Annexure A - Pollutant formation, dispersion and transformation

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A.1 Overview

This Annexure summarises the processes that are involved in the formation of traffic pollutants, and their subsequent dispersion and transformation in the atmosphere. It is not designed to be comprehensive, but to provide additional contextual information for the assessment.

A.2 Formation of primary pollutants

A.2.1 Combustion

Most road vehicles are powered by internal combustion engines in which energy is derived from the burning of fuel in air. The main products of combustion are CO_2 and water vapour. However, several different processes lead to other compounds being present in vehicle exhaust in lower concentrations. The formation of these compounds during combustion is summarised below.

A.2.1.1 Carbon monoxide

Not all of the fuel is completely consumed during combustion. Incomplete combustion usually results from insufficient oxygen in the combustion mixture, and this leads to the production of carbon monoxide (CO). Historically, the main source of CO in urban areas has been petrol vehicles. However, emissions of CO from petrol vehicles have reduced substantially in recent years as a result of emission legislation effectively mandating the fitting of a three-way catalyst (TWC)[1]. Diesel engines produce little CO as they burn the fuel with excess air in the combustion chamber, even at high engine loads.

A.2.1.2 Hydrocarbons

During combustion the flame is 'quenched' by the cylinder walls, leaving behind unburnt and partially burnt fuel that is expelled with the exhaust. The unburnt and partially burnt fuel contains many different organic compounds, referred to collectively as total hydrocarbons (THC). As with CO, hydrocarbon emissions from petrol vehicles have greatly decreased as a result of TWCs, and hydrocarbon emissions from diesel engines are low for the reason mentioned above for CO.

A.2.1.3 Oxides of nitrogen

At the high temperatures and pressures in the combustion chamber some of the nitrogen in the air is oxidised, forming mainly nitric oxide (NO) with some nitrogen dioxide (NO_2). NO formation is also enhanced by oxygen-rich fuelling conditions, and proceeds via two main mechanisms. The main NO mechanism is known as the 'thermal' (or Zel'dovich) cycle, and this is responsible for more than 90 per cent of emissions (Heywood, 1988; Vestreng *et al.*, 2009). NO_2 is predominantly a secondary pollutant, being produced by the oxidation of NO in atmospheric photochemical reactions (see Section A.3.3.1). Any NO_2 that is emitted directly from vehicles is referred to as 'primary NO_2'.

NO_X emissions from petrol vehicles have also decreased as a consequence of TWCs. However, analyses in Europe have shown that, despite the considerable reductions in vehicle emissions that are calculated in inventories, NO_2 concentrations at many roadside monitoring sites are not decreasing to the same extent. Further analyses have indicated that a significant proportion of ambient NO_2 is emitted directly from vehicle exhaust, and that the direct road traffic contribution to

[1] Concentrations of pollutants in the exhaust gas depend on the air/fuel mixture. For lean mixtures (*i.e.* where there is an excess of air in the combustion chamber) the exhaust gases contain little CO or HC, but high concentrations of NO_X. Rich mixtures (*i.e.* where there is an excess of fuel) produce high concentrations of CO and HC, with little NO_X. A TWC results in the simultaneous conversion of CO to CO_2, HC to water, and NO_X to nitrogen. The emission rates of these pollutants are typically an order of magnitude lower than those for non-catalyst petrol cars. A closed-loop air-fuel ratio controller is required to maintain stoichiometric conditions for the TWC to work effectively. Precise control is especially important for efficient NO_X reduction, as the NO_X conversion drops dramatically for lean mixtures.

ambient NO_2 has (Jenkin, 2004; Carslaw and Beevers, 2004; Carslaw, 2005; Hueglin *et al*., 2006; Grice *et al*., 2009). Two contributing factors have been cited:

- The market share of diesel vehicles has increased in many European countries in recent years. Diesel vehicles emit more NO_x than petrol vehicles, and with a larger proportion of NO_2 in NO_x (termed *f*-NO_2).
- The average value of *f*-NO_2 in diesel exhaust has increased. This appears to be linked to the growth in the use of specific after-treatment technologies in modern diesel vehicles which involve *in situ* generation of NO_2, such as catalytically regenerative particle filters (Carslaw, 2005).

Furthermore, it seems likely that real-world NO_x emissions from road vehicles are not decreasing as rapidly as models are predicting (e.g. Rexeis and Hausberger, 2009). Although this does not, in itself, affect actual NO_2 concentrations, it does suggest that NO_x controls have not been sufficiently stringent, or that vehicles are not performing as expected. This issue was widely publicised in 2015, when the USEPA issued a notice of violation of the Clean Air Act to Volkswagen, after it was found that the manufacturer had programmed certain diesel cars to activate emission-control systems only during laboratory emission testings. The consequence is that there is now a great deal of interest in the tighter regulation of NO_x and NO_2 emissions from diesel vehicles and the effects of different after-treatment devices.

Historically a fairly low value for *f*-NO_2 (5-10 per cent) has been used in air quality and in-tunnel assessments in NSW. However, primary NO_2 emissions from vehicles in Sydney are not well documented. A recent update of the evidence was provided by Boulter and Bennett (2015). Several different data sets and analytical techniques were presented, including emission modelling, the analysis of ambient air quality measurements, and the analysis of emissions from tunnel ventilation outlets. The work focussed on highway traffic conditions, as these were considered to be the most relevant to tunnels in Sydney. The findings suggested that there has been a gradual increase in *f*-NO_2 in recent years, from less than 10 per cent before 2008 to around 15 per cent in 2014.

Time series (2003-2041) of NO_X and NO_2 emission factors for highway traffic in the NSW EPA inventory model (see Annexure C), weighted for the default traffic mix in each year, and the associated values of *f*-NO_2, are shown in Figure A-1. The *f*-NO_2 values for different vehicle types and emission legislation were taken from Pastramas *et al.* (2014). Emission factors are also presented for situations with and without the adoption of the Euro VI regulation for HDVs. Although the NO_X emission factors are predicted to decrease with time, there is a sharp increase in *f*-NO_2 after 2008, with a levelling-off at around 12-15 per cent (no Euro VI case) between 2020 and 2030.

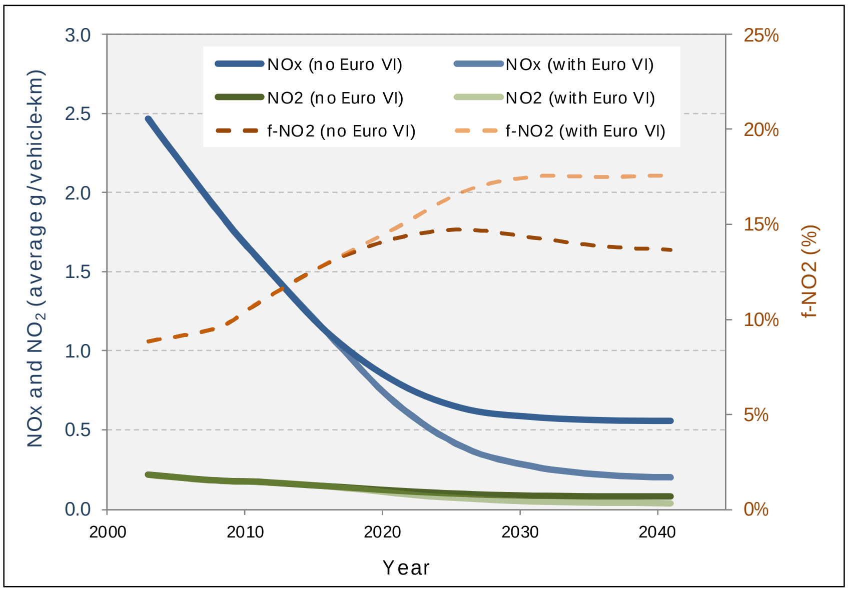

Figure A-1 **Emission factors for NO_x, NO_2 and f-NO_2 from the NSW EPA model for highways/freeways (80 km/h), weighted for default traffic mix (Boulter and Bennett, 2015)**

The main reason for the increase in *f*-NO_2 is the increased market penetration of diesel cars into the Sydney vehicle fleet. There is insufficient information on the types and distributions of exhaust after-treatment devices fitted to vehicles in Sydney to determine the contributions of different technologies to primary NO_2.

A.2.1.4 Particulate matter

Incomplete combustion also results in the production of particulate matter (PM). Diesel vehicles represent the main (exhaust) source of PM from road transport, although studies indicate that gasoline-powered vehicles with direct fuel injection also contribute to PM emissions (PIARC, 2012). Particles in diesel exhaust cover a range of sizes, and the shape of the size distribution depends on whether the weighting is by number or mass, as shown in Figure A-2. There are three distinct size modes: the nucleation mode (sometimes referred to as 'nuclei' or 'nanoparticles'), the accumulation mode, and the coarse mode. The nucleation mode has traditionally been defined as particles with a diameter of less than 50 nanometres (nm), but other size cut-offs have been used. Accumulation mode particles range in size from around 50 nm to around 1 µm, with particles smaller than 0.1 µm being referred to as ultrafine particles. The coarse mode consists of particles larger than around 1 µm.

The usual means of complying with the stringent PM mass emission limits for modern diesel vehicles is through the use of a diesel particulate filter (DPF) which physically captures particles in the exhaust stream.

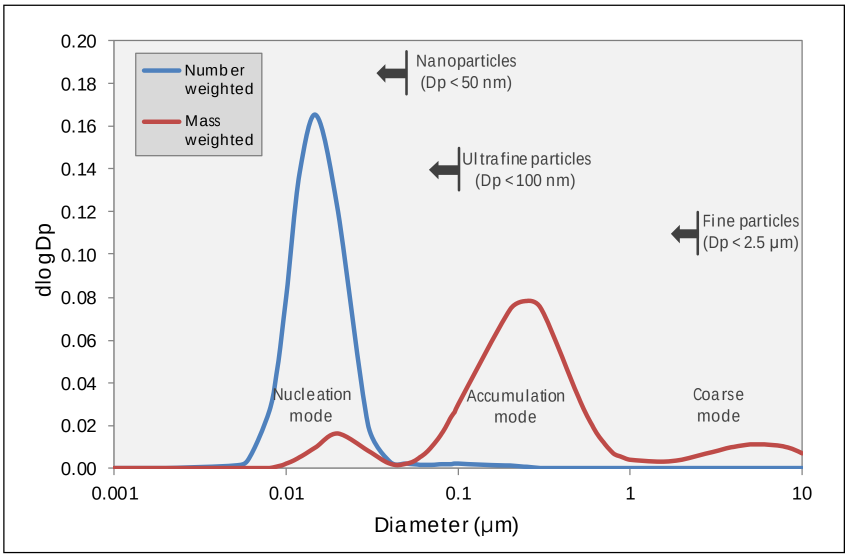

Figure A-2 **Typical particle size distributions in vehicle exhaust; the y-axis is a normalised log scale (adapted from Kittelson, 1998)**

A.2.2 Evaporation

Volatile organic compounds (VOCs) are emitted from the fuel systems of petrol vehicles as a result of evaporation. The compounds which are emitted are mainly light hydrocarbons (C_4-C_6) (CONCAWE, 1987). Evaporative emissions from diesel-fuelled vehicles are considered to be negligible due to the low volatility of diesel fuel.

There are several different mechanisms of evaporation. 'Diurnal losses' result from the thermal expansion and emission of vapour, mainly in the fuel tank, in response to changes in ambient temperature during the day. 'Hot-soak losses' occur when a warm engine is turned off and heat is dissipated into the fuel system. Whilst a vehicle is being driven the engine provides a continuous input of heat into the fuel system, resulting in 'running losses'.

Evaporative emissions are dependent upon four major factors: the vehicle design, the ambient temperature, the volatility of the petrol and the driving conditions. Emissions are decreasing as a result of new cars being equipped with sealed fuel injection systems and activated carbon canisters in fuel tank vents (Krasenbrink *et al*., 2005).

A.2.3 Abrasion and resuspension

As well as being present in vehicle exhaust, PM is generated by various abrasion processes including tyre wear and brake wear.

Tyre wear is a complex process. The amount, size, and chemical composition of the emitted PM is influenced by various factors including tyre characteristics, the type of road surface, vehicle characteristics and vehicle operation. Tyres contain a vast array of organic compounds and several important inorganic constituents. Although some research has been carried out to characterise wear particles, the understanding remains incomplete (Thorpe and Harrison, 2008).

Brake wear particles are composed of metals (iron, copper, lead, etc.), organic material, and silicon compounds which are used as binders in brake pads, but again composition varies greatly (Thorpe and Harrison, 2008). Test track and wind tunnel measurements have revealed that typically 50 per cent of the brake wear debris escapes the vehicle and enters the atmosphere, although the actual proportion depends on the severity of the braking and the design of the vehicle (Sanders *et al*., 2003). It appears that most airborne brake wear particles are quite coarse, although a substantial proportion has a diameter of less than 2.5 μm (Garg *et al*., 2000; Abu-Allaban *et al*., 2003; Iijimia *et al*., 2007).

Another process – the resuspension of material previously deposited on the road surface – occurs as a result of tyre shear, vehicle-generated turbulence, and the action of the wind. Studies in the United States have indicated that resuspension is responsible for between 30 per cent and 70 per cent of total PM_{10} in urban areas (Zimmer *et al*., 1992; Gaffney *et al*., 1995; Kleeman and Cass, 1999). Large contributions of resuspension have also been observed in some European studies (notably in Scandinavia), although the conditions in these studies (e.g. responses to climate such as the use of studded tyres and grit on roads in winter) are not necessarily representative of those in Sydney.

It is possible that non-exhaust PM is less important for tunnels than for surface roads, as under normal operating conditions in many road tunnels there is probably less braking and cornering than on surface roads. This is likely to result in less material being deposited on roads in tunnels than on roads in the external environment, resulting in a smaller contribution from resuspension. However, these effects are not well quantified at present.

A.2.4 Construction dust and odour

Dust emissions occur as a result of construction activities, and these can lead to elevated PM_{10} concentrations and nuisance. A potential source of PM (both airborne and on the road surface), especially during the project construction phase, is fugitive dust from uncovered loads. However, the Protection of the Environment Operations (Waste) Regulation 2014 requires waste transported by a vehicle to be covered during its transportation. Exhaust emissions from diesel-powered construction equipment can also be substantial.

Where construction activities involve, for example, the excavation of waste and its subsequent exposure to the atmosphere, this is likely to result in odour emissions which also need to be managed.

Construction-related air quality issues need to be considered and managed on a site-by-site basis.

A.3 Pollutant dispersion and transformation

A.3.1 Spatial distribution of pollution in an urban area

Once pollutants have been released into the atmosphere they are subject to various physical dispersion processes. These processes, in combination with a varying density of emission sources and chemical transformations (see Section A.3.3), result in a very uneven distribution of pollution across an urban area.

Figure A-3 shows a simplified representation of pollutant concentrations in and around an urban area with a high density of population and activity in the centre and a lower density in the surrounding districts. Regional background pollution originates from a range of sources, extends over a wide area, and is relatively constant outside the urban area. Within the urban area there is an additional 'urban background' component which is influenced by area-wide emission sources such as domestic and commercial heating, as well as general contributions from transport and industry. Alongside heavily-trafficked roads there is likely to be a significant local contribution to the concentration. This local traffic contribution is more pronounced for some pollutants (notably NO_X) than others (such as PM).

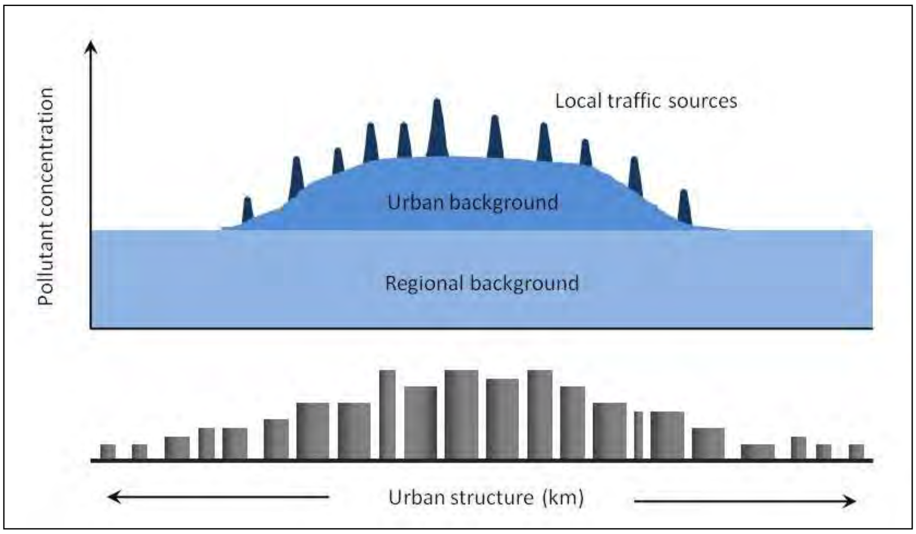

Figure A-3 **Simplified representation of urban structure and pollution levels (adapted from Keuken *et al.*, 2005)**

The general dispersion and transformation of pollutants is influenced to a large extent by the local meteorology. For example, the temperature inversions and low wind speeds associated with stable high-pressure systems can restrict dispersion and lead to high concentrations. High temperatures in summer promote the formation of ozone and other photochemical pollutants, and extreme weather events are often associated with peak levels of pollution. The frequency and severity of pollution events in Sydney are strongly influenced by the regional terrain and the presence of the sea, which affect the circulation of air (DSEWPC, 2011).

Dispersion is also influenced by the local topography (terrain) and by the presence of local obstacles such as buildings. The topography of the land in an area plays an important role in the dispersion of air pollutants. It steers winds, generates turbulence and large scale eddies, and generates drainage flows at night and upslope flows during the day.

Buildings generate turbulence and can create complicated air flow patterns including areas of accelerated flow and wakes. The influence of buildings on the plume from, say, a tunnel ventilation outlet is known as 'building downwash'. This can occur when the aerodynamic turbulence induced by nearby buildings causes a pollutant emitted from the elevated outlet to be rapidly mixed to the ground. This will depend on a number of factors such as the height and speed at which the plume is released, as well as the height of the nearest buildings and their distance from the outlet. Whether or not a plume is directly influenced by building downwash will also depend on the speed of the ambient air at the time the plume is released. In other words, if wind speeds are low, the effect the building has on the plume may be negligible. These are important considerations for the design of tunnel ventilation outlets.

In the vicinity of roads, vehicle-induced turbulence needs to be considered; the turbulence caused by the moving vehicles is likely to be more significant than that caused by buildings.

A.3.2 Concentration gradients near roads

Traffic pollutants undergo rapid changes in the near-road environment, and concentration gradients in the vicinity of roads have been examined in various studies. Some examples of the results for different pollutants and periods of the day are shown in Figure A-4. The Figure is based on the findings of Gordon *et al.* (2012), who used a mobile laboratory to measure the concentration gradients of ultrafine particles (UFP), black carbon (BC), CO_2, NO, and NO_2 at varying distances from a major highway in Toronto, Canada.

For primary pollutants such as NO and BC, concentrations decay exponentially with increasing distance from the road. Reviews have shown that these typically decrease to background levels between around 100 and 500 metres from roads (e.g. Karner *et al*., 2010; Zhou and Levy, 2007).

Many primary pollutants react together, and with pollutants from other sources, to form secondary pollutants (a substantial proportion of NO_2 is secondary). For these the situation is more complex; because of the time required for their formation, the concentrations of secondary pollutants are not always highest near the emission source.

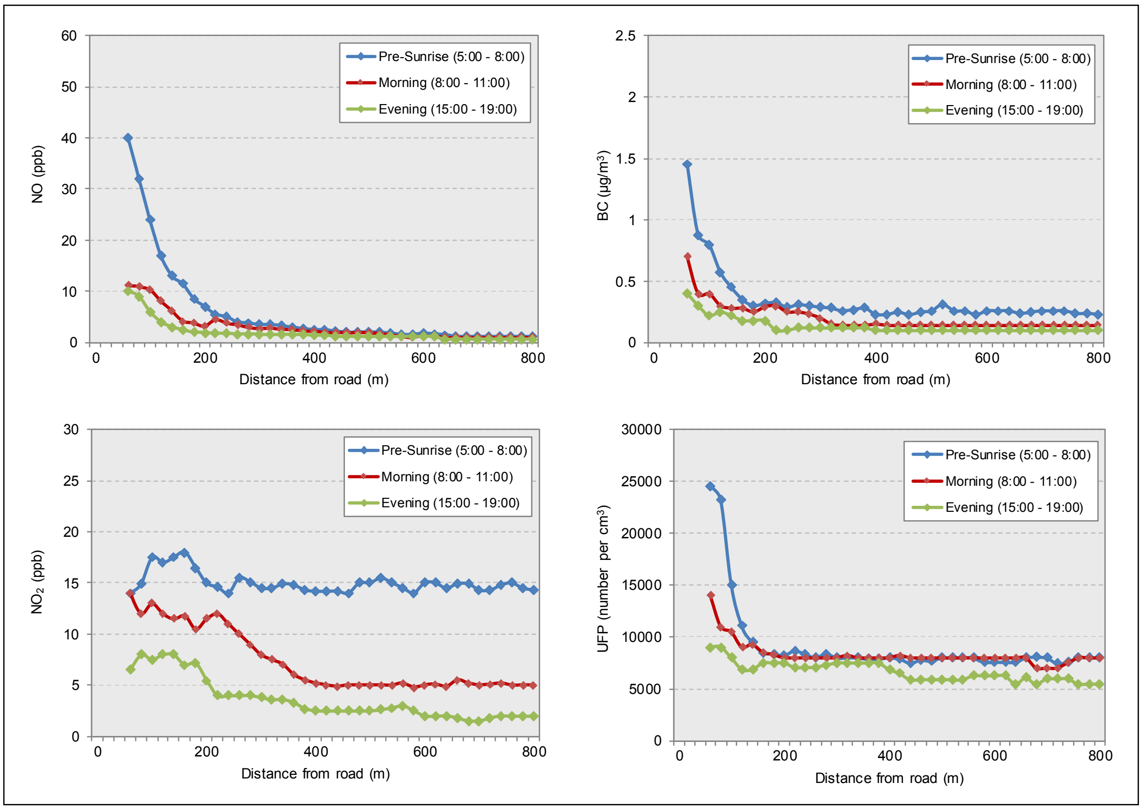

Figure A-4 Median concentrations of pollutants in the vicinity of a major highway (adapted from Gordon et al., 2012)

A.3.3 Pollutant transformation

A.3.3.1 Nitrogen dioxide

Some of the most important reactions for near-road air quality are those that lead to the formation and destruction of NO_2. Under the majority of atmospheric conditions, the main mechanism for NO_2 formation in the atmosphere is through rapid reaction of NO with ozone (O_3):

Equation A1

$$\mathbf{NO + O_3 \rightarrow NO_2 + O_2}$$

Where this is the only important reaction (e.g. at night-time), NO is transformed into NO_2 until either all the NO has been converted to NO_2 or until all the ozone has been used up. At polluted locations comparatively close to sources of NO_x (such as roads) NO is in large excess and it is the availability of O_3 which limits the quantity of NO_2 that can be produced by this reaction. The timescale for consumption of O_3 depends on the concentration of NO. Under normal ambient daytime conditions the reverse process also occurs – the destruction of NO_2 by photolysis to form NO and ozone, as shown in Equation A2 and Equation A3:

Equation A2

$$\mathbf{NO_2 + sunlight \rightarrow NO + O}$$

Equation A3

$$\mathbf{O + O_2\ (+M) \rightarrow O_3\ (+M)}$$

where **M** is a third body, most commonly nitrogen.

Dilution processes decrease the NO_2 concentration with distance from the road, whereas chemical reactions tend to favour NO_2 production. As a result, the decay rate of NO_2 is lower than that of NO in near-road environments (see Figure A-4). However, the NO_2/NO_X ratio increases with increasing distance from the roadway until it reaches the background level.

It is worth noting that inside a road tunnel there is usually a high concentration of NO from vehicle exhaust, and any available oxidant - principally ozone - is removed relatively quickly. Once the ozone is removed, NO_2 formation via Equation A1 will stop (Barrefors, 1996). As there is little natural sunlight inside a road tunnel, the destruction of NO_2 via Equation A2 is also limited. Consequently, much of the NO_2 in tunnel air is primary in origin.

A.3.3.2 Particulate matter

The fate of freshly emitted particles in the atmosphere depends upon their size. Nucleation mode particles have a short lifetime in the atmosphere since they readily transform into larger particles and deposit efficiently onto surfaces. Accumulation mode particles are too large to be subject to rapid diffusion and too small to settle from the air rapidly under gravity. Their further growth is inhibited because they do not coagulate quickly and there are diffusion barriers to their growth by condensation. Particles in the accumulation mode can therefore have a long atmospheric lifetime (typically 7–30 days). For coarse particles, gravitational settling velocities become appreciable and therefore atmospheric lifetimes are shorter than for accumulation mode particles.

A substantial fraction of the fine PM mass, especially at background locations, is secondary in nature. Secondary particles are formed by atmospheric reactions involving both inorganic and organic gaseous precursors, several of which are emitted by road vehicles.

The formation of secondary inorganic aerosol is comparatively well understood, although some mechanistic details still remain to be determined (USEPA, 2009). This aerosol is composed mainly of ammonium sulfate ($(NH_4)_2SO_4$) and ammonium nitrate (NH_4NO_3), with some sodium nitrate. These compounds originate from the conversion of sulfur oxides (SO_X) and nitrogen oxides (NO_X) in the atmosphere to sulfuric and nitric acids, which are then neutralised by atmospheric ammonium (NH_4^+). The precursor to atmospheric ammonium is ammonia (NH_3). SO_X and NO_X typically arise from combustion sources. NH_3 emissions are dominated by agricultural sources, such as the decomposition of urea and uric acid in livestock waste (AQEG, 2005).

Secondary organic aerosol is linked to the formation and transformation of low-volatility organic compounds in the atmosphere. The formation of these compounds is governed by a complex series of reactions involving a large number of organic species (Kroll and Seinfeld, 2008). As a result of this complexity a great deal of uncertainty exists around the process of formation (USEPA, 2009).

The formation of secondary particles happens slowly; the overall oxidation rates of SO_2 and NO_2 are around 1 per cent per hour and 5 per cent per hour respectively. The slowness of these processes – and the fact that the resulting particles are small and therefore have a relatively long atmospheric lifetime – means that secondary particles are usually observed many kilometres downwind of the source of the precursors.

Particles are removed from the atmosphere by both dry deposition and wet deposition processes. Dry deposition is caused by gravitational sedimentation, interception/impaction, diffusion or turbulence, although other processes can occur. In wet deposition, atmospheric water (raindrops, snow, *etc.*) scavenges airborne particles, with subsequent deposition on the earth's surface.

Annexure B - Review of legislation and criteria relating to emissions and air quality

Annexure B - Review of legislation and criteria relating to emissions and air quality

B.1 Overview

This Annexure provides supplementary information, including an international context, on key legislative instruments and guidelines of relevance to the project.

B.2 National emission standards for new vehicles

B.2.1 Exhaust emissions

For emission testing purposes, the legislation distinguishes between the following:

- Light-duty vehicles. These have a gross vehicle mass (GVM) of less than 3,500 kilograms, and are subdivided into:
    - Light-duty passenger vehicles, including cars, sports utility vehicles (SUVs), four-wheel drive (4WD) vehicles and 'people movers'.
    - Light-duty commercial vehicles, including vans and utility vehicles used for commercial purposes.

  The light-duty vehicle legislation also distinguishes between petrol and diesel vehicles.
- Heavy-duty vehicles, with a GVM of more than 3,500 kilograms.

Exhaust emissions are inherently variable, and so the best way to ensure that an emission test is reproducible is to perform it under standardised laboratory conditions. Light-duty vehicles are tested using a power-absorbing chassis dynamometer. The emissions from heavy-duty vehicles are regulated by engine dynamometer testing, given that the same engine model could be used in many different vehicles.

The Australian Design Rules (ADRs) set limits on the exhaust emissions of CO, HC, NO_X and PM. Some of the pollutants in vehicle exhaust are not regulated, including specific 'air toxics' and the greenhouse gases CO_2, CH_4 and N_2O. The specific emission limits which apply to light-duty and heavy-duty vehicles, and their timetable for adoption in the ADRs, are listed on the Australian Government website[1]. Although the test procedures have changed with time, the exhaust emission limits have been tightened significantly in recent years. There has been a greater alignment with the international vehicle emissions standards set by the UNECE[2], although the Australian standards have delayed introduction dates (DIT, 2010).

Australia is currently implementing the Euro 5[3] emission standards for new light-duty vehicle models (cars and light commercial vehicles). New vehicle models have been required to comply with these standards since November 2013. The introduction in Australia of Euro 6 emissions standards is currently on hold and is being reviewed by the Ministerial Forum on Vehicle Emissions. With full implementation of Euro 6, the World Harmonized Light-duty Vehicle Test Cycle (WLTC) will replace the current test cycle (Mock et al., 2014).

In the case of heavy-duty vehicles the Euro V standards are currently being implemented in Australia, and the Euro VI standards are currently under discussion. Although the Euro VI standards will reduce the limit on NO_X emissions by 77 per cent relative to Euro V, and by 89 per cent relative to Euro IV,

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[1] http://www.infrastructure.gov.au/roads/environment/emission/

[2] United Nations Economic Commission for Europe.

[3] In accordance with the European legislation, a slightly different notation is used in this Report to refer to the emission standards for LDVs, HDVs and two-wheel vehicles. For LDVs and two-wheel vehicles, Arabic numerals are used (e.g. Euro 1, Euro 2…etc.), whereas for HDVs Roman numerals are used (e.g. Euro I, Euro II…etc.).

advanced test protocols that improve real-world conformity to NO_X limits should result in reductions that are closer to 95 per cent (Muncrief, 2015).

The ADRs do not mandate the use of particular technology. However, it was necessary for vehicle manufacturers to fit catalytic converters to light-duty petrol vehicles in order to meet the emission limits introduced by ADR37/00. For light-duty diesel vehicles, particulate traps will generally be required for compliance with the very low PM emission limits at the Euro 5 stage. For Euro 6/VI the required NO_X reductions will be achieved with combustion improvements (high-pressure fuel injection and advanced air/fuel management), exhaust gas recirculation, closed-loop SCR systems and lean NO_x trap (LNT) technology. To support the introduction of new technologies there is usually a need for improved fuel quality (e.g. reduced fuel sulfur content). Fuel regulations therefore tend to be updated to support new emission standards.

The European Commission is introducing a mandatory test procedure for 'real driving emissions' (RDE), to be applied during the type approval of light-duty vehicles. These are measured on the road by a portable emission measurement system (PEMS), rather than in the laboratory. The RDE initiative complements the introduction of the WLTC and procedures. The new RDE procedure will require exhaust emission control systems to perform under a broad range of different operating conditions.

Several shortcomings of the regulations have been identified in the EU. For heavy-duty vehicles the Euro V standards did not achieve the anticipated reductions in NO_X emissions (Ligterink et al., 2009). Although the Euro 5 standards have resulted in dramatic reductions in PM emissions from light-duty diesels, real-world NO_X emissions from Euro V trucks and buses have continued to far exceed certification limits (Carslaw et al., 2011).

B.2.2 Evaporative emissions

The test procedure for evaporative emissions involves placing a vehicle inside a gas-tight measuring chamber equipped with sensors to monitor the temperature and VOC concentrations, and following a prescribed operational procedure. The chamber is known as a SHED (Sealed Housing for Evaporative Determination). The limits for evaporative emissions are specified in the ADRs.

B.3 In-tunnel limits – international practice

Guidelines for the calculation of the fresh air requirements of tunnel ventilation systems are presented by PIARC (2012). Three types of value are defined:

- Design values: These determine the required capacity of the tunnel ventilation system. The ventilation capacity for normal tunnel operation is defined by the air demand required to dilute vehicle emissions to maintain allowable in-tunnel air quality.
- Set points: These are used for the incremental operation of the tunnel ventilation system. For example, tunnel sensors trigger mechanical ventilation in stages before the measured concentration of a gas reaches its limit value (Highways Agency et al., 1999). Set points are generally lower than design values, and are selected so that the design conditions are not exceeded, taking into account the time lag between the traffic conditions and the ventilation system.
- Threshold values: These ensure safe operation of the tunnel, and must not be exceeded. If a threshold value is attained, immediate action is required.

It is prudent for design modelling to include predictions for a range of traffic speeds, and to establish worst case conditions. However, PIARC notes that the application of overly stringent design values can result in over-sizing of the ventilation system, and thresholds or set points that are too low can cause excessive operational energy use and cost. Nevertheless, the PIARC document states that the emission factors it provides for designing tunnel ventilation tend to be conservative (they include a margin of safety).

Table B-1 provides a summary of the PIARC in-tunnel CO and visibility limits for ventilation design, tunnel operation, and tunnel closure. The 100 ppm value for CO corresponds to a WHO recommendation for short-term (15-minute) exposure, and is widely used for ventilation design. Exposure at this concentration should not persist for more than 15 minutes, although the length of most tunnels is such that the exposure duration is much less than 15 minutes. In such cases, a higher level of CO may be allowed in the tunnel. The limits for visibility are designed for the purpose of safe driving rather than the protection of health. The limit values for in-tunnel CO and visibility in a number of countries are shown in Table B-2. The national limits for CO in each country are broadly similar to the values recommended by PIARC.

Table B-1 CO and visibility limit values (PIARC, 2012)

Traffic situation	CO conc. (ppm)	Visibility	
		Extinction coefficient (/m)	Transmission *s* (beam length: 100 m)
Free-flowing peak traffic 50-100 km/h	70	0.005	60
Daily congested traffic, stopped on all lanes	70	0.007	50
Exceptional congested traffic, stopped on all lanes	100	0.009	40
Planned maintenance work in a tunnel under traffic[a]	20	0.003	75
Threshold for closing the tunnel[b]	200	0.012	30

(a) National workplace guidelines should be considered.
(b) To be used for tunnel operation only, and not for ventilation design.

Table B-2 In-tunnel CO and visibility limits for ventilation design and tunnel closure

Country	Condition for ventilation design	Limit values for ventilation design		Limit values for tunnel closure	
		CO (ppm)	Visibility (/m)	CO (ppm)	Visibility (/m)
Austria	Regular congestion	100	0.007	150[a]	0.012[a]
				100[b]	-
France	Free-flow and congested	50	0.005	-	-
Germany	Regular congestion	70	0.005	200	0.012
	Occasional congestion	100	0.007	-	-
Hong Kong	5-min average	100	-	-	-
Japan	60 km/h	50-100	<0.009	150	0.012
	80 km/h	50-100	<0.007		
Norway[c]	Mid-tunnel	75	-	100[d]	-
Switzerland	Any	70	0.005	200[e]	0.012[e]
UK[f]	Tunnel <500 m	10	PIARC	-	-
	Tunnel 500 m to 1,000 m	50	PIARC	-	-
	Tunnel 1,000 m to 2,500 m	35	PIARC	-	-
USA	Fluid peak traffic, 60 km/h	100	<0.009	150	0.012
	Fluid peak traffic, 80-100 km/h	100	<0.007		
	Congested traffic	100	<0.009		

(a) If exceeded for more than 1 minute.
(b) If exceeded for more than 10 minutes.
(c) In Norway, NO/NO_2 and particulate matter are also used for design and control purposes.
(d) If exceeded at tunnel mid-point for more than 15 minutes.
(e) If exceeded for more than 3 minutes.
(f) Limit values for tunnels longer than 2,500 m are derived from first principles.

Sources: Norwegian Public Roads Administration (2004), ASTRA (2003), CETU (2010), MEPC (1993), RABT (2003), RVS (2004)

PIARC has not released definitive recommendations for NO_2 in tunnels, and there are scientific and technical challenges in managing compliance with NO_2 limits. Based on the findings of health studies PIARC has proposed an in-tunnel limit for NO_2 of 1 ppm as the design value, defined as an average value along the length of the tunnel (PIARC, 2012).

It is noted by PIARC that many countries do not apply a NO_2 limit specifically for tunnels, but occupational short-term exposure limits apply. These are typically higher than the 1 ppm proposed by PIARC. Some countries have introduced NO_2 as the target pollutant for in-tunnel air quality monitoring, with the threshold value normally following national and/or WHO recommendations. Depending on the situation, either NO_2 or NO_x inside the tunnel, or NO_2 outside the tunnel, can be taken as the design parameter for ventilation sizing.

Examples of in-tunnel NO_2 values for ventilation control from several countries are summarised in Table B-3. It is noted in PIARC (2012) that the WHO limits aim at improving air quality in general, and are not intended to be applied to peak exposures. Nevertheless, different values have been adopted for different timeframes, and some of these are quite stringent. In the UK, consideration was given to lowering the NO_2 limit to 1 ppm, but tunnel operators stated that it would not be feasible to comply with this limit (Tarada, 2007). PIARC adds that passage through a tunnel typically only lasts for a few minutes, and therefore stringent NO_2 thresholds should only be considered where it might be warranted by traffic conditions and/or ambient conditions.

The CO, NO_2 and PM concentrations in the ambient fresh air used for dilution are normally relatively low, but should be checked for tunnels in urban areas, where ambient CO concentrations are typically between 1 ppm and 5 ppm. A typical ambient peak NO_2 concentration would be 200 µg/m^3. The situation can be modified, however, when air from the portal of one bore enters the portal of the adjacent bore as ‘fresh air’, although simple structural design features (*e.g.* anti-recirculation walls) can minimise or even eliminate such effects (PIARC, 2012).

For longitudinally ventilated tunnels in which traffic demands are high, or may change suddenly, PIARC recommends a minimum air flow speed of 1.0-1.5 m/s.

Table B-3 International in-tunnel NO_2 limits

Country	NO_2 (ppm)	Notes	Source
PIARC	1.0	Averaged over tunnel length	PIARC (2012)
Belgium	0.2	1 hour	WHO (2006)
	0.5	<20 minutes	PIARC (2012)
France	0.4	15 minutes, average for length of tunnel	CETU (2010)
Hong Kong	1.0	5 minutes, ventilation control	Hong Kong EPD (1995)
Norway[(a)]	0.75	15 minutes, tunnel mid-point	Norwegian Public Roads Administration (2004)
Sweden[(b)]	0.2	1 hour	WHO (2006)
UK[(c)]	4	Tunnel <500 m	Highways Agency *et al.* (1999)
	3	Tunnel 500 m to 1,000 m	
	1.5	Tunnel 1,000 m to 2,500 m	

(a) Resulting in tunnel closure.
(b) PIARC states that Sweden is in the process of abandoning the WHO threshold.
(c) Design and control. Limit values for tunnels longer than 2,500 m are derived from first principles.

B.4 Ambient air quality standards and goals

B.4.1 Criteria pollutants

The metrics, criteria and goals set out for criteria pollutants in the NSW Approved Methods are listed in Table B-4. The pollutants shaded in grey were not included in the assessment (see section 5.5.3).

Table B-4 Impact assessment criteria for 'criteria pollutants' in NSW Approved Methods (NSW EPA, 2016)

Pollutant or metric	Criterion: Concentration	Criterion: Averaging period	Calculation	Source
Carbon monoxide (CO)	87 ppm or 100 mg/m^3	15 minutes		WHO (2000)
	25 ppm or 30 mg/m^3	1 hour	One hour clock mean	WHO (2000)
	9 ppm or 10 mg/m^3	8 hours	Rolling mean of 1-hour clock means	NEPC (1998)
Nitrogen dioxide (NO_2)	120 ppb or 246 µg/m^3	1 hour	One hour clock mean	NEPC (1998)
	30 ppb or 62 µg/m^3	1 year	Calendar year mean	NEPC (1998)
Particulate matter <10 µm (PM_{10})	50 µg/m^3	24 hours	Calendar day mean	NEPC (2016)
	25 µg/m^3	1 year	Calendar year mean	NEPC (2016)
Particulate matter <2.5 µm ($PM_{2.5}$)	25 µg/m^3	24 hours	Calendar day mean	NEPC (2016)
	8 µg/m^3	1 year	Calendar year mean	NEPC (2016)
Sulfur dioxide (SO_2)	250 ppb or 712 µg/m^3	10 minutes		NHMRC (1996)
	200 ppb or 570 µg/m^3	1 hour	One hour clock mean	NEPC (1998)
	80 ppb or 228 µg/m^3	1 day	Calendar day mean	NEPC (1998)
	20 ppb or 60 µg/m^3	1 year	Calendar year mean	NEPC (1998)
Lead (Pb)	0.5 µg/m^3	1 year	Calendar year mean	NEPC (1998)
Total suspended particulate matter (TSP)	90 µg/m^3	1 year	Calendar year mean	NHMRC (1996)
Photochemical oxidants (as ozone (O_3))	100 ppb or 214 µg/m^3	1 hour	One hour clock mean	NEPC (1998)
	80 ppb or 171 µg/m^3	4 hours	Rolling mean of 1-hour clock means	NEPC (1998)
Hydrogen fluoride (HF)[(a)]	0.50/0.25 µg/m^3	90 days		ANZECC (1990)
	0.84/0.40 µg/m^3	30 days		ANZECC (1990)
	1.70/0.40 µg/m^3	7 days		ANZECC (1990)
	2.90/1.50 µg/m^3	24 hours		ANZECC (1990)

(a) The first value is for general land use, which includes all areas other than specialised land use. The second value is for specialised land use, which includes all areas with vegetation that is sensitive to fluoride, such as grape vines and stone fruits.

For the criteria pollutants included in the assessment, the impact assessment criteria in the NSW Approved Methods and the AAQ NEPM from February 2016 are compared with the WHO guidelines and the standards in other countries/organisations in Table B-5. For CO the NSW standards are numerically lower than, or equivalent to, those in most other countries and organisations. The NSW standards for NO_2 are higher than in the other countries and organisations except for the United States. In the case of PM_{10}, the NSW standard for the 24-hour mean is lower than, or equivalent to, the standards in force elsewhere, whereas the annual mean standard is in the middle of the range of values for other locations. The $PM_{2.5}$ standards are lower than, or equivalent to, those used elsewhere.

