.5): For assessing impacts from ventilation outlets
- TAPM (Section 8.1.6): For regional scale studies. Not considered suitable for assessing near roadside impacts.

9.3.5 Methodology

The key components of a Level 2 assessment include:

- establishment of ambient air objectives
- characterisation of the existing meteorological environment
- definition and estimation of the background air quality environment as specified in Section 6
- development of a fleet emissions inventory
- selection of an appropriate model
- conduct of an assessment
- interpretation of the results of the assessment
- statement of assessment limitations and assumptions
- provision of recommendations.

Additional details of other components of the assessment methodology that may require consideration are discussed in Appendix D-A. These include (but may not be limited to):

- defining links
- assigning gradients
- assigning vehicle volumes
- setting other model parameters.

The air quality assessment of Dutton Park is used as an example throughout the Appendix. Additional details can be found in Katestone Environmental (2008).

10 Reporting and results presentation

10.1 Pollutant species

The assessment is to include the presentation of all chemical species that have been identified as of interest to TMR (Section 3). Justification for omission of particular species should be considered on a project by project basis and in consultation with TMR. For a Level 1 assessment, nitrogen dioxide and particulate matter (as PM_{10}) need only be presented.

When presenting results for individual species the following are typically reported:

- the 99.9th percentile 1 hour average ground-level concentration
- the maximum 8 hour average ground-level concentration
- the maximum 24 hour average ground-level concentration
- the maximum annual average ground-level concentration (if assessing multiple years of meteorology) else annual average ground-level concentration (if assessing a single year).

Additional comments for individual pollutant species based on the methodology applied for previous busway studies are included in the following.

10.1.1 Nitrogen dioxide

As noted in Section 5, the Air EPP specifies ambient air objectives for both the 1 hour and annual averages of nitrogen dioxide.

Current modelling techniques cannot characterise the chemical reactions that cause nitrogen dioxide to form from oxides of nitrogen (NO_x) released from motor vehicles at the scale of roadway and busway projects. Instead, conservative assumptions are made with respect to the rate of conversion of NO_x.

Specifically, when presenting results from the dispersion modelling for the maximum 1 hour average ground-level concentration of nitrogen dioxide it has typically assumed that 20% of the oxides of nitrogen are converted to nitrogen dioxide. For the annual average ground-level concentration of nitrogen dioxide it has been typically assumed that 60% of the oxides of nitrogen have been converted to nitrogen dioxide. (Holmes, 2006)

10.1.2 Carbon monoxide

As noted in Section 5, the Air EPP specifies ambient air objectives for the 8 hour average of carbon monoxide. Results of the dispersion modelling for the maximum 8 hour average ground-level concentration based on an 8 hour rolling average is to be presented.

10.1.3 Particulate matter

Particulate matter may be conservatively modelled assuming no deposition of particulate matter material.

As noted in Section 5, the Air EPP specifies objectives for TSP, PM_{10} and $PM_{2.5}$. Due to the nature of the particulate matter emissions from vehicles, assessment against the Air EPP objective for TSP is not typically explicitly undertaken since the Air EPP objectives for PM_{10} and $PM_{2.5}$ are more strict than that for TSP. It has been typically argued that a demonstrated compliance with the Air EPP for PM_{10} and $PM_{2.5}$ will ensure compliance with the Air EPP objective for TSP.

The increment in the maximum 24 hour average and annual-average ground-level concentrations of $PM_{2.5}$ at the location of the sensitive receptors due to the contribution of busways has been conservatively estimated based on the assumption that 70% of PM_{10} is in the form of $PM_{2.5}$. This assumption has been determined from the worst-case ratios calculated from measurements of the concentrations of PM_{10} and $PM_{2.5}$ in road tunnels in Australia (Holmes, 2004).

10.1.4 Ultrafine particles

As noted in Section 3, due to uncertainties in the nature and level of impact associated with ultrafine particles, TMR requires that consideration be given to estimating ground-level concentrations of ultrafine particles associated with the busways. In busway studies undertaken to date in Southeast

Queensland, ground-level concentrations of ultrafine particles have been reported as annual averages. No air quality objective for ultrafine particles is currently available. Additional requirements in relation to the reporting of impacts associated with ultrafine particles may be specified as additional information becomes available.