Such comparisons do not necessarily mean that the Australian standards are more or less stringent than those elsewhere. For example, to a large degree the lower standards in Australia for PM are made possible by relatively low natural background concentrations and the absence of significant anthropogenic transboundary pollution (which is a major issue in Europe, for example). Moreover there are differences in implementation. For example, there is no legal requirement for compliance with the standards and goals in Australia, whereas there is in some other countries and regions.

Table B-5 Comparison of international health-related ambient air quality standards and criteria[(a)]

Country/Region/ Organisation	CO			NO_2			PM_{10}		$PM_{2.5}$	
	15 min. (mg/m³)	1 hour (mg/m³)	8 hours (mg/m³)	1 hour (µg/m³)	1 day (µg/m³)	1 year (µg/m³)	24-hours (µg/m³)	1 year (µg/m³)	24-hours (µg/m³)	1 year (µg/m³)
NSW Approved Methods	100(0)	30(0)	10(0)	246(0)	-	62	50(0)	25	25(0)	8
AAQ NEPM	-	-	10(1)[(b)]	246(1)[(b)]	-	62	50(0)	25	25(0)/20(0)[(c)]	8/7[(c)]
WHO	100(0)	30(0)	10(0)	200	-	40	50[(d)]	20	25[(d)]	10
Canada	-	-	-	-	-	-	120[(e,f)]	-[(e)]	28/27[(g)]	10/8.8[(g)]
European Union	-	-	10(0)	200(18)	-	40	50(35)	40	-	25[(h)]
Japan	-	-	22(0)	-	75-115	-	-	-	-	-
New Zealand	-	-	10(1)	200(9)	-	-	50(1)	-	-	-
UK	-	-	10(0)[(i)]	200(18)	-	40	50(35)	40	-	25
UK (Scotland)	-	-	10(0)[(j)]	200(18)	-	40	50(7)	18	-	12
United States (USEPA)	-	39(1)	10(1)	190[(k)]	-	100	150(1)	-	35[(l,m)]	12[(l)]
United States (California)	-	22(0)	10(0)	344(0)	-	57	50	20	-	12

(a) Numbers in brackets shows allowed exceedances per year for short-term standards. Non-health standards (e.g. for vegetation) have been excluded.
(b) One day per year.
(c) Goal by 2025.
(d) Stated as 99^{th} percentile.
(e) Although there is no national standard, some provinces have standards.
(f) As a goal.
(g) By 2015/2020.
(h) The 25 µg/m³ value is initially a target, but became a limit in 2015. There is also an indicative 'Stage 2' limit of 20 µg/m³ for 2020.
(i) Maximum daily running 8-hour mean.
(j) Running 8-hour mean.
(k) 98^{th} percentile, averaged over 3 years.
(l) Averaged over three years.
(m) Stated as 98^{th} percentile.

B.4.2 Air toxics

The investigation levels in the Air Toxics NEPM are summarised in Table B-6. These are not compliance standards but are for use in assessing the significance of the monitored levels of air toxics with respect to protection of human health.

Table B-6 Investigation levels for air toxics

Source	Substance	Concentration	Averaging period
Air toxics NEPM (investigation levels)	Benzene	0.003 ppm	1 year[(a)]
	Toluene	1.0 ppm	24 hours
		0.1 ppm	1 year[(a)]
	Xylenes	0.25 ppm	24 hours
		0.20 ppm	1 year[(d)]
	PAHs[(b)] (as b(a)p)[(c)]	0.3 ng/m^3 [(d)]	1 year[(a)]
	Formaldehyde	0.04 ppm	24 hours

(a) Arithmetic mean of concentrations of 24-hour monitoring results
(b) PAH – polycyclic aromatic hydrocarbons
(c) b(a)p – benzo(a)pyrene, the most widely studied PAH and used as an indicator compound
(d) ng/m^3 – nanograms per cubic metre

The NSW Approved Methods specify air quality impact assessment criteria and odour assessment criteria for many other substances (mostly hydrocarbons), including air toxics, and these are too numerous to reproduce here. The SEARs for the project require an evaluation of BTEX compounds: benzene, toluene, ethylbenzene, and xylenes. The impact assessment criteria in the NSW Approved Methods for priority air toxics and BTEX compounds are given in Table B-7.

Table B-7 Impact assessment criteria for air toxics

Source	Substance	Concentration	Averaging period
NSW Approved Methods (impact assessment criteria)	Benzene	0.009 ppm or 0.029 mg/m^3	1 hour
	Toluene[(a)]	0.09 ppm or 0.36 mg/m^3	1 hour
	Ethylbenzene	1.8 ppm or 8 mg/m^3	1 hour
	Xylenes[(a)]	0.04 ppm or 0.19 mg/m^3	1 hour
	PAHs (as b(a)p)	0.0004 mg/m^3	1 hour
	1,3-butadiene	0.018 ppm or 0.04 mg/m^3	1 hour
	Acetaldehyde[(a)]	0.023 ppm or 0.042 mg/m^3	1 hour
	Formaldehyde	0.018 ppm or 0.02 mg/m^3	1 hour

(a) Odour criterion

Annexure C - Description and evaluation of NSW EPA emission model

Annexure C- Description and evaluation of NSW EPA emission model

C.1 Overview

A spatial emissions inventory was developed for the road traffic sources in the GRAL domain. The modelling of emissions was required for the following components:

- Emissions from the proposed ventilation outlets of the project tunnel. These were calculated using the emission factors provided by PIARC (2012). This part of the work is described in Annexure K and is not considered further here.
- Emissions from the traffic on the surface road network, including any new roads associated with the project. These were calculated on a link-by-link basis using an emission model[1] developed by NSW EPA (2012b). A description of the NSW EPA model, and an evaluation of its performance, is provided in the following sections.

C.2 NSW EPA model

C.2.1 Hot running exhaust emissions

The NSW EPA method for calculating hot running exhaust emissions involves the use of matrices of 'base composite' emission factors for the following cases:

- Six pollutants (CO, NO_X, NO_2, PM_{10}, $PM_{2.5}$, THC)[2].
- Nine vehicle types: petrol passenger vehicles, diesel passenger vehicles, light-duty commercial petrol vehicles (<=3,500 kg), light-duty commercial diesel vehicles (<=3,500 kg), heavy-duty commercial petrol vehicles (>3,500 kg), rigid trucks (3.5-25 t, diesel), articulated trucks (> 25 t, diesel), heavy public transport buses (diesel only), and motorcycles. The composite emission factor for each vehicle type takes into account VKT by age and the emission factors for specific emission standards.
- Five road types (residential, arterial, commercial arterial, commercial highway, highway/ freeway), to allow for differences in traffic composition and driving patterns.
- Nine model years (2003, 2008, 2011, 2016, 2021, 2026, 2031, 2036 and 2041). The year defines the composition of the fleet for each type of vehicle, allowing for technological changes. The base year for the inventory is 2008, and therefore the data for years after 2008 are projections.

The road types used in the NSW GMR emissions inventory have been mapped to Roads and Maritime functional classes by NSW EPA (Table C-1). Further information on the mapping of these categories is provided in the inventory report (NSW EPA, 2012b).

Each base composite emission factor is defined for a VKT-weighted average speed (the base speed) associated with the corresponding road type. Dimensionless correction factors – in the form of 6^{th}-order polynomial functions – are then applied to the base emission factors to take into account the actual speed on a road. According to NSW EPA, the speed correction factors are valid up to 110 kilometres per hour for light-duty vehicles, and up to 100 kilometres per hour for heavy-duty vehicles.

Emission factors have also been provided by NSW EPA for heavy-duty vehicles with and without the implementation of the Euro VI regulation. Given the uncertainty in the implementation of Euro VI in Australia, the (higher) 'without Euro VI' emission factors were used in the assessment.

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[1] The model used for this assessment was a simplified version of the full inventory model that was developed by NSW EPA for use in the Roads and Maritime air quality screening model TRAQ.

[2] It is assumed that $PM_{2.5}$ is equivalent to PM_{10}, which is appropriate for exhaust emissions. The NO_2 emission factors were not used in the assessment.

Table C-1 Road types used in the NSW EPA emissions inventory model

NSW GMR inventory road type	Roads and Maritime functional class	Definition/description
Local/residential	Local road	Secondary road with prime purpose of access to property. Low congestion and low level of heavy vehicles. Generally one lane each way, undivided with speed limit up to 50 kilometres per hour. Regular intersections, mostly unsignalised, and low intersection delays.
Arterial	Sub-arterial and arterial	Connection from local roads to arterials. May provide support role to arterial roads for movement of traffic during peak periods. Distribute traffic within residential, commercial and industrial areas. Speed limit 50-70 kilometres per hour, 1-2 lanes. Regular intersections, mostly uncontrolled. Lower intersection delays than residential roads, but significant congestion impact at high volume:capacity ratio (V/C).
Commercial arterial	Arterial	Major road for purpose of regional and inter-regional traffic movement. Provides connection between motorways and sub-arterials/collectors. May be subject to high congestion in peak periods. Speed limit 60-80 kilometres per hour, typically dual carriageway. Regular intersections, many signalised, characterised by stop-start flow, moderate to high intersection delays and queuing with higher V/C.
Commercial highway	Arterial	Major road for purpose of regional and inter-regional traffic movement. Provides connection between motorways and sub-arterials/collectors. May be subject to moderate congestion in peak periods. Speed limit 70-90 kilometres per hour, predominantly dual carriageway. Fewer intersections than commercial arterial, with smoother flow but subject to some congestion at high V/C.
Highway/freeway	Motorway	High volume road with primary purpose of inter-regional traffic movement with strict access control (i.e. no direct property access). Speed limit 80-110 kilometres per hour, predominantly 2+ lanes and divided carriageway. Relatively free-flowing when not congested, slowing with congestion approaching V/C limit but minimal stopping.

The emission factor for a given traffic speed is calculated as follows:

Equation C1

$$\mathbf{EF_{HotSpd} = EF_{HotBasSpd} \times \frac{SCF_{Spd}}{SCF_{BasSpd}}}$$

Where:

$\mathbf{EF_{HotSpd}}$ is the composite emission factor (in g/km) for the defined speed

$\mathbf{EF_{HotBasSpd}}$ is the composite emission factor (in g/km) for the base speed

$\mathbf{SCF_{Spd}}$ is the speed-correction factor for the defined speed

$\mathbf{SCF_{BasSpd}}$ is the speed-correction factor for the base speed

Each speed-correction factor is a 6th order polynomial: $\mathbf{SCF = aV^6 + bV^5 + \ldots + fV + g}$, where **a** to **g** are constants and **V** is the speed in kilometres per hour.

Some examples of the resulting emission factors are shown in the Figures below. Figure C-1 shows how NO_X emissions (mass per vehicle-km) from petrol cars vary as a function of average speed[3] on different road types. The Figures show that some types of road, notably arterial roads, are associated with higher emissions for a given average speed than others. Figure C-2 shows how emissions (again, per vehicle-km) of different pollutants from petrol cars will decrease in the future as emission-control technology improves. PM emissions from petrol vehicles are projected to be dominated by

[3] 'Average speed' should not be confused with 'constant speed'. The former is calculated for a driving cycle which includes periods of acceleration, deceleration, cruise, and idle, as encountered in real-world traffic.

non-exhaust particles. Because these are unregulated the reduction in emissions in the future will be lower than for the other pollutants.

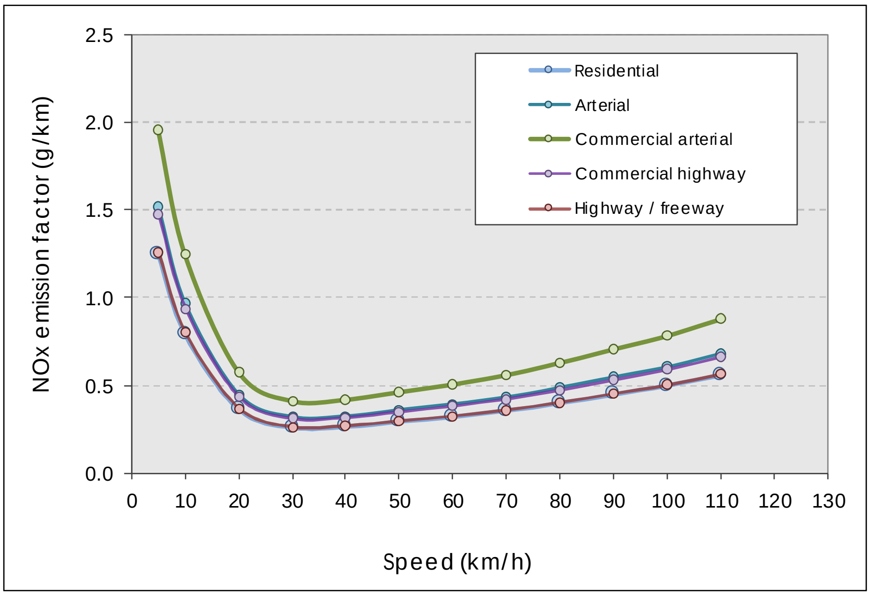

Figure C-1 NO_X emission factors for petrol cars in 2014

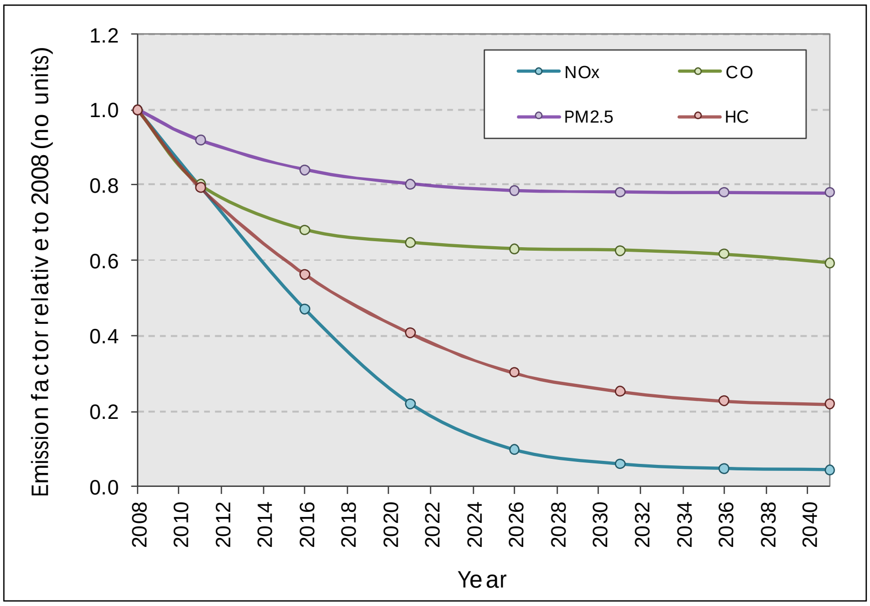

Figure C-2 Emission factors for petrol cars at 80 kilometres per hour, normalised to 2008

C.2.2 Gradient factors

NSW EPA has not developed any factors to allow for the effects of road gradient on hot running emissions. For this assessment, gradient factors were determined using the emission rates in PIARC (2012). For each gradient and speed, the gradient correction factor was determined by dividing the corresponding PIARC emission rate by the emission rate for zero gradient.

The gradient correction is introduced as follows:

Equation C2

$$EF_{HotGradCor} = EF_{HotSpd} \times G$$

Where:

$EF_{HotGradCor}$ is the composite emission factor (in g/km), corrected for road gradient

G is the road gradient correction factor. Different values of **G** are used for each pollutant, vehicle type and speed.

No gradient corrections were applied to THC (any vehicles) or to PM emissions from petrol vehicles.

C.2.3 Cold-start emissions

The method for calculating cold-start emissions involves the application of adjustments to the base hot emission factors to represent the extra emissions which occur during 'cold running'. The adjustments take into account the distance driven from the start of a trip, the parking duration and the ambient temperature. Cold-start emissions are only calculated for light-duty vehicles, and no cold-start adjustment is made for PM. The amount of 'cold running' is dependent on the road type, and no cold running is assumed for highways.

Cold-start emissions are therefore calculated as follows:

Equation C3

$$EF_{Cold} = EF_{HotBasSpd} \times (CS-1)$$

Where:

EF_{Cold} is the cold-start emission factor (in g/km)

CS is a cold start adjustment factor (>1). Different values of **CS** are used for each pollutant, vehicle type, road type and year.

C.2.4 Non-exhaust PM emissions

The method for non-exhaust PM_{10} and $PM_{2.5}$ emissions was taken from the EMEP/EEA Air Pollutant Emission Inventory Guidebook (EEA, 2016), and included tyre wear, brake wear and road surface wear. Emission factors (in g/km) were provided for each vehicle type, road type and year. Information was required for parameters such as vehicle load and number of axles, and the assumptions used for vehicles in the NSW GMR are described in NSW EPA (2012b).

C.2.5 Evaporative emissions

Evaporative emissions of VOCs are not included in the version of the NSW EPA model described here, although they are included in the more detailed full inventory model. The calculation of evaporative emissions is relatively complex, as it requires an understanding of temperature profiles, fuel vapour pressure, fuel composition, and operational patterns. Moreover, it is difficult to allocate evaporative emissions to traffic activity on specific road links, as running losses are only one component (for example, evaporative emissions also occur when vehicles are stationary). For these reasons evaporative emissions have been excluded from the assessment. Ambient concentrations of VOCs are also very low, and the inclusion of evaporative emissions would be unlikely to result in adverse impacts on air quality.

C.3 Fleet data

In order to combine the emission factors in the models with traffic data, information was also required on the following:

- The fuel split (petrol/diesel) for cars. This was assumed to be the same for all road types.

- The fuel split (petrol/diesel) for LCVs. This was also assumed to be the same for all road types.
- The sub-division of HDVs into rigid HGVs, articulated HGVs and buses. This was dependent on road type. For example, the proportion of HGVs on major roads is typically higher than that on minor roads.

The fuel splits were originally provided by NSW EPA for the road types included in the emission model. More recently, Roads and Maritime has provided a revised fleet model to support the calculation of in-tunnel emissions (O'Kelly, 2016). The fuel splits for cars and LCVs from the Roads and Maritime work were used by Pacific Environment to update the fleet data provided by NSW EPA. Figure C-3 and Figure C-4 compare the projections - shown as the percentage of diesel vehicles in the fleet - for cars and LCVs respectively. For cars, in the years between around 2012 and 2027 the percentage of diesel vehicles estimated by Roads and Maritime is very similar to that estimated by NSW EPA. Between 2027 and 2037 the projections diverge, with the diesel percentage in the Roads and Maritime fleet model being higher than that in the NSW EPA fleet model. In the case of LCVs, the Roads and Maritime fleet model has a consistently larger percentage of diesel vehicles than the NSW EPA model between 2012 and 2037. The difference also increases with time, from around 10 percentage points in 2012 to around 30 percentage points in 2037.

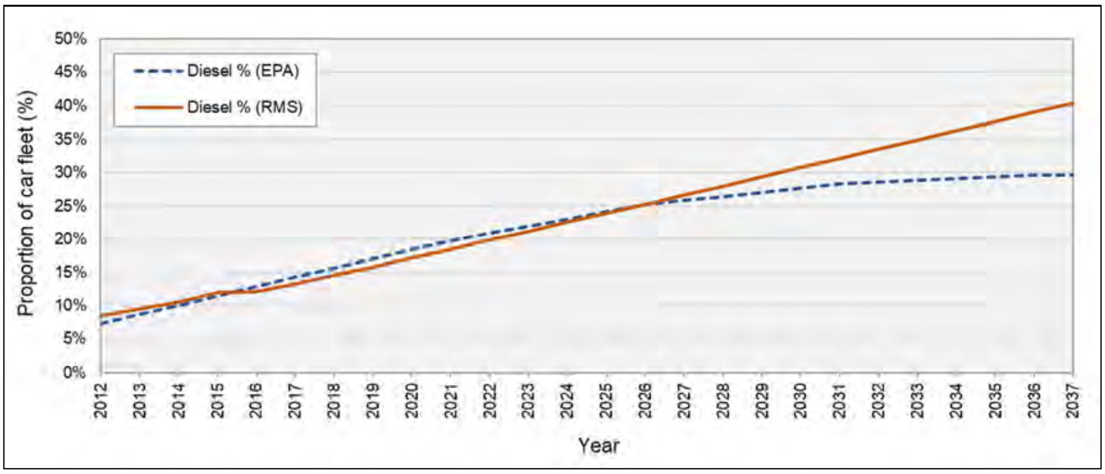

Figure C-3 **Fuel split for cars: original NSW EPA data and Roads and Maritime data**

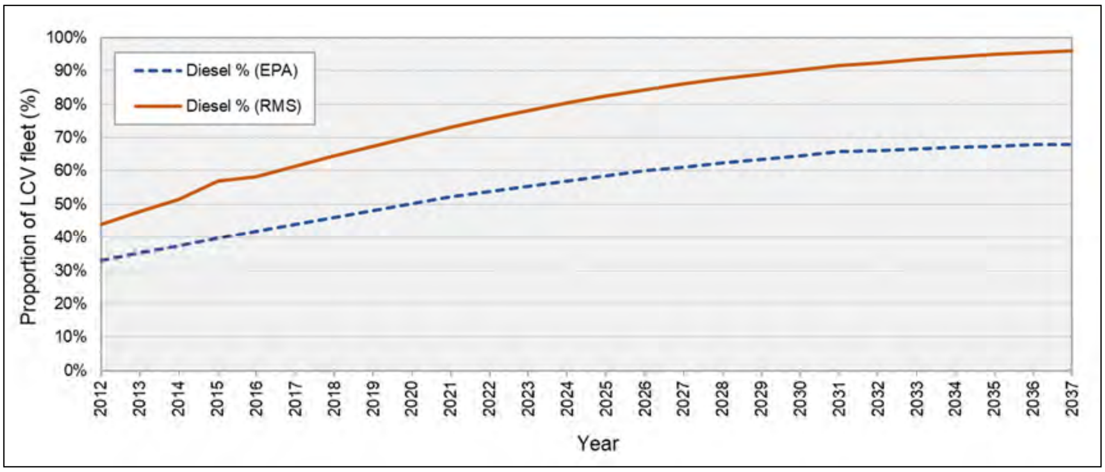

Figure C-4 **Fuel split for LCVs: original NSW EPA data and Roads and Maritime data**

The Roads and Maritime fleet model did not differentiate between different types of road. For the sub-division of HDVs the default traffic mix information provided by NSW EPA was therefore used. The sub-division of HDVs into rigid HGVs, articulated HGVs and buses is shown in Figure C-5.

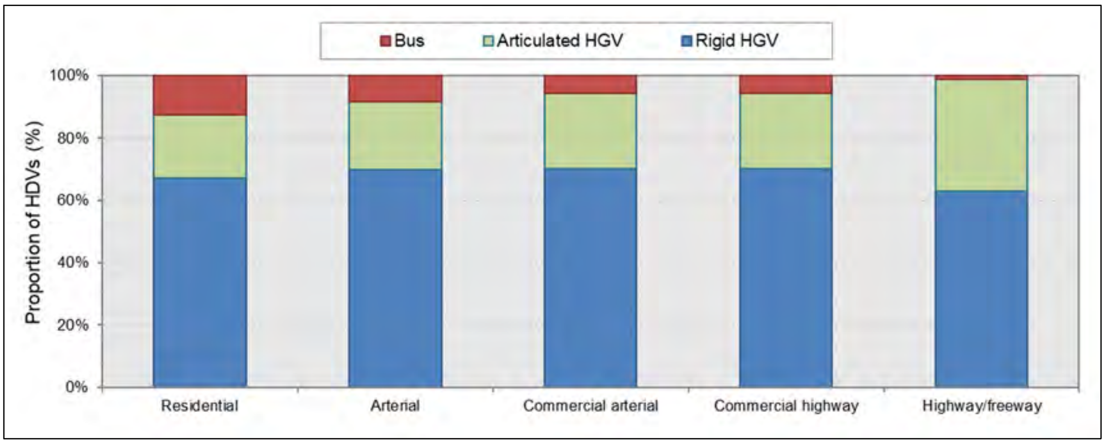

Figure C-5 Vehicle type split by road type for HDVs (year = 2027)

C.4 Model validation

C.4.1 Overall model performance

The accuracy of the NSW EPA model[4] in representing vehicle emissions (CO, NO_X, NO_2, PM_{10} and $PM_{2.5}$) was investigated using measurements from the ventilation outlets of the Lane Cove Tunnel during October and November 2013, as described by Boulter and Manansala (2014). The ventilation conditions in the tunnel result in all vehicle emissions being released from the ventilation outlets. No pollution is released from the tunnel portals. This makes it possible to compare the predicted mass emission rate (in g/h) for the traffic in each direction of the tunnel with the observed emission rate in the corresponding ventilation outlet. The measurement equipment is shown in Figure C-6. Laboratory-grade instruments compliant with Australian Standards were used for measuring in-stack concentrations, and these are summarised in Table C-2. The air flows in the stacks were measured using pitot tubes; to minimise artefacts, the measurements were taken at a point approximately 2 metres from the stack walls.

Figure C-6 Air pollution measurements at Lane Cove Tunnel outlet

[4] It should be noted that this work excludes the changes to the fuel splits for cars and LCVs following the Roads and Maritime fleet model revision in 2016.

Table C-2 Instruments used for in-stack pollution measurements

Pollutant(s)	Method	Instrument	Range/limit of detection
CO	Non-dispersive infrared (NDIR) gas filter correlation spectroscopy	Ecotech EC9830A	0-200 ppm / 50 ppb
$NO/NO_2/NO_X$	Chemiluminescence detection (CLD)	Ecotech EC9841AS	0-1,000 ppm / 10 ppb
PM_{10}	Tapered Element Oscillating Microbalance (TEOM)	Thermo Scientific TEOM 1400ab	0-5 g/m^3 / 0.06 $\mu g/m^3$
$PM_{2.5}$	TEOM	Thermo Scientific TEOM 1400ab	0-5 g/m^3 / 0.06 $\mu g/m^3$
THC/NMHC	Flame ionisation detector (FID)	Baseline-Mocon Series 9000	1-200 ppm / 60 ppb

The predicted and observed total (i.e. for all traffic) emission rates in the Lane Cove Tunnel were compared using a linear regression approach. The regression plots are shown in Figure C-7. Separate results are shown for each pollutant and each direction in the tunnel; the eastbound tunnel is predominantly uphill, and the westbound tunnel is predominantly downhill. In each graph the dashed red line represents a 1:1 ratio between the predicted and observed emission rates, and the solid lines show the linear regression fits to the data, forced through the origin[5]. The average quotients of the predicted and observed values are given in Table C-3.

Some general patterns were apparent in the results:

- On average, the model **overestimated** emissions of each pollutant in the tunnel, and by a factor of between 1.7 and 3.3.

  This overestimation is likely to be due, at least in part, to the following:

  - The over-prediction built into the PIARC gradient factors, as well as other conservative assumptions.
  - The tunnel environment itself affecting emissions. The piston effect and any forced ventilation in the direction of the traffic flow may combine to produce an effective tail wind that reduces aerodynamic drag on the vehicles in the tunnel (John et al., 1999; Corsmeier et al., 2005).
  - A possible overestimation of the age of the vehicle fleet in the tunnel.

  However, the differences between the predicted and observed emission rates are influenced not only by errors in the emission factors in the model, but also errors in the assumptions concerning the fleet composition and age distribution.

- There was a strong correlation between the predicted and observed emission rates for CO, NO_x, PM_{10} and $PM_{2.5}$, with an R^2 value of between 0.75 and 0.88. The strong correlations were due in large part to the narrow range of operational conditions (*i.e.* traffic composition, speed) in the Lane Cove Tunnel. In fact, the modelled emission rates were more or less directly proportional to the traffic volume.
- Different regression slopes were obtained for the eastbound and westbound directions. The eastbound tunnel has a net uphill gradient which would increase engine load and emissions, whereas in the downhill westbound tunnel engines would tend to be under lower load, with some newer vehicles with electronic fuel injection possibly having very low fuelling on downgrades. Such effects may not be adequately reflected in the gradient adjustment approach in the model.

[5] As the outlet emission rates were adjusted for the background contribution, and there were no other in-tunnel emission sources, it was considered acceptable to run the regression model with the constant constrained to zero.

- In the westbound tunnel the NO_2 data had more scatter than the NO_X data, and a low correlation coefficient was obtained. This is in part due to the relatively low emissions in the westbound tunnel and is possibly also a consequence of the measurement technique (chemiluminescence), which does not generally respond well to NO_2 concentrations which fluctuate rapidly on short timescales. The NO_X measurements are less affected by this problem, and ought to be more reliable.

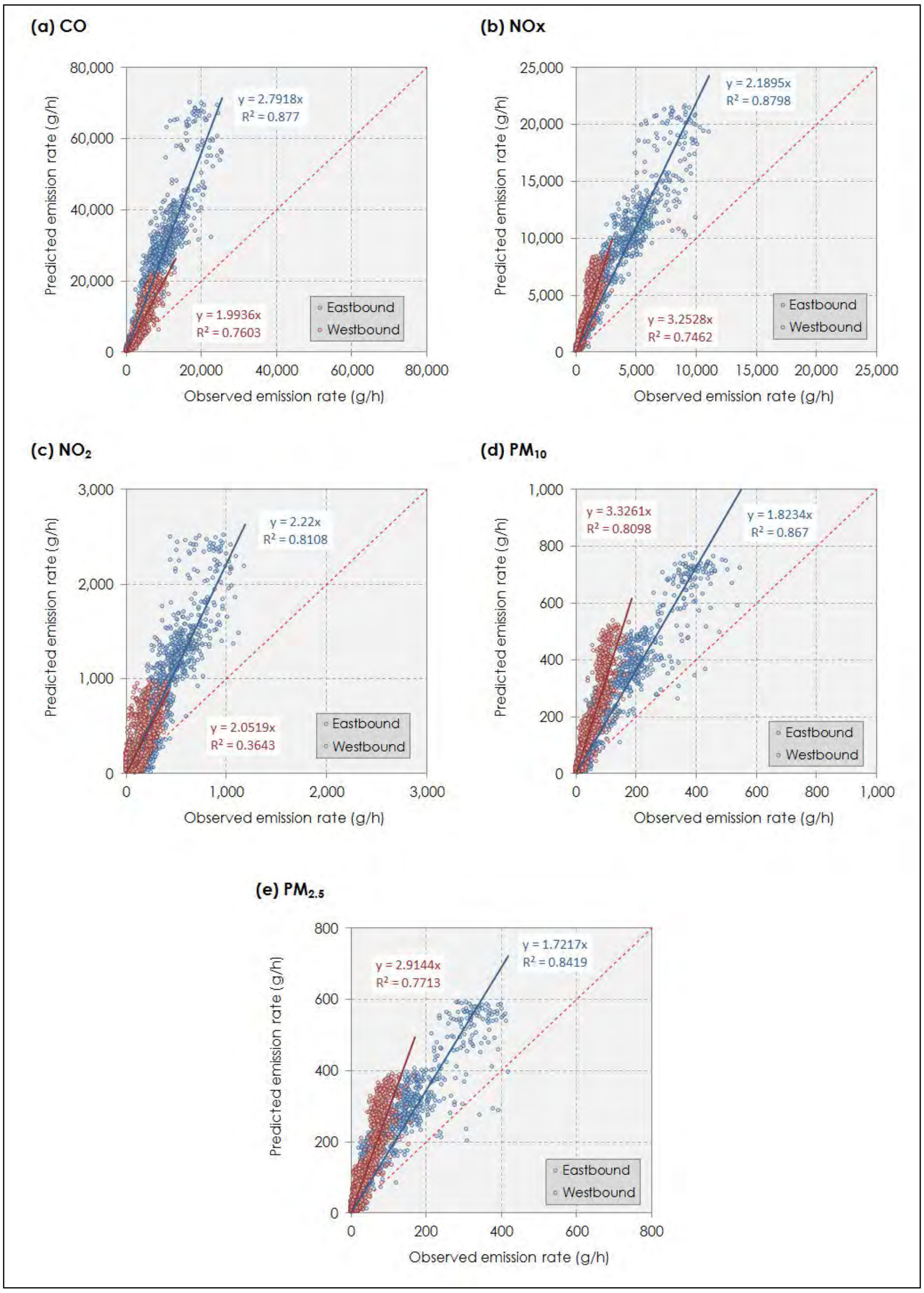

Figure C-7 Predicted vs observed emission rates – NSW EPA model

Table C-3 Summary of predicted vs observed emission rates – NSW EPA model

Model	Predicted emission rate / observed emission rate				
	CO	NO_X	NO_2	PM_{10}	$PM_{2.5}$
Eastbound					
NSW EPA	2.79	2.19	2.22	1.82	1.72
Westbound					
NSW EPA	1.99	3.25	2.06	3.32	2.91

C.4.2 Emission factors by vehicle type

A multiple linear regression (MLR) approach was used to determine mean emission factors (in g/km) for LDVs and HDVs based on the adjusted outlet emission rates (CO, NO_X, PM_{10} and $PM_{2.5}$). Multiple linear regression can be used to test how well a dependent variable can be predicted on the basis of multiple independent variables. The inputs to the MLR were the hourly mean emission factor for the traffic (dependent variable) and the corresponding numbers of LDVs and HDVs in the tunnel each hour (independent variables). A similar MLR method has been used in various studies to derive emission factors (e.g. Imhof et al., 2005; Colberg et al., 2005). The following regression model was applied to derive the emission factors:

Equation C4

$$\mathbf{EF_{total} = (N_{LDV} \times EF_{LDV}) + (N_{HDV} \times EF_{HDV}) + c}$$

where:

$\mathbf{EF_{total}}$ = the hourly mean emission factor for all traffic in the tunnel, as determined from the tunnel ventilation outlet measurements (g/km/h)

$\mathbf{N_{LDV}}$ = the number of LDVs in the tunnel per hour (vehicles/hour)

$\mathbf{N_{HDV}}$ = the number of HDVs in the tunnel per hour (vehicles/hour)

$\mathbf{EF_{LDV}}$ = the emission factor per LDV in the tunnel (g/vehicle.km)

$\mathbf{EF_{HDV}}$ = the emission factor per HDV in the tunnel (g/vehicle.km)

c = a constant (intercept on y-axis)

The hourly mean emission factor for all traffic in the tunnel was obtained by dividing the emission rate by the length of the main line tunnel (3.61 km), with the on- and off-ramps being ignored. The emissions on the ramps were negligible (less than around 2 per cent) compared with the emissions on the main lines. As the outlet emission rates had already been adjusted to allow for the background contribution, and as there were no other in-tunnel emission sources it was considered acceptable to run the regression model with the constant constrained to zero.

The overall mean observed and predicted emission factors for LDVs, HDVs and all traffic (weighted for traffic volume) are shown in Table C-4, and the predicted/observed ratios are given in Table C-5.

It has already been observed that the NSW EPA model overestimated emissions in the Lane Cove Tunnel. It was noted by Boulter and Manansala (2014) that this is due in large part to the use of conservative gradient scaling factors. These additional results show that:

- For LDVs the predicted emissions were higher than the observed emissions in both the eastbound and westbound tunnels.
- For HDVs, emissions of CO, NO_X, PM_{10} and $PM_{2.5}$ in the eastbound tunnel were underestimated by the model, whereas emissions of NO_2 were overestimated. In the westbound tunnel the predicted emissions were considerably higher than the observed emissions, especially for NO_2.

Table C-4 Emission factors by vehicle type and direction

Direction	Pollutant	LDV (g/vehicle.km)		HDV (g/vehicle.km)		All traffic (g/vehicle.km)[a]	
		Observed	NSW EPA	Observed	NSW EPA	Observed	NSW EPA
Eastbound	CO	1.47	4.61	3.66	1.09	1.62	4.48
	NO_X	0.29	1.18	8.42	6.93	0.61	1.39
	NO_2	0.06	0.14	0.37	0.85	0.08	0.16
	PM_{10}	0.01	0.04	0.36	0.31	0.03	0.05
	$PM_{2.5}$	0.01	0.03	0.32	0.27	0.02	0.04
Westbound	CO	0.72[b]	1.53	-[c]	0.48	0.78	1.49
	NO_X	0.13	0.51	1.07	2.78	0.18	0.60
	NO_2	0.03	0.06	0.03	0.34	0.03	0.07
	PM_{10}	0.01	0.03	0.08	0.21	0.01	0.04
	$PM_{2.5}$	0.01	0.02	0.07	0.17	0.01	0.03

(a) Weighted for traffic volume.
(b) Based on regression for LDV only (see point (c) below).
(c) Multiple regression analysis did not result in a valid emission rate.

Table C-5 Predicted/observed emission factors by vehicle type and direction

Direction	Pollutant	LDV (predicted/observed)	HDV (predicted/observed)	All traffic (predicted/observed)[a]
Eastbound	CO	3.1	0.3	2.8
	NO_X	4.0	0.8	2.3
	NO_2	2.4	2.3	2.1
	PM_{10}	3.0	0.9	1.9
	$PM_{2.5}$	3.2	0.8	1.9
Westbound	CO	N/A	N/A	1.9
	NO_X	3.8	2.6	3.2
	NO_2	2.2	11.6	2.2
	PM_{10}	3.9	2.7	3.3
	$PM_{2.5}$	3.3	2.6	2.9

(a) Weighted for traffic volume.

Annexure D - Existing air quality and background concentrations

Annexure D- Existing air quality and background concentrations

D.1 Introduction and objectives

This Annexure provides the results of a thorough analysis of the air quality monitoring data from multiple monitoring stations in a large area of Sydney and in the F6 Extension model domain.

The data were used for the following purposes:

(A) To define long-term trends and patterns in air quality in Sydney.

(B) To define background concentrations[1] in the 2016 base year. Only monitoring stations with data for 2016 (partially or in full) were used to derive background concentrations.

(C) To describe the project-specific air quality monitoring for the F6 Extension.

(D) To develop empirical methods for converting modelled NO_X to NO_2, and maximum 1-hour CO to maximum 8-hour CO. These were based on all available data for all stations.

(E) To evaluate model performance. This involved a comparison of model predictions with roadside measurements for the 2016 base year.

This Annexure focusses on items (A), (B) and (C). Items (D) and (E) are presented in Annexures E and H, respectively. However, all the stations used in the analysis are identified here.

D.2 Monitoring stations

The siting and classification of air quality monitoring stations is governed, as far as practicable, by the requirements of *Australian Standard AS/NZS 3580.1.1:2007 - Methods for sampling and analysis of ambient air - Guide to siting air monitoring equipment*. The Standard recognises that air quality is monitored for different purposes, and for convenience it classifies monitoring stations as follows based on functional requirements:

- Peak stations. These are located where the highest concentrations and exposures are expected to occur (such as near busy roads or industrial sources).
- Neighbourhood stations. These are located in areas which have a broadly uniform land use and activity (e.g. residential areas or commercial zones).
- Background stations. These stations are located in urban or rural areas to provide information on air quality away from specific sources of pollution such as major roads or industry.

The Standard also recognises that, in practice, a given station may serve more than one function.

Considerations when siting a monitoring station include the possibility of restricted airflow caused by vicinity to buildings, trees, walls, *etc.*, and chemical interference due to, for example, local industrial emissions.

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[1] When predicting the impact of any new or modified source of air pollution, it is necessary to take into account the ways in which the emissions from the source will interact with existing pollutant levels. Defining these existing levels and the interactions can be challenging, especially in a large urban area such as Sydney where there is a complex mix of sources. Pollutant concentrations can fluctuate a great deal on short time scales, and substantial concentration gradients can occur in the vicinity of sources such as busy roads. Meteorological conditions and local topography are also very important; cold nights and clear skies can create temperature inversions which trap air pollution near ground level, and local topography can increase the frequency and strength of these inversions. In the case of particulate matter, dust storms, natural bush fires and planned burning activities are often associated with the highest concentrations (SEC, 2011).

Air pollutants and meteorological parameters – such as temperature, wind speed and wind direction – are usually measured automatically and continuously, and such monitoring is conducted at several locations across Sydney.

All the monitoring stations used in the air quality assessment, in one way or another, are listed in Table D-1, and the application of each station is identified. For the purpose of the analysis the air quality monitoring data were separated according to station type. The locations of the background stations within around 10-15 kilometres of the modelling domain for GRAL are shown in Figure D-1. The corresponding map for the roadside and near-road stations is provided in Figure D-2. Several of the stations listed in Table D-1 were further away from the GRAL domain, and are not shown in the Figures, but were still included in some aspects of the assessment (e.g. trend analysis, NO_X-to-NO_2 conversion).

Until relatively recently, almost all of the air quality monitoring in Sydney has focussed on background locations within urban agglomerations but away from specific sources such as major roads. The monitoring stations in Sydney that are operated by OEH are located in such environments, and these have provided a long and vital record of regional air quality. The only OEH monitoring station within the GRAL domain was that at Earlwood. The OEH stations at Chullora, Randwick and Rozelle were several kilometres from the domain boundary.

Roads and Maritime Services has established several long-term monitoring stations in response to community concerns relating to the ventilation outlet of the M5 East Tunnel, and to monitor operational compliance of the tunnel with ambient air quality standards. Four of the M5 East stations (CBMS, T1, U1, X1) are in the vicinity of the M5 East ventilation outlet. Stations U1 and X1 are located on a ridge to the north of the outlet, in the region of the predicted maximum impact. However, the impacts of the outlet at the monitoring stations are very small in practice, and these could effectively be considered as urban background stations. Two M5 East stations (F1 and M1) are much closer to busy roads near the M5 East tunnel portals.

Consideration was also given to shorter time series data from other Roads and Maritime air quality monitoring stations. Several monitoring stations were established for the NorthConnex project (the stations are identified in AECOM, 2014a), with data being available from December 2013 to January 2015. Data were also available from an additional Roads and Maritime roadside station (‘Aristocrat’), located near the junction of Epping Road and Longueville Road. The Aristocrat station was only operational between 2008 and 2009, but given the low number of roadside monitoring stations in Sydney until recently, the data were still considered to be valuable to the analysis. Three monitoring stations were established for the Western Harbour Tunnel and Beaches Link projects by Roads and Maritime in 2017. One of these was at a background location, and the other two were at locations near busy roads.

Sydney Motorway Corporation (SMC) has established a WestConnex monitoring network to address some of the gaps in the OEH and Roads and Maritime monitoring in terms of pollutants and locations, and SMC has engaged Pacific Environment to operate and maintain the network. The WestConnex network includes monitoring stations at both urban background and near-road stations. Five new monitoring stations were introduced in the M4 East area, seven new stations in the New M5 area, and two new stations in the M4-M5 Link area to support the development and assessment of the respective projects. Some of the WestConnex monitoring stations were subsequently relocated or decommissioned.

Two project-specific monitoring stations were established for the F6 Extension by Roads and Maritime in late 2017. One of these was at a background location, and the other at a roadside location. Given the date of deployment, the time period covered was too short for these to be included in the development of background concentrations and model evaluation. However, the data from the stations are presented in this Annexure.

Table D-1 Air quality monitoring stations

Organisation	Project	Station name	Location	Station type	Easting	Northing	Period covered in analysis	Application					
								Air quality trends	Background concentrations	Project monitoring	NO_X to NO_2 conversion	CO 1h to 8h conversion	Model performance
OEH	N/A	Chullora	Southern Sydney TAFE - Worth St	Urban background	319315	6248145	Jan 2004 to Dec 2016	✓	✓	-	✓	✓	-
		Earlwood	Beaman Park	Urban background	327663	6245576	Jan 2004 to Dec 2016	✓	✓	✓[b]	✓	-	-
		Lindfield	Bradfield Road	Urban background	328802	6260577	Jan 2004 to Dec 2016	✓	✓	-	✓	-	-
		Liverpool	Rose Street	Urban background	306573	6243485	Jan 2004 to Dec 2016	✓	✓	-	✓	✓	-
		Macquarie Park	Macquarie University Sport Fields	Urban background	325695	6262277	Oct 2017 to Nov 2017	-	-	-	✓	-	-
		Prospect	William Lawson Park	Urban background	306901	6258703	Jan 2004 to Dec 2016	✓	✓	-	✓	✓	-
		Randwick	Randwick Barracks	Urban background	337588	6244021	Jan 2004 to Dec 2016	✓	✓	✓[b]	✓	-	-
		Rozelle	Rozelle Hospital	Urban background	330169	6251372	Jan 2004 to Dec 2016	✓	✓	-	✓	✓	-
RMS	Lane Cove Tunnel	Aristocrat	Longueville road / Epping Road	Peak (roadside)	330661	6257118	Oct 2008 to Nov 2009	-	-	-	✓	✓	-
	M5 East Tunnel	M5E: CBMS	Gipps Street, Bardwell Valley	Urban background	327713	6243517	Jan 2008 to Dec 2016	✓	-	-	✓	✓	-
		M5E: T1	Thompson Street, Turrella	Urban background	328820	6244172	Jan 2008 to Dec 2016	✓	-	-	✓	✓	-
		M5E: U1	Jackson Place, Earlwood	Urban background	328277	6244422	Jan 2008 to Dec 2016	✓	-	-	✓	✓	-
		M5E: X1	Wavell Parade, Earlwood	Urban background	327923	6244507	Jan 2008 to Dec 2016	✓	-	-	✓	✓	-
		M5E: F1	Flat Rock Rd, Kingsgrove (M5 East)	Peak (roadside)	325204	6243339	Jan 2008 to Dec 2016	-	-	-	✓	✓	-
		M5E: M1	M5 East tunnel portal	Peak (roadside)	329258	6243283	Jan 2008 to Dec 2016	-	-	-	✓	✓	✓
	NorthConnex	NC:01	Headen Sports Park	Urban background	322016	6266696	Dec 2013 to Jan 2015	-	-	-	✓	✓	-
		NC:02	Rainbow Farm Reserve	Urban background	318901	6262641	Dec 2013 to Jan 2015	-	-	-	✓	✓	-
		NC:03	James Park	Urban background	325165	6269440	Dec 2013 to Jan 2015	-	-	-	✓	✓	-
		NC:04	Observatory Park	Peak (roadside)	320643	6264950	Dec 2013 to Jan 2015	-	-	-	✓	✓	-
		NC:05	Brickpit Park	Peak (roadside)	323027	6266847	Dec 2013 to Jan 2015	-	-	-	✓	✓	-
	WHTBL	WHTBL:01	Reserve Street, Bantry Bay	Urban background	337216	6260688	Oct 2017 to Nov 2017	-	-	-	✓	-	-
		WHTBL:02	Hope Street, Seaforth	Peak (near-road)[a]	338307	6259481	Oct 2017 to Nov 2017	-	-	-	✓	-	-
		WHTBL:03	Rhodes Avenue, Naremburn	Peak (near-road)[a]	333652	6256571	Oct 2017 to Nov 2017	-	-	-	✓	-	-
	F6 Extension	F6:01	Kings Road, Rockdale	Urban background	328954	6240641	Dec 2017 to Jun 2018	-	-	✓	✓	-	-
		F6:02	Tancred Avenue, Kyeemagh	Peak (roadside)	330321	6241909	Dec 2017 to Jun 2018	-	-	✓	✓	-	-
SMC	WestConnex M4 East	M4E:01	Wattle Street, Haberfield	Peak (roadside)	327563	6250234	Aug 2014 to Mar 2016	-	-	-	✓	✓	-
		M4E:02	Edward Street, Concord	Peak (near-road)[a]	323764	6251146	Sep 2014 to Mar 2016	-	-	-	✓	✓	-
		M4E:03	Bill Boyce Reserve, Homebush	Peak (near-road)[a]	322467	6251602	Sep 2014 to Mar 2016	-	-	-	✓	✓	-
		M4E:04	Concord Oval, Concord	Peak (roadside)	325030	6250752	Nov 2014 to Dec 2016	-	-	-	✓	✓	-
		M4E:05	St Lukes Park, Concord	Urban background	325187	6251158	Nov 2014 to Dec 2016	-	✓	-	✓	✓	-
	WestConnex New M5	New M5:01	St Peters Public School, Church St	Urban Background	331330	6246007	Aug 2015 to Dec 2016	-	✓	✓[b]	✓	✓	-
		New M5:02	Princes Highway, St Peters	Peak (roadside)	331661	6246053	Jul 2015 to Apr 2016	-	-	-	✓	-	✓
		New M5:03	West Botany St, Arncliffe	Peak (roadside)	329182	6243268	Aug 2015 to Jun 2016	-	-	-	✓	-	✓
		New M5:04	Bestic St, Rockdale	Urban Background	329175	6241749	Jul 2015 to Sep 2016	-	✓	-	✓	-	-
		New M5:05	Bexley Rd, Kingsgrove	Peak (roadside)	325359	6243491	Jul 2015 to Apr 2016	-	-	-	✓	-	-
		New M5:06	Beverly Hills Park, Beverly Hills	Urban Background	323296	6242297	Jul 2015 to Sep 2016	-	✓	-	✓	-	-
		New M5:07	Canal Rd, St Peters	Peak (road/industrial)	331520	6245420	Jul 2015 to Apr 2016	-	-	-	✓	-	✓
	WestConnex M4-M5 Link	M4-M5:01	City West Link, Rozelle	Peak (roadside)	331142	6250768	Apr 2016 to Dec 2016	-	-	-	✓	-	-
		M4-M5:02	Ramsay Street, Haberfield	Peak (roadside)	327363	6250306	Apr 2016 to Dec 2016	-	-	-	✓	-	-

(a) Due to practical constraints at this location, the monitoring station is some distance from the closest major road (M4 motorway). Nevertheless, the monitoring station should adequately characterise exposure to air pollution at nearby properties.

(b) For comparison against F6 Extension monitoring data.

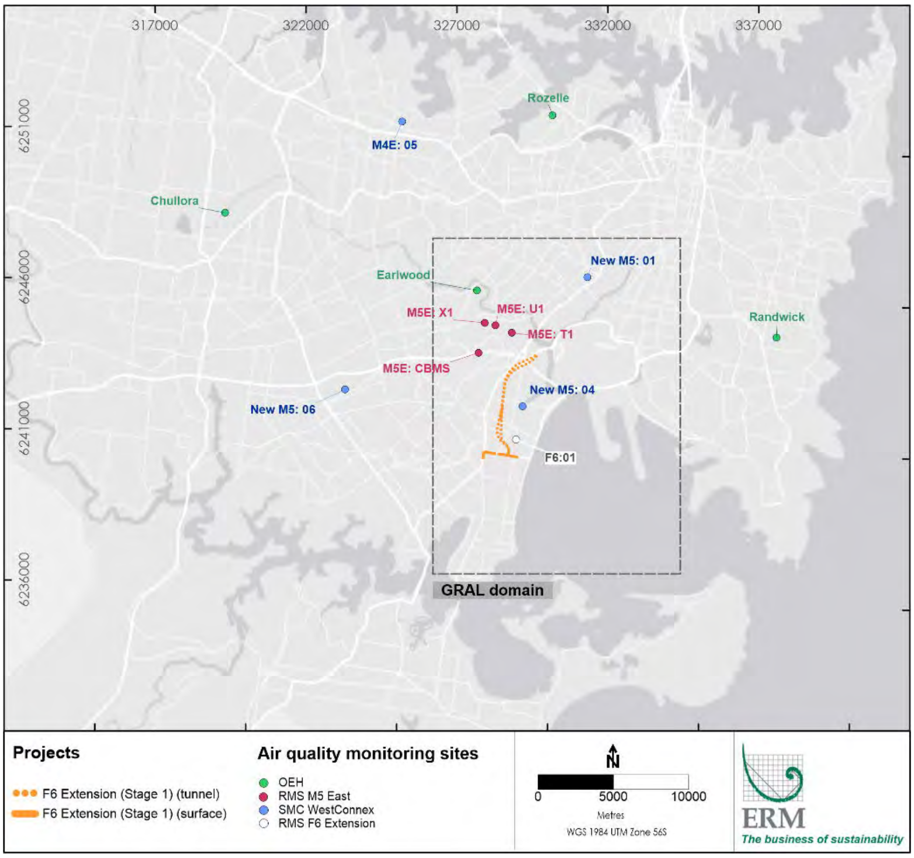

Figure D-1 Locations of background air quality monitoring stations

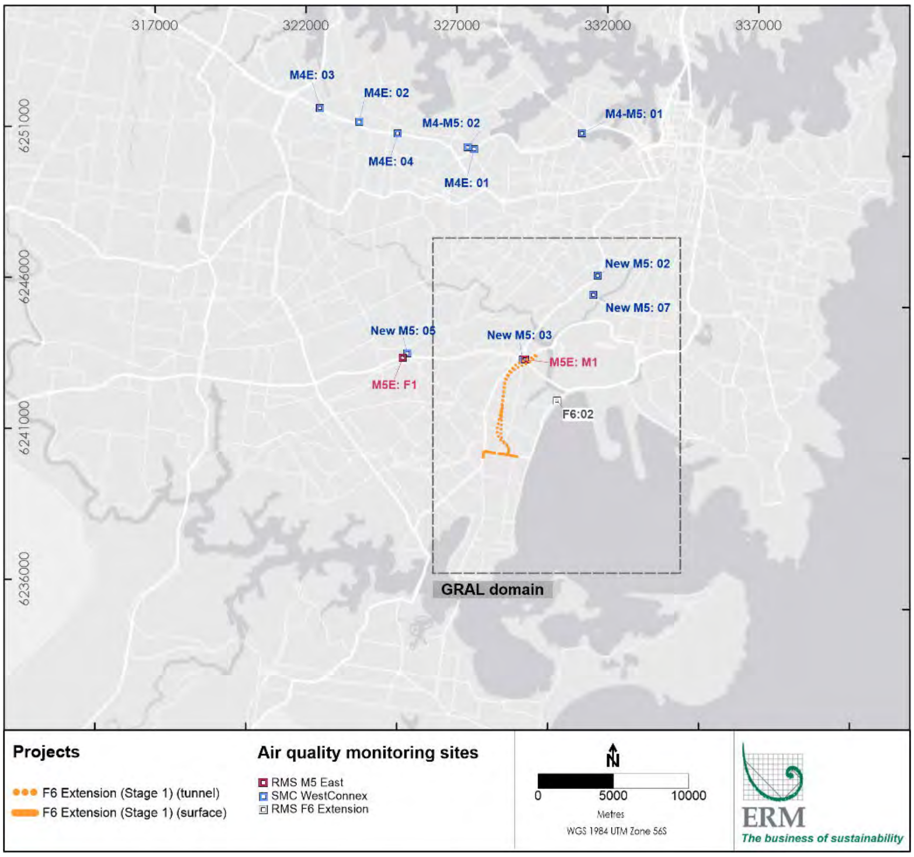

Figure D-2 Locations of road air quality monitoring stations

D.3 Measured parameters and methods

The parameters measured at each station are given in Table D-2. The coverage of pollutants was variable. NO, NO_2 and NO_X were measured at all stations, and CO was measured at most stations. Ozone was not measured at the Roads and Maritime M5 East and Aristocrat stations. PM_{10} was measured at all stations except Aristocrat. $PM_{2.5}$ was measured at fewer stations, and there was only a longer-term record of $PM_{2.5}$ at three OEH stations. Although not shown in Table D-2, hydrocarbons[2] are measured continuously at the SMC and Roads and Maritime WHTBL stations. Hydrocarbons are not measured routinely at the OEH and Roads and Maritime M5 East stations.

Table D-2 Parameters by monitoring station

Monitoring station		Pollutants					Meteorological parameters			
		CO	NO, NO_2, NO_X	O_3	PM_{10} (a)	$PM_{2.5}$ (a)	WS, WD (b)	Temp.	Humidity	Solar radiation
OEH	Chullora	✓	✓	✓	✓†	✓§	✓	✓	✓	✓
	Earlwood	-	✓	✓	✓†	✓§	✓	✓	✓	-
	Lindfield	-	✓	✓	✓†	-	✓	✓	✓	-
	Liverpool	✓	✓	✓	✓†	✓§	✓	✓	✓	✓
	Macquarie Park	✓	✓	✓	✓†	✓‡	✓	✓	✓	✓
	Prospect	✓	✓	✓	✓†	✓‡	✓	✓	✓	✓
	Randwick	-	✓	✓	✓†	-	✓	✓	✓	-
	Rozelle	✓	✓	✓	✓†	✓‡	✓	✓	✓	✓
RMS	Aristocrat	✓	✓	-	-	-	✓	✓	✓	✓
	M5E: CBMS	✓	✓	-	✓†	-	✓	✓	✓	✓
	M5E: T1	✓	✓	-	✓†	-	✓	✓	✓	✓
	M5E: U1	✓	✓	-	✓†	-	✓	✓	✓	✓
	M5E: X1	✓	✓	-	✓†	-	✓	✓	✓	✓
	M5E: F1	✓	✓	-	✓†	-	✓	✓	✓	✓
	M5E: M1	✓	✓	-	✓†	-	✓	✓	✓	✓
	NC:01	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	NC:02	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	NC:03	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	NC:04	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	NC:05	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	WHTBL:01	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	WHTBL:02	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	WHTBL:03	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	F6:01	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	F6:02	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
SMC	M4E:01	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	M4E:02	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	M4E:03	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	M4E:04	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	M4E:05	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	New M5:01	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	New M5:02	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	New M5:03	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	New M5:04	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	New M5:05	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	New M5:06	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	New M5:07	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	M4-M5:01	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓
	M4-M5:02	✓	✓	✓	✓‡	✓‡	✓	✓	✓	✓

(a) † TEOM; ‡ BAM; § TEOM/BAM depending on year

(b) WS = wind speed; WD = wind direction

[2] Total hydrocarbons, methane, and non-methane hydrocarbons.

The pollutant measurements at each station were conducted in accordance with the relevant Australian Standards[3]. The methods used were, in general terms:

- CO - gas filter correlation infrared (GFC-IR)
- $NO/NO_2/NO_X$ - chemiluminescence detection (CLD)
- O_3 - non-dispersive ultra-violet (NDUV) spectroscopy
- $PM_{10}/PM_{2.5}$ - tapered-element oscillating microbalance (TEOM) and/or beta-attenuation monitor (BAM)

In the case of PM, it is well documented that the measurements are sensitive to the technique used. The data used in this analysis were collected using different instruments, and this clearly introduces some uncertainty in the results. For example, TEOMs were used at the Roads and Maritime M5 East stations, whereas BAMs were used at the WestConnex, WHTBL and F6 Extension stations. For the measurement of $PM_{2.5}$ at the OEH stations, TEOMs were used until early 2012. A combination of TEOMs and BAMs were used during 2012, when a decision was made to replace the continuous TEOM $PM_{2.5}$ monitors with the USEPA equivalent-method BAM. However, for traceability, in this assessment all data were used as received.

D.4 Data processing and analysis

The monitoring data were used in the form provided, with the following exceptions:

- For gases, any volumetric concentrations (*e.g.* ppm or ppb) were converted to mass units (*e.g.* mg/m^3 or $\mu g/m^3$). For consistency, an ambient pressure of 1 atmosphere and a temperature of 0^oC were assumed throughout for the conversions. In the NSW Approved Methods, for some pollutants a conversion temperature of 25^oC is used, which gives slightly lower mass concentrations. The use of 0^oC is therefore slightly conservative.

- For PM_{10} and $PM_{2.5}$, the data on days with bush fires and/or dust storms were removed, as the inclusion of the high concentrations that occurred on some of these days could have obscured any underlying trends. The days that were affected by such events were identified by OEH.

All measurements were initially analysed using an averaging period of one-hour. The data were then further averaged, where appropriate, according to the time periods for the criteria in the NSW Approved Methods. Values were only deemed to be valid where the data capture rate was greater than 75 per cent[4] in any given period.

D.5 Long-term trends at background stations

In this part of the analysis the long-term trends in air pollution at background monitoring stations in Sydney were investigated. Only the OEH and Roads and Maritime monitoring stations with a multi-year record were considered (i.e. Chullora, Earlwood, Lindfield, Liverpool, Prospect, Randwick, Rozelle, CBMS, T1, U1 and X1).

The trend analysis was based mainly on measurements conducted during the 13-year period between 1 January 2004 and 31 December 2016, the principal aims being (i) to understand the temporal and spatial patterns in the data and (ii) to establish background pollutant concentrations for use in the project assessment (2016 base year), taking into account factors such as those identified in section F.1.

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[3] Full details of the methods and procedures used at the SMC monitoring stations are presented in monthly monitoring reports for the M4 East network, and these are available on request from SMC.

[4] Clause 18 (5) of the AAQ NEPM specifies that the annual report for a pollutant must include the percentage of data available in the reporting period. An average concentration can be valid only if it is based on at least 75 per cent of the expected samples in the averaging period. The 75 per cent data availability criterion is specified as an absolute minimum requirement for data completeness (PRC, 2001).

This approach was in accordance with the NSW Approved Methods, which states:

> ‘Including background concentrations in the assessment enables the total impact of the proposal to be assessed. The background concentrations of air pollutants are ideally obtained from ambient monitoring data collected at the proposed station. As this is extremely rare, data is typically obtained from a monitoring station as close as possible to the proposed location where the sources of air pollution resemble the existing sources at the proposal station.’ (NSW EPA, 2016)

Trends were determined for the following pollutants and metrics, as these are especially relevant to road transport:

- CO – one-hour mean
- CO – rolling 8-hour mean
- NO_X – annual mean
- NO_X – one-hour mean
- PM_{10} – annual mean
- PM_{10} – 24-hour mean
- $PM_{2.5}$ – annual mean
- $PM_{2.5}$ – 24-hour mean

The Mann–Kendall nonparametric test was used to determine the statistical significance of trends at the 90 per cent confidence level.

Trends in NO_2 and O_3 were also investigated, as these were required for the testing of different NO_X-to-NO_2 conversion methods (see Annexure E).

For air toxics the NSW Approved Methods do not require the consideration of background concentrations. However, some data have been presented to demonstrate that prevailing concentrations in Sydney are very low.

D.5.1 Carbon monoxide

D.5.1.1 Annual mean concentration

In NSW there is no air quality criterion for the annual mean CO concentration, but the trends and patterns are still of interest. The annual mean CO concentrations at the OEH and Roads and Maritime M5 East monitoring stations are shown in Figure D-3, and the corresponding statistics are provided in Table D-3.

At the OEH stations which measured CO (these were all outside the GRAL domain) the annual mean concentrations were rather variable. Concentrations decreased between 2004 and the start of 2008, but then began to increase again during 2008, and continued to do so until around 2010. These changes coincided with a programme of instrument replacement. Between 2010 and 2016 CO concentrations then generally decreased again. A more systematic - and perhaps more representative - downward trend in CO was apparent in the data from the Roads and Maritime M5 East background stations, where there was a net overall decrease of between around 20 and 30 per cent between 2008 and 2016. The Mann-Kendall test showed that there was a significant downward trend in annual mean CO concentration at three stations.

The long-term mean (2008-2016) concentrations at the background stations were between 0.28 and 0.44 mg/m^3. During the same period, the mean CO concentrations at the Roads and Maritime roadside stations F1 and M1 (0.49 and 0.43 mg/m^3 respectively) were not very elevated above the background.

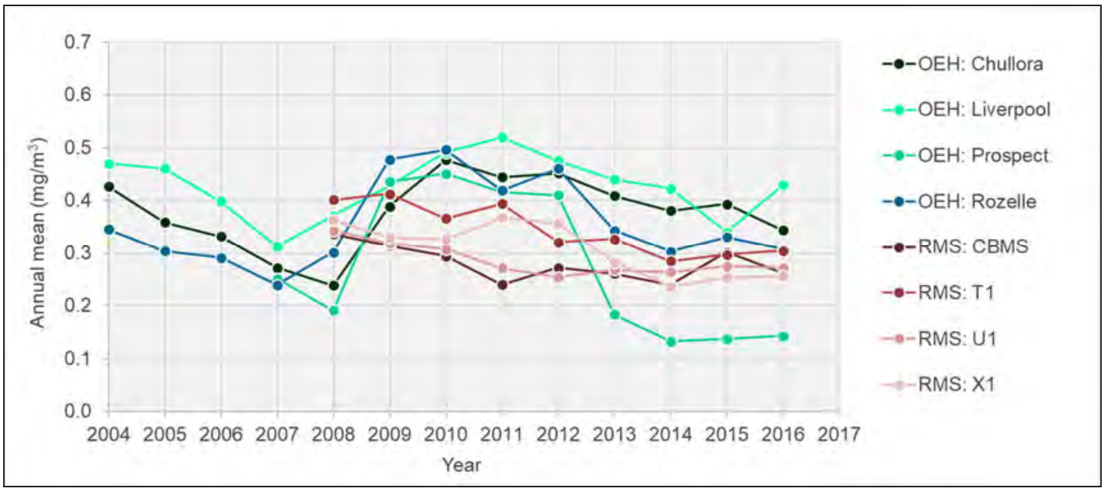

Figure D-3 Trend in annual mean CO concentration

Table D-3 Annual mean CO concentration at OEH and Roads and Maritime background stations

Year	Annual mean concentration (mg/m^3)[(a)]										
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2004	0.43	-	-	0.47	-	-	0.34	-	-	-	-
2005	0.36	-	-	0.46	-	-	0.30	-	-	-	-
2006	0.33	-	-	0.40	-	-	0.29	-	-	-	-
2007	0.27	-	-	0.31	0.25	-	0.24	-	-	-	-
2008	0.24	-	-	0.37	0.19	-	0.30	0.34	0.40	0.34	0.36
2009	0.39	-	-	0.43	0.44	-	0.48	0.31	0.41	0.32	0.33
2010	0.48	-	-	0.49	0.45	-	0.50	0.29	0.37	0.31	0.33
2011	0.44	-	-	0.52	0.42	-	0.42	0.24	0.39	0.27	0.37
2012	0.45	-	-	0.48	0.41	-	0.46	0.27	0.32	0.25	0.36
2013	0.41	-	-	0.44	0.18	-	0.34	0.26	0.33	0.27	0.28
2014	0.38	-	-	0.42	0.13	-	0.30	0.24	0.28	0.26	0.24
2015	0.39	-	-	0.34	0.14	-	0.33	0.30	0.30	0.27	0.25
2016	0.34	-	-	0.43	0.14	-	0.31	0.26	0.30	0.27	0.26
Mean (2008-16)	**0.39**	-	-	**0.44**	**0.28**	-	**0.38**	**0.28**	**0.35**	**0.29**	**0.31**
Mean (2004-16)	**0.38**	-	-	**0.43**	-	-	**0.36**	-	-	-	-
Significance[(b)]	◀▶	-	-	◀▶	▼	-	◀▶	◀▶	▼	◀▶	▼

(a) Only years with >75 per cent complete data shown

(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◀▶ = stable/no trend

D.5.1.2 Maximum one-hour mean concentration

The trends in the maximum one-hour mean CO concentration by year are shown in Figure D-4 and Table D-4. All maximum values were well below the air quality criterion of 30 mg/m^3. The patterns at all background stations were broadly similar, with a general downward trend. The trend was statistically significant at all but one of the stations.

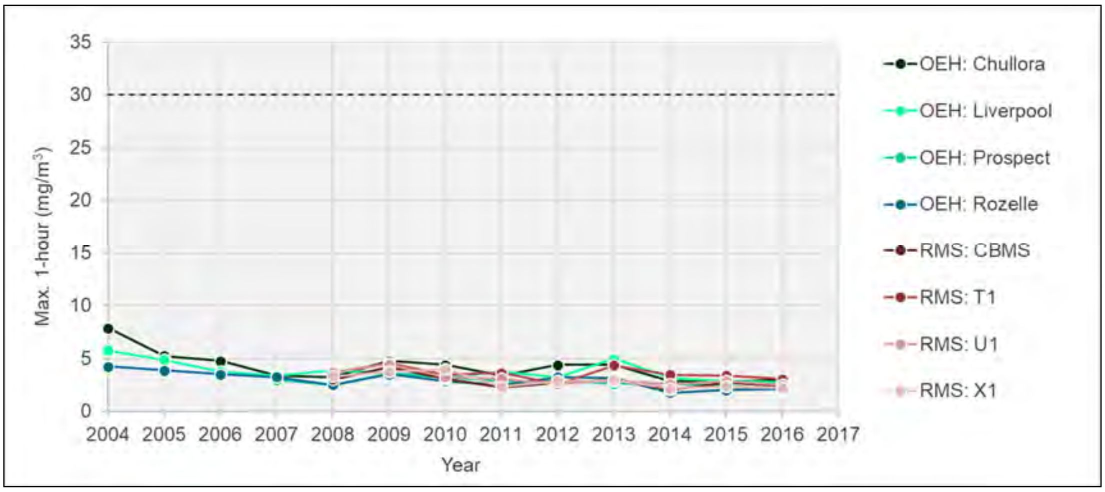

Figure D-4 **Trend in maximum one-hour mean CO concentration**

Table D-4 **Maximum one-hour mean CO at OEH and Roads and Maritime background stations**

Year	Annual mean concentration (mg/m³)(a)										
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2004	7.87	-	-	5.75	-	-	4.25	-	-	-	-
2005	5.25	-	-	4.87	-	-	3.87	-	-	-	-
2006	4.75	-	-	3.75	-	-	3.50	-	-	-	-
2007	3.37	-	-	3.37	3.00	-	3.25	-	-	-	-
2008	3.25	-	-	3.87	2.50	-	2.50	3.03	3.66	3.69	3.30
2009	4.75	-	-	3.62	3.62	-	3.50	4.18	4.55	4.47	3.77
2010	4.37	-	-	3.25	3.25	-	2.87	3.10	3.43	3.24	3.98
2011	3.37	-	-	3.75	2.87	-	2.50	2.29	3.65	3.09	2.33
2012	4.37	-	-	3.25	2.87	-	3.25	2.73	2.57	2.58	2.87
2013	4.37	-	-	5.00	2.62	-	3.12	3.00	4.36	2.89	2.95
2014	2.87	-	-	3.12	2.62	-	1.75	2.06	3.45	2.56	2.15
2015	2.75	-	-	2.87	2.37	-	2.00	2.68	3.37	2.88	2.34
2016	3.00	-	-	2.75	2.00	-	2.12	2.36	3.06	2.52	2.22
Mean (2008-16)	**3.68**	-	-	**3.50**	**2.75**	-	**2.62**	**2.83**	**3.57**	**3.10**	**2.88**
Mean (2004-16)	**4.18**	-	-	**3.79**	-	-	**2.96**	-	-	-	-
Significance(b)	▼	-	-	▼	▼	-	▼	▼	◀▶	▼	▼

(a) Only years with >75 per cent complete data shown
(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◀▶ = stable/no trend

D.5.1.3 Maximum rolling 8-hour mean concentration

The trends in the maximum rolling 8-hour mean CO concentration by year are shown in Figure D-5 and Table D-5. All maximum values were well below the air quality criterion of 10 mg/m³; the long-term averages were between around 2 and 3 mg/m³. For comparison, the long-term mean values at the Roads and Maritime roadside stations (F1 and M1) were 3.3 and 2.4 mg/m³ respectively. The patterns at all background stations were broadly similar; there was a general downward trend that was statistically significant at all but one of the stations. Although there was some spatial variation in CO, it was not systematic, and the between-station variation was small compared with the criterion.

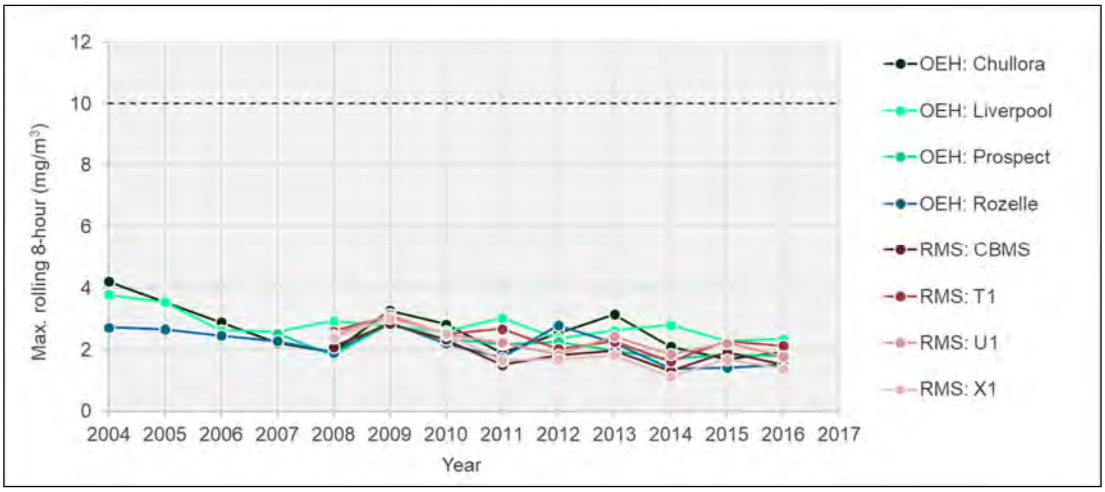

Figure D-5 Trend in maximum rolling 8-hour mean CO concentration

Table D-5 Maximum rolling 8-hour mean CO at OEH and Roads and Maritime background stations

Year	Annual mean concentration (mg/m^3)[(a)]										
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2004	4.22	-	-	3.78	-	-	2.73	-	-	-	-
2005	3.53	-	-	3.54	-	-	2.66	-	-	-	-
2006	2.89	-	-	2.62	-	-	2.46	-	-	-	-
2007	2.22	-	-	2.57	2.52	-	2.28	-	-	-	-
2008	1.93	-	-	2.93	1.82	-	1.91	2.08	2.60	2.46	2.38
2009	3.27	-	-	2.75	2.83	-	2.87	2.84	3.10	3.14	3.01
2010	2.82	-	-	2.59	2.35	-	2.21	2.33	2.51	2.50	2.51
2011	1.89	-	-	3.03	2.18	-	1.73	1.51	2.67	2.23	1.66
2012	2.53	-	-	2.36	2.25	-	2.79	1.81	2.02	1.83	1.68
2013	3.14	-	-	2.62	1.96	-	2.23	1.97	2.27	2.43	1.82
2014	2.11	-	-	2.80	1.68	-	1.37	1.31	1.61	1.84	1.13
2015	1.70	-	-	2027	1.84	-	1.41	1.91	2.27	2.22	1.69
2016	1.93	-	-	2.34	1.80	-	1.50	1.52	2.13	1.79	1.38
Mean (2008-16)	**2.37**	-	-	**2.63**	**2.08**	-	**2.00**	**1.92**	**2.35**	**2.27**	**1.92**
Mean (2004-16)	**2.63**	-	-	**2.78**	-	-	**2.17**	-	-	-	-
Significance[(b)]	▼	-	-	▼	▼	-	▼	◀▶	▼	▼	▼

(a) Only years with >75 per cent complete data shown
(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◀▶ = stable/no trend

D.5.1.4 Exceedances of air quality criteria

Between 2004 and 2016 there were no exceedances of the rolling 8-hour mean criterion for CO of 10 mg/m^3, or the one-hour criterion of 30 mg/m^3, at any of the background stations.

D.6 Nitrogen oxides

D.6.1.1 Annual mean concentration

The annual mean NO_X concentrations at the monitoring stations are shown in Figure D-6, and the corresponding statistics are provided in Table D-6. There are no air quality criteria for NO_X in NSW, but it is important to understand NO_X in order to characterise NO_2 (see Annexure E).

The T1 station had a systematically higher NO_X concentration than the other Roads and Maritime stations, which all had very similar concentrations. Given that all the Roads and Maritime stations are relatively close together, the measurements at the T1 station could have been influenced by a local source. The station is alongside Thompson Street, but the traffic volume is likely to be very low. However, concentrations may have been affected by truck movements at a factory (manufacture of crop protection products) across the road.

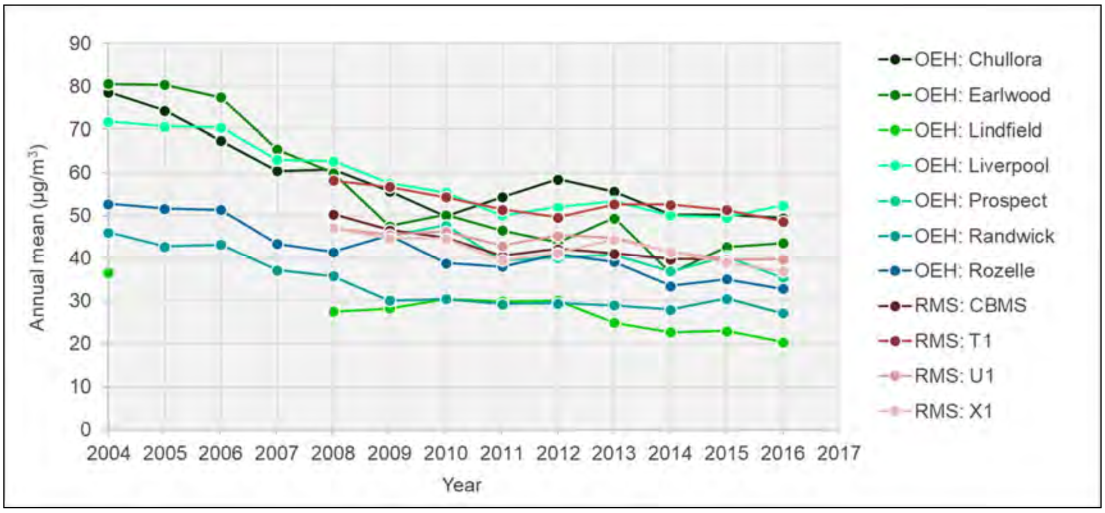

Figure D-6 **Trend in annual mean NO_X concentration**

Table D-6 **Annual mean NO_X concentration at OEH and Roads and Maritime background stations**

Year	Annual mean concentration (µg/m³)(a)										
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2004	78.7	80.6	36.6	71.8	-	46.0	52.7	-	-	-	-
2005	74.4	80.5	-	70.7	-	42.7	51.7	-	-	-	-
2006	67.5	77.5	-	70.5	-	43.2	51.3	-	-	-	-
2007	60.4	65.5	-	63.0	-	37.2	43.4	-	-	-	-
2008	60.7	60.0	27.5	62.7	-	35.8	41.5	50.3	58.2	47.0	47.1
2009	55.7	47.5	28.2	57.5	45.1	30.1	45.4	46.7	56.7	45.5	44.6
2010	49.7	50.2	30.4	55.4	47.7	30.4	38.9	44.8	54.3	46.2	44.6
2011	54.3	46.5	29.9	50.0	39.5	29.2	38.0	40.5	51.5	42.9	39.4
2012	58.5	43.8	30.0	52.0	40.1	29.4	40.9	42.2	49.6	45.3	41.3
2013	55.6	49.4	24.8	53.3	40.8	28.9	39.1	41.0	52.7	44.8	44.4
2014	50.2	36.5	22.6	50.1	36.9	27.9	33.5	39.8	52.5	41.4	41.4
2015	50.1	42.6	22.9	49.6	40.5	30.6	35.1	39.9	51.3	39.7	38.9
2016	49.4	43.6	20.4	52.4	35.5	27.1	32.8	-	48.7	39.7	36.9
Mean (2008-16)	**53.8**	**46.7**	**26.3**	**53.7**	**40.8**	**29.9**	**38.3**	**43.1**	**52.8**	**43.6**	***42.1***
Mean (2004-16)	**58.9**	**55.7**	**27.3**	**58.4**	-	**33.7**	**41.9**	-	-	-	-
Significance(b)	▼	▼	▼	▼	◄►	▼	▼	▼	▼	▼	▼

(a) Only years with >75 per cent complete data shown

(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = stable/no trend

There has been a general tendency for annual mean NO_X concentrations to decrease. At the OEH stations concentrations decreased by between 27 per cent and 46 per cent between 2004 and 2016. The Mann-Kendall test showed that the downward trend in concentrations was statistically significant at all stations except Prospect, although this station had a shorter time series. There is, however, a suggestion of a levelling-off of concentrations at some stations in recent years.

There was a pronounced spatial variation in the annual mean NO_X concentration when the results were considered for a consistent time period (e.g. 2008-2016). For example, at the OEH Chullora, Earlwood and Liverpool stations the long-term mean concentration during this period was around 50 µg/m^3, compared with around 40 µg/m^3 at Prospect and Rozelle, and 30 µg/m^3 at Randwick and Lindfield. The long-term concentration at the Roads and Maritime T1 station was around 53 µg/m^3, with concentrations at the Roads and Maritime stations CBMS, U1 and X1 being slightly lower (around 43 µg/m^3). This spatial variation was taken into account in the derivation of background NO_X concentrations for the F6 Extension project.

Although not shown, the long-term mean (2008-2016) NO_X concentrations at the Roads and Maritime roadside stations (F1 and M1) were substantially higher than those at the background stations, and very similar at 103 and 101 µg/m^3 respectively. The road increment – the average roadside concentration minus the average background concentration remained relatively stable, at around 50-60 µg/m^3, between 2008 and 2016 (there was a slight downward trend overall). This illustrates the ongoing contribution of NO_X emissions from road transport.

D.6.1.2 Maximum one-hour mean concentration

The long-term trends in the maximum one-hour mean NO_X concentration are shown in Figure D-7**.** Again, there are no air quality criteria for NO_X, and these are largely of interest in relation to the one-hour criterion for NO_2. As with the annual mean concentration, there has been a general downward trend in peak concentrations, with some levelling-off in recent years.

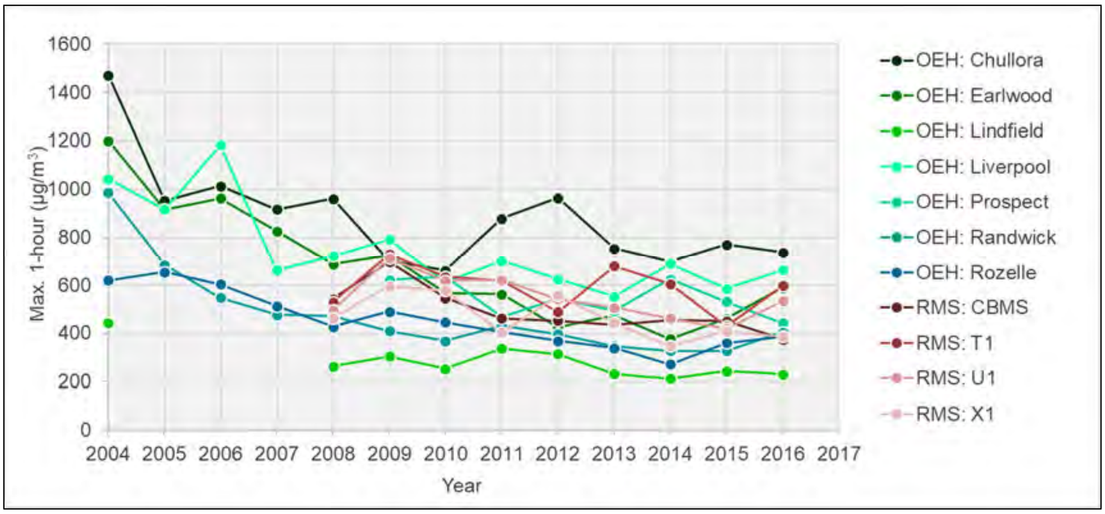

Figure D-7 Trend in maximum one-hour mean NO_X concentration

For comparison, the maximum one-hour mean NO_X concentrations at the Roads and Maritime roadside stations (F1 and M1) in 2016 were 1,043 and 696 µg/m^3 respectively. These values are similar to or higher than the upper end of the range of values for the background stations.

D.6.2 Nitrogen dioxide

D.6.2.1 Annual mean concentration

The long-term trends in annual mean NO_2 concentrations are shown in Figure D-8, and the corresponding statistics are provided in Table D-7. The concentrations at all stations were well below the NSW air quality assessment criterion of 62 µg/m^3.