10.1.5 Volatile organic compounds

10.1.5.1 Averaging periods of one hour or greater

As noted in Section 5, the Air EPP contains air quality objectives for the annual average ground level concentration of 1,3-butadiene and benzene.

In previous studies, estimates of the maximum 24 hour average ground-level concentrations of formaldehyde, toluene and xylene were calculated based on the maximum 24 hour average ground-level concentration of carbon monoxide.

Annual average ground-level concentrations of benzene, benzo(a)pyrene, toluene and xylene were estimated using the annual average ground-level concentration of carbon monoxide.

10.1.5.2 Sub-one hour averaging periods

The shortest averaging period that is typically explicitly calculated by dispersion models such as CAL3QHCR and CALPUFF is a 1 hour average.

Previous versions of the Air EPP did not include ambient air criteria for 1,3-butidiene or benzene. As such, for busway assessment undertaken prior to the release of the AIR EPP 2008, ambient criteria from the Victorian EPA were used for assessment purposes. The Victorian EPA has 3 minute average design criteria for a range of species. For previous assessments that used these short-term ambient criteria, the predicted ground-level concentrations for the 3 minute averaging periods were calculated using the power law relationship.

$$C_t = C_{60}\left(\frac{60}{3}\right)^{0.2}$$

The power law relationship is considered applicable for use with low level line sources (Hibberd, 1998). This power law equates to a ratio of 1.82 being applied to the 1 hour average concentrations to obtain a 3 minute average concentration.

In previous studies, estimates of the maximum 24 hour average ground-level concentrations of formaldehyde, toluene and xylene were calculated based on the maximum 24-hour average ground-level concentration of carbon monoxide.

Annual average ground-level concentrations of benzene, benzo(a)pyrene, toluene and xylene were estimated using the annual average ground-level concentration of carbon monoxide.

10.2 Scaling versus modelling

Impacts associated with a particular chemical species may be inferred from the modelling results of another species if the following hold:

- The pollutants are well represented by a passive scalar
- Modelling has been undertaken for a passive scalar
- The pollutants are emitted from the same source (for example ventilation outlet) and thus the source characteristics are identical for both pollutants

- The ratio of the inferred and modelled pollutant is known
- Additional quantities of the pollutant are not being created through secondary reactions over the time scale of the modelling.

10.3 Presentation of results at sensitive receptor locations

10.3.1 Tables

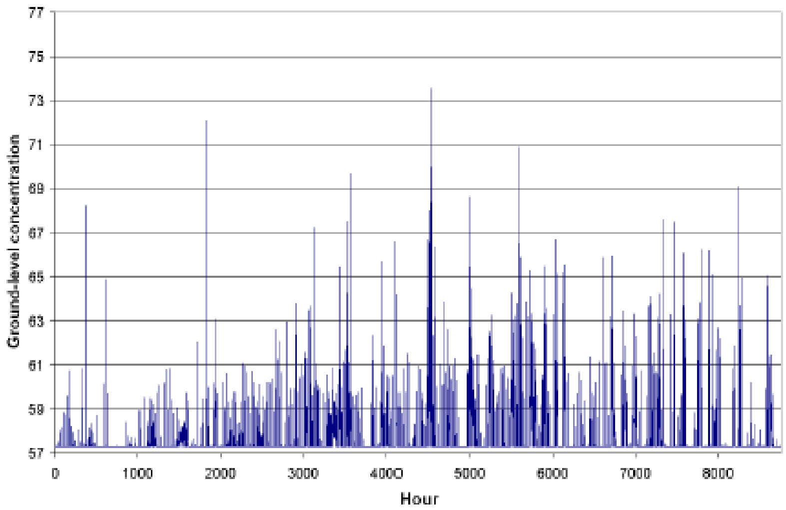
Results of the air quality assessment at sensitive receptor locations should be presented in tabular form. The number of decimal places presented should be representative of the level of accuracy of the assessment undertaken.

10.3.2 Time series

Depending on the level of assessment undertaken, the presentation of additional information may assist in the interpretation of the results presented.

Presented in Figure 9 through Figure 11 are examples of other types of plots that have been used in previous air quality assessments of impacts from emissions from busways. They include time series, hour-of-day and plots of wind direction versus ground-level concentration.