The NO_2 concentrations at the OEH stations exhibited a systematic downward trend, with a reduction of between around 15 per cent and 30 per cent between 2004 and 2016, depending on the station. The trend was statistically significant at six of the seven stations. However, in recent years the concentrations at some stations appear to have stabilised. At the Roads and Maritime background stations there was a significant downward trend at two stations (CBMS, T1) but no trend at the other two (U1, X1).

As with NO_X, there was some spatial variation in NO_2 concentrations, but the pattern across the monitoring stations was not quite the same. Nevertheless, concentrations were again generally highest at the Chullora station and lowest at Lindfield and Randwick, although concentrations increased markedly at Randwick between 2014 and 2016.

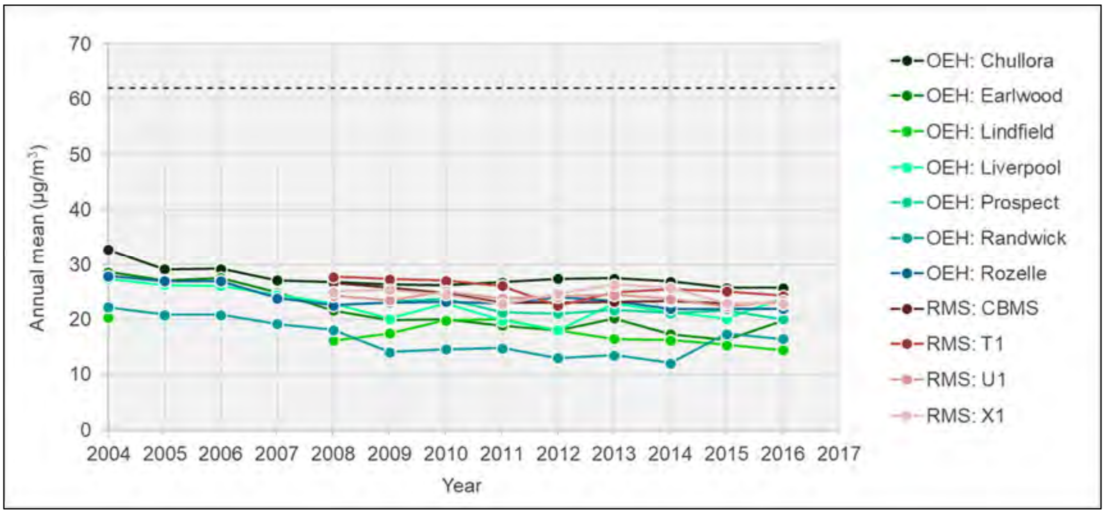

Figure D-8 Trend in annual mean NO_2 concentration

Table D-7 Annual mean NO_2 concentration at OEH and Roads and Maritime background stations

Year	Annual mean concentration $(\mu g/m^3)^{(a)}$										
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2004	32.8	28.7	20.4	27.4	-	22.2	27.9	-	-	-	-
2005	29.1	27.1	-	26.2	-	20.9	27.0	-	-	-	-
2006	29.2	27.6	-	26.1	-	20.8	27.0	-	-	-	-
2007	27.1	24.9	-	24.5	-	19.2	23.9	-	-	-	-
2008	26.7	21.7	16.1	22.9	-	18.1	22.6	26.7	27.7	24.3	25.0
2009	26.3	19.9	17.4	20.1	23.1	14.1	23.1	25.7	27.4	23.5	25.4
2010	26.2	20.1	19.8	22.9	23.7	14.6	23.2	24.8	27.1	25.1	24.5
2011	26.8	18.9	20.0	19.9	21.3	14.8	22.9	23.1	26.1	23.8	22.8
2012	27.4	18.1	18.0	18.1	21.1	13.0	24.0	23.1	22.5	24.2	24.7
2013	27.5	20.2	16.5	22.9	21.7	13.5	23.4	23.2	25.0	24.5	26.3
2014	26.9	17.3	16.3	21.3	21.1	12.1	21.9	23.4	25.5	23.7	25.7
2015	25.8	16.2	15.4	20.2	21.6	17.4	21.9	22.9	25.1	22.4	23.0
2016	25.8	19.8	14.4	23.8	20.1	16.4	21.9	-	24.3	23.3	22.8
Mean (2008-16)	**26.6**	**19.1**	**17.1**	**21.3**	**21.7**	**14.9**	**22.8**	**24.1**	**25.6**	**23.9**	**24.5**
Mean (2004-16)	**27.5**	**21.6**	**17.4**	**22.8**	-	**16.7**	**23.9**	-	-	-	-
Significance[(b)]	▼	▼	▼	▼	◄►	▼	▼	▼	▼	◄►	◄►

(a) Only years with >75 per cent complete data shown.
(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = stable/no trend

The long-term (2008-2016) average NO_2 concentrations at the Roads and Maritime roadside stations (F1 and M1) were 34 and 37 µg/m³ respectively, and therefore around 10-13 µg/m³ higher than those at the Roads and Maritime background stations. Even so, the NO_2 concentrations at roadside were also well below the NSW assessment criterion.

D.6.2.2 Maximum one-hour mean concentration

The trends in the maximum one-hour mean NO_2 concentration by year are given in Figure D-9. The within-station variation for this metric is similar to the between-site variation, but when viewed overall the values have been quite stable with time (broadly varying around 100 µg/m³), and are all below the NSW air quality assessment criterion of 246 µg/m³. The maximum one-hour mean NO_2 concentrations at the Roads and Maritime roadside stations (F1 and M1) in 2016 were 144 µg/m³ and 165 µg/m³ respectively. As with NO_X, these values are similar to or higher than the highest values for the background stations.

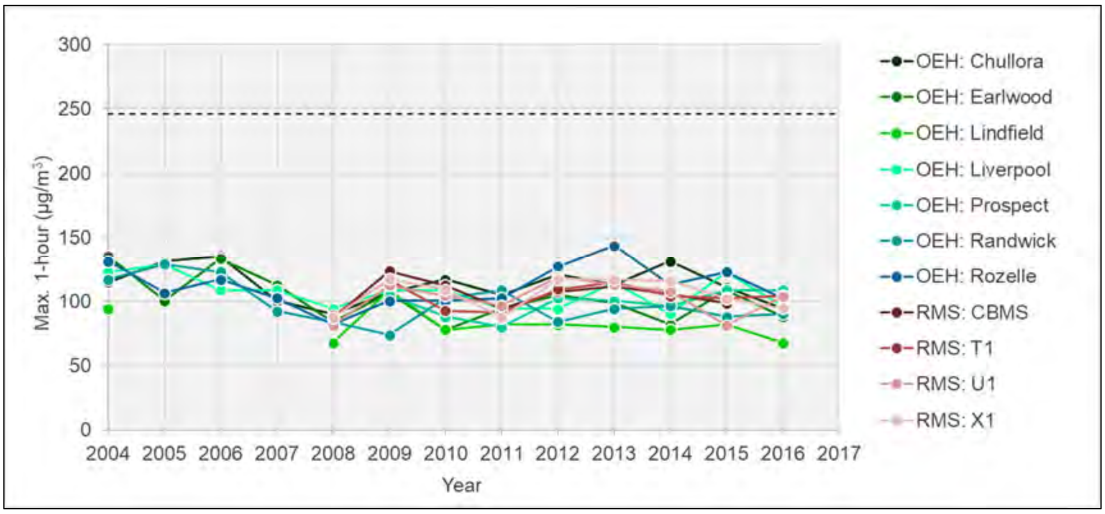

Figure D-9 **Trend in maximum one-hour mean NO_2 concentration**

D.6.2.3 Exceedances of air quality criteria

There were no exceedances of the annual mean criterion for NO_2 of 62 µg/m³ (Table D-7). In fact, annual mean concentrations were well below the criterion at all stations and in all years. There were also no exceedances of the one-hour mean criterion for NO_2 (246 µg/m³).

D.6.3 Ozone

D.6.3.1 Annual mean concentration

Annual mean ozone concentrations at the OEH stations - presented in Figure D-10 and Table D-8 - were relatively stable between 2004 and 2016, being typically around 30-35 µg/m³. The main exception was the Randwick station, where the typical annual mean concentration was substantially higher, at closer to 40 µg/m³. This is likely to be due to the coastal nature of Randwick, with easterly winds having low concentrations of ozone-scavenging species, notably NO_X (see Figure D-6).

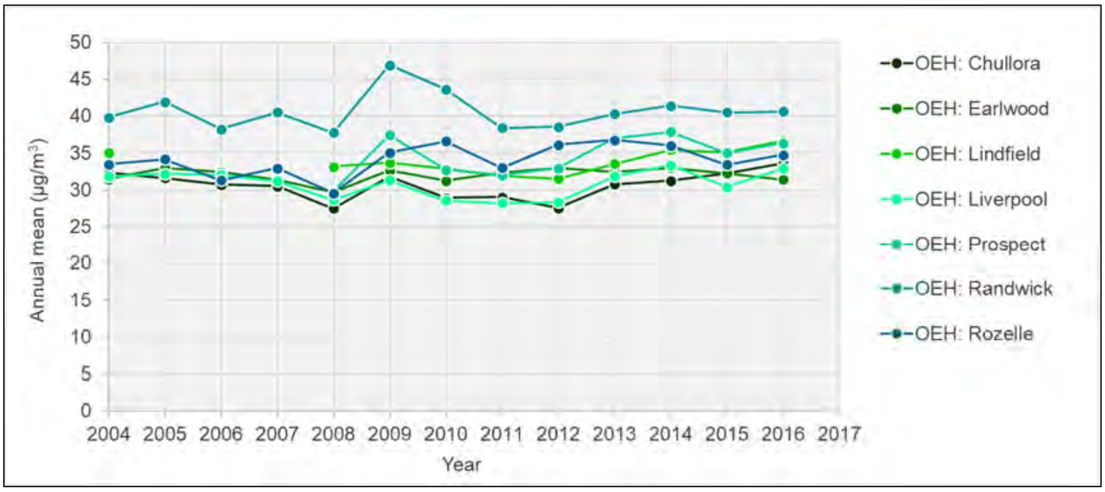

Figure D-10 **Trend in annual mean O_3 concentration**

Table D-8 Annual mean O_3 concentration at OEH background stations

Year	Annual mean concentration (µg/m³) [(a)]						
	Chullora	Earlwood	Lindfield	Liverpool	Prospect	Randwick	Rozelle
2004	323.	31.5	35.0	31.8	-	39.8	33.5
2005	31.6	33.0	-	32.2	-	42.0	34.2
2006	30.7	32.4	-	32.0	-	38.3	31.3
2007	30.5	31.4	-	31.2	-	40.5	32.9
2008	27.5	29.7	33.2	28.7	29.8	37.8	29.6
2009	31.8	32.7	33.7	31.3	37.5	46.9	35.1
2010	28.9	31.3	32.9	28.6	32.8	43.6	36.6
2011	29.0	32.4	31.9	28.2	32.0	38.4	33.0
2012	27.5	33.0	31.5	28.4	33.0	38.6	36.1
2013	30.8	32.4	33.5	31.8	37.0	40.3	36.8
2014	31.3	33.0	35.4	33.4	37.9	41.4	36.0
2015	32.3	32.2	35.1	30.4	35.0	40.5	33.5
2016	33.6	31.4	36.7	32.9	36.3	40.6	34.7
Mean (2008-16)	**30.3**	**32.0**	**33.8**	**30.4**	**34.6**	**40.9**	**34.6**
Mean (2004-16)	**30.6**	**32.0**	**33.9**	**30.8**	**-**	**40.7**	**34.1**
Significance[(b)]	◄►	◄►	◄►	◄►	◄►	◄►	◄►

(a) Only years with >75 per cent complete data shown

(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = stable/no trend

D.6.3.2 Exceedances of air quality criteria

Table D-9 and Table D-10 show that there were exceedances of the rolling 4-hour mean and 1-hour mean standards for ozone at several monitoring stations.

Table D-9 Exceedances of rolling 4-hour mean O_3 standard

Year	Number of exceedances of rolling 4-hour standard per year (171 µg/m³)						
	Chullora	Earlwood	Lindfield	Liverpool	Prospect	Randwick	Rozelle
2004	**7**	**1**	**5**	**11**	-	**2**	**2**
2005	**1**	0	-	**6**	-	0	0
2006	**10**	**4**	-	**17**	-	0	**2**
2007	0	0	-	**7**	-	**2**	0
2008	0	0	0	**1**	**2**	0	0
2009	**6**	**7**	**3**	**10**	**18**	0	0
2010	0	0	0	**1**	**7**	0	0
2011	**4**	**3**	**1**	**5**	**13**	0	0
2012	0	0	0	0	0	0	0
2013	**3**	**3**	0	**6**	**6**	0	0
2014	0	0	0	**3**	**5**	0	0
2015	0	**1**	**1**	0	0	**2**	0
2016	0	**2**	**4**	**3**	0	**3**	0

Table D-10 Exceedances of 1-hour O_3 standard

Year	Number of exceedances of 1-hour standard per year (214 µg/m³)						
	Chullora	Earlwood	Lindfield	Liverpool	Prospect	Randwick	Rozelle
2004	**2**	0	**1**	**5**	-	**2**	0
2005	0	0	-	**3**	-	0	0
2006	**3**	**2**	-	**11**	-	0	0
2007	0	0	-	**3**	-	0	0
2008	0	0	0	0	**1**	0	0
2009	**3**	**3**	**1**	**3**	**4**	0	0
2010	0	0	0	0	**3**	0	0
2011	**1**	0	0	**1**	**5**	0	0
2012	0	0	0	0	0	0	0
2013	**1**	**1**	0	**5**	**2**	0	0
2014	0	0	0	**1**	**2**	0	0
2015	0	0	0	0	0	**1**	0
2016	0	0	**1**	0	**1**	0	0

D.6.4 PM_{10}

D.6.4.1 Annual mean concentration

Annual mean PM_{10} concentrations at the OEH and Roads and Maritime stations are given in Figure D-11 and Table D-11. Concentrations at the OEH stations showed a net decrease between 2004 and 2016, by as much as 21-23 per cent in the case of the Chullora and Earlwood stations. Some stations had a statistically significant downward trend in concentration.

In recent years the annual mean PM_{10} concentration at the OEH stations has been between around 17 µg/m^3 and 19 µg/m^3, except at Lindfield where the concentration is substantially lower (around 14-15 µg/m^3). The concentration at the Roads and Maritime stations in recent years appears to have stabilised at around 15 µg/m^3, although the CBMS station had a concentration closer to 18 µg/m^3 in 2016. These values can be compared with the air quality criterion of 25 µg/m^3 in the NSW Approved Methods.

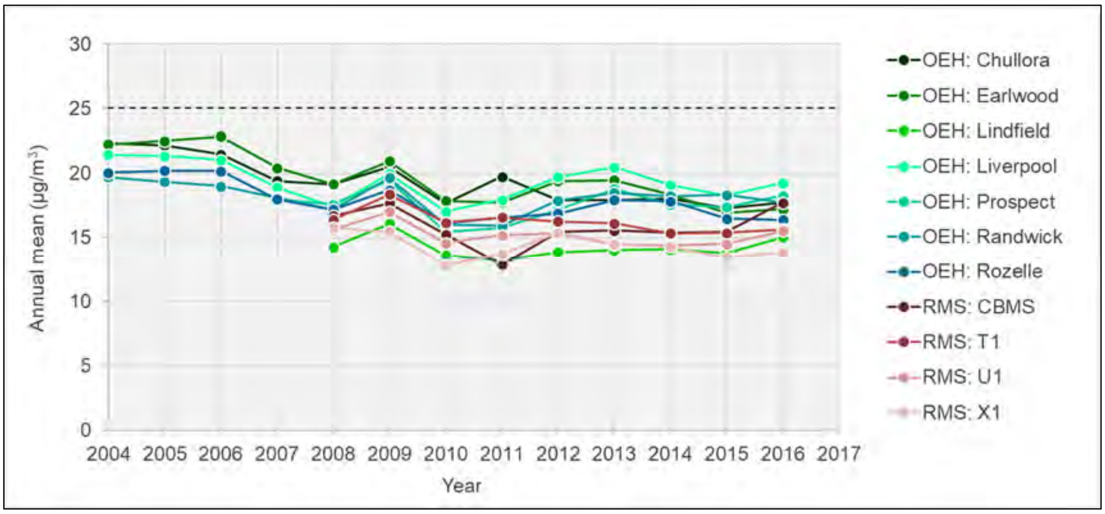

Figure D-11 Trend in annual mean PM_{10} concentration

Table D-11 Annual mean PM_{10} concentration at OEH and Roads and Maritime background stations

Year	Annual mean concentration ($\mu g/m^3$)$^{(a)}$										
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2004	22.3	22.2	-	21.4	-	19.7	20.0	-	-	-	-
2005	22.2	22.5	-	21.3	-	19.3	20.2	-	-	-	-
2006	21.5	22.8	-	21.0	-	19.0	20.2	-	-	-	-
2007	19.4	20.4	-	18.9	18.0	18.1	18.0	-	-	-	-
2008	19.1	19.1	14.2	17.4	17.6	17.2	17.2	16.7	16.4	15.6	15.8
2009	20.5	20.9	16.1	20.0	19.5	19.6	18.7	17.7	18.3	17.0	15.5
2010	17.7	17.9	13.6	17.0	15.4	16.0	16.1	15.2	16.2	14.6	12.8
2011	19.7	17.7	13.2	18.0	15.7	15.9	16.6	12.8	16.6	15.2	13.7
2012	17.9	19.4	13.8	19.7	17.2	17.9	16.9	15.5	16.2	15.3	15.4
2013	17.9	19.4	14.0	20.5	18.8	18.5	17.9	15.6	16.1	14.4	14.5
2014	18.1	18.3	14.1	19.1	17.6	18.2	17.8	15.4	15.3	14.4	14.3
2015	17.3	16.9	13.8	18.3	17.4	18.3	16.5	15.4	15.4	14.5	13.4
2016	17.7	17.2	15.0	19.2	18.3	17.7	16.4	17.7	15.6	15.5	13.8
Mean (2008-16)	**18.4**	**18.6**	**14.2**	**18.8**	**17.5**	**17.7**	**17.1**	**15.8**	**16.2**	**15.2**	**14.3**
Mean (2004-16)	**19.3**	**19.6**	**-**	**19.4**	**-**	**18.1**	**17.9**	**-**	**-**	**-**	**-**
Significance$^{(b)}$	▼	▼	◀▶	▼	◀▶	◀▶	▼	◀▶	▼	◀▶	◀▶

(a) Only years with >75 per cent complete data shown
(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◀▶ = stable/no trend

D.6.4.2 24-hour mean concentration

The maximum 24-hour mean PM_{10} concentrations are shown in Figure D-12. These appear to exhibit a slight underlying downward trend overall, but there is a large variation from year to year at most stations, and 2009 in particular had a large variation between stations. In 2016 the concentrations at the various stations were clustered around 35 $\mu g/m^3$.

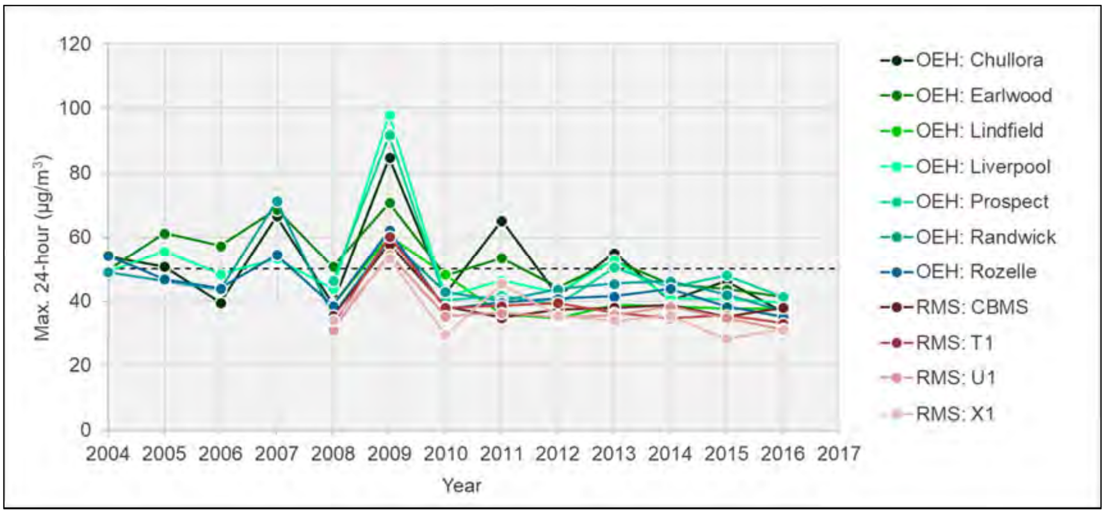

Figure D-12 Trend in maximum 24-hour mean PM_{10} concentration

D.6.4.3 Exceedances of air quality criteria

There were no exceedances of the annual mean criterion for PM_{10} in the NSW Approved Methods of 25 $\mu g/m^3$, but Table D-12 shows that there were multiple exceedances of the 24-hour criterion of 50 $\mu g/m^3$, notably in the warm, dry year of 2009 (days with bush fires and dust storms were excluded from this analysis).

Table D-12 Exceedances of 24-hour PM_{10} standard

Year	Number of exceedances of 24-hour criterion per year (50 µg/m³)[(a)]						
	Chullora	Earlwood	Lindfield	Liverpool	Prospect	Randwick	Rozelle
2004	**3**	**1**	0	1	-	**1**	**1**
2005	**1**	**2**	**1**	**2**	-	0	0
2006	0	**5**	-	0	-	0	0
2007	**2**	**3**	0	**1**	0	**1**	**1**
2008	0	**1**	0	0	0	0	0
2009	**2**	**4**	**1**	**3**	**3**	**2**	**2**
2010	0	0	0	0	0	0	0
2011	**8**	**1**	0	0	0	0	0
2012	0	0	0	0	0	0	0
2013	**1**	**2**	0	**1**	**1**	0	0
2014	0	0	0	0	0	0	0
2015	0	0	0	0	0	0	0
2016	0	0	0	0	0	0	0

(a) Note that extreme events reported by OEH are not included.

D.6.5 $PM_{2.5}$

D.6.5.1 Annual mean concentration

An extensive time series of $PM_{2.5}$ measurements was only available for three stations: Chullora, Earlwood and Liverpool (Figure D-13, Table D-13). Concentrations at these stations had a broadly similar pattern, with a reduction between 2004 and 2012 followed by a substantial increase in 2013 and then stabilisation. It is important to recognise that during 2012 OEH made a decision to replace its continuous TEOM $PM_{2.5}$ monitors with USEPA-equivalent BAMs. This is the main reason for the increase in the measured concentrations. It is well documented that there are considerable uncertainties in the measurement of $PM_{2.5}$, and the results are instrument-specific (e.g. AQEG, 2012). The increases meant that background $PM_{2.5}$ concentrations at the three stations between 2013 and 2016 were very close to, or above, the NSW criterion of 8 µg/m³, as well as being above the AAQ NEPM long-term goal of 7 µg/m³.

Shorter time series of $PM_{2.5}$ (2015 and 2016) were also available for the Rozelle and Prospect stations, and for several SMC stations (not shown). Mean concentrations at Prospect were similar to those at the long-term stations. However, the concentrations at Rozelle were noticeably lower at around 7 µg/m³. The measurements at four SMC background stations in 2016 had slightly wider ranges (between 6.7 µg/m³ and 9.2 µg/m³).

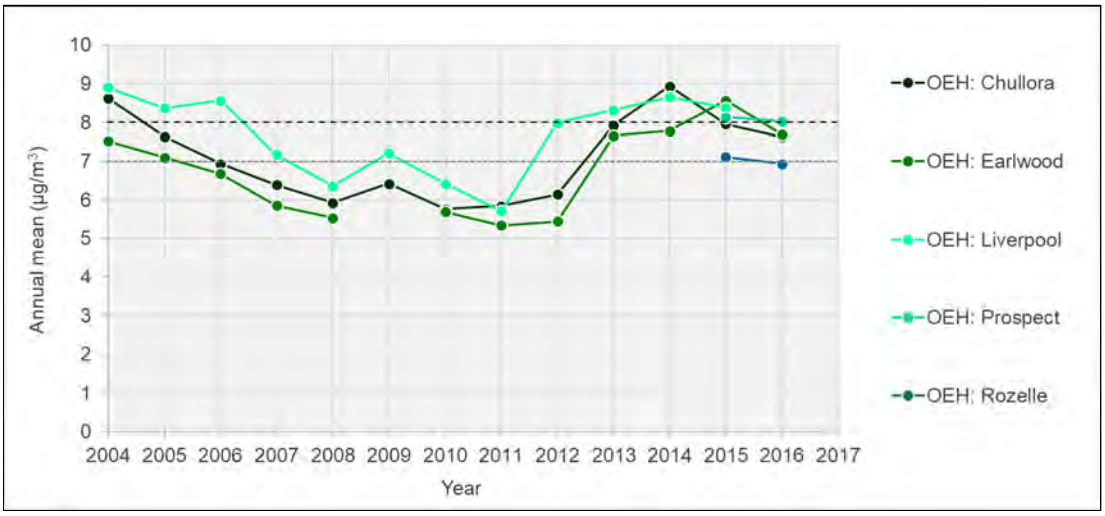

Figure D-13 Long-term trends in annual mean $PM_{2.5}$ concentration

Table D-13 Annual mean $PM_{2.5}$ concentration at OEH background stations

Year	Annual mean concentration (µg/m³) [(a)]						
	Chullora	Earlwood	Lindfield	Liverpool	Prospect	Randwick	Rozelle
2004	8.6	7.5	-	8.9	-	-	-
2005	7.6	7.1	-	8.4	-	-	-
2006	6.9	6.7	-	8.6	-	-	-
2007	6.4	5.9	-	7.2	-	-	-
2008	5.9	5.5	-	6.4	-	-	-
2009	6.4	-	-	7.2	-	-	-
2010	5.8	5.7	-	6.4	-	-	-
2011	5.9	5.3	-	5.7	-	-	-
2012	6.1	5.5	-	8.0	-	-	-
2013	7.9	7.7	-	8.3	-	-	-
2014	8.9	7.8	-	8.7	-	-	-
2015	8.0	8.6	-	8.4	8.1	-	7.1
2016	7.6	7.7	-	-	8.0	-	6.9
Mean (2004-16)	**7.1**	**6.7**	**-**	**7.7**	**-**	**-**	**-**
Significance[(b)]	◄►	◄►	-	◄►	-	-	-

(a) Only years with >75 per cent complete data shown
(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = stable/no trend

Overall, the data indicated that there was likely to be some spatial variation in $PM_{2.5}$ concentrations across the GRAL domain, although it would not be very pronounced.

D.6.5.2 24-hour mean concentration

The maximum 24-hour mean $PM_{2.5}$ concentrations at the three long-term $PM_{2.5}$ monitoring stations are shown in Figure D-14. There has been no systematic trend in the maximum value. The maximum concentrations have tended to be close to the NSW criterion of 25 µg/m³, and in some cases significantly above it. In most years the maximum concentrations have been above the NEPM long-term goal of 20 µg/m³.

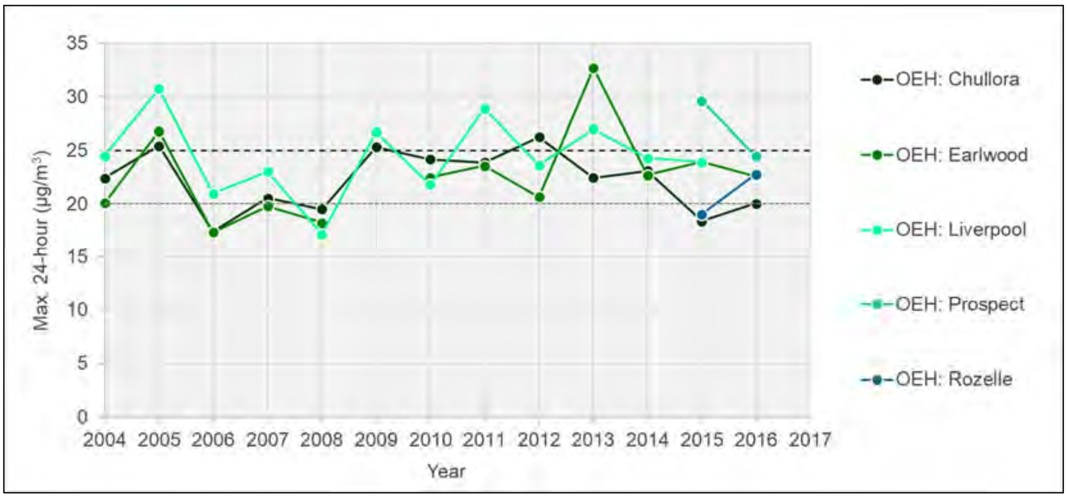

Figure D-14 Trend in maximum 24-hour mean $PM_{2.5}$ concentration

D.6.5.3 Exceedances of air quality criteria

As noted earlier, there have been some exceedances of the NSW criterion for annual mean $PM_{2.5}$ of 8 µg/m^3, and these also seem likely to occur in the future given the recent trend in concentrations.

Table D-14 summarises the exceedances of the NSW criterion for 24-hour mean $PM_{2.5}$ of 25 µg/m^3, as well as the long-term NEPM goal of 20 µg/m^3.

Table D-14 Exceedances of 24-hour $PM_{2.5}$ criterion

Year	Number of exceedances of 24-hour criterion per year (25 µg/m^3) (exceedances of the NEPM goal of 20 µg/m^3 are given in brackets)[(a)]						
	Chullora	Earlwood	Lindfield	Liverpool	Prospect	Randwick	Rozelle
2004	0 (3)	0 (1)	-	0 (**7**)	-	-	-
2005	**2** (**4**)	**2** (**4**)	-	**2** (**7**)	-	-	-
2006	0 (0)	0 (0)	-	0 (**2**)	-	-	-
2007	0 (**1**)	0 (0)	-	0 (**2**)	-	-	-
2008	0 (0)	0 (0)	-	0 (0)	-	-	-
2009	**1** (**1**)	-	-	**1** (**3**)	-	-	-
2010	0 (**3**)	0 (**1**)	-	0 (**2**)	-	-	-
2011	0 (**1**)	0 (**2**)	-	**1** (**3**)	-	-	-
2012	**1** (**5**)	0 (1)	-	0 (3)	-	-	-
2013	0 (**2**)	**1** (**6**)	-	**1** (**8**)	-	-	-
2014	0 (**3**)	0 (**1**)	-	0 (**5**)	-	-	-
2015	0 (0)	0 (**6**)	-	0 (**6**)	**1** (**5**)	-	0 (0)
2016	0 (**1**)	0 (**2**)	-	**-**	0 (**5**)	-	0 (**1**)

(a) Note that extreme events reported by OEH are not included.

D.6.6 Air toxics

Fewer data were available to characterise the concentrations of air toxics in Sydney. The main sources of data used in the assessment were the following:

- An Ambient Air Quality Research Project that was conducted between 1996 and 2001 (NSW EPA, 2002). The project investigated concentrations of 81 air toxics, including dioxins, VOCs, PAHs and heavy metals. More than 1,400 samples were collected at 25 sites. Three air toxics – benzene, 1,3-butadiene and benzo(α)pyrene – were identified as requiring ongoing assessment to ensure they remain at acceptable levels in the future.
- An additional round of data collection between October 2008 and October 2009. The five NEPM air toxics and additional VOCs were monitored at two sites in Sydney:
    - o Turrella: formaldehyde, acetaldehyde, 19 PAHs including benzo(a)pyrene, and 41 VOCs including benzene, toluene and xylenes.
    - o Rozelle: formaldehyde, acetaldehyde, 41 VOCs including benzene, toluene and xylenes.

  This study collected 24-hour concentrations of formaldehyde, acetaldehyde, and 34 organic compounds every sixth day, and 19 PAHs at one location on the same days. Sixty-one samples were collected at each location during the sampling period.
- Measurements conducted to support the WestConnex M4 East, New M5 and M4-M5 Link projects: benzene, toluene, ethylbenzene and xylenes.

The findings of the first two studies were summarised by DECCW (2010), and some results for selected pollutants are given in Table D-15. In the 1996-2001 monitoring campaign the concentrations of most compounds were very low. Some 23 compounds were not, or rarely, detected. Annual average concentrations of benzene were below the Air Toxics NEPM investigation level (0.003 ppm or 3 ppb) at all sites. The maximum annual concentrations of toluene and xylenes were less than 5 per cent of the investigation levels, and maximum 24-hour concentrations were less than 2 per cent and 4 per cent of the investigation levels respectively. The 2008-09 monitoring campaign also found low concentrations of all compounds, with many observations below detection limits. Concentrations of the five pollutants in the Air Toxics NEPM were low compared to the respective investigation levels.

The concentrations of the pollutants in Table D-15 generally halved between the two campaigns. Improved engine technology and a greater proportion of the vehicle fleet being fitted with catalysts reduced emissions from road vehicles. Benzene concentrations showed a larger decrease as a result of a reduction in the maximum allowed benzene concentration in automotive fuels (DECCW, 2010).

Table D-15 Average concentrations of selected organic pollutants

Pollutant	Concentration (ppb)				
	1996-2001			2008-2009	
	Sydney CBD	Rozelle	St Marys	Turrella	Rozelle
Benzene	2.3	1.1	0.4	0.4	0.3
Toluene	4.2	2.2	0.8	1.8	0.9
Xylene (m + p)	2.2	1.0	0.4	0.7	0.5
Xylene (o)	0.8	0.4	0.1	0.3	0.2
1,3-butadiene	0.4	0.2	0.1	<0.1	<0.1

Source: (DECCW, 2010)

In the 2008-2009 campaign the highest benzo(a)pyrene concentration was 0.4 ng/m^3, and the average for the year was 0.12 ng/m^3. Concentrations of formaldehyde were low: the highest concentration was only 11 per cent of the investigation level (DECCW, 2010).

The results clearly showed levels of air toxics were below the monitoring investigation levels, and well below levels observed in overseas cities. There were no occasions on which any of the air toxics monitored exceeded the monitoring investigation levels at any location. The results for benzo(a)pyrene, with levels of approximately 65 per cent of the NEPM monitoring investigation level, were the most significant (NEPC, 2011b).

To support the air quality assessments for the M4 East, New M5 and M4-M5 Link projects, Pacific Environment measured the concentrations of BTEX compounds (benzene, toluene, ethylbenzene and xylenes) at each of the project-specific air quality monitoring stations (five stations for the M4 East, seven stations for the New M5, and three stations for the M4-M5 Link) (Oswald, 2015a, 2015b; Phillips, 2017). The sites included background and roadside locations. Samples of air were obtained and analysed for BTEX compounds during four rounds of sampling between September and October of 2015 for the M4 East and New M5, and between January and February of 2017 for the M4-M5 Link. The results are summarised in Table D-16. In many cases the concentration for a given compound was lower than the corresponding limit of reporting (LOR)[5]. The results were therefore similar to those from the earlier studies, and confirmed that the concentrations of air toxics in Sydney remain very low.

[5] The LOR represents the lowest concentration at which a compound can be detected in the samples during laboratory analysis.

Table D-16 **Results of BTEX sampling for the M4 East, New M5 and M4-M5 Link projects**

Compound(s)	Range of concentrations measured		
	M4 East sites (5)	New M5 sites (7)	M4-M5 Link sites (3)
Benzene	All measurements <1.6 $\mu g/m^{3}$ (a) (<0.5 ppb)	All measurements <1.6 $\mu g/m^{3}$ (a) (<0.5 ppb)	All measurements <1.6 $\mu g/m^{3}$ (a) (<0.5 ppb)
Toluene	<1.9 $\mu g/m^{3}$ (a) to 6.8 $\mu g/m^3$ (<0.5 to 1.7 ppb)	<1.9 $\mu g/m^{3}$ (a) to 6.8 $\mu g/m^3$ (<0.5 to 1.7 ppb)	<1.9 $\mu g/m^{3}$ (a) to 5.3 $\mu g/m^3$ (<0.5 to 1.4 ppb)
Ethylbenzene	All measurements <2.2 $\mu g/m^{3}$ (a) (<0.5 ppb)	All measurements <2.2 $\mu g/m^{3}$ (a) (<0.5 ppb)	All measurements <2.2 $\mu g/m^{3}$ (a) (<0.5 ppb)
Total xylenes(b)	All measurements <6.6 $\mu g/m^{3}$ (a) (<1.4 ppb)	All measurements <6.6 $\mu g/m^{3}$ (a) (<1.4 ppb)	All measurements <6.6 $\mu g/m^{3}$ (a) (<1.4 ppb)

(a) Limit of reporting
(b) Sum of meta-, para- and ortho- isomers

D.7 Seasonal patterns

Seasonal patterns in air quality in Sydney were described in the EISs for the WestConnex projects, most recently by Pacific Environment (2017). Monthly mean concentrations were analysed to provide additional data on seasonal patterns in air pollution. This analysis showed the following:

- There is a strong seasonal influence on CO, NO_X and NO_2 concentrations, with values being much higher in winter than in summer. This is due to a combination of winter-time factors such as an increase in combustion for heating purposes, elevated ‘cold start’ emissions from road vehicles, and more frequent and persistent temperature inversions in the atmosphere reducing the effectiveness of dispersion. Another contributing factor may be the reaction of NO_2 with the hydroxyl radical (OH) acting as a sink for NO_X. Concentrations of OH are highest in the summer.
- Ozone concentrations are highest in the late spring and early summer – when photochemical activity is high - and lowest in the autumn and winter.
- For PM_{10} there is a weaker seasonal effect than for the gaseous pollutants, with concentrations tending to be higher in summer and lower in winter.
- For $PM_{2.5}$ concentrations there are some differences between seasons, but they are not systematic.

It was desirable to ensure that such seasonal effects were represented in the assumed background concentrations for the F6 Extension project.

D.8 Directional patterns

D.8.1 Overview

In the EIS for the M4-M5 Link (Pacific Environment, 2017), polar plots for each of the OEH background monitoring stations were created using the *Openair* software (Carslaw, 2015). These plots covered the period 2004-2015. They were not used directly in the determination of background concentrations, but they did assist (qualitatively) in the understanding of pollutant sources. A feature of several of the plots was an apparent influence of road traffic at background locations, which suggested a degree of conservatism in the modelling approach. For the closest stations to the F6 Extension domain (Chullora, Earlwood, Randwick and Rozelle), the findings are summarised below.

Chullora

At the Chullora station the patterns for CO, NO_X and NO_2 showed strong similarities, with the highest concentrations occurring at low wind speeds and a tendency for elevated concentrations along a broad north-south wind direction axis. The similarities between these patterns indicated a common combustion source - probably the local road network. The patterns for CO and NO_X did not show up strongly in the PM_{10} and $PM_{2.5}$ plots. PM_{10} concentrations appeared to be influenced by a source to the west of the monitoring site under higher wind speeds. This may have been wind-blown dust from open land to the west of the monitoring station. For $PM_{2.5}$ there were strong sources to the north-west and south under high wind conditions. There were also seasonal differences between PM_{10} and $PM_{2.5}$; the highest PM_{10} concentrations were in winter, whereas the highest $PM_{2.5}$ concentrations were in summer.

Earlwood

For the Earlwood station NO_X and NO_2 concentrations were highest when the winds were strong and from an easterly direction. This influence was especially strong during winter, hinting that this was an effect of combustion for heating purposes. PM_{10} concentrations were highest when the winds were strong and from a westerly direction (especially in winter and spring). $PM_{2.5}$ concentrations, while more evenly distributed than PM_{10}, were high when the winds were strong from a southerly direction (especially in summer). The reasons for these patterns were not investigated further, but different sources and effects were evidently influencing PM_{10} and $PM_{2.5}$.

Randwick

At Randwick NO_X and NO_2 concentrations were highest when the wind speed was low and the wind was coming from the west. There was no seasonal effect for NO_X. This indicated the presence of a road near to the monitoring station, which could have been Anzac Parade and/or Avoca Street. Sydney Airport, around 5 kilometres to the west of the monitoring station, may also have affected NO_X concentrations in this area. The highest PM_{10} concentrations occurred when the wind speed was high and the wind was from three distinct directions. Given that these directions coincided with open land and land under development, this seems to be a confirmation that high PM_{10} concentrations are associated with wind-blown dust from local sources.

Rozelle

At the Rozelle station there were multiple combustion sources affecting CO concentrations. These were likely to be associated with the University of Sydney campus immediately to the south-west, and roads within 500 metres (Victoria Road to the north-east, and Darling Street to the south-west). The highest NO_X/NO_2 concentrations occurred when winds were along an east-west axis, which suggested contributions from the University campus and residential areas. The peak associated with easterly winds may also have been linked to Victoria Road. The highest PM_{10} concentrations at the monitoring station were associated with strong southerly winds, especially in summer. As at the other OEH monitoring stations, this seemed to be due to wind-blown dust from open land to the south of the station.

D.9 Assumed background concentrations

D.9.1 Overview

Various approaches can be used to define long-term (annual mean) and short-term (*e.g.* 1-hour, 24-hour) background concentrations. The selection of a suitable method is strongly dependent on the quantity and quality of available data, and this varies from project to project.

Firstly, it is important that that the same year is used for background air quality data and the meteorological data used in the dispersion modelling, given the influence of the latter on the former. The year selected for the meteorological data was 2016. This was also the base year for the assessment, which permitted model evaluation for this year. Becasue there was a general downward trend, or stabilisation, in pollutant concentrations between 2004 and 2016 (see section D.5), the concentrations in 2016 were considered to be appropriate for use in the F6 Extension – Stage 1 assessment. On balance, it was considered that the concentrations in 2016 would represent typical (but probably slightly conservative) background concentrations in the future.

The approaches for establishing background concentrations in the F6 Extension assessment, and for combining these with model predictions, were similar to those developed to support the EISs for the WestConnex M4 East, New M5 and M4-M5 Link projects (Boulter et al., 2015; Manansala et al., 2015; Pacific Environment, 2017). Three types of background concentration data were required:

- For community receptors, time series of background concentrations for the whole of 2016, and using time intervals that corresponded to the air quality criteria (e.g. 1-hour average, 24-hour average). These profiles were used in the 'contemporaneous' assessment for each receptor.
- For RWR receptors, annual mean background concentrations.
- For RWR receptors, short-term background concentrations.