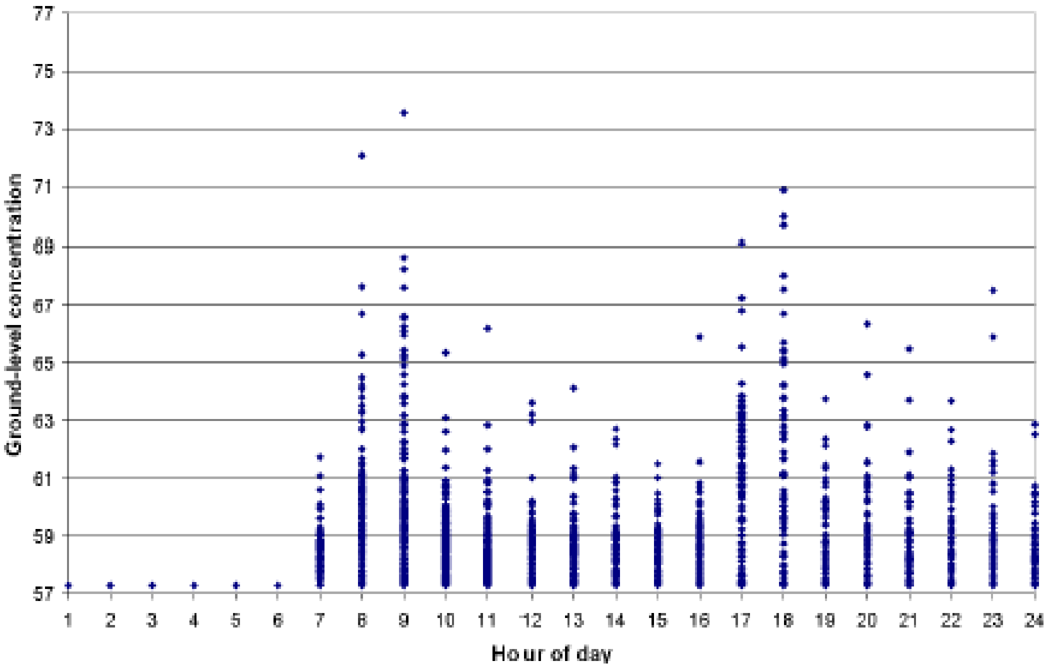
Figure 9: Time series of the 1 hour average ground-level concentration of nitrogen dioxide at a sensitive receptor location. The Air EPP objective is 250 µg/m^3 (Katestone Environmental, 2008)



10.3.3 Hour of day

Presented in Figure 10 is a scatter plot of ground-level concentration at a receptor location as a function of the hour-of-day. Higher concentrations associated with morning and afternoon peak hour busway traffic are clearly identifiable.

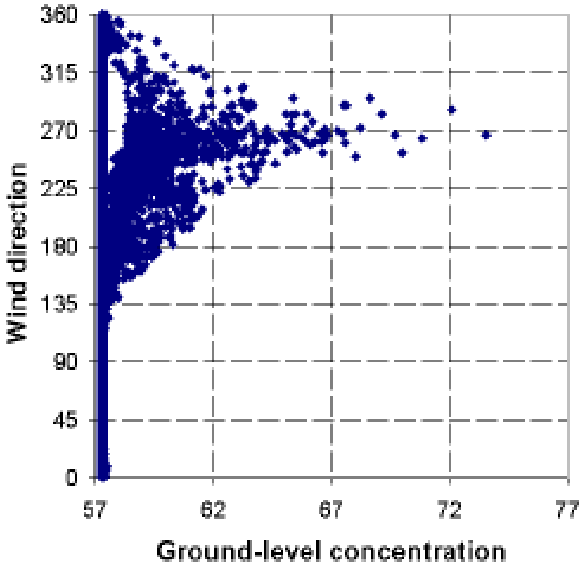
Figure 10: Scatter plot of 1 hour average ground-level concentration of nitrogen dioxide as a function of the time of day at a sensitive receptor location. The Air EPP objective is 250 µg/m^3 (Katestone Environmental, 2008)



10.3.4 Ground-level concentrations a function of wind direction

Plots of ground-level concentration versus wind direction (Figure 11) can in general assist in identifying key emission sources. With respect to the assessment of impacts associated with vehicle emissions from busways or road networks, plots such as these assist in demonstrating the variable nature of the impacts and provide an indication of the relative scale of impact associated with different road segments. The figure presented below indicates that at this location, the key pollutant source located to the west of the receptor is dominant at this location.

Figure 11: Scatter plot of the 1 hour average ground-level concentration of nitrogen dioxide as a function wind direction at a sensitive receptor. The Air EPP objective is 250 µg/m^3 (Katestone Environmental, 2008)



10.4 Contour plots of the study area

When presenting total ground-level impacts (i.e. including background levels), contour plots should include a contour that represents the applicable ambient air objective if the total concentration exceeds the objective.

When presenting the project-only contribution to ground-level impacts, contour plots should not include a contour that represents the applicable ambient air objective. The relevant ambient air objective should be noted in the figure caption.

10.5 Study limitations

Air quality assessments are to include a section detailing the limitations of the assessment as well as the implications of the limitations in terms of the results presented for each of the following:

- dispersion modelling undertaken (such as model parameters, model resolution, etc.)
- assessment methodology applied (such as Level 1, assumptions, etc.)
- input data sets (such as emission factors, monitoring data, project information, etc.).

11 Suggestions for further work

11.1 Gaps in knowledge

The busway studies that have been undertaken have highlighted a number of gaps in our current knowledge. Unanswered questions include:

- Are the emission factors representative of the wider fleet?
- What are the nature and extent of health impacts associated with exposure to ultrafine particles?
- How applicable is the Ginzburg approach to busway portal emissions?

- What are the key sensitivities in terms of input values into the dispersion modelling? For example:
  - Does a small error in the estimation of the acceleration distance lead to a large error in the total estimate of the emissions inventory?
  - How much influence do model default values (for example minimum mixing height (CALMET) have on predicted ground level concentrations?
- How representative are the drive-cycles used for vehicle testing compared with real-life driving patterns?
- When is the use of constant values for estimates of background levels of pollutants appropriate and what are the alternative methodologies that could be applied?
- Is one year of meteorology sufficient? Should the year of meteorological parameters used in the dispersion modelling be ‘typical’ or representative of ‘worst-case’ meteorological conditions? Is a single year of meteorology representative of inter-annual variability?
- Are the models adequately capturing observed worst-case events?

11.2 Extension of knowledge

- Model validation of approach used in the modelling of portal emissions using CAL3QHCR (Ginzburg)
- TMR is an industry partner with QUT (ILAQH) on the following projects:
  - The Effects of Ultrafine Particles from Traffic Emissions on Children’s Health (UPTECH). The project seeks to determine the effect of the exposure to airborne UF particles emitted from motor vehicles on the health of children in school
  - Development of greenhouse and air quality comparator
  - Quantification of traffic generated ultrafine particle dynamics in transit hubs.

12 Additional details

Additional details of other components of the assessment methodology that may require consideration are discussed in the following. The air quality assessment of Dutton Park is used as an example throughout the following sections. Additional details can be found in Katestone Environmental (2008).

12.1 Defining linkages

For each project, the roadways are divided into a number of ‘links’ of varying length depending on the characteristics of the emission source.

As an example, four categories of links were defined in the Dutton Park Air Quality Assessment (Katestone Environmental, 2008) that were associated with: free flowing buses, portal emissions, idling buses, and buses accelerating away from the stations. The choice of links is discussed in the following sections.

12.2 Links: free flowing buses

In order to incorporate as much of the important features of the busway as possible, linkages used to model the free flowing buses were defined based on consideration of changes in road gradients as well as changes in road usage or type (i.e. a bus station, tunnel, busway at grade, or main road). Both eastbound and westbound linkages were defined (Katestone Environmental, 2008).

12.3 Links: tunnel portals

For this assessment (Katestone Environmental, 2008), it was assumed that the ventilation of emissions within the tunnel would only occur from the western end of the tunnel.

The methodology used to assign portal emissions to links at western end of the tunnel was based on that used in the air quality assessment of the Northern Busway (Holmes, 2006) and Eastern Busway (Katestone Environmental, 2006). The Ginzburg method (Ginzburg and Schattanek, 1997) was used to estimate the length of the plume that extends from the portal.

For the portal located in Dutton Park twelve links of approximately 10 metres in length were defined. The emissions were then assigned to each of these portal links using a graded approach as summarised in Table 14. Link 1 is located at the entrance to the tunnel.

The Ginzberg approach (Ginzburg and Schattanek, 1997) has been used to model plume emissions from the portal using CAL3QHCR. Tunnel emissions are partitioned along each of the twelve 10 metre long portal links as indicated in Figure 12. Note that link 1 is closest to the portal entrance.