The general approaches used, and the results for the various pollutants and metrics, are described in sections D9.2, D9.3 and D9.4. The various approaches are summarised in section D9.5, and some limitations are discussed in section D9.5.

D.9.2 Synthetic background profiles for community receptors (contemporaneous assessment)

D.9.2.1 General approach

A contemporaneous approach used for community receptors in the F6 Extension – Stage 1 assessment. This was broadly consistent with the 'Level 2' method described in the NSW Approved methods. The approach requires that existing background concentrations of a pollutant in the vicinity of a proposal should be included in the assessment as follows (NSW EPA, 2016):

- At least one year of continuous ambient pollutant measurements should be obtained for a suitable background station. The background data should be contemporaneous with the meteorological data used in the dispersion modelling.
- At each receptor, each individual dispersion model prediction is added to the corresponding measured background concentration (*e.g.* the first hourly average dispersion model prediction is added to the first hourly average background concentration) to obtain total hourly predictions.
- At each receptor, the maximum concentration for the relevant averaging period is determined.

The unstated assumption is that one of the paired project-background concentration combinations will result in a realistic estimate of the maximum concentration that could be expected.

For the F6 Extension – Stage 1, this approach was applied to the short-term concentration metrics for CO (1-hour mean, rolling 8-hour mean), NO_X (1-hour mean), PM_{10} (24-hour mean) and $PM_{2.5}$ (24-hour mean). NO_X (1-hour mean) was used in place of NO_2 for the reasons given in Annexure E.

For 1-hour NO_X, 24-hour PM_{10} and 24-hour $PM_{2.5}$, the three stations inside the GRAL domain were used to construct *synthetic* background profiles:

- OEH Earlwood
- SMC NewM5:01
- SMC NewM5:04

As CO was not measured at Earlwood, the data from the two SMC stations were used for this pollutant.

It was assumed that the three stations would represent the range of short-term concentrations in the GRAL domain. Gap-filling techniques were used to ensure that a complete time series of concentrations was available. The approach for each pollutant is described in the relevant section below. To maintain a margin of safety, in each synthetic profile the concentration for a given time step (e.g. 1 hour or 24 hours) was taken as the maximum of the values from all the relevant stations.

D.9.2.2 Carbon monoxide: one-hour mean

Figure D-15 shows examples of one-hour mean CO concentration profiles at the two SMC stations n the GRAL domain during June of 2016. Peak concentrations generally occurred simultaneously at the different stations, indicating a regional background influence. This synthetic background profile for 2016, which was constructed using the data from these stations, is shown in Figure D-16.

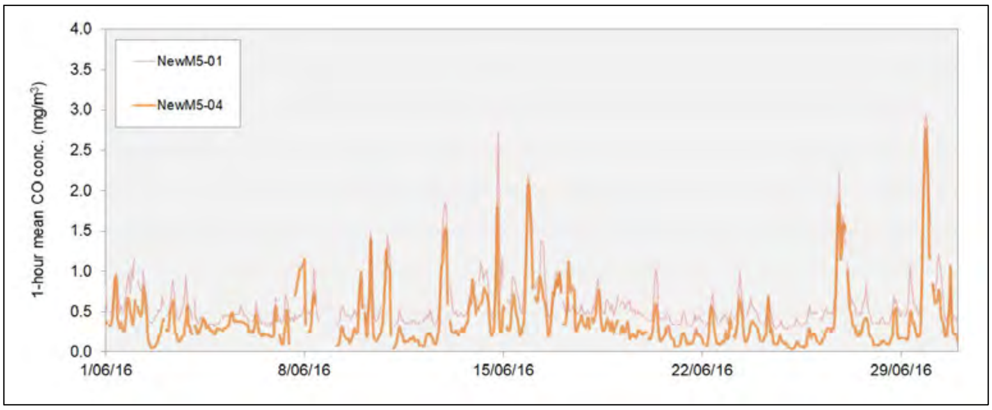

Figure D-15 One-hour mean CO concentration at SMC stations (example for June 2016)

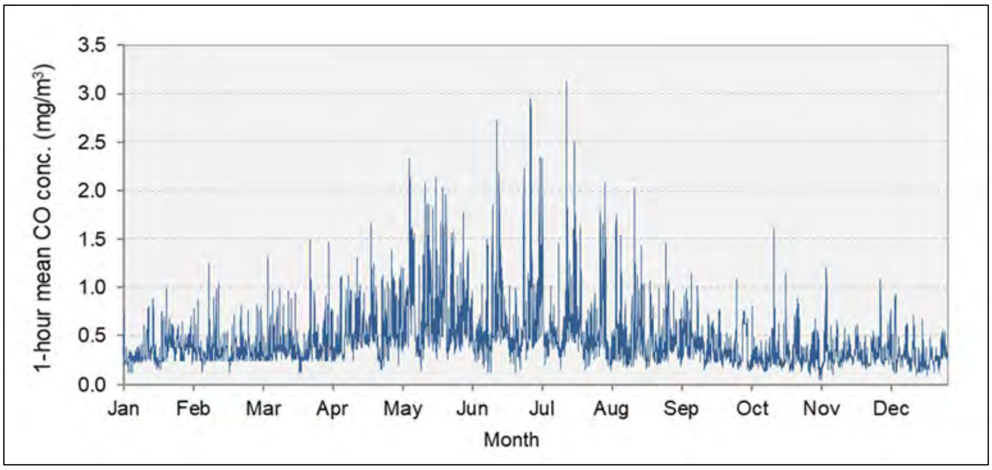

Figure D-16 Synthetic background concentration profile for one-hour mean CO in 2016

D.9.2.3 Carbon monoxide: rolling 8-hour mean

The synthetic profile for the rolling 8-hour mean CO concentration was constructed using the data from the two stations in Figure D-15. This profile is shown in Figure D-17.

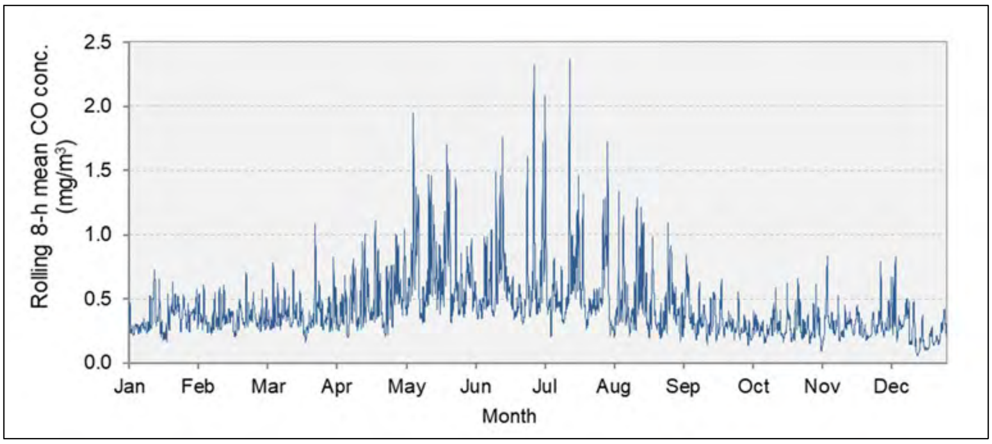

Figure D-17 Synthetic background concentration profile for rolling 8-hour mean CO in 2016

D.9.2.4 NO_X: one-hour mean

Figure D-18 shows examples (for June 2016) of 1-hour NO_X concentration profiles at the three background stations inside the GRAL domain. As with CO, peak concentrations regularly occurred simultaneously at the different stations, indicating a regional influence. The synthetic profile is shown in Figure D-19.

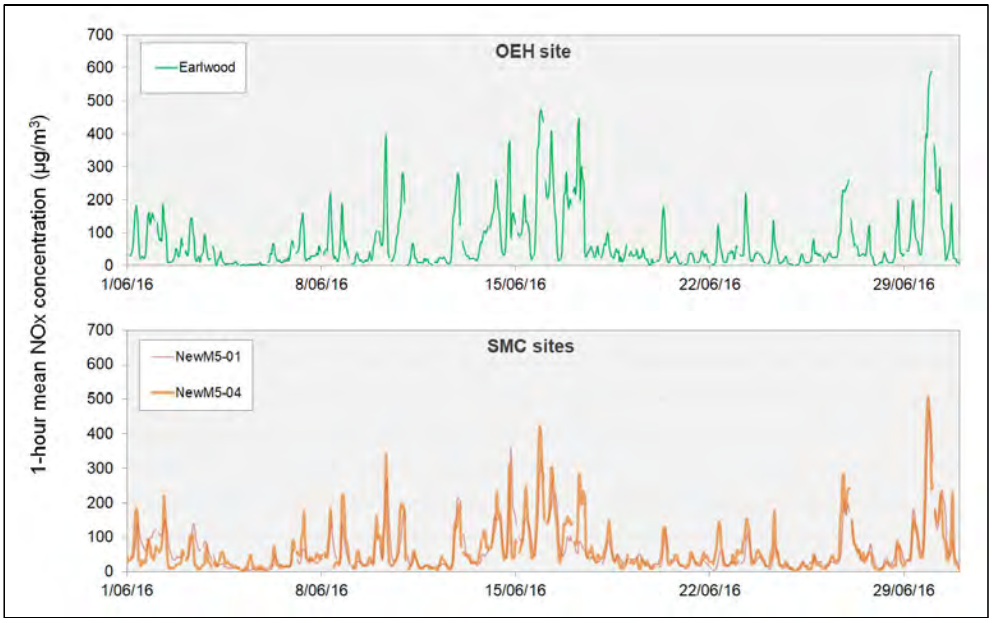

Figure D-18 **One-hour mean NO_X concentration at OEH and SMC stations (example for June 2016)**

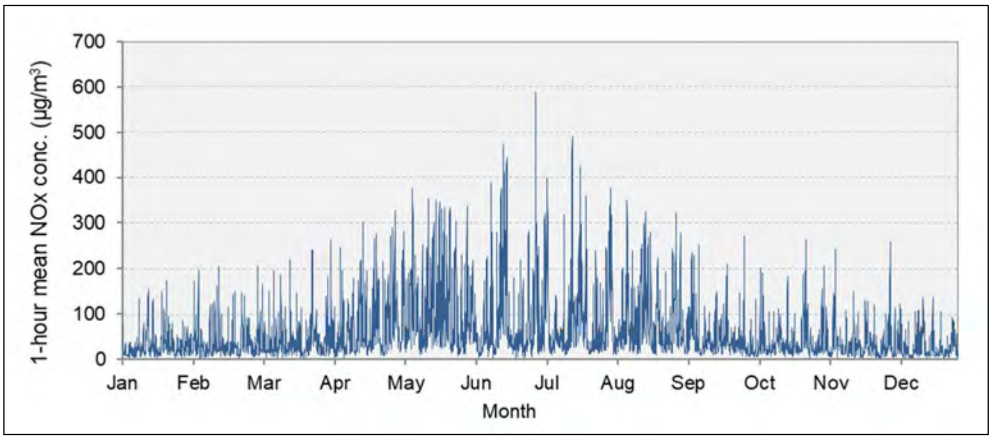

Figure D-19 **Synthetic background concentration profile for one-hour mean NO_X in 2016**

D.9.2.5 PM_{10}: 24-hour mean

Figure D-20 shows the concentration profiles for 24-hour mean PM_{10} in 2016 at the three stations inside the GRAL domain. As before, the strong similarities between the peaks and troughs in the profiles at the three stations show that the stations are characterising the same (*i.e.* regional) patterns in PM_{10}. The synthetic background concentration profile for 24-hour PM_{10} is shown in Figure D-21. There were no exceedances of the criterion of 50 µg/m³.

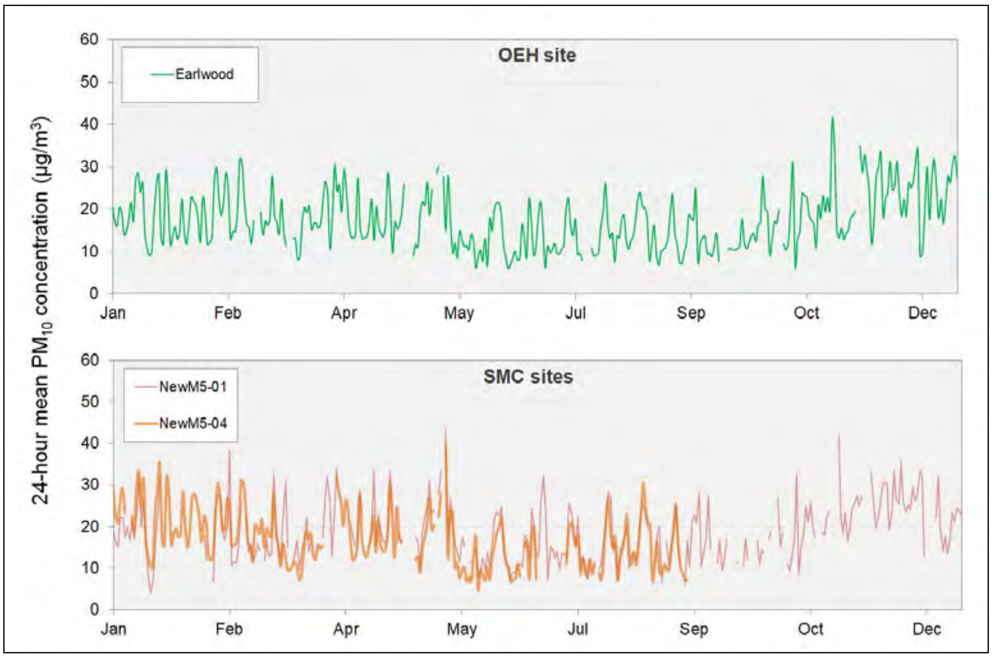

Figure D-20 **24-hour mean PM_{10} concentration at OEH and SMC stations in 2016**

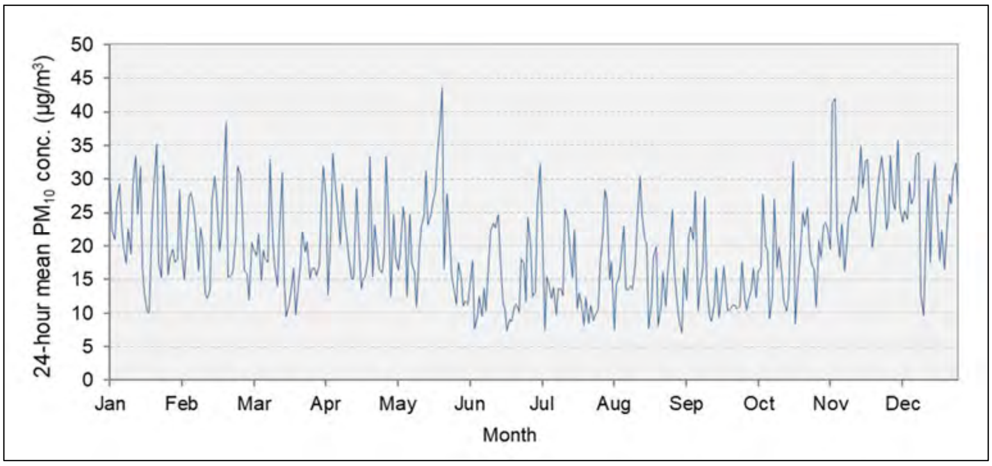

Figure D-21 **Synthetic background concentration profiles for 24-hour mean PM_{10} in 2016**

D.9.2.6 $PM_{2.5}$: 24-hour mean

The concentrations from the these stations are shown in Figure D-22, and the synthetic profile is given in Figure D-23. There were no exceedances of the criterion of 25 µg/m³, although the peak concentrations in the profile were approaching this value.

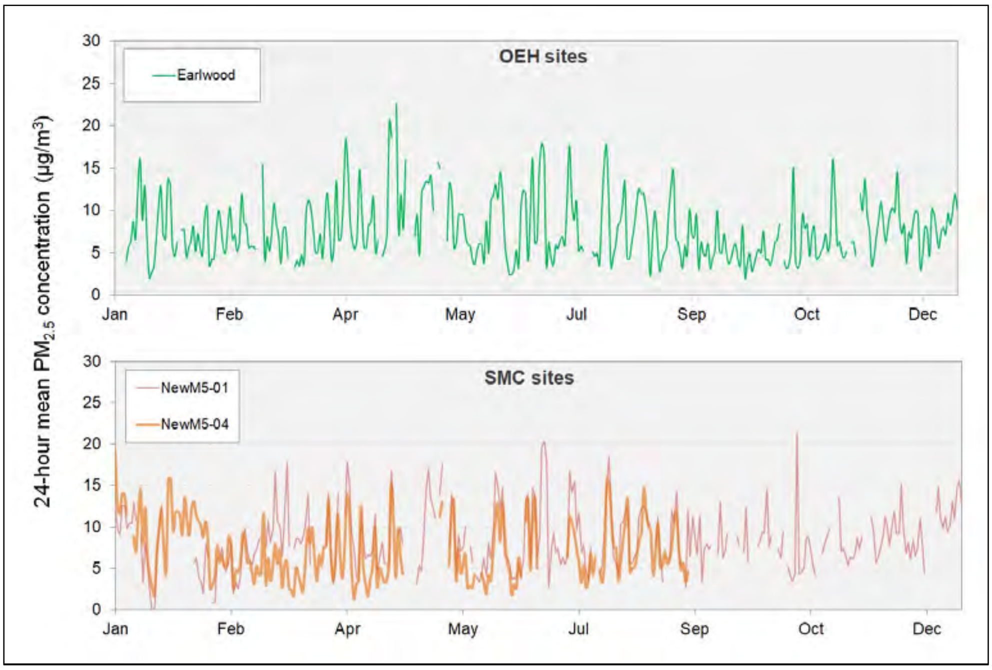

Figure D-22 **24-hour mean $PM_{2.5}$ concentration at OEH and SMC stations in 2016**

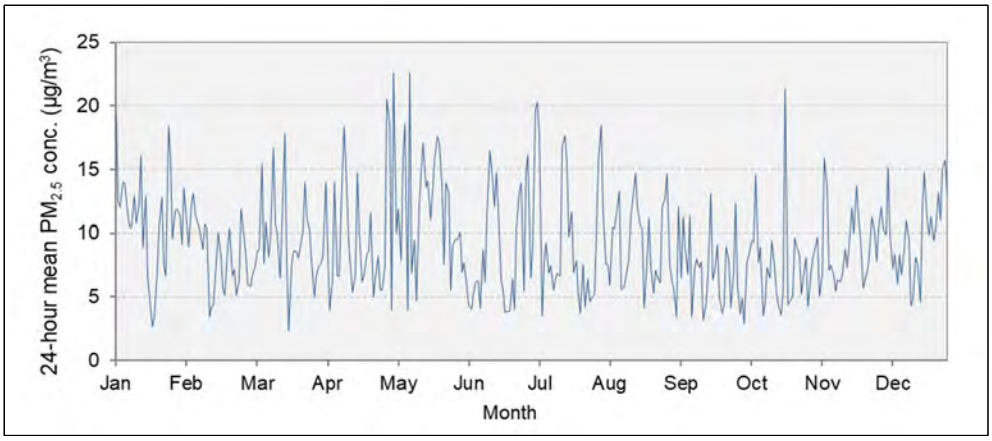

Figure D-23 **Synthetic background concentration profile for 24-hour mean $PM_{2.5}$ in 2016**

D.9.3 Annual mean background concentrations at RWR receptors

In the case of annual mean concentrations it is relatively straightforward to define background values. For smaller projects it has often been sufficient to use a single background value, and to assume that this is representative of the whole study area. However, for a project such as F6 Extension, which covers a large geographical area and features different types of land use, it was considered important to allow for spatial variation in annual mean concentrations where possible. Maps of background annual mean concentrations of the most important road transport pollutants pollutants (NO_X, PM_{10} and $PM_{2.5}$) were therefore developed for the GRAL domain. When developing these maps the data from any non-background stations were excluded.

The background maps were created in the Golden Software Surfer package using a geostatistical Kriging method, whereby gridded values are interpolated based on the statistical relationship of the surrounding measured values. Clearly, the absence of monitoring data for much of the GRAL domain meant that there was some uncertainity in the extrapolation. For the creation of the background maps the data from all background stations in Sydney with relevant measurements were used.

To determine background pollutant concentrations for any discrete receptor location within the GRAL domain, the 'grid residual' function in Surfer was used. This function calculates the difference between the grid value and a specified data value at any x-y location. By setting the data value for a given x-y point to zero, it can be used to return the estimated concentration for the point. Although this approach did not allow for localised influences on background concentrations, it was considered to be better than the alternatives (e.g. using a single annual mean value for the whole domain).

D.9.3.1 NO_X: annual mean

It was noted in the trend analysis that there was a spatial variation in NO_X concentrations. To allow for this spatial variation, the data from the OEH and SMC background monitoring stations were used to determine a background map for annual mean NO_X across Sydney in 2016, as shown in Figure D-24. The GRAL domain is also identified in the Figure. The Roads and Maritime M5 East stations were not used in the development of these maps as they resulted in a localised and adjacent ares of relatively low and high concentration. It was therefore assumed that these stations were spatially unrepresentative of the general pattern if NO_X concentrations across the domain.

The Figure shows that there was a decreasing NO_X concentration gradient across Sydney, from the south-west to the north-east. This was also the case for the GRAL domain, with concentrations decreasing from around 48 µg/m^3 in the south-west to around 34 µg/m^3 in the north-east.

Because measurements were made at only three stations in the GRAL domain in 2016, the NO_X gradient was somewhat uncertain. However, data from the F6 Extension background monitoring station (F6:01) in December of 2017 and January of 2018 were compared statistically with the data from the OEH Earlwood, OEH Randwick and SMC New M5:01 stations during the same period (Table D-17).

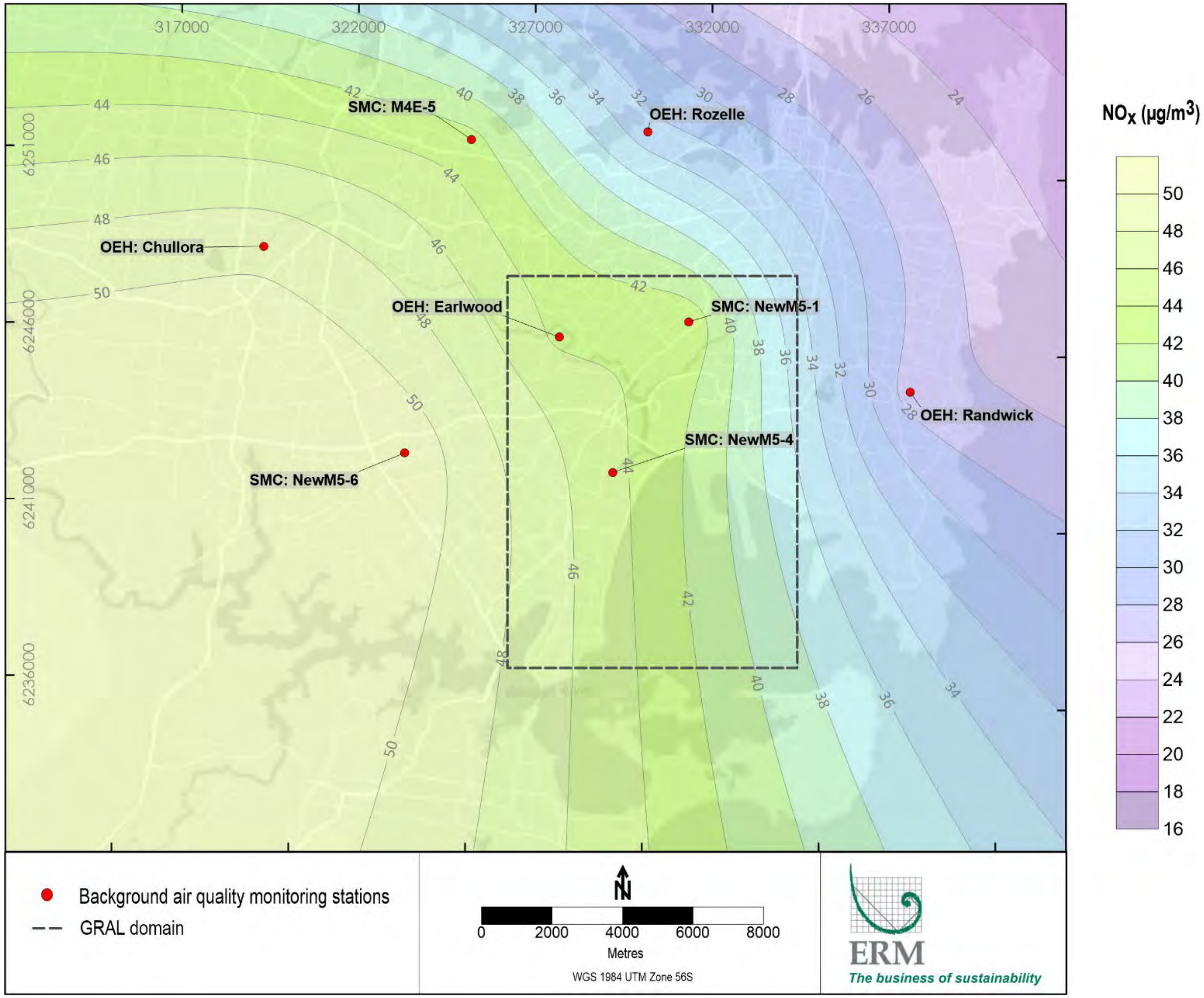

Figure D-24 **Background map for annual mean NO_X concentration across Sydney in 2016**

Table D-17 NO_X concentrations at OEH, SMC and F6 stations (December 2017 and January 2018)

Statistic for period	1-hour mean NO_X concentration (µg/m^3)			
	OEH Earlwood	OEH Randwick	SMC New M5:01	F6:01
Mean	20.7	7.9	26.6	**25.4**
Median	12.3	2.1	17.9	**17.7**
Max	219.6	127.2	412.5	**203.1**
98th percentile	104.7	61.6	93.8	**99.3**

The F6:01 station is close to the centre of the GRAL domain, and the background map suggests that the annual mean NO_X concentration in 2016 at this location would be similar to those at the Earlwood, and NewM5:01 stations, and around 18 µg/m^3 higher than at Randwick. This patterns is well reflected in the statistics in Table D-17, providing evidence that the background NO_X concentration gradient in the GRAL domain is reasonably accurate.

D.9.3.2 PM_{10}: annual mean

The background map for annual mean PM_{10} in Sydney in 2016 is shown in Figure D-25. As with NO_X, there was a localised concentration low point to the north-west of Sydney Airport, associated with the Roads and Maritime M5 East stations (not shown). This may have been real or may have been related to differences in the PM_{10} measurement technique. However, it appeared to be unrepresentative of the general pattern, and therefore the M5 East stations were removed.

Compared with NO_X, the concentration gradient for PM_{10} across the GRAL domain was quite small ranging from around 16.8 µg/m^3 in the north-west to around 19.3 µg/m^3 in the south. As with NO_X, the size of the PM_{10} gradient was somewhat uncertain, and again the data from the F6:01 station in December of 2017 and January of 2018 were compared statistically with those from the OEH, SMC and F6 stations during the same period (Table D-18).

Table D-18 PM_{10} concentrations at OEH, SMC and F6 stations (December 2017 and January 2018)

Statistic for period	1-hour mean PM_{10} concentration (µg/m^3)			
	OEH Earlwood	OEH Randwick	SMC New M5:01	F6:01
Mean	20.8	22.9	29.5	**21.0**
Median	20.2	21.8	27.0	**20.0**
Max	105.8	76.5	164.0	**65.0**
98th percentile	44.2	51.2	77.0	**41.0**

The background map indicates that the annual mean PM_{10} concentration in 2016 at the F6:01 station would be around 0.4 µg/m^3 higher than that at the NewM5:01 station, around 1.5 µg/m^3 higher than that at Randwick, and around 2 µg/m^3 higher than at Earlwood. Whilst the values in Table D-18 do not quite match this pattern (especially for the NewM5:01 station[6]), when allowing for differences in year and time of year they do indicate that the background PM_{10} gradient in the GRAL domain is likely to be reasonably accurate for 2016.

[6] The NewM5:01 station had elevated PM_{10} concentrations between 14 and 18 January 2018, which appear to have originated from a local source (possibly construction dust associated with the construction of the New M5 project, although this would require further investigation).

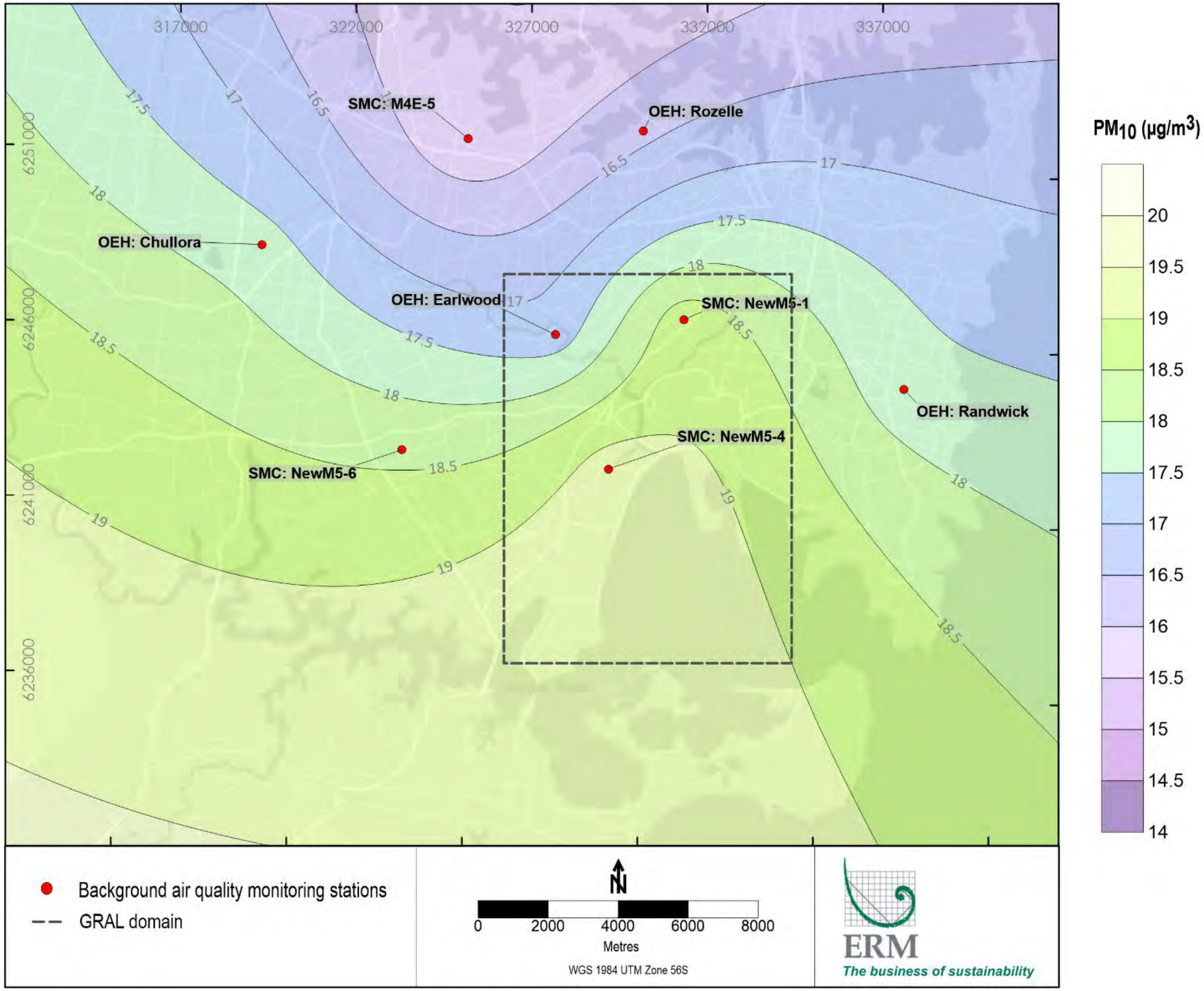

Figure D-25 Background map for annual mean PM_{10} concentration across Sydney in 2016

D.9.3.3 $PM_{2.5}$: annual mean

The background map for annual mean $PM_{2.5}$ in Sydney in 2016 is shown in Figure D-26. The concentration range across the GRAL domain was small, varying from around 7.3 µg/m^3 in the north-west to around 9.1 µg/m^3 in the south-east. $PM_{2.5}$ was not measured at Randwick in 2016.

The data from the F6:01 station in December of 2017 and January of 2018 were compared statistically with those from the OEH and SMC stations during the same period (Table D-19). The background map suggests that the annual mean PM_{10} concentration in 2016 at the F6:01 station would be around 0.4 µg/m^3 higher than that at NewM5:01 and around 1.3 µg/m^3 higher than that at Earlwood. Overall, the data from the F6:01 station do provide a definite confirmation of the $PM_{2.5}$ gradient in the GRAL domain.

Table D-19 $PM_{2.5}$ concentrations at OEH and WHTBL stations (December 2017 and January 2018)

Statistic for period	1-hour mean $PM_{2.5}$ concentration (µg/m^3)			
	OEH Earlwood	OEH Randwick	SMC New M5:01	F6:01
Mean	7.1	7.4	7.5	**6.7**
Median	6.6	6.6	7.0	**6.0**
Max	51.7	38.5	63.0	**24.0**
98th percentile	17.6	23.4	18.0	**19.0**

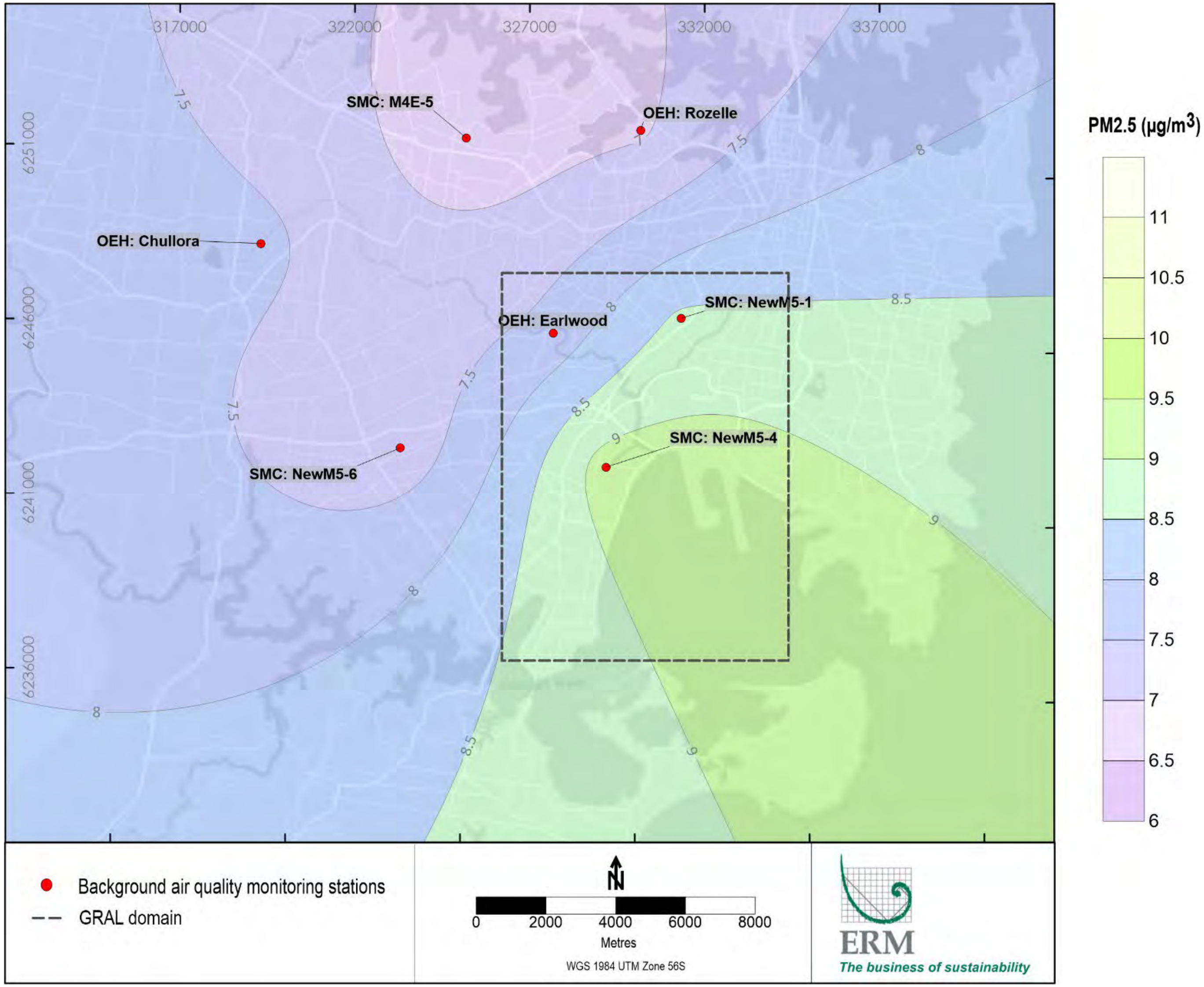

Figure D-26 **Background map for annual mean $PM_{2.5}$ concentration across Sydney in 2016**

D.9.4 Background concentrations for short-term metrics at RWR receptors

In the WestConnex assessments the background concentrations for short-term metrics at all RWR receptors were taken to be single values - either the 98th percentile (M4 East, New M5) or the maximum (M4-M5 Link) of the synthetic profile - that did not vary in space. This corresponds to the 'Level 1' method in the NSW Approved Methods. In the case of the M4-M5 Link assessment, this contributed to an over-prediction of concentrations at some RWR receptors (Pacific Environment, 2017). However, given the limited amount of air quality monitoring data in the GRAL domain, it was also necessary to retain this approach for the F6 Extension – Stage 1 project. It should be noted that the approaches described below for RWR receptors were also applied to the development of the contour plots for the corresponding pollutant metrics.

D.9.4.1 CO

For RWR receptors the maximum 1-hour CO concentration from GRAL was added to the maximum 1-hour background concentration from the synthetic profile (3.13 mg/m^3). The result from the above calculation was also used to derive the maximum rolling 8-hour CO concentration using a relationship based on the data from the air quality monitoring stations in Sydney between 2004 and 2016 (Figure D-27). This relationship is expressed in Equation D1.

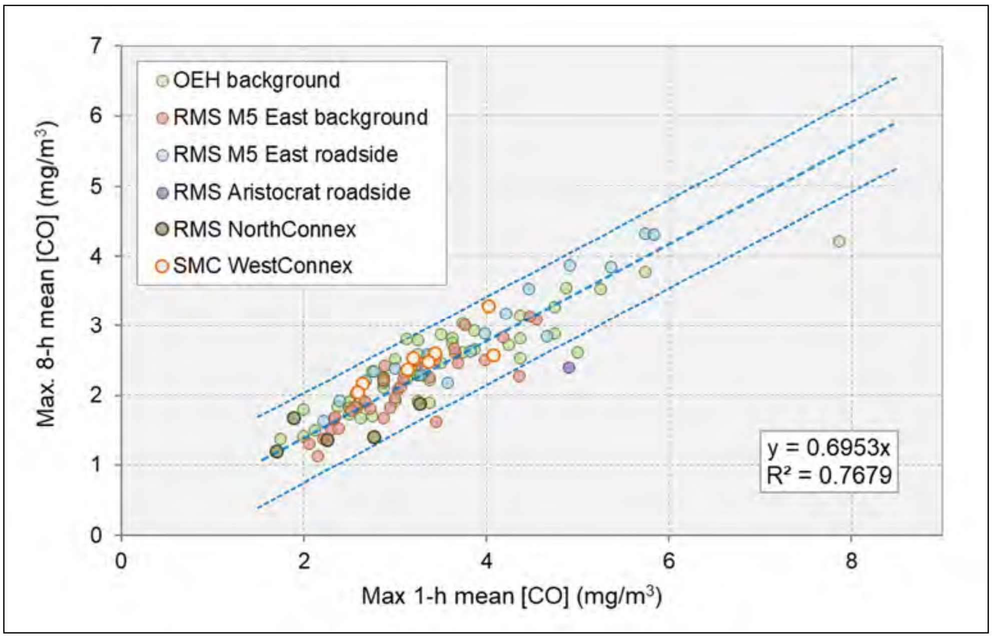

Figure D-27 Relationship between maximum rolling 8-hour mean CO and maximum 1-hour mean CO (dotted blue lines show 95 per cent prediction intervals)

Equation D1

$$[CO]_{8h,max} = 0.6953 \times [CO]_{1h,max}$$

Where:

$[CO]_{8h,max}$ = maximum rolling 8-hour CO concentration (including background) (mg/m^3)

$[CO]_{1h,max}$ = maximum 1-hour CO concentration (including background) (mg/m^3)

D.9.4.2 NO_X, PM_{10} and $PM_{2.5}$

For NO_X the maximum 1-hour concentration from GRAL was added to the maximum 1-hour concentration from the synthetic background profile (589 µg/m^3), and the resulting total was converted to NO_2 using the empirical approach described in Annexure E.

For PM_{10} and $PM_{2.5}$ the maximum 24-hour concentration from GRAL was added to the maximum 24-hour concentration from the synthetic background profile (43.6 µg/m^3 for PM_{10} and 22.6 µg/m^3 for $PM_{2.5}$).

D.9.5 Summary of background concentration approaches

The approaches used to characterise background concentrations for community and RWR receptors, and some basic statistics, are provided in Table D-20.

Table D-20 Characteristics of assumed background concentrations (year = 2016)

Pollutant/ metric	Averaging period	Form	Units	Statistical descriptors		
				Mean	Max.	98th percentile
Community receptors – contemporaneous assessment						
CO	1-hour	Synthetic profile	mg/m^3	0.43	3.13	1.34
	8 hour (rolling)	Synthetic profile	mg/m^3	0.43	2.37	1.19
NO_X	Annual, 1-hour	Synthetic profile	µg/m^3	56.2	589.0	257.2
PM_{10}	Annual, 24-hour	Synthetic profile	µg/m^3	19.7	43.6	34.6
$PM_{2.5}$	Annual, 24-hour	Synthetic profile	µg/m^3	9.2	22.6	18.6
RWR receptors – statistical assessment						
CO	1-hour	Maximum	mg/m^3	-	3.13	-
	8 hour (rolling)	Not applicable (see Equation D1)				
NO_X	Annual	Map	µg/m^3	Spatially varying	-	-
	1-hour	Maximum	µg/m^3	-	589.0	-
PM_{10}	Annual	Map	µg/m^3	Spatially varying	-	-
	24-hour	Maximum	µg/m^3	-	43.6	-
$PM_{2.5}$	Annual	Map	µg/m^3	Spatially varying	-	-
	24-hour	Maximum	µg/m^3	-	22.6	-

D.10 Limitations

It is important to understand the limitations of the various approaches for combining model predictions with background concentrations, and the inherent uncertainty in the overall results.

For annual mean concentrations the approaches used were considered to be robust, taking into account the spatial variation in the background concentration with reasonable accuracy. However, for short-term metrics there is always more uncertainty in both the model predictions and the background. Measured short-term concentration peaks vary considerably in terms of the magnitude, time of occurrence and location. It is well know that models do not accurately predict peak concentrations in both time and space. Secondly, it is very difficult to define both the spatial and temporal variation in short-term background concentrations in great detail, especially where the monitoring data are not very extensive.

The uncertainty in the prediction of short-term concentrations relates to both the contemporaneous and statistical approaches used in this assessment, as noted below.

D.10.1 ‘Contemporaneous’ approach

The contemporaneous approach gives a good representation of the *temporal* variation in model predictions and background concentrations. As the temporal variation in concentrations is generally more pronounced than the spatial variation, it is usually considered to be more important to focus on this.

The main shortcoming of the contemporaneous approach is that a single background profile is applied across a wide geographic area, whereas peak concentrations vary spatially. For example, for NO_X the monitoring data for all stations and years were analysed to determine the relationships between the annual mean concentration and various short-term concentration metrics (eg. maximum, 98th percentile). The relationship between the annual mean concentration and the maximum 1-hour concentration was found to be strong (Figure D-28, R^2 = 0.74). For the annual mean and the 98th percentile 1-hour concentration the relationship was very strong (Figure D-29, R^2 = 0.90). Given that the annual mean NO_X concentration varies spatially, it can be inferred that the peak concentrations would also vary spatially. Consequently, it is likely that that the synthetic profile would underestimate peak concentrations and some locations, and would over estimate concentrations at other locations (given the conservative nature of the synthetic profile, the latter would be more likely to occur). A similar logic applies to 24-hour concentrations of PM_{10} and $PM_{2.5}$.

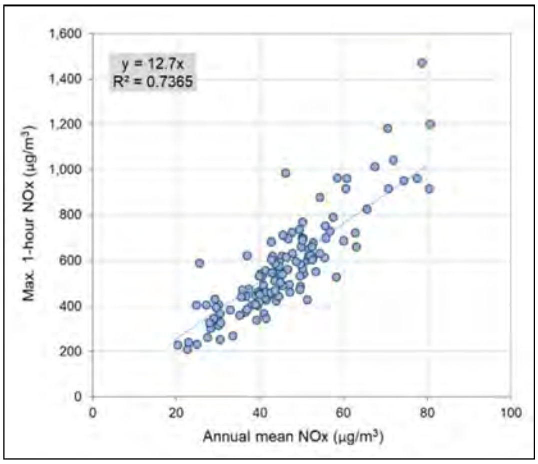

Figure D-28 Relationship between annual mean and maximum 1-hour NO_X

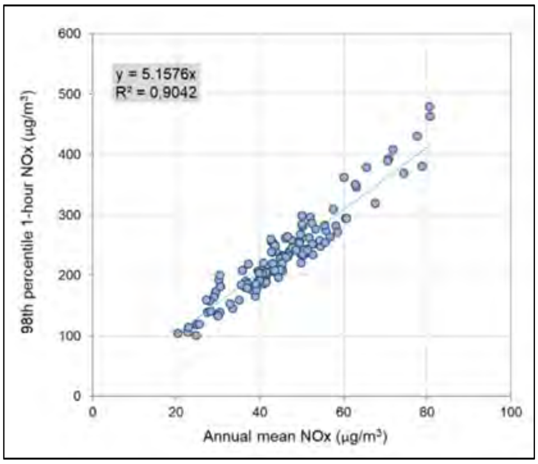

Figure D-29 Relationship between annual mean and 98th percentile 1-hour NO_X

D.10.2 ‘Statistical’ approach

For RWR receptors a single (maximum) value was used for short-term background concentrations. However, such an approach can be very conservative, and can result in unrealistically high cumulative concentrations; it is very unlikely that the maximum background values will coincide in space and time with the maximum predicted values.

For NO_X and PM_{10}, consideration was given to the use of the (very strong) relationship between the annual mean concentration and the 98th percentile 1-hour or 24-hour concentration (eg. Figure D-29) in conjunction with the annual mean map to give a spatially-varying 98th percentile background for the RWR receptors. However, this would have been inconsistent with the contemporaneous assessment for the community receptors, and it is possible that the use of the 98th percentile background could have meant that the maximum total NO_2 concentrations at most RWR receptors would have been underestimated. Specifically, it was found that, in the contemporaneous assessment, the maximum total concentration very frequently coincided in time with the maximum background concentration. For the community receptors there would therefore be a poor relationship between the results for the contemporaneous and statistical approaches when the background for the latter is linked to the annual mean (basically, there would be a lot more variation in the results for the statistical approach). The use of the single maximum background concentration for NO_X and PM_{10} across the domain gave slightly higher results as the contemporaneous approach (see Figure D-30 and Figure D-31). Nevertheless, as noted earlier, the contemporaneous approach has some spatial uncertainty.

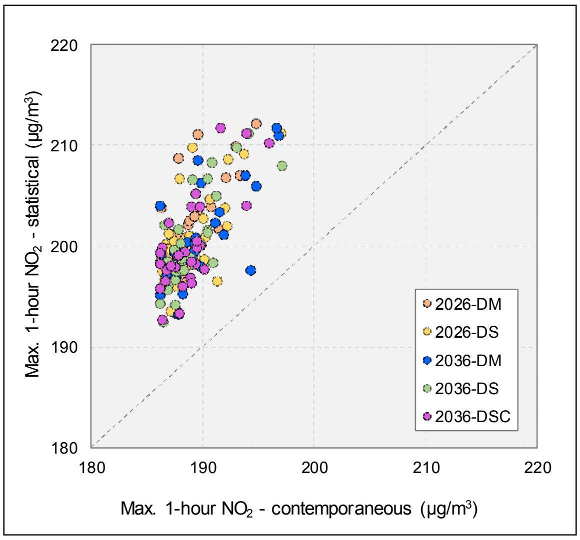

Figure D-30 Comparison between statistical and contemporaneous approaches for calculating 1-hour NO_2 at community receptors (maximum background NO_X)

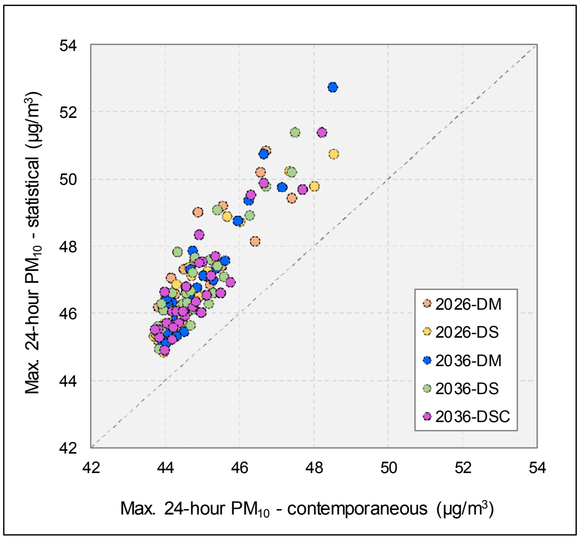

Figure D-31 Comparison between statistical and contemporaneous approaches for calculating maximum 24-hour PM_{10} at community receptors (maximum background PM_{10})

For $PM_{2.5}$ the relationships between the annual mean and peak concentrations were much weaker than for NO_X and PM_{10} (R^2 = 0.03 for the maximum 24-hour, and R^2 = 0.25 for the 98th percentile 24-hour). Therefore, there was no alternative approach that could have been used for background $PM_{2.5}$ at RWR receptors. As with NO_2 and PM_{10}, the use of a single maximum background concentration in combination gave slightly higher concentrations than the contemporaneous method (Figure D-32).

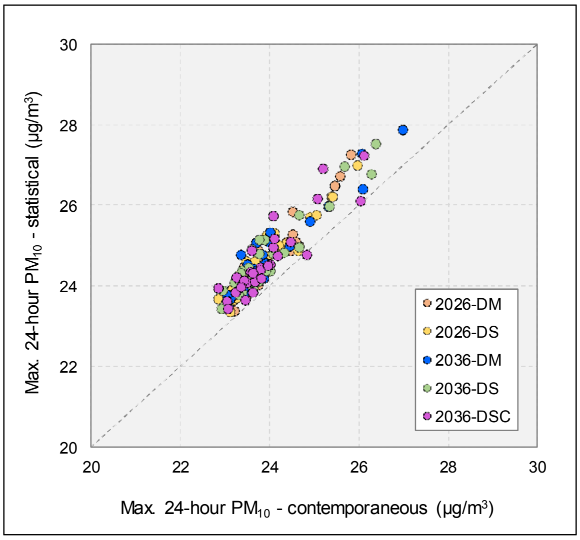

Figure D-32 Comparison between statistical and contemporaneous approaches for calculating 24-hour $PM_{2.5}$ at community receptors (maximum background $PM_{2.5}$)

D.11 Measurements at project stations

As noted earlier, two project-specific monitoring stations for the F6 Extension were established in 2017 (see Table D-1). One of these was at a background location, and the other at a location near a busy roads. Given the date of deployment, the time period covered was too short for these to be included directly in the development of background concentrations and for model evaluation. However, the data from the stations from December 2017 to June 2018 are presented in this Annexure.

For background air quality, the data from the F6:01 station have been compared with the the range of measurements at OEH/SMC stations, and these comparisons are shown in Figure D-33 to Figure D-38. Some basic statistics for the F6 Extension stations are also provided in Table D-21. Only the stations closest to the project and had data for the period (i.e. Chullora, Earlwood, Randwick, Rozelle and NewM5:01) were included in the evaluation. This work expanded upon the comparisons between F6:01 and the OEH/SMC stations earlier in this Annexure.

Each figure shows the following:

- The 1-hour time series for the project background and roadside stations.
- For station F6:01, the comparsion with the OEH/SMC data for the daily mean and daily maximum concentrations. The 24-hour averaging period was chosen as a convenient way of representing the whole monitoring period while retaining some of the temporal detail.

It is worth noting that background stations are located so as to characterise regional air quality, and therefore the data ought to show similar patterns from station to station, albeit with some variation in absolute concentrations. The data from roadside stations are, on the other hand, dependent on additional factors - such as the type of road (level in hierarchy), the level of traffic, and the distance between the road and the monitoring station - and are inherently more variable.

Given that the various monitoring stations are located at a range of stations across Sydney, differences in concentration are to be expected. It is therefore more helpful to consider the general patterns in the data than features of specific stations.

Average CO concentrations at the F6:01 station were broadly comparable to those at the OEH/SMC stations. It is worth observing that all the measured 1-hour CO concentrations were well below the corresponding criterion of 30 mg/m^3, and any differences between the OEH and F6 Extension data would not have had a material impact on the outcomes of the assessment for this pollutant.

For NO_X, NO_2 and O_3 the average measurements at the F6:01 station were comparable to those at the OEH/SMC sites, and showed broadly similar patterns in terms of peak concentrations. However, for NO_X not all of the concentration peaks in the OEH/SMC data were apparent in the F6:01 data. This suggests that the the use of the OEH/SMC stations could have resulted in rather conservative maximum concentrations of NO_2 in the air quality assessment.

The average PM_{10} and $PM_{2.5}$ measurements at the F6:01 station were very similar to those at the OEH stations. Various peaks in the OEH/SMC data were not apparent in the data for the F6:01 station, which again suggests that the maximum concentrations in the air quality assessment would be conservative.

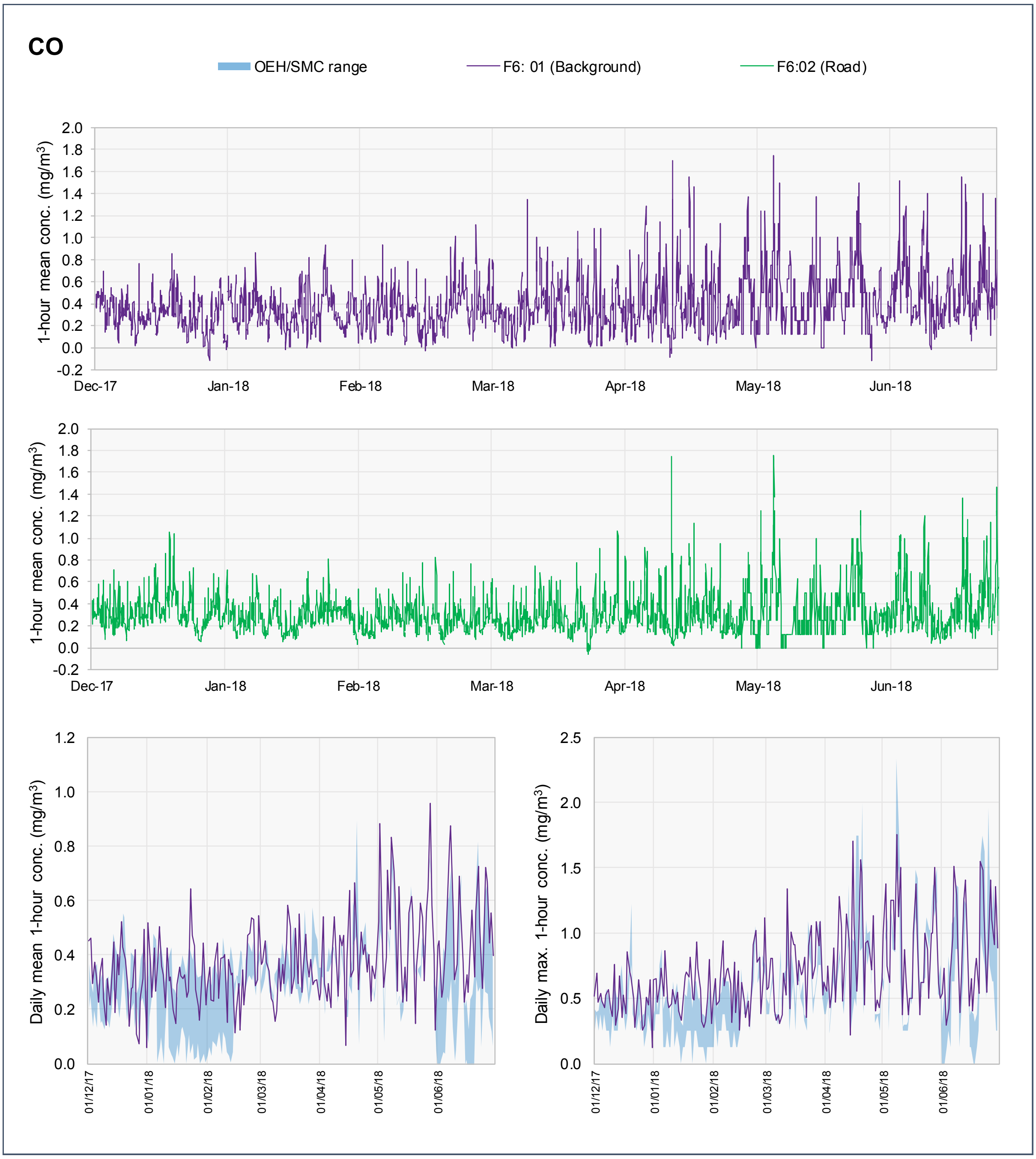

Figure D-33 **CO concentrations at project monitoring stations (blue shading shows range of values at OEH stations)**

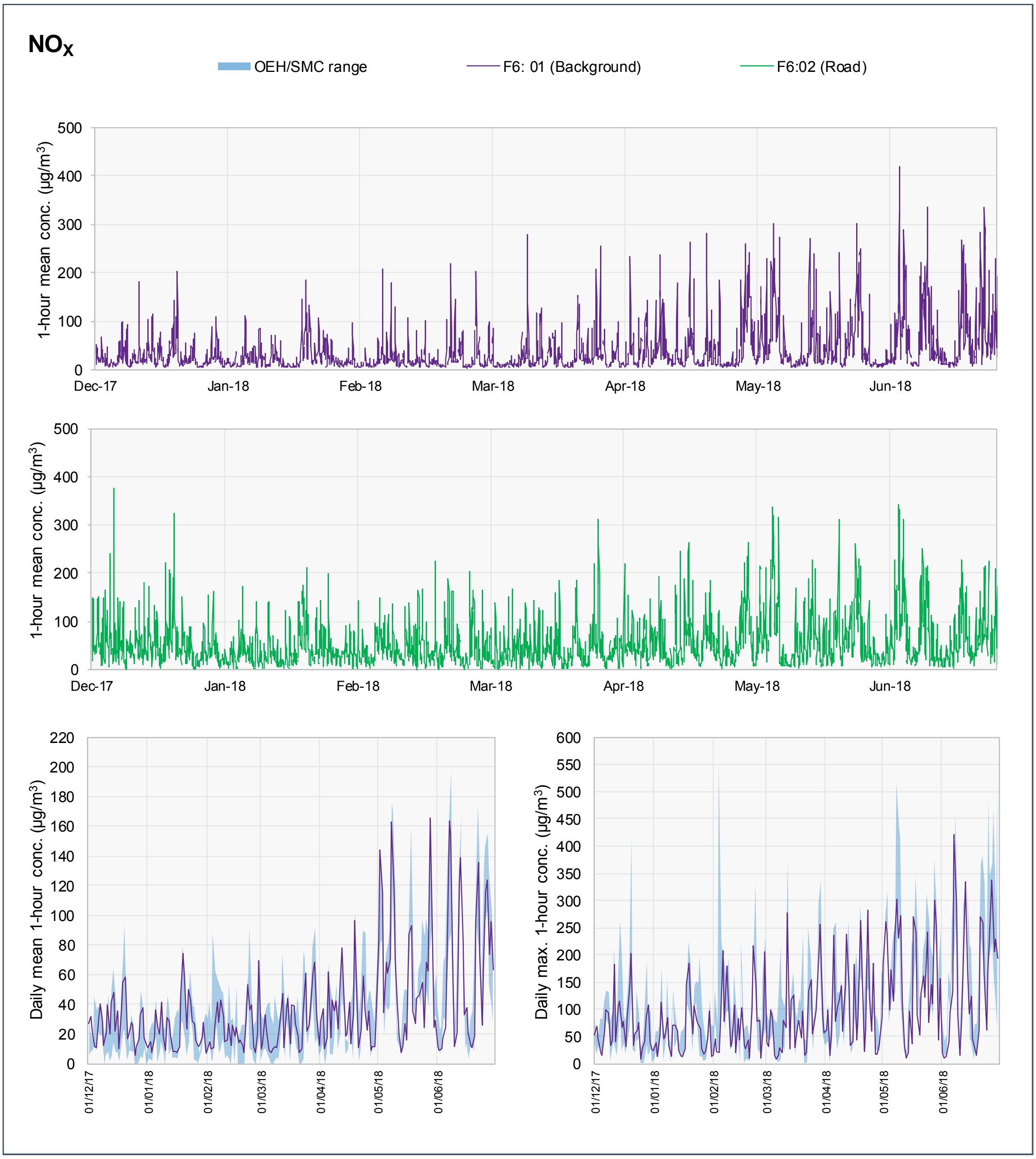

Figure D-34 **NO_X concentrations at project monitoring stations (blue shading shows range of values at OEH stations)**

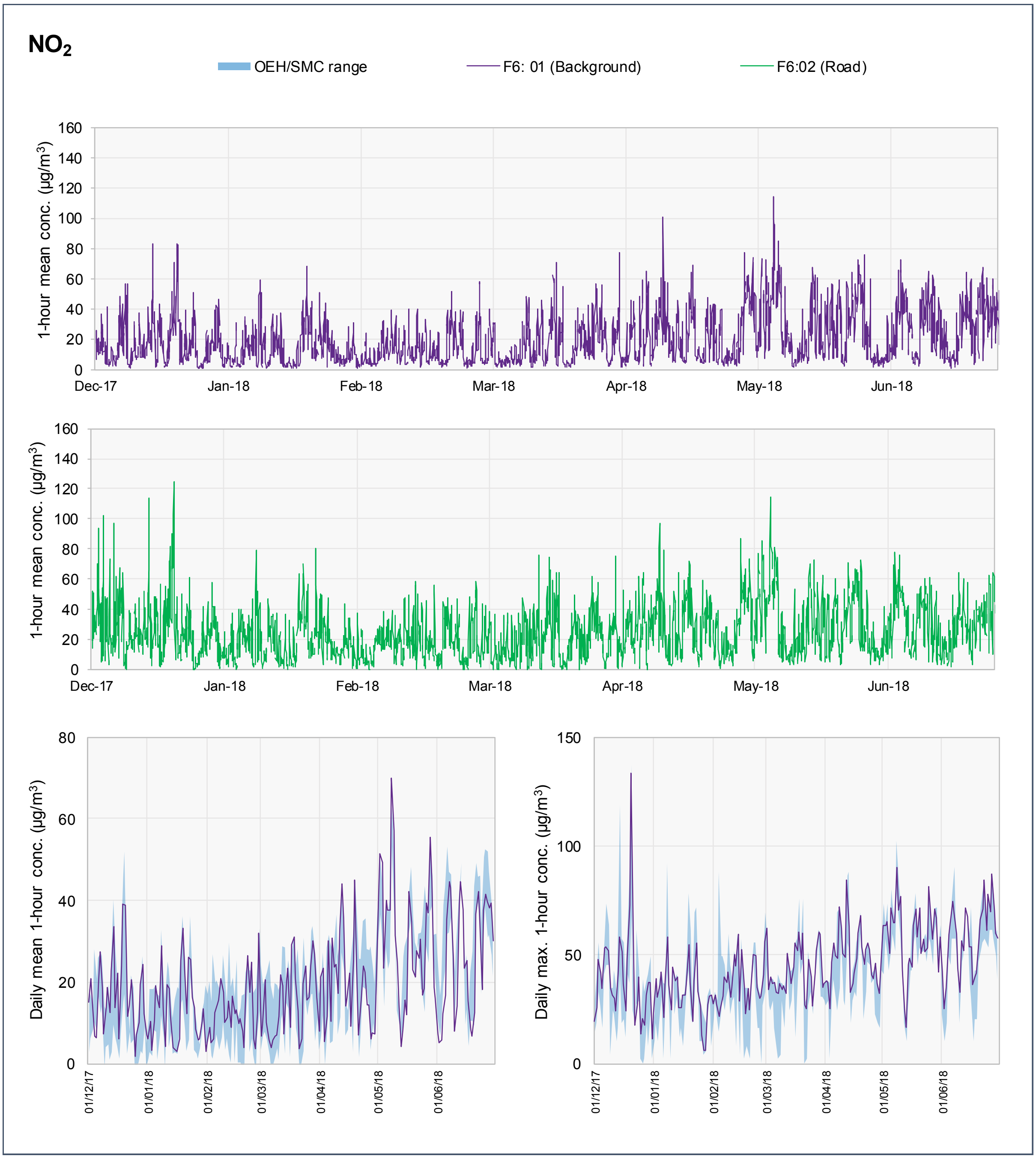

Figure D-35 NO$_2$ concentrations at project monitoring stations (blue shading shows range of values at OEH stations)

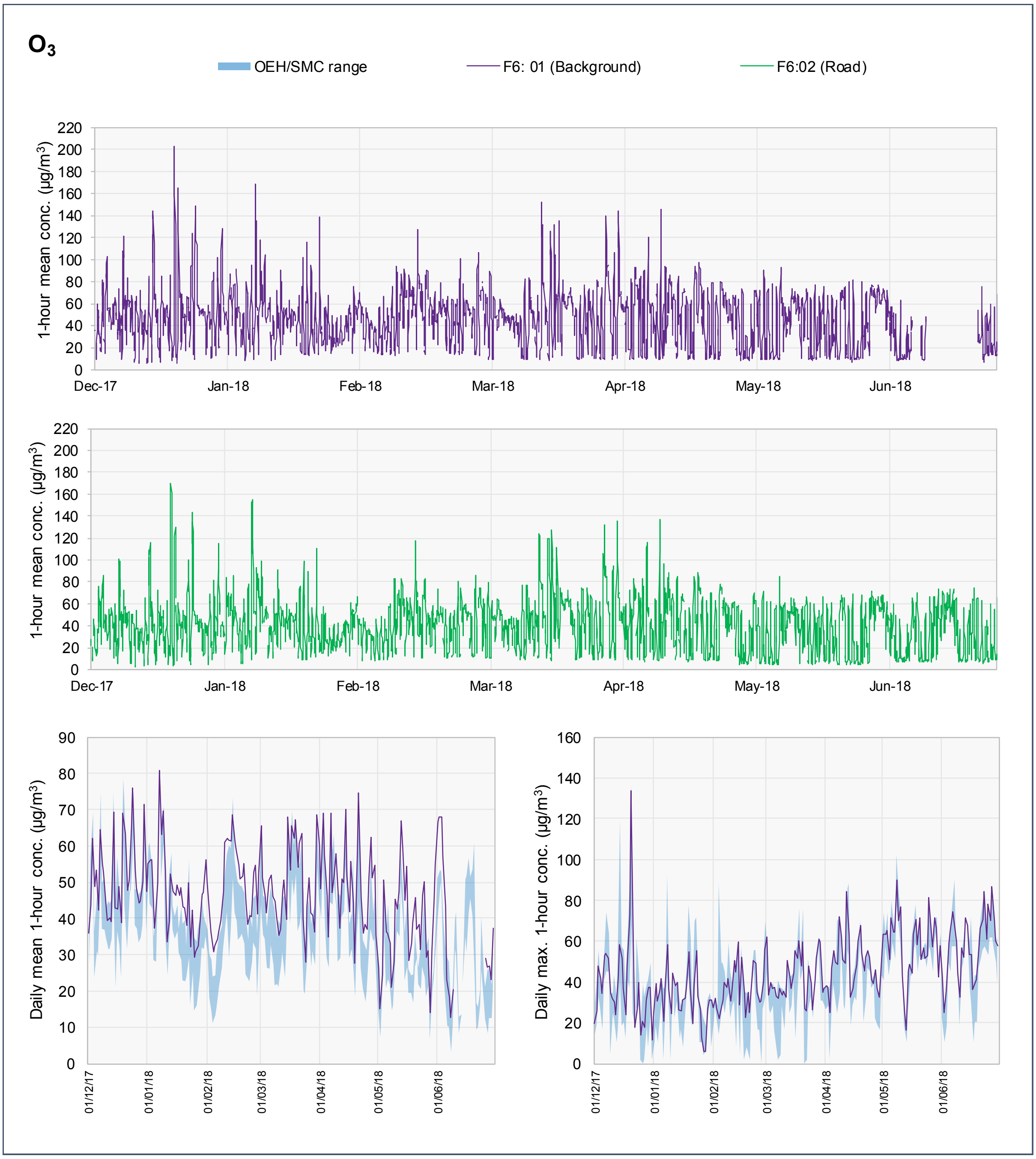

Figure D-36 O_3 concentrations at project monitoring stations (blue shading shows range of values at OEH stations)

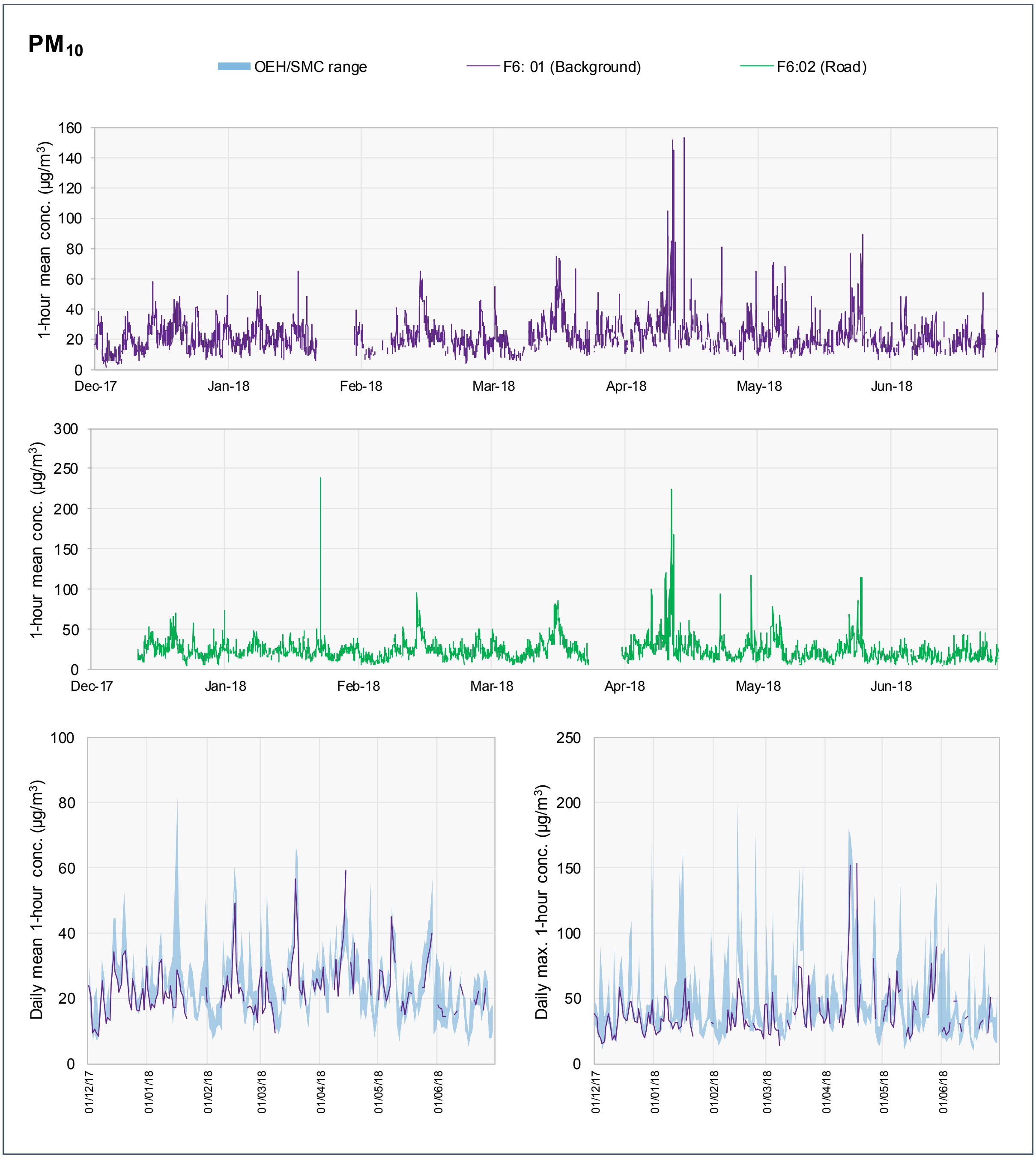

Figure D-37 **PM_{10} concentrations at project monitoring stations (blue shading shows range of values at OEH stations)**

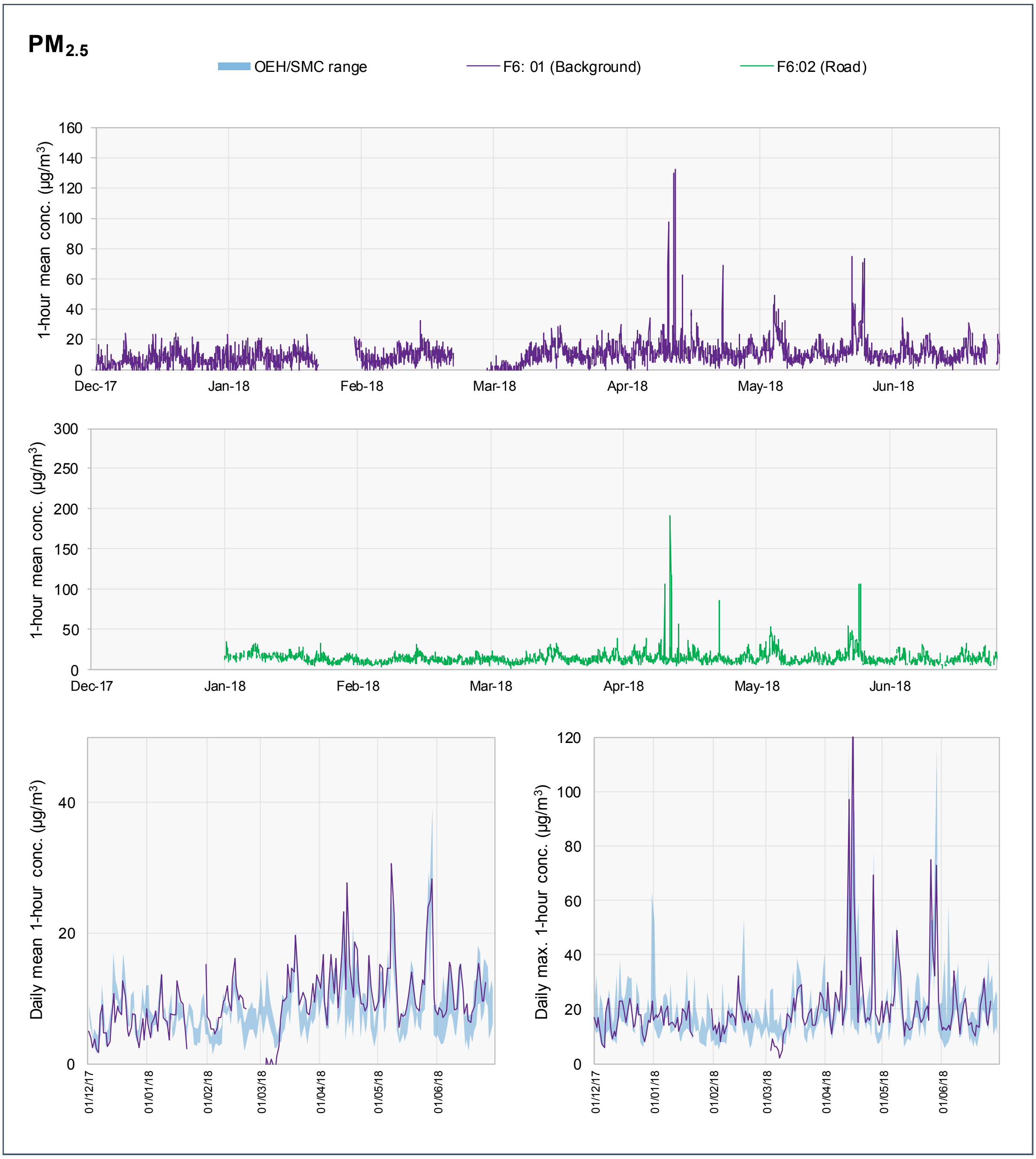

Figure D-38 **$PM_{2.5}$ concentrations at project monitoring stations (blue shading shows range of values at OEH stations)**

Table D-21 Pollutant concentrations at F6 Extension stations (December 2017 to June 2018)

Statistic	1-hour concentration		24-hour concentration	
	F6:01 (Background)	F6:02 (Road)	F6:01 (Background)	F6:02 (Road)
CO (mg/m^3)				
Mean	0.38	0.31	0.38	0.31
Median	0.34	0.27	0.36	0.30
Max	1.75	4.15	0.96	0.79
98th percentile	1.01	0.86	0.78	0.59
NO_X (µg/m^3)				
Mean	37.2	52.8	37.2	52.8
Median	19.7	38.9	27.0	47.7
Max	419.8	377.1	165.7	176.0
98th percentile	194.5	194.0	142.8	143.5
NO_2 (µg/m^3)				
Mean	19.5	24.4	15.1	24.4
Median	14.0	20.9	13.7	22.4
Max	114.3	124.4	39.1	69.4
98th percentile	61.8	65.8	37.7	54.4
O_3 (µg/m^3)				
Mean	46.6	40.4	46.8	40.5
Median	47.6	40.6	46.7	39.8
Max	203.3	170.4	80.7	75.9
98th percentile	104.5	94.0	70.1	67.4
PM_{10} (µg/m^3)				
Mean	22.6	24.6	23.2	24.7
Median	20.0	22.0	21.9	23.1
Max	153.0	239.0	59.4	63.8
98th percentile	52.3	58.0	44.8	52.2
$PM_{2.5}$ (µg/m^3)				
Mean	9.8	14.7	9.7	14.6
Median	9.0	13.0	9.0	13.4
Max	132.1	191.0	30.6	42.0
98th percentile	28.1	32.0	24.3	28.2

Annexure E - NO_X to NO_2 conversion

Annexure E - NO_X-to-NO_2 conversion

E.1 Overview

Some atmospheric pollutants have slow chemical reaction rates, and for air quality modelling on an urban scale they can essentially be treated as inert (Denby, 2011). This is not the case for NO_2 since it is rapidly formed through the atmospheric reaction of NO with O_3, and is destroyed by sunlight during the day (see Annexure B). This is one reason why air pollution models are generally configured to predict NO_X concentrations, with the spread of NO_X being simulated as though it were a non-reactive gas (NZMfE, 2008). However, as air quality criteria address NO_2 rather than NO_X it is necessary to estimate NO_2 concentrations from the modelled NO_X concentrations. Many different approaches to this conversion have been developed over the years, and this Annexure describes some of these. The approach used for the F6 Extension Stage 1 assessment is also detailed.

The estimation of NO_2 concentrations near roads is not straightforward - it requires an understanding of NO_2 formation and destruction, and here there are a number of challenges. These include:

- How to account for the amount of primary NO_2 emitted in vehicle exhaust. This is dependent on the composition of the traffic, and is changing as the vehicle fleet evolves.
- How to account for the amount of conversion of NO to NO_2 in the atmosphere following release from the source, as this is dependent on the local atmospheric conditions, including the amount of ozone available.
- How to determine cumulative NO_2 concentrations, or in other words how to combine the road traffic contribution and the background (non-road) contribution.
- How to provide a realistic estimate of the change (whether this be an increment or decrement) in the NO_2 concentration that results from a road project.

The challenges are also greater for the 1-hour air quality criterion than for the annual mean criterion. For example, the maximum predicted NO_X concentration will not occur during the same hour of the year at all locations in the model domain.

In order to ensure that an appropriate and pragmatic method was selected for the F6 Extension Stage 1 assessment, a review of the literature and data was undertaken. This Annexure presents the findings of the review and contains the following:

- A brief summary of the available guidance relating to the estimation of NO_2 concentrations.
- A review of the methods that are commonly used for estimating NO_2 concentrations. These either involve the use of empirical data or the modelling of atmospheric chemistry. In practice empirical approaches tend to be applied, as local knowledge on the inputs required for modelling chemistry is often incomplete.
- An analysis of the NO_X and NO_2 data from ambient air quality monitoring stations in Sydney, including the monitoring stations that were established specifically for the F6 Extension Stage 1 project. This analysis was used to estimate NO_X-to-NO_2 conversion methods for the specific purpose of the F6 Extension Stage 1 assessment, and more widely for complex road projects in Sydney.

E.2 Guidance on NO_2 estimation

E.2.1 New South Wales

Guidance on the conversion of NO_X to NO_2 is provided in the NSW Approved Methods (NSW EPA, 2016). Three methods are described, from Method 1, the most simple, to Method 3, the most complex.

E.2.2 North America

The USEPA's Guideline on Air Quality Models (GAQM) provides recommendations on the use of air quality models to determine compliance with National Ambient Air Quality Standards (NAAQS). The Guideline is published as Appendix W of 40 CFR Part 51. In this case, three 'Tiers' of assessment are provided, with Tier1 being the simplest and Tier 3 the most complex. Additional guidance on the assessment of 1-hour NO_2 concentrations has recently been provided in the following:

- Applicability of Appendix W Modeling Guidance for the 1-hour NO_2 National Ambient Air Quality Standard, June 28, 2010[1].
- Additional Clarification Regarding Application of Appendix W Modeling Guidance for the 1-hour NO_2 National Ambient Air Quality Standard, March 1, 2011[2].

Other recent guidelines from North America include:

- Modeling Compliance of the Federal 1-Hour NO_2 NAAQS (CAPCOA, 2011).
- Air Quality Model Guideline (Alberta Government, 2013).
- Guidelines for Air Quality Dispersion Modelling in British Columbia (BCMoE, 2008).

E.2.3 New Zealand

The following documents provide guidance on the estimation of NO_2 for air quality assessments in New Zealand:

- Good Practice Guide for Atmospheric Dispersion Modelling (NZMfE, 2004).
- Good Practice Guide for Assessing Discharges to Air from Industry (NZMfE, 2008), which updates the 2004 document.

E.2.4 United Kingdom

Guidance documents from the UK include:

- Review of background air-quality data and methods to combine these with process contributions (Environment Agency, 2006).
- Review of methods for NO to NO_2 conversion in plumes at short ranges (Environment Agency, 2007). This report focusses on the regulation of large industrial point sources.
- Local Air Quality Management Technical Guidance LAQM.TG(16) (Defra, 2016). This document is designed to support UK local authorities in carrying out their duties with respect to air quality management. A number of tools have been developed to support the guidance, including background maps of air pollutants, with year adjustment factors and a calculator that can be used to derive NO_2 from NO_X which is predicted when modelling emissions from roads.