Figure 12: Distribution of portal emissions using the Ginzburg approach (Source: Katestone Environmental, 2008)

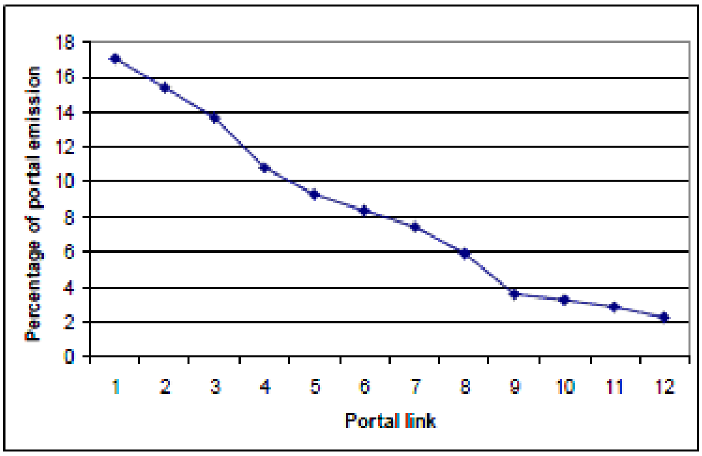


Table 14: Partitioning of emissions from the tunnel to each portal link (Katestone Environmental, 2008)

Link	1	2	3	4	5	6	7	8	9	10	11	12
Fraction %	17.1	15.3	13.68	10.83	9.3	8.37	7.44	5.89	3.6	3.24	2.88	2.37

12.4 Links: idling buses at bus stations and intersections

In order to model the impacts of emissions from idling buses at either the bus station or the intersections, a single link of 30 metres or multiple links totalling 30 metres was defined depending on road curvature (Katestone Environmental, 2008).

Links: acceleration of buses away from bus stations and intersections

In order to model the impacts of emissions from buses accelerating away from either the bus stop or the intersections, a single link of 60 metres or multiple links totalling 60 metres was defined depending on road curvature.

The proximity of the intersection of Green Bridge Link Road to the portal entrance means that 30 metres of the 60 metres over which eastbound traffic (towards the tunnel) would be accelerating is within the tunnel. Since the proposed ventilation practice is to vent 100% of the portal emissions from the western portal, these 30 metres of acceleration emissions within the tunnel are assumed to be emitted over the preceding 30 metres (Katestone Environmental, 2008).

12.5 Summary of busway links

Illustrated in Figure 13 are the locations of the free flowing, portal, idling and acceleration links used to model the impacts of emissions from the Boggo Road Busway. The code for the links is given in Table 15 (Katestone Environmental, 2008).

Figure 13: Indication of the links used to model impacts in the vicinity of Dutton park (Source: Katestone Environmental, 2008)

Table 15: Busway link colour codes

Colour	Definition
Yellow	Open road
Pale blue	Tunnel
Red	Idling links associated with the traffic lights
Green	Acceleration links
Dark blue	Idling links associated with the Dutton Park bus station
Purple	Portal links

12.6 Assigning gradients

Information supplied by Translink was used to assign gradients to all free flowing busway links. A zero gradient was applied to all idle links, portal links and acceleration links as emissions from these links do not depend on the gradient of the busway.

12.7 Receptor grid

The receptor grid used in the air quality assessment of the impact of emissions from the Boggo Road Busway in the vicinity of Dutton Park consisted of 4602 receptors that were uniformly spaced at 10 metre intervals (Figure 14).

Figure 14: Receptor grid (Source: Katestone Environmental, 2008)

12.8 Hourly bus load profile

In order to assign an hourly bus load to each of the links, half of the morning and afternoon peak volumes were allocated to each of the two peak hours. Daytime off peak volumes were allocated evenly over the seven hours between 0900 and 1600. Evening off peak numbers were allocated evenly over the six hours between 1800 and 2400.

12.9 Other modelling parameters

In addition to the input data as discussed in the previous sections, values of other parameters used in CAL3QHCR are given in Table 16.

Table 16: Miscellaneous CAL3QHCR modelling parameters (Source: Katestone Environmental, 2008)

Parameter	Value
Surface roughness (cm)	127
Urban/Rural Setting	Urban
Receptor height (m)	1
Source height (m)	0
Mixing zone width – free lane	3.5 m per lane + an additional 6 m

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