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[1] http://www.epa.gov/scram001/guidance/clarification/ClarificationMemo_AppendixW_Hourly-NO2-NAAQS_FINAL_06-28-2010.pdf

[2] http://www.epa.gov/region7/air/nsr/nsrmemos/appwno2_2.pdf

E.3 Estimation methods

E.3.1 General approaches

In some assessments the road traffic and background concentrations to NO_2 at any given receptor have simply been added together to give the cumulative concentration, i.e.:

Equation E1

$$[NO_2]_{total} = [NO_2]_{road} + [NO_2]_{background}$$

Where:

$[NO_2]_{total}$	is the total estimated NO_2 concentration at the receptor
$[NO_2]_{road}$	is the modelled NO_2 concentration at the receptor due to a road (or roads) in the modelling domain
$[NO_2]_{background}$	is the existing background NO_2 concentration at the receptor due to emissions from all sources other than roads

As the background is often assumed to be fixed, in this formulation the NO_2 increment or decrement associated with a project is simply the change in the value of $[NO_2]_{road}$ for model runs with and without the project. This has to be determined in some way from the road NO_X increment. However, there is a flaw in this approach. Although the road and background contributions to NO_X are additive, this is not the case for NO_2. The potential for oxidising NO to NO_2 is dependent on the amount of ozone that is available, which in turn is dependent on the NO concentration. The higher the existing background NO concentration, the less ozone that is available and the smaller the possibility of oxidising the NO from road vehicles to NO_2.

For any given model prediction/scenario it is therefore more appropriate to determine the total NO_2 concentration from the total NO_X concentration. This can be expressed as follows:

Equation E2

$$[NO_X]_{total} = [NO_X]_{road} + [NO_X]_{background}$$

Equation E3

$$[NO_2]_{total} = f([NO_X]_{total})$$

Where $f([NO_X]_{total})$ is the method used to convert total NO_X to total NO_2.

The NO_2 increment or decrement associated with the project is then calculated as follows:

Equation E4

$$[NO_2]_{project} = [NO_2]_{total\ (with\ project)} - [NO_2]_{total\ (without\ project)}$$

E.3.2 Specific methods

Several methods are available for characterising the transformation of NO to NO_2. These include:

- Total conversion method:
  - Assuming that all NO_X from the emission source being modelled is present as NO_2 (i.e. there is always total conversion of NO to NO_2. This is 'Method 1' in the NSW Approved Methods and the USEPA's 'Tier 1' approach).
- NO_2/NO_X ratio methods, including:
  - Assuming a constant NO_2/NO_X ratio. This is the USEPA's 'Tier 2' approach, which is referred to as the 'ambient ratio method' (ARM).
  - Assuming a variable NO_2/NO_X ratio to all for influences such as the season and distance from source.

  NO_X to NO_2 conversion methods that use ambient ratios are usually based on empirical data. Empirical relationships fall within the 'Method 3' in the NSW Approved Methods.

- Reactant-limited methods, whereby the instantaneous conversion of NO is constrained only by the amount of oxidant(s) available. Such methods include:
  - The 'ozone limiting method (OLM)', in which NO to NO_2 conversion is limited by the amount of ozone available (known as 'ozone titration'). This is 'Method 2' in the NSW Approved Methods, and is a USEPA Tier 3 approach.
  - The plume volume molar ratio method (PVMRM), which is also based on ozone titration. This is a USEPA 'Tier 3' approach. It is not mentioned in the NSW Approved Methods.
- Reactive plume methods. These use complex or simplified atmospheric photochemical reaction schemes which derive NO_2 concentrations from first principles. Such approaches have been incorporated into some of the latest generation of air pollution models.

The different methods presented in the literature are summarised in the following Sections.

E.3.3 Total conversion of NO to NO_2

E.3.3.1 Description

The most basic – and most conservative – method for estimating the NO_2 concentration at a receptor is based on the assumption that all emitted NO is oxidised to NO_2, or in other words all modelled NO_X from roads is present as NO_2:

Equation E5

$$\mathbf{[NO_2]_{road} = [NO_X]_{road}}$$

Equation E6

$$\mathbf{[NO_2]_{total} = [NO_2]_{road} + [NO_2]_{background}}$$

This approach is often used as a screening step; if compliance with air quality standards is obtained using this approach, then it can be assumed that there will be negligible risk of exceedances in reality and more detailed calculations for NO_2 are not required. If, on the other hand, the estimated NO_2 concentrations are close to or higher than the air quality standards then more detailed, less conservative methods should subsequently be applied.

E.3.3.2 Application in NSW Approved Methods

For annual mean concentrations the modelled NO_x concentration is converted to NO_2 (assuming 100% conversion of NO), and the result is then simply added to the background NO_2 concentration.

For 1-hour means, the cumulative concentration can be determined in one of two ways:

- Level 1 (maximum): The maximum modelled 1-hour mean NO_2 concentration is added to the maximum background 1-hour mean NO_2 concentration.
- Level 2 (contemporaneous): Using contemporaneous assessment of model predictions and ambient concentrations. The cumulative NO_2 concentration is determined by adding the modelled 1-hour mean NO_2 concentration with the contemporaneous background 1-hour mean NO_2 concentration.

E.3.3.3 Limitations and performance

This method represents a worst case situation. It does not allow for the availability of ozone or NO_2 destruction through photolysis, and will overestimate NO_2 concentrations. The overestimation will be largest at high NO_X concentrations where NO_2 formation is ozone-limited. This is explored further in Section G5. The total conversion method is therefore of limited use where an accurate estimate of NO_2 is required.

E.3.4 NO_2/NO_X ratio methods

E.3.4.1 Description

Constant ratio

In the USEPA's ARM, the predicted NO_X concentration for a receptor is multiplied by an empirically derived NO_2/NO_X ratio to determine the NO_2 concentration at the receptor. The NO_2/NO_X ratio is based upon average NO_2 and NO_X concentrations in ambient air at a representative site. For example, in the USEPA 'Tier 2' approach the modelled annual mean NO_X concentrations is multiplied by a default NO_2/NO_X ratio of 0.75. For 1-hour concentrations a NO_2/NO_X ratio of 0.80 is used.

Variable ratio

ARM2

A new empirical method, known as ARM2, has recently been developed by the American Petroleum Institute in response to the frequent observation that hourly NO_2 concentrations estimated using the existing USEPA three-tier approach are much higher than observed concentrations. ARM2 is based on an empirical fit to the 98th percentiles of the binned 1-hour NO_2/NO_X and NO_X values collected from different monitoring stations between 2001 and 2010 (RTP, 2013; Podrez, 2015). The USEPA has approved the use of ARM2 for regulatory 1-hour NO_2 assessments under certain circumstances.

Janssen method

The NSW Approved Methods refer to the approach of Janssen et al. (1988). This involves the use of an empirical equation for estimating the oxidation rate of NO in power plant plumes. The equation is dependent on distance downwind from the source, and has the following form:

Equation E7

$$[NO_2]/[NO_X] = A(1 - \exp(-\alpha x))$$

Where:

x = the distance from the source

A and **α** are classified according to the O_3 concentration, wind speed and season; Janssen et al. (1988) provide values for **A** and **α**.

Given that this method requires the distance from the source to be quantified, the method is not suitable for complex road networks.

Defra method

An empirical approach to calculating NO_2 from NO_X concentrations at roadside sites was developed by Defra in the UK in 2002, and has most recently been updated in 2017. The approach takes account of the difference between fresh emissions of NO_X, the background NO_X, the concentration of O_3, and the different proportions of primary NO_2 emissions in different years. The approach has been incorporated into a spreadsheet which is available from the Defra web site[3].

E.3.4.2 Limitations and performance

The ARM2 method has some advantages over other USEPA Tier 3 methods. For example, it does not require ambient ozone data. The performance of the ARM2 method is comparable to that of the OLM and the PVMRM. However, all three methods over-predict NO_2/NO_X ratios (RTP, 2013).

According to NZMfE (2004) the Janssen approach is based upon the rate of diffusion of O_3 into the emission plume rather than the rates of reaction. It is therefore probably only applicable to the particular power station studied, and is of questionable application to other sources. Although the Approved Methods describe the application of the Janssen method to determine annual mean and 1-hour mean concentrations, its lack of applicability to road networks means that it has not been explored in detail in this Annexure. There is little information on how the NO_2/NO_X ratio changes with distance from the road; monitoring data are usually only available for roadside and/or background locations.

Given that it has been developed to represent vehicle fleets and near-road atmospheres in the UK, it is unlikely that the Defra calculator is suitable for use in Sydney, although this ought to be investigated further. However, this was beyond the scope of the F6 Extension Stage 1 assessment.

E.3.5 Reactant-limited methods

E.3.5.1 Description

Ozone limiting method

The USEPA's ozone limiting method (OLM) is one of several reactant-limited approaches. It uses a simple approach to the reaction chemistry of NO and O_3 in order to estimate NO_2 concentrations. It is assumed that all the available O_3 in the atmosphere will react with the NO from the source until either all the O_3 is consumed or all the NO is used up (Cole and Summerhays, 1979; Tikvart, 1996). A slightly different approach to the OLM has been developed for use in New Zealand (NZMfE, 2008).

Plume volume molar ratio method

The plume volume molar ratio method (PVMRM) extends the basic chemistry of the OLM. The PVMRM determines the conversion rate for NO_x to NO_2 based on a calculation of the number of NO_x moles emitted into the plume, and the number of O_3 moles contained within the volume of the plume between the source and receptor. The ratio between the two molar quantities is multiplied by the NO_X concentration to calculate the NO_2 concentration.

Both the OLM and PVMRM require two key model inputs, namely the NO_2/NO_X emission ratio at the source and background ozone concentrations.

[3] https://laqm.defra.gov.uk/review-and-assessment/tools/background-maps.html#NOxNO2calc

E.3.5.2 Implementation in NSW Approved Methods

The USEPA version of the OLM is represented by the equation (NSW EPA, 2016):

Equation E8

$$[NO_2]_{total} = \{0.1 \times [NO_X]_{road}\} + MIN \{(0.9) \times [NO_X]_{road} \text{ or } (46/48) \times [O_3]_{background}\} + [NO_2]_{background}$$

Where:

$[NO_2]_{total}$	=	predicted concentration of NO_2 in µg/m^3
$[NO_X]_{road}$	=	dispersion model prediction of NO_X from roads in µg/m^3
MIN	=	minimum of the two quantities within the braces
$[O_3]_{background}$	=	background ambient O_3 concentration in µg/m^3
(46/48)	=	molecular weight of NO_2 divided by the molecular weight of O_3 in µg/m^3
$[NO_2]_{background}$	=	background ambient NO_2 concentration in µg/m^3

The method involves an initial comparison of the estimated maximum NO_X concentration and the ambient O_3 concentration to determine the limiting factor to NO_2 formation:

- If the O_3 concentration is greater than the maximum NO_X concentration, then total NO_X to NO_2 conversion is assumed.
- If the maximum NO_X concentration is greater than the ozone concentration, the formation of NO_2 is limited by the ambient ozone concentration.

The OLM – in the above form – is based on the assumption that 10% of the initial NO_X emissions are NO_2. The emitted NO reacts with ambient ozone to form additional NO_2. If the ozone concentration is greater than 90% of the predicted NO_X concentration, all the NO_X is assumed to be converted to NO_2. Otherwise, NO_2 concentrations are calculated on the assumption of total conversion of the ozone. The predicted NO_2 concentration is then added to the background NO_2 concentration.

The following approaches are presented in the Approved methods for the 'maximum' and 'contemporaneous' calculations:

- Level 1 (maximum): The maximum 1-hour and annual average background concentrations of NO_2 and O_3 ($[NO_2]_{background}$, $[O_3]_{background}$) are used in Equation E8.
- Level 2 (contemporaneous): Continuous 1-hour average background concentrations of NO_2 and O_3 are obtained for the same period as the dispersion modelling predictions (usually one year). The value of $[NO_2]_{total}$ is then calculated for every hour of the dispersion model simulation by substituting the hourly values of $[NO_X]_{road}$, $[NO_2]_{background}$ and $[O_3]_{background}$ into Equation E8.

As before, the Level 1 approach is used as a screening step. The OLM is usually applied using the Level 2 approach, and this has the advantage of yielding various statistics for NO_2, including:

- The annual mean concentration (based on the 1-hour predictions for a year).
- The maximum concentration.
- Percentile concentration values.
- The frequency with which the 1-hour NO_2 criterion is exceeded.

In the NSW EPA's submission to the EIS for the NorthConnex project in Sydney, it is stated that that an average value for the NO_2/NO_X ratio of 16%[4] would be more appropriate than 10%. The OLM equation should therefore be adjusted as follows (AECOM, 2014b):

Equation E9

$$[NO_2]_{total} = \{0.16 \times [NO_X]_{road}\} + MIN\ \{(0.84) \times [NO_X]_{road}\ or\ (46/48) \times [O_3]_{background}\} + [NO_2]_{background}$$

The effect of the adjustment is to increase the amount of NO_2 emitted directly, potentially increasing the NO_2 concentrations that are predicted under low ambient O_3 concentrations.

E.3.5.3 Limitations and performance

Several limitations of the OLM have been noted in the literature. For example:

- The approach is known to be conservative:
  - The method assumes that the atmospheric conversion of NO to NO_2 occurs instantaneously. In reality, the reaction requires time. This assumption therefore leads to an overestimate of NO_2 concentrations close to the source (NZMfE, 2004).
  - The method assumes that all ozone is available to the emission source being evaluated. The OLM will be too conservative when, for example, a new source is to be located in close proximity to existing sources. The new source will be competing with the existing sources for the available ozone, and the rate of conversion of NO to NO_2 will not be as great as if the new source was in an isolated location (NZMfE, 2004).
  - Ozone is assumed to be uniformly and continuously mixed across the cross section of the plume. The OLM does not account for the molar ratio of NO to ozone in the plume (reactions occur in proportion to the moles of each gas rather than in proportion to the concentrations assumed by the OLM), nor does it account for the gradual entrainment and mixing of ambient ozone in the plume.
  - Situations in which the OLM has been demonstrated to substantially overestimate NO_2 concentrations include during daylight hours when the photochemical equilibrium reverses the oxidation of NO by O_3, and during stable, night-time conditions when both NO_2 and O_3 are removed by reaction with vegetation and other surfaces (NZMfE, 2004).
- The OLM model requires a record of 1-hour average background concentrations over a year. Apart from the expense of obtaining such information at a single location, there are significant problems in locating the monitoring site relative to existing emission sources and a proposed new emission source because of the perceived difficulty of accounting for scavenging of O_3 by NO (NZMfE, 2004).
- The USEPA states that the OLM should only be used on a 'plume-by-plume' basis. This is a severe limitation in relation to road projects.

Some of these limitations also apply to the PVMRM. Because of the different methods used, there are cases where PVMRM will perform better than OLM, and vice versa. The PVMRM better simulates the NO to NO_2 conversion chemistry during plume expansion, and works well for isolated elevated point sources. However, OLM may be the better choice for low-level releases and area sources. For low-level releases the modelled plume may extend below ground level, but the PVMRM will still use the full volume of the plume to estimate the NO_X-to-NO_2 conversion. This may again lead to overly conservative NO_2 concentrations.

[4] This is the upper bound of the estimated ratio used for the in-tunnel modelling in Annexure K for primary NO_2. The in-tunnel modelling considers the ratio variations for different traffic speeds and different tunnel grades.

E.3.6 Reactive plume models

Various photochemical reaction schemes are applied in regional-scale and urban-scale air pollution models. One of the most commonly used is the Generic Reaction Scheme (Azzi *et al.*, 1992). More detailed photochemical models and schemes have been developed in recent years, including the EMEP scheme (Simpson *et al*., 2003), the Carbon Bond-IV mechanism (Gery *et al*., 1989), and the CB05 photochemical mechanism (Yarwood *et al*., 2005).

However, the use of such models is uncommon for regulatory local air quality assessments. A major drawback of these methods is that the near-source chemical reactions may not be well described. Many of the atmospheric chemistry schemes developed for regional and global models include reactions on timescales that are much longer than the residence times of pollutants in urban areas, and as such introduce an additional complexity and computational time that is unnecessary (Denby, 2011). As noted by the Environment Agency (2007) in the UK, care is required to select a chemical mechanism, and advanced photochemical modelling requires a comprehensive set of emissions data for a wide range of compounds (notably hydrocarbons), as well as the appropriate meteorological data. These are major constraints for any regulatory work.

E.4 Development of empirical conversion methods for Sydney

E.4.1 Overview

Various guidance documents recommend the use of local monitoring data, where available, to estimate NO_2 from modelled NO_X. Functions have been fitted to NO_X and NO_2 monitoring data for many years, notably in the form of the 'Derwent-Middleton' equation (Derwent and Middleton, 1996), and this continues to be the case (e.g. Podrez, 2015).

Both NO_X and NO_2 have been measured for several years at a range of stations across Sydney, as described in Annexure E. A substantial amount of data from these stations was used to develop empirical NO_X-to-NO_2 conversion functions for the WestConnex M4 East and New M5 projects (Boulter et al., 2015; Manansala et al., 2015), with separate approaches for annual mean and 1-hour mean NO_2. These functions were also used for the F6 Extension Stage 1 assessment, although the supporting data were updated. One reason for the analysis was to quantify and address the conservatism in some of the other methods in use, whereby exceedances of NO_2 air quality standards can be predicted for a given NO_X concentration, even where the monitoring data show that this situation is extremely uncommon for real-world receptor locations. The methods for the WestConnex projects will also be applicable to other complex road projects in the airshed.

The methods that were developed are described below.

E.4.2 Methods used in the project assessment

E.4.2.1 Annual mean concentrations

Figure E-1 shows the relationship between the annual mean concentrations of NO_X and NO_2 at the monitoring stations in Sydney across all years. As the values shown are measurements, they equate to $\mathbf{[NO_X]_{total}}$ and $\mathbf{[NO_2]_{total}}$. In the low-NO_X range of the graph there is an excess of ozone and therefore NO_2 formation is limited by the availability of NO. In the high-NO_X range there is an excess of NO, and therefore NO_2 formation is limited by the availability of ozone. The Figure also shows that there is not a large amount of scatter in the data, and for this reason a central-estimate approach was considered to be appropriate.

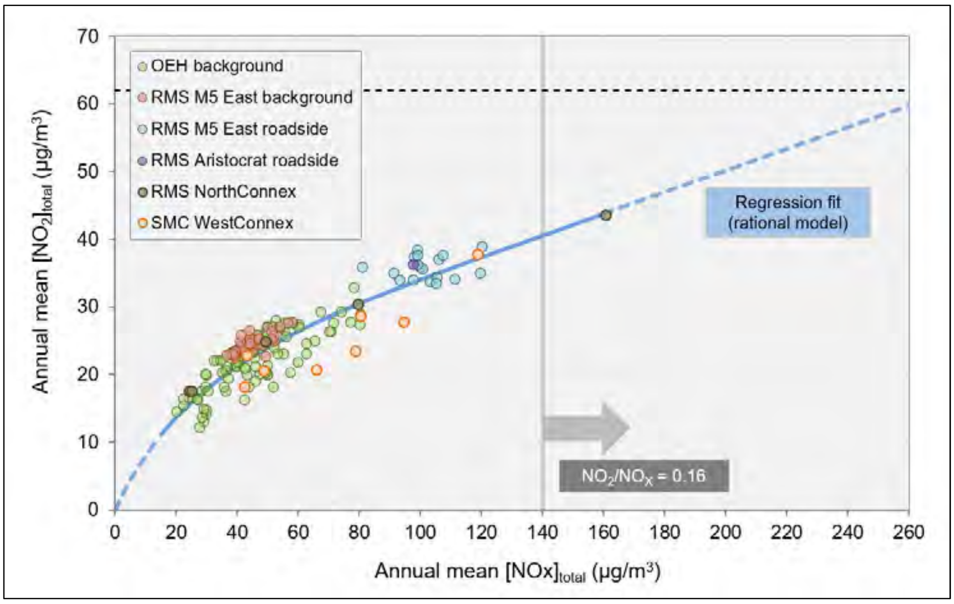


Figure E-1 Annual mean NO_X and NO_2 concentrations at monitoring stations in Sydney

The solid blue in Figure E-1 represents a regression model fit to the data (i.e. the central-estimate situation) which will give the most likely NO_2 concentration for a given NO_X concentration. The function giving the best fit – the rational model – was selected from a large number of alternatives using curve-fitting software. This function, which was used in the F6 Extension Stage 1 assessment, is described by the following equations:

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

Equation E10

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

Where:

a = -7.6313×10^{-4}

b = 9.9470×10^{-1}

c = 2.3750×10^{-2}

d = -4.5287×10^{-5}

For $[NO_X]_{total}$ greater than 140 µg/m^3 it has been assumed that the available ozone has been consumed and so NO_2 is linearly proportional to NO_X with a NO_2/NO_X ratio of 0.16, representing the current f-NO_2 value for vehicle exhaust quoted by NSW EPA in its response to the EIS for the NorthConnex project (AECOM, 2014b):

Equation E11

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

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

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

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

Equation E13

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

Where both $[NO_2]_{total}$ and $[NO_2]_{background}$ were determined using Equations G10 and G11.

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

The use of the function could theoretically lead to exceedances of the annual mean criterion for NO_2 in NSW of 62 μg/m^3. However, a very high annual mean NO_X concentration - more than 260 μg/m^3 - would be required. This is much higher than the measurements in Sydney have yielded to date.

E.4.2.2 One-hour mean concentrations

For the maximum 1-hour mean NO_2 concentrations the situation was more complicated. One-hour mean NO_X and NO_2 concentrations are much more variable than annual mean concentrations. Patterns in the hourly data can be most easily visualised by plotting the 1-hour mean NO_2/NO_X ratio against the 1-hour mean NO_X concentration, as shown for the various monitoring stations in Figure E-2 to Figure E-7. In Figure E-7 the recent and relatively short-term data for the Western Harbour Tunnel and Beaches Link (WHTBL) and F6 Extension Stage 1 stations are shown together.

In each dataset it is clear that for low NO_x concentrations there is a wide range of possible NO_2/NO_x ratios, whereas for higher NO_X concentrations the range is much more constrained. A distinct outer envelope can be fitted to the data which includes all (or very nearly all) the measurement points, and this envelope has a strong inverse relationship with the NO_X concentration. In the envelope the NO_2/NO_X ratio is highest (1.0) at low NO_X concentrations, representing complete, or near-complete, conversion of NO to NO_2. At the high end of the NO_X concentration range the ratio is much lower and levels out at a value of around 0.1. The highest NO_X concentrations occur mostly during the winter months when temperature inversions prevent the effective dispersion of pollution.

Although the range and variability of the data varied by station type, the general patterns in the data were quite consistent. It was therefore considered appropriate to combine the datasets. In particular, the outer envelope of the NO_X:NO_2 ratio was very consistent, and so it was also considered appropriate to define one (conservative) approach to reflect this envelope.

The derivation of a conversion method from these data for the F6 Extension Stage 1 assessment was adapted from that recommended by BCMoE (2008)[5]. This method involved the following steps:

- The range of NO_X concentrations for which the NO_2/NO_X ratio is equal to 1.0 is estimated.
- The NO_X concentration for which NO_2/NO_X is equal to 0.1 is estimated.
- An exponential equation of the following form is fitted to the upper envelope of the scatter:

  $$NO_2/NO_X = a \times [NOx]^b$$

  where **a** and **b** are selected through an iterative process to produce a curve that fits the upper bound of the envelope of the scatter.

  The equation is defined so that the NO_2/ NO_x ratio never exceeds unity or falls below 0.1.
- The equation is checked to ensure that NO_2 does not decrease with an increase in NO_X.

[5] BCMoE (2008) recommends that the ozone limiting method should only be applied if adequate monitoring data are not available to establish representative NO/NO_2 ratios.

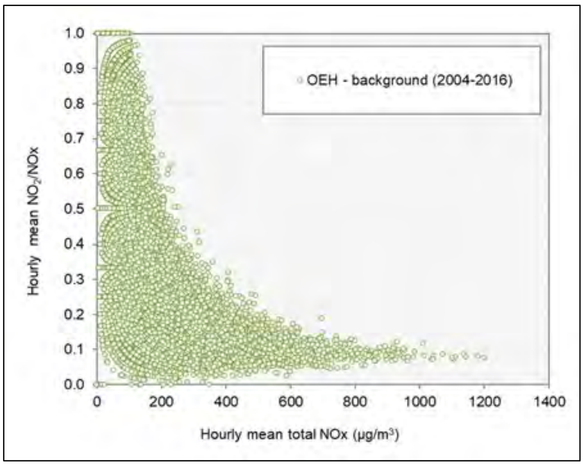


Figure E-2 Hourly mean NO_2/NO_X vs NO_X at OEH (background) stations

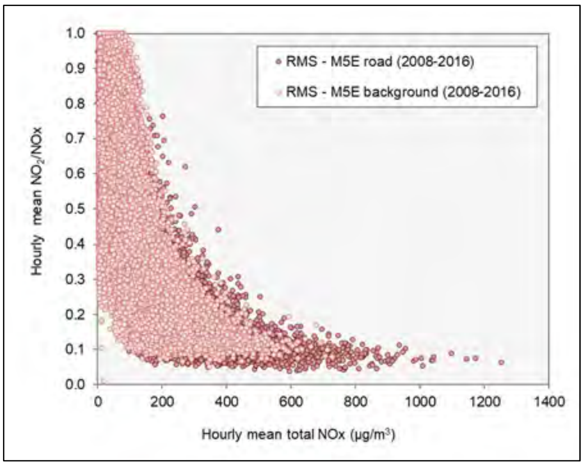


Figure E-3 Hourly mean NO_2/NO_X vs NO_X at Roads and Maritime M5 East (road and background) stations

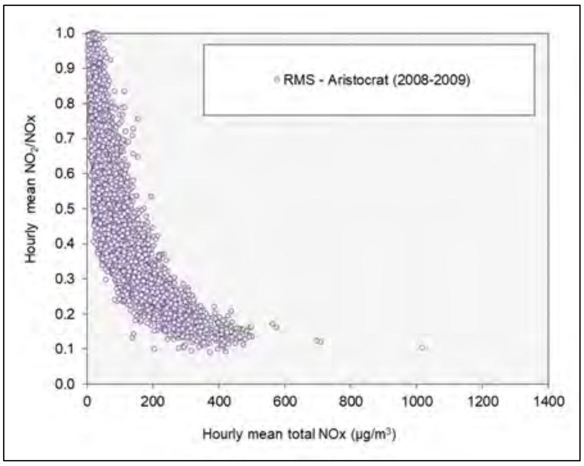


Figure E-4 Hourly mean NO_2/NO_X vs NO_X at Roads and Maritime Aristocrat (road) station

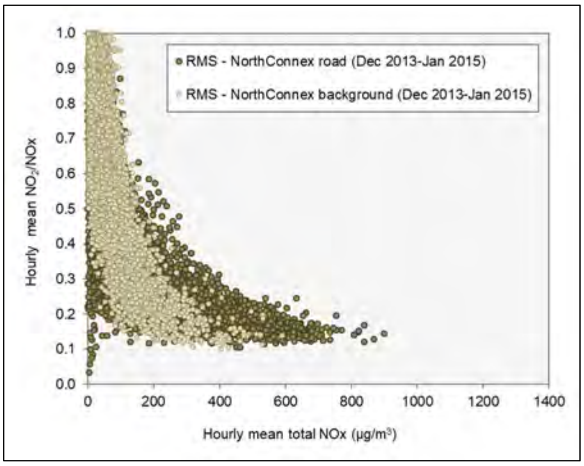


Figure E-5 Hourly mean NO_2/NO_X vs NO_X at Roads and Maritime NorthConnex (road and background) stations

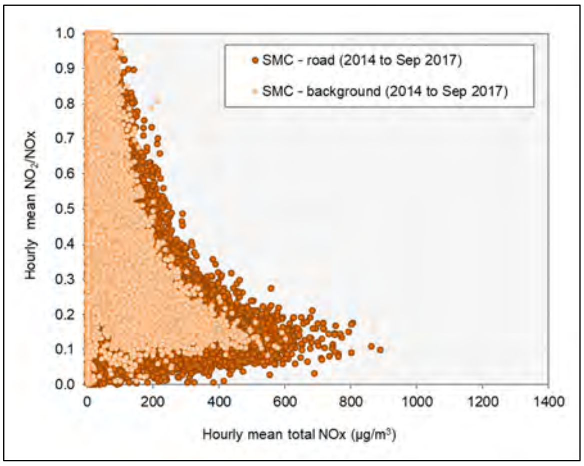


Figure E-6 Hourly mean NO_2/NO_X and NO_X at SMC (road and background) stations

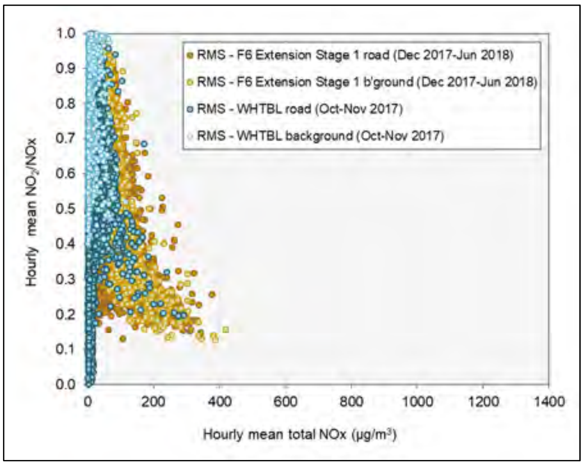


Figure E-7 Hourly mean NO_2/NO_X and NO_X at Roads and Maritime WHTBL and F6 Extension Stage 1 stations

The data from all Sydney monitoring stations between 2004 and 2016 – a total of more than 1.3 million data points – are shown in Figure E-8, and the steps described above have been applied. Around 20% of the data points were for roadside monitoring stations.

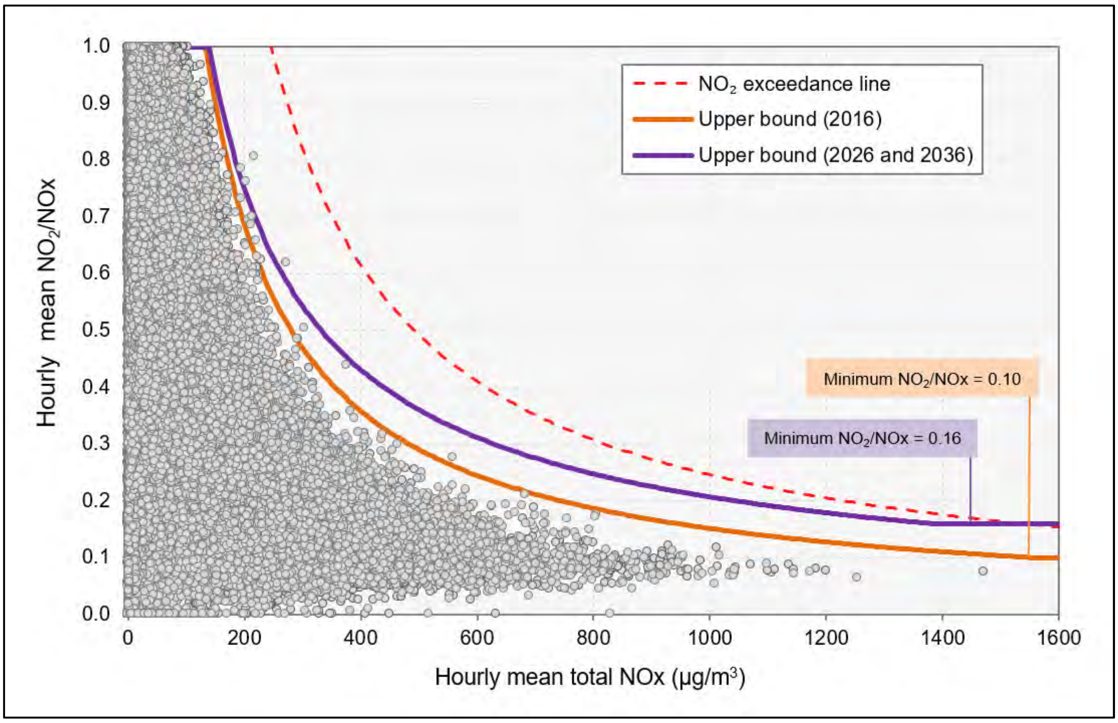


Figure E-8 **Hourly mean NO_2/NO_X ratio vs NO_X for monitoring stations at various locations in Sydney**

The solid orange line in Figure E-8 represents the outer envelope of all data points, and approximates to a conservative upper bound estimate for 2016, or in other words the maximum NO_2/NO_X ratio for a given NO_X concentration in 2016. This is described by the following equations:

For $[NO_X]_{total}$ values less than or equal to 130 μg/m³:

Equation E14

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

For $[NO_X]_{total}$ values greater than 130 μg/m³ and less than or equal to 1,555 μg/m³:

Equation E15

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

where:

a = 100
b = -0.94

For $[NO_X]_{total}$ values greater than 1,555 μg/m³ a cut-off for the NO_2/NO_X ratio of 0.10 has been assumed. That is:

Equation E16

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

The dashed red line in Figure E-8 shows the NO_2/NO_X ratio that would be required for an exceedance of the NO_2 criterion of 246 µg/m^3 at each NO_X concentration. It is clear from Figure E-8 that an exceedance of the 1-hour criterion for NO_2 cannot be predicted using the upper bound curve for 2016 across a wide range of NO_X concentrations.

For future years it is possible that the upper bound estimate for 2016 will not be appropriate, given that primary NO_2 emissions could increase. An exploratory analysis by Pacific Environment indicated that, on average for highway traffic in Sydney, *f*-NO_2 could increase to 0.16 by around 2030 (Boulter and Bennett, 2015). Although the increase in *f*-NO_2 would be combined with lower overall NO_X emissions, it could be expected that for high ambient NO_X concentrations the ambient NO_2/NO_X ratio could exceed 0.1. Here, it has therefore been assumed that a minimum value for the NO_2/NO_X ratio of 0.16 would be appropriate for the 2026 and 2036 scenarios, and a corresponding (conservative) upper bound function is shown as a purple line in Figure E-8.

This function, which is essentially arbitrary, is described by the following equations:

For $\mathbf{[NO_X]_{total}}$ values less than or equal to 140 µg/m^3, Equation E14 applies.

For $\mathbf{[NO_X]_{total}}$ values greater than 140 µg/m^3 and less than or equal to 1,375 µg/m^3, Equation 15 applies with the following coefficients:

a = 52

b = -0.80

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

Equation E17

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

Even this assumption would only result in an exceedance of the NO_2 criterion at very high NO_X concentrations (above around 1,500 µg/m^3). If a more conservative estimate for the minimum ambient NO_2/NO_X ratio of 0.20 were to be assumed, the total NO_X concentration required for NO_2 exceedance in Figure E-8 would be around 1,200 µg/m^3.

Given that the background NO_X concentrations developed for the F6 Extension Stage 1 assessment were also slightly conservative (see Annexure E), it is likely that there will be a conservative overall estimate of NO_2 using this approach.

E.4.2.3 Limitations and performance

The general limitations of empirical methods for NO_X-to-NO_2 conversion include the following:

- They do not make any allowance for future changes, such as a potential increase in primary NO_2 emissions or changes in ozone concentrations. Here, this has been addressed as in part through the use of a more conservative function for converting NO_X to NO_2 than the ambient measurements in Sydney to date would suggest.
- They do not differentiate between receptor locations at different distances from emission sources.
- They are only useful for the general locations where they were developed. The methods will not provide the correct dynamic response to changes in emissions, boundary conditions or meteorology unless these influences are implicitly included in their formulation (Denby, 2011).

However, despite, or as a result of, their empirical nature such models can give satisfactory results, especially for annual mean concentrations as there is a clear dependence of NO_2 on NO_X concentrations (Denby, 2011).

E.5 Comparison of methods

As part of the analysis for the M4 East project the functions for calculating NO_2 from NO_X based on the monitoring data from Sydney (up to and including 2016) were compared with some alternative approaches (Boulter et al., 2015). The results of these comparisons for both annual mean and 1-hour mean NO_2 concentration are given below.

E.5.1 Annual mean NO_2 concentrations

The following methods for calculating annual mean NO_2 concentrations were compared:

- The central-estimate approach based on the Sydney monitoring data (see Section G.4.2.1).
- The complete conversion method (see Section G.3.3).
- The USEPA constant ambient ratio method (ARM), with a NO_2/NO_X ratio of 0.75 (see Section G.3.4.1).
- The ozone limiting method (OLM), with an *f*-NO_2 value of 0.16 (see Section G.3.5.1).

In order to compare the different methods for annual mean NO_2 it was necessary to assume background concentrations of NO_X, NO_2 and, in the case of the OLM, O_3. The synthetic profiles for the M4 East modelling domain (and associated annual mean concentrations) described by Boulter et al. (2015) were used for this purpose.

In the case of the OLM, the conversion method was applied to the contemporaneous hourly background data and project increment data for one year. An example dataset from another road project was used to provide the NO_X project increments. This project had an hourly time series for more than 500 receptor points. However, many of the receptors had similar concentrations and therefore a much smaller sample was extracted. The sample included a wide range of NO_X concentrations. The results of the comparison are shown in Figure E-9.

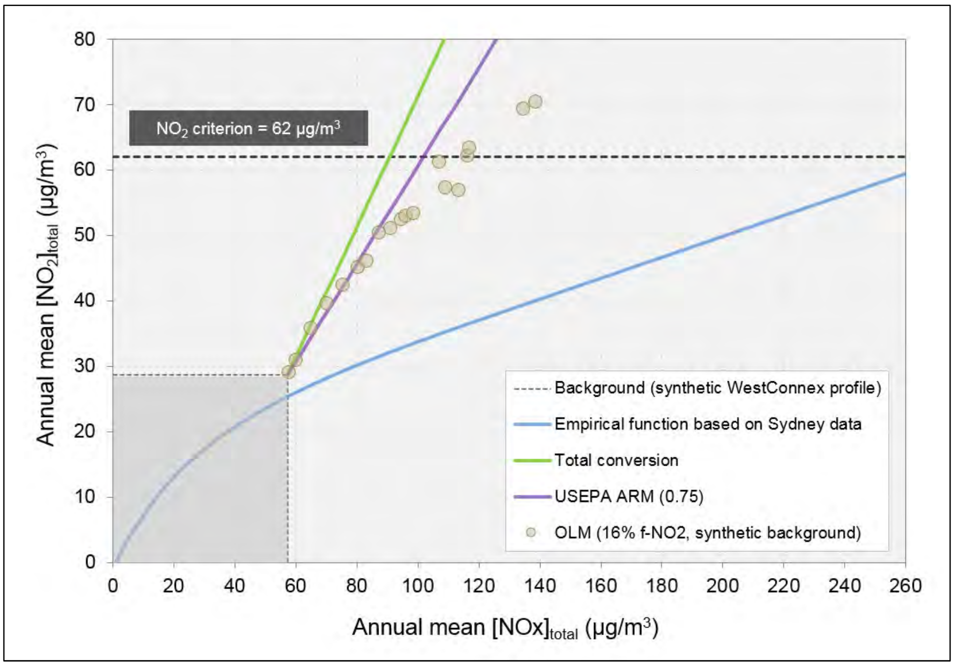


Figure E-9 Comparison of methods for calculating annual mean NO_2 concentration

The total conversion method gave the highest NO_2 concentrations, and for the conditions defined here it resulted in an exceedance of the NO_2 criterion of 62 µg/m^3 when the total NO_X concentration was around 90 µg/m^3. The ARM and the OLM gave quite similar results, and also resulted in exceedances of the NO_2 criterion when the total NO_X concentration was around 100-120 µg/m^3. All three of these methods gave much higher NO_2 concentrations than the envelope and regression functions based on the Sydney monitoring data.

It is also worth repeating that work in the United States has shown that the performance of the ARM2, PVMRM, and OLM methods is very similar (RTP, 2013).

Although the concentrations in the synthetic background profiles were quite conservative, the results show that that the annual mean NO_2 concentrations predicted using the total conversion, ARM and OLM methods are unrealistically high, and would tend to result in an improbable number of exceedance of the NO_2 criterion. These methods were therefore considered to be unsuitable for the F6 Extension Stage 1 assessment.

E.5.2 One-hour mean NO_2 concentrations

In the case of 1-hour mean NO_2 concentrations, only the OLM was compared with the empirical method. Again, the synthetic background profiles for the M4 East modelling domain were used, and an *f*-NO_2 value of 0.16 was assumed.

For the road contribution to NO_X, the same example dataset as that mentioned above for annual mean concentrations was used. The hourly results for ten receptors from the dataset, with representative NO_X concentrations across the range, are shown in Figure E-10. It can be seen that the OLM predicted NO_2/NO_X ratios for many 1-hour periods that were higher than those predicted by the conservative upper bound function. The OLM gave a small number of exceedances of the NO_2 criterion of 246 µg/m^3. This work shows that the OLM will yield overly conservative maximum NO_2 concentrations for road projects in Sydney.

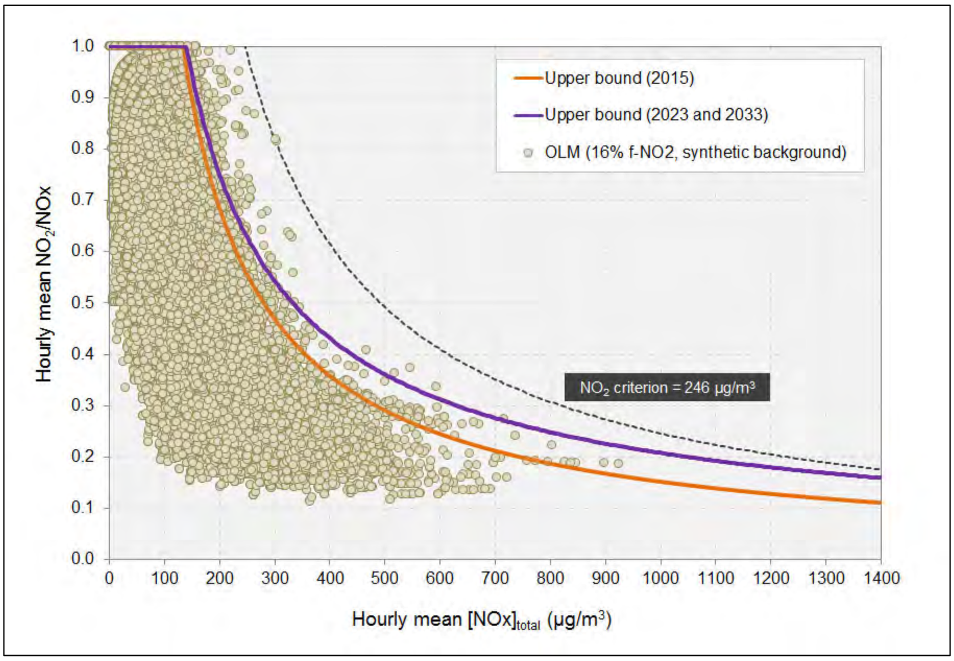


Figure E-10 Comparison of OLM and empirical methods for calculating 1-hour mean NO_2 concentration

Annexure F - Analysis of meteorological data and GRAMM evaluation

Annexure F - Analysis of meteorological data and GRAMM evaluation

F.1 Introduction

The F6 Extension GRAMM domain covered an area with diverse land use types, including a mixture of ocean coast, harbour and near-coastal inland locations which would have different local meteorological characteristics.

Whilst meteorology may not always be the main driver of predicted concentrations near to roads, where the peak impacts could be expected to occur, it is nevertheless important to characterise the meteorology as accurately as possible within the GRAL domain. It is worth noting that the F6 Extension project corridor is aligned along a broad north-south axis through the GRAL domain, with most receptors being located along this axis.

F.2 Introduction

F.2.1 Monitoring stations

There were few meteorological stations within the GRAL domain. The only stations located within the domain were OEH Rozelle, BoM Fort Denison and BoM Wedding Cake West. However, when setting up GRAMM it is possible to include meteorological stations outside of the GRAL domain but within the GRAMM domain. For this reason, a number of other meteorological stations have been considered as a part of the wider analysis of meteorological data. These stations were a mixture of OEH, BoM and SMC and Roads and Maritime owned stations. These are listed below.

- OEH meteorological stations:
  - Earlwood
  - Randwick
- BoM meteorological stations:
  - Canterbury Racecourse Automatic Weather Station (AWS) (Station No. 066194)
  - Kurnell AWS (Station No. 066043)
  - Little Bay (The Coast Golf Club) (Station No. 066051)
  - Sydney Airport AMO (Station No. 066037)
- SMC and Roads and Maritime meteorological stations:
  - SMC NewM5:01
  - SMC NewM5:04
  - SMC NewM5:06
  - Roads and Maritime T1
  - Roads and Maritime X1
  - Roads and Maritime CBMS

F.2.2 Summary statistics

Some of the stations listed in the previous section were not carried through for further consideration in the GRAMM modelling given their distance from the project, data availability and siting issues. For example, all SMC and Roads and Maritime sites were excluded as some are located at roadside and they also had limited data availability to inform a long-term site representativeness analysis. The data from these sites may be useful, however, to provide an idea of the general wind patterns in the area and have been discussed in this context in subsequent sections.

Table F-1 provides a summary of the annual data recovery, average wind speed and percentage of calms (wind speeds < 0.5 m/s) for six of the remaining OEH and BoM meteorological stations to be considered for further analysis. The parameters that were obtained were wind speed, wind direction, temperature and cloud cover for the years 2009 to 2016 inclusive.

The table shows a generally high percentage of data recovery at each station. The NSW Approved Methods require a meteorological dataset for modelling to be at least 90 per cent complete to be deemed acceptable for a Level 2 (detailed) impact assessment.

There was a high level of year-on-year consistency in the annual average wind speed and annual percentage of calms at each meteorological station. The wind speeds at the BoM Kurnell, BoM Little Bay (The Coast Golf Club) and BoM Sydney Airport stations were relatively high, with annual averages of 4.2 m/s to 5.9 m/s. This is not unusual given the exposed nature of these stations and their proximity to large coastal waterbodies (Sydney Harbour and Botany Bay). Wind speeds at Earlwood were the lowest, with annual averages between 1.3 m/s and 1.6 m/s.

There was also a fairly good year-on-year consistency in the annual percentage of calms at each station, although the values at the OEH Earlwood station showed an increasing trend between 2009 and 2016. There were few calm conditions at Sydney Airport.

Table F-1 Summary of data recovery, average wind speed and percentage calms

Site and parameter	2009	2010	2011	2012	2013	2014	2015	2016
OEH Earlwood								
Data recovery (%)	100	100	97	100	99	100	100	99
Average wind speed (m/s)	1.6	1.6	1.4	1.4	1.4	1.3	1.3	1.3
Annual calms (%)	18.1	16.8	17.5	22.0	23.1	22.0	23.6	24.6
OEH Randwick								
Data recovery (%)	99	98	98	99	99	97	96	98
Average wind speed (m/s)	2.2	1.9	2.4	2.6	2.6	2.6	2.6	2.6
Annual calms (%)	11.5	14.5	10.7	9.3	10.5	9.4	9.1	9.6
BoM Canterbury Racecourse AWS								
Data recovery (%)	61	88	91	89	89	90	90	89
Average wind speed (m/s)	3.3	3.2	3.3	3.3	3.3	3.3	3.2	3.3
Annual calms (%)	9.4	8.4	8.0	8.7	8.8	8.6	9.1	9.0
BoM Kurnell (AWS)								
Data recovery (%)	100	69	100	100	100	99	100	100
Average wind speed (m/s)	5.6	5.9	5.9	5.8	5.8	5.7	5.6	5.7
Annual calms (%)	1.7	0.5	0.4	0.5	0.6	0.4	0.6	0.6
BoM Little Bay (The Coast Golf Club)								
Data recovery (%)	99	99	99	100	98	100	99	99
Average wind speed (m/s)	5.1	4.9	5.4	4.6	4.5	4.4	4.4	4.2
Annual calms (%)	0.6	2.8	1.1	0.9	1.2	1.2	1.2	1.0
BoM Sydney Airport AMO								
Data recovery (%)	67	66	100	100	100	100	100	100
Average wind speed (m/s)	5.7	5.7	5.7	5.6	5.7	5.5	5.5	5.5
Annual calms (%)	0.3	0.2	0.2	0.3	0.1	0.1	0.2	0.1

F.3 Rationale for selection of reference station and year for modelling

The measurements from the OEH Randwick and OEH Earlwood stations in 2016 were chosen as the reference meteorological data for modelling across the GRAMM domain. The reasons for the selection of these stations and the year are given below.

F.3.1 Introduction

The meteorological stations located within the GRAMM domain are owned and operated by various organisations, and each organisation uses different instrumentation. Notably, the OEH stations use a sonic anemometer and the BoM stations use a cup and vane system. It is important to understand that these differences in instrumentation are likely to contribute to the variability in the measurements (e.g. BoM wind speeds may be higher on average due to a higher stall speed using the cup and vane instrumentation compared with an OEH sonic anemometer).

It is also known that several of the sites in the GRAMM domain are affected by siting effects/issues that are likely to result in localised meteorological effects which mean that the measurements may not be representative of the GRAL domain. BoM stations such as Kurnell and Little Bay will be less affected by obstacles such as trees, but are located close to large water bodies or at elevated locations, and have particularly high wind speeds. The use of these data in GRAMM would obviously have an effect on the resultant wind fields in the GRAL domain, as the area has both inland and coastal characteristics.

The above issues also need to be considered with the GRAMM modelling process in mind. GRAMM, unlike other common meteorological models (CALMET etc.), uses a different process to develop meteorological wind fields for use in GRAL. The common and recommended GRAMM process was implemented for the F6 Extension GRAMM modelling. In short, this includes an initial GRAMM run using a synthetic meteorological file (with a range of meteorological conditions). The resultant GRAMM wind fields will then be matched to selected meteorological station data using the GRAMM 'Match-to-Observations' (MtO) function. Whilst a 'radius of influence' cannot be set for different stations, weighting factors for wind speed and direction can be defined by the user to gain the 'best fit' of data across the domain. This means that all meteorological data included in the matching process will affect the wind fields across the entire GRAMM domain, and to a greater or lesser degree depending on the weighting factors. The weighting factors are based on user judgment, taking into account, for example, the representativeness of the data for the study area. The final wind fields for GRAL will then be a 'compromise' of the meteorological data used in the MtO process. It is then important to select the most appropriate stations to represent the domain, along with appropriate weighting factors.

For the reasons stated above, a basic multi-criteria analysis has been used to select the most appropriate meteorological stations for the F6 Extension GRAMM modelling.

F.3.2 Year selection

The selection of a meteorological year is linked to the selection of the ambient air quality monitoring (background) year, as the two years need to be the same in any assessment. In both cases the selected year should also be taken as the base year for the assessment. One of the main purposes of including a base year is to enable the dispersion modelling methodology to be verified against real-world air pollution monitoring data.

The base year for the F6 Extension air quality assessment was taken to be 2016. The main reasons for this can be summarised as follows:

- There is often an expectation that the most recent air quality data (for a complete year) are used in an assessment. The last complete year of validated data at the time of the assessment was 2016.
- The use of 2016 data allowed for a roadside monitoring station (M4-M5:01 – City West Link) to be included in the dispersion model evaluation.
- The air quality monitoring data for 2016 were representative of the longer-term trends.

- The long-term wind speed and direction analysis for the selected meteorological stations showed consistency across the monitored years.

F.3.3 Station selection

F.3.3.1 Analysis of average wind speeds

To provide an overview of all the available meteorological data in the F6 Extension GRAMM domain for 2016, Figure F-1 shows a contour plot of annual average wind speeds based on all of the meteorological stations within the study area. It is important to keep in mind that the plot shows annual average wind speeds from each site interpolated over the GRAMM domain area. Therefore, areas with few or no measurements will be influenced by the closest meteorological station(s). As noted in the previous section, many of these stations (mostly the SMC and RMS stations) have not been considered for the GRAMM modelling. Basic wind speed data has been shown here however to provide some context of the overall patterns in the area.

Figure F-1 shows that BoM Sydney Airport, Little Bay, and Kurnell drive the higher average wind speeds in south-eastern part of the GRAMM domain, which is unsurprising given their proximity to the coast and (in the case of Sydney Airport) local activities. The first third of the domain (from west to east) shows average wind speeds of around 2 m/s to 3.5 m/s, with the project corridor falling mostly Figure F-1 shows the monthly average wind speeds in 2016 for the stations presented in Figure F-1. Again, it shows that a large number of stations within the GRAMM domain have average wind speeds between 2 and 3.5 m/s.

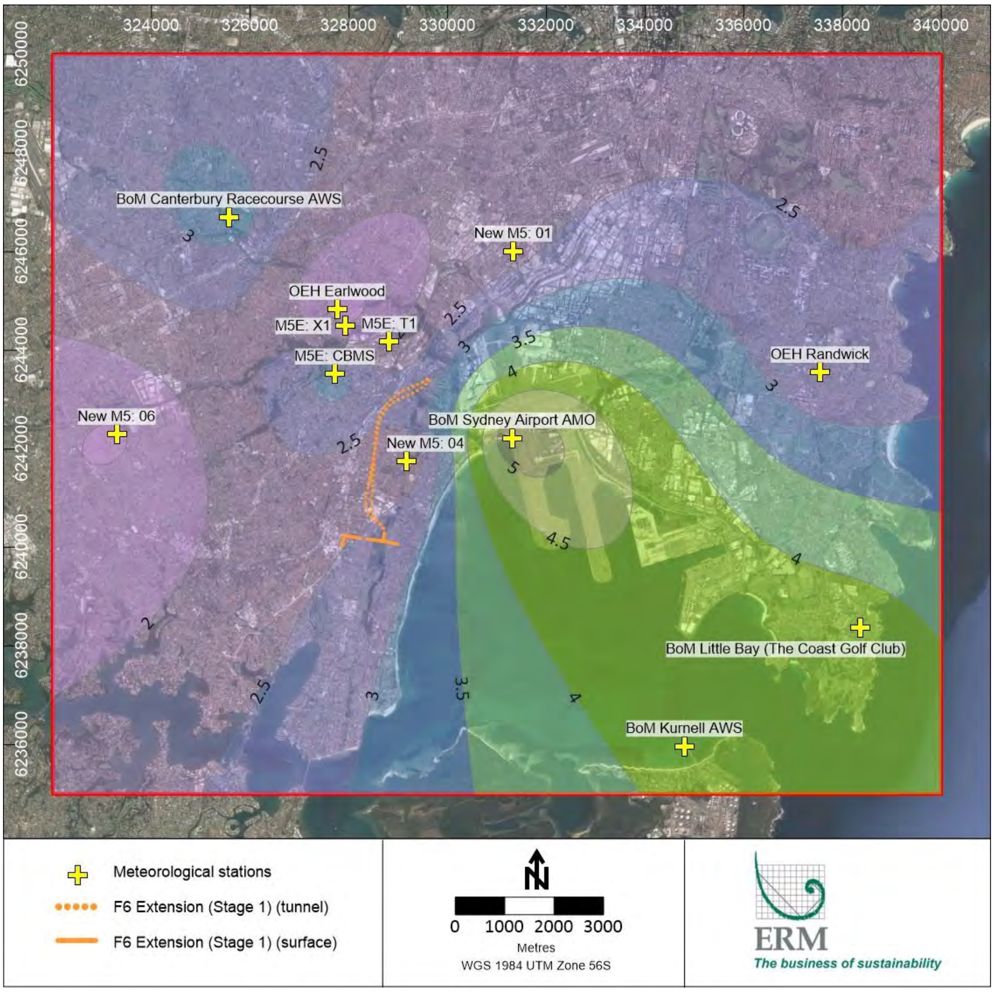


Figure F-1 Contour plot of average wind speed in the GRAMM domain in 2016

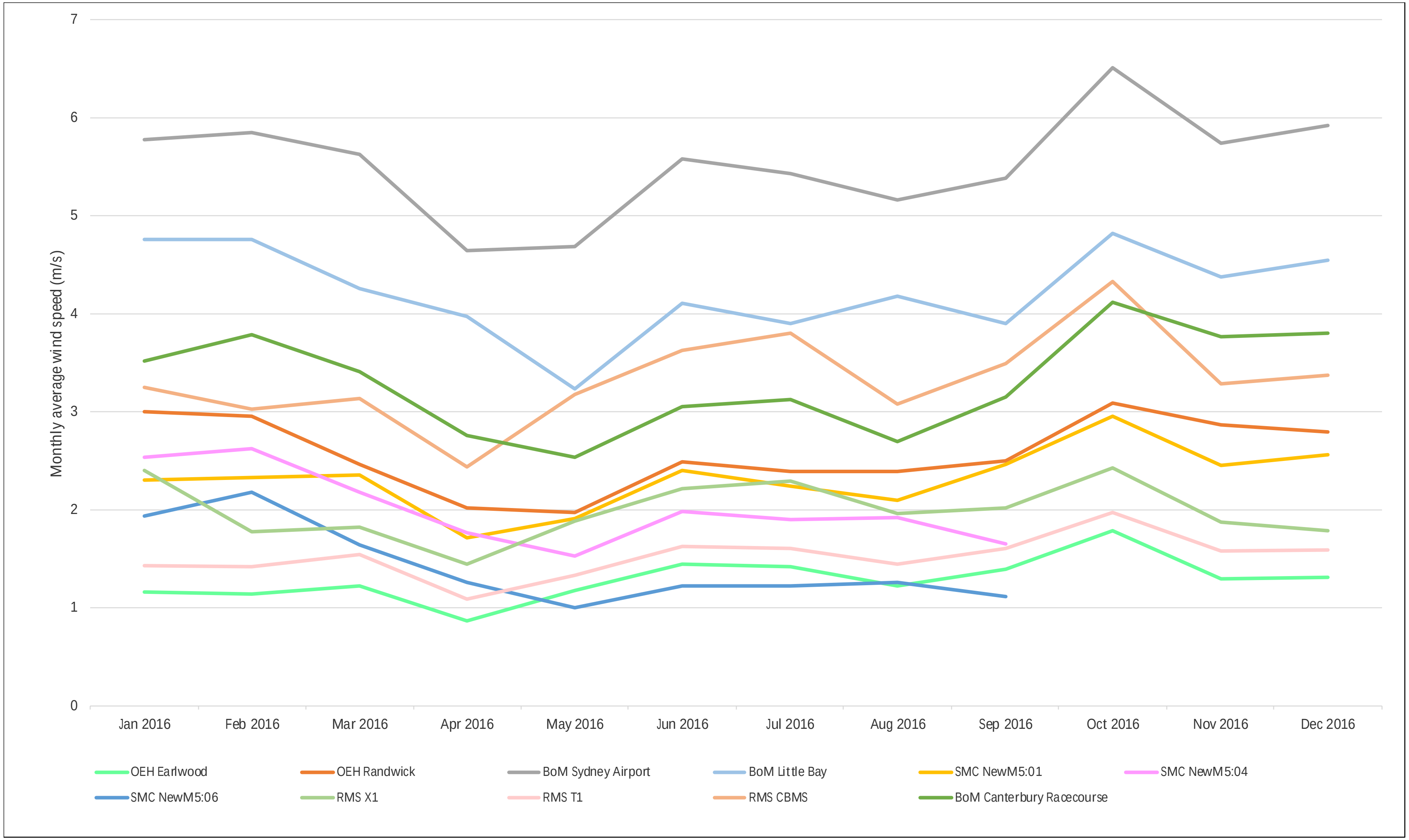


Figure F-2 Monthly average wind speed in 2016

F.3.3.2 Analysis of wind directions

Annual and seasonal wind roses were created for all ten meteorological stations presented in **Figure F-3**.

The wind patterns across all of the stations in 2016 are quite varied and the reasons will include those mentioned previously (different instrumentation, siting issues etc.). Stations OEH Earlwood and OEH Randwick showed most similar patterns to each other with dominant wind directions from the west, west north-west and north-eastern directions. With the exception of Sydney Airport, these stations are also closest to the project.

Previous years of data have also been analysed as wind roses for all meteorological stations. These data have not been included here for practicality purposes but are discussed in subsequent sections for the meteorological stations selected for the GRAMM modelling.

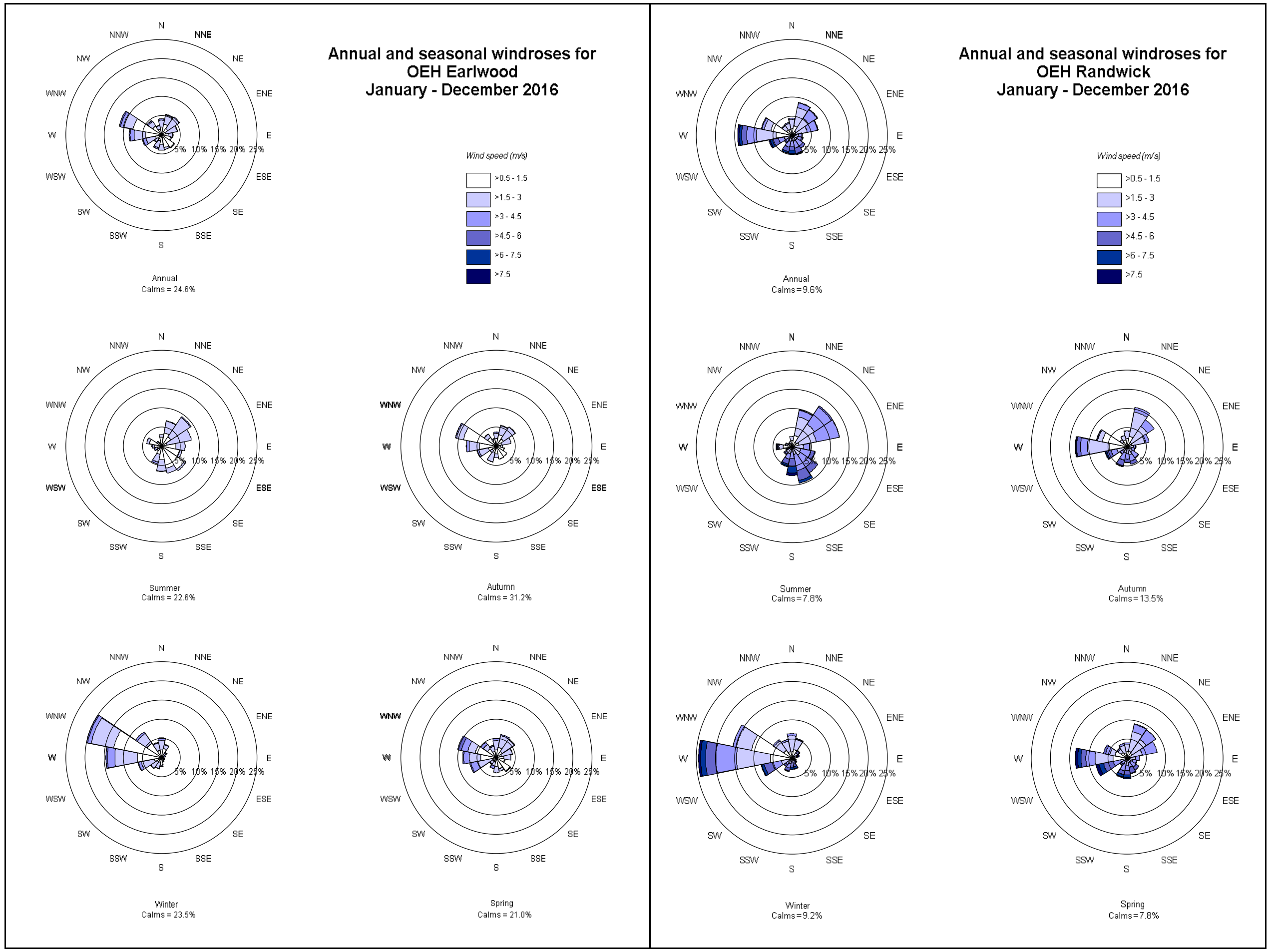


Figure F-3 Annual and seasonal wind roses for OEH meteorological stations Earlwood and Randwick (2016)

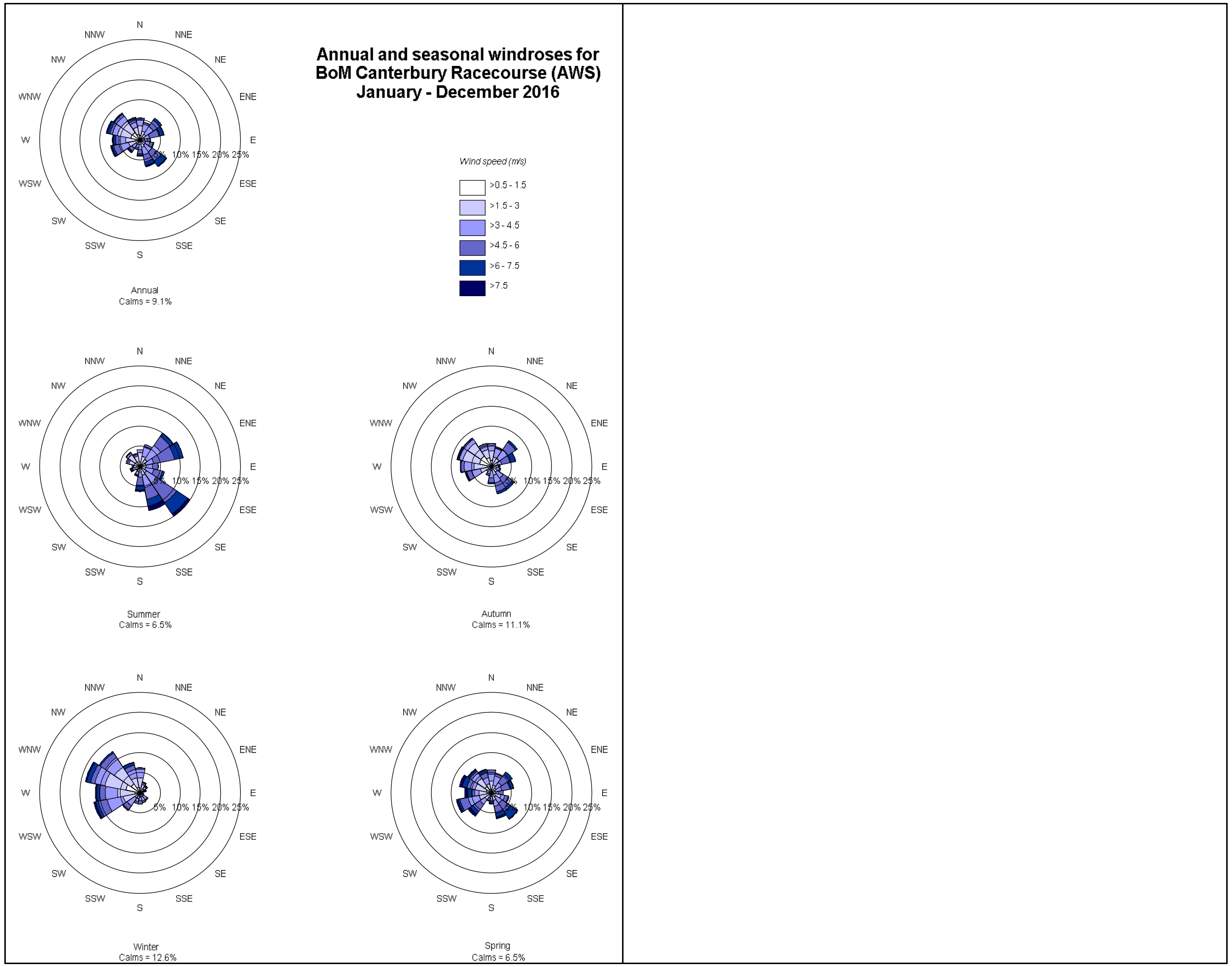


Figure F-4 Annual and seasonal wind roses for BoM stations Canterbury Racecourse (AWS) and Kurnell AWS, (2016)

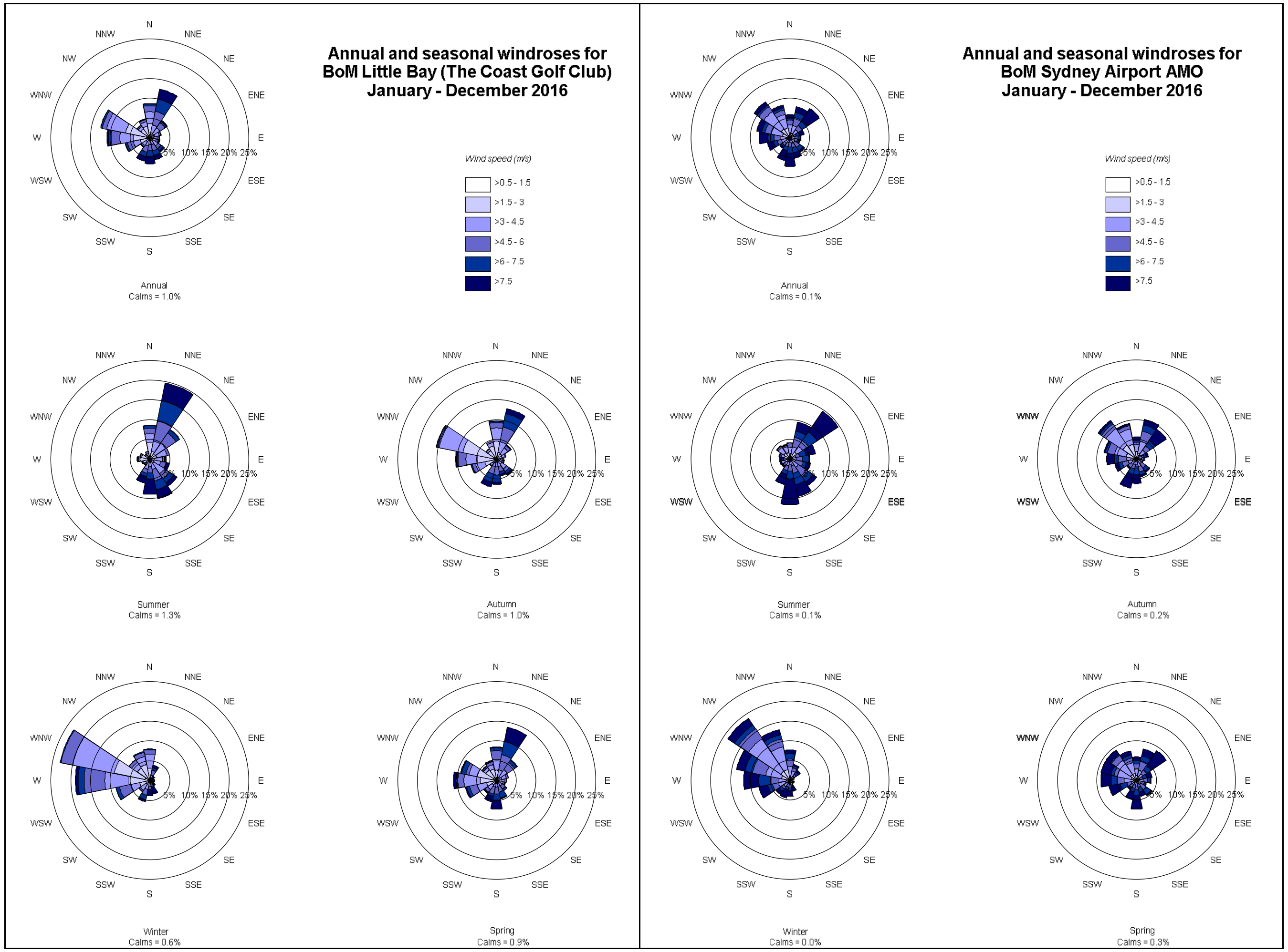


Figure F-5 Annual and seasonal wind roses for BoM meteorological stations Little Bay (The Coast Golf Club) and Sydney Airport AMO, (2016)

F.3.3.3 Determination of meteorological stations for GRAMM modelling

Based on the consideration of station siting, wind speed and wind direction analysis, stations were included/excluded from additional consideration in the GRAMM modelling for the reasons provided in Table F-2 below.

Table F-2 Consideration of meteorological stations for use in GRAMM modelling

Station	Further consideration for use in modelling
OEH Earlwood	Considered in GRAMM modelling given its location within the GRAL domain. Long-term wind speed analysis shows that wind speeds are low and annual calms are high. This may be in part due to some siting issues (proximity to trees). However, wind patterns are consistent year-on-year and general wind directions are consistent when compared to other stations in the area. Due to the reasons stated above, Earlwood was included in the GRAMM modelling but with lower weighting factors.
OEH Randwick	Considered in GRAMM modelling given its proximity to the GRAL domain and its location inland but also slightly coastal. Average wind speeds at this site appear to be representative of general project corridor (2.5 to 3 m/s). This station is located outside of the GRAL domain but appears to be well sited and wind speeds/directions are consistent throughout the past years. Higher weightings will therefore be applied in the modelling for this station.
BoM Canterbury Racecourse	Excluded from further consideration given its distance from the GRAL domain and the dominant wind direction patterns observed which differ from the dominant patterns observed at sites closer to the GRAL domain.
BoM Sydney Airport	Excluded from further consideration given the nature of the very localised land use (higher wind speeds driven by airport activities and location in exposed ocean). Inclusion of these data may result in an overestimate of higher wind speeds as modelled by GRAMM and which could ultimately lead to an underestimate of higher GRAL concentrations.
BoM Little Bay	
BoM Kurnell	
SMC NewM5:01	Excluded from further consideration given distance from the GRAL domain, roadside location of some sites, and (for the SMC stations) lack of historical data to provide a long-term representativeness analysis to show that 2016 is an appropriate year.
SMC NewM5:04	
SMC NewM5:06	
RMS X1	
RMS T1	
RMS CBMS	

The above assessment has therefore resulted in the following stations being selected for the GRAMM modelling:

- OEH Earlwood
- OEH Randwick

Table F-3 presents the weighting factors applied in the GRAMM MtO modelling for the four stations selected. These factors were based on the analysis provided above.

Table F-3 **Weighting factors applied to meteorological stations in GRAMM modelling**

Station	Overall MtO weighting factor	Directional MtO weighting factor
OEH Randwick	1	1
OEH Earlwood	0.2	0.5

F.4 Meteorological model evaluation

F.4.1 GRAL optimisation study

Manansala et al. (2017) examined the performance of the GRAMM-GRAL system in an urban area of Sydney. The main objectives of the study were to assess the performance of GRAMM (version: July 2016) and GRAL (version: August 2016) against meteorological measurements and air quality measurements respectively. GRAMM and GRAL were also compared against other models that are commonly used in Australia: CALMET version 6.334 for meteorology, and CAL3QHCR version 2.0 for dispersion. The study provided recommendations regarding the configuration and application of GRAMM and GRAL to the assessment urban road networks/projects in Australia.

The recommendations on GRAMM modelling from that project have been considered in the GRAMM set up for the Western Harbour Tunnel project. The main outcome was the use of the Match to Observations (MtO) function, with recommendations regarding testing and input data. These recommendations have been adopted in the GRAMM modelling for this project, and are detailed below

F.4.2 Wind speed

Table F-4 provides, for 2016, a comparison between the predicted and measured annual average wind speed, standard deviation of wind speed, and percentage of calms at OEH Earlwood and OEH Randwick. To enable a direct comparison, the table contains statistics that cover only the time periods for which valid data were available at all monitoring stations. The results show that there was a good agreement between the predicted and observed meteorology at the OEH Randwick site, but a lesser agreement at OEH Earlwood. This is unsurpising given the weighting factors applied at this station.

The MtO function applies a 'comprimise' across the model domain using the meteorological data included in the matching process. This explains why the agreement of observations and predictions at OEH Randwick, albiet very strong, is not exact.

Table F-4 **Summary statistics – observed and predicted (2016)**

Site	Observed			Predicted		
	Annual average wind speed (m/s)	Standard deviation wind speed (m/s)	% calms	Annual average wind speed (m/s)	Standard deviation wind speed (m/s)	% calms
OEH Earlwood	1.3	1.0	25.5	2.1	1.5	10.2
OEH Randwick	2.6	1.7	9.6	2.3	1.6	12.7

Time series, regression and percentile plots of wind speed in 2016 for OEH Randwick and OEH Earlwood are shown in **Figure F-6**.

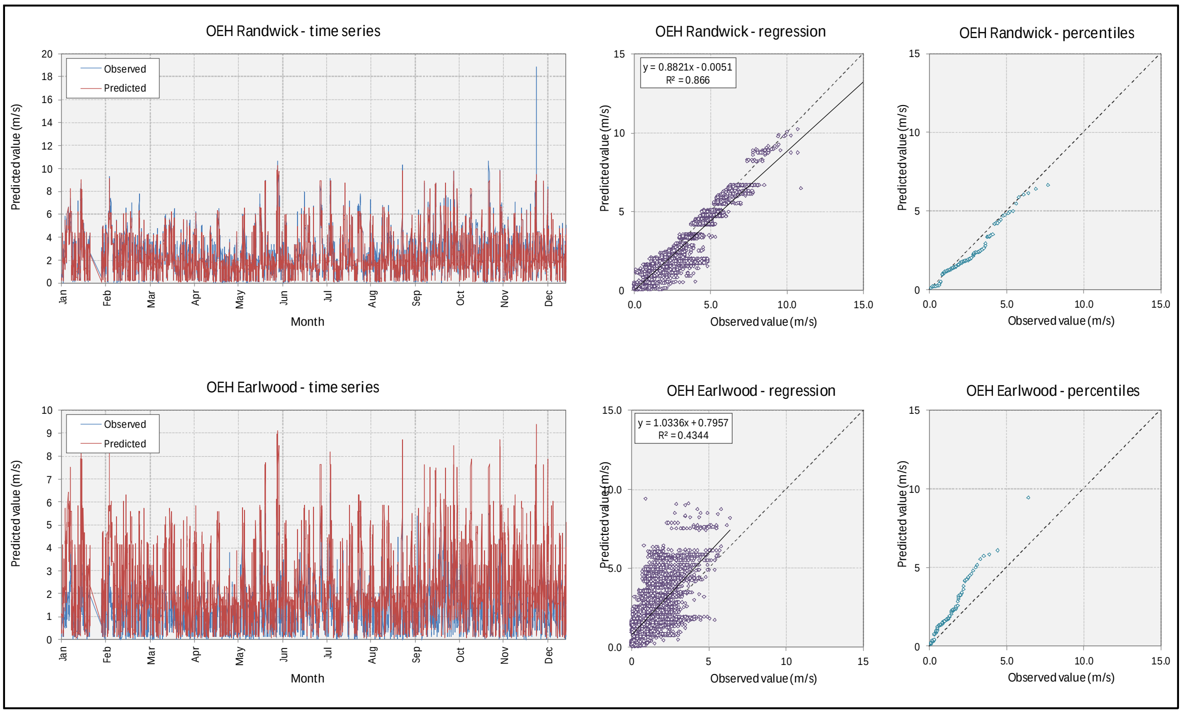


Figure F-6 **GRAMM predicted and observed hourly average wind speed (time series, regression and percentile plots) (2016)**

The results of the regression analysis (predicted wind speed versus observed wind speed) are summarised below. For the correlation coefficient (r), and the associated coefficient of determination (R2), the strength of any relationship was described according to the scheme by Evans (1996) (for R^2: 0.00-0.04 = “very weak”, 0.04-0.16 = “weak”, 0.16-0.36 = “moderate”, 0.36-0.64 = “strong”, 0.64-1.00 = “very strong”).

- OEH Randwick R^2 = 0.87
- OEH Earlwood R^2 = 0.43

The analysis showed a very good agreement between the predicted and observed wind speeds at the OEH Randwick station, which was the site with the highest weightings applied in the MtO function (1 for overall weighting and 1 for wind direction weighting). It is therefore unsurprising that there is a very strong agreement between the observed and predicted wind speeds at the OEH Randwick site.

There was a strong agreement at OEH Earlwood site although the performance was not as strong as at OEH Randwick. This reflects the lower weighting applied compared to at Randwick.

The percentile plots shown in Figure F-6 demonstrates a slight under-prediction of mid-rangewind speeds at OEH Randwick but OEH an overall very strong agreement of the wind speed range at this site. There is an over prediction at Earlwood at the lower wind speeds.

Whilst meteorological conditions are an important aspect of any dispersion modelling excercise, it may not always be the most important aspect in determining predicted concentrations in near-source environments such as this. Annexure H of the report provides a validation of the GRAL predictions as compared with measured data. The analysis showed a reasonably good agreement between the pattterns in the predictions and measurements). Although GRAMM may not be predicting meteorology accurately at all locations across the domain, the GRAL model (for which GRAMM is an input), is predicting results at an appropriate level at locations across the study area (see Annexure H).

Summaries of the average temporal patterns in wind speed at OEH Randwick and OEH Earlwood are provided in Figure F-7 to Figure F-8. These plots reflect the discussions provided above and show:

- A very strong agreement between the observed and predicted average wind speeds at OEH Randwick. There is a tendency for GRAMM to underestimate the higher wind speeds during the middle of the day, but this will add a level of conservatism to the modelling. Times of peak traffic volumes when wind speeds are often lower, show better agreement.
- GRAMM has over-predicted average wind speeds at OEH Rozelle which again is a reflection of the weighting factors applied. Typical diurnal and monthly average wind speeds patterns have been picked up by the model.

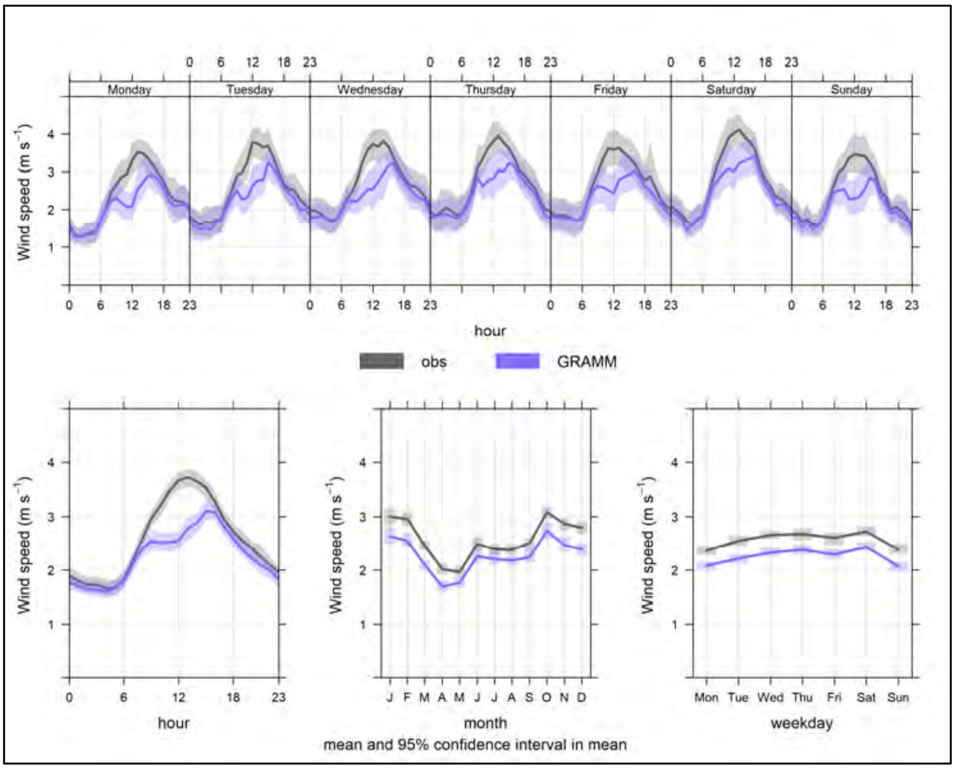


Figure F-7 **Openair `timeVariation` plot of observed vs predicted wind speeds at OEH Randwick (2016)**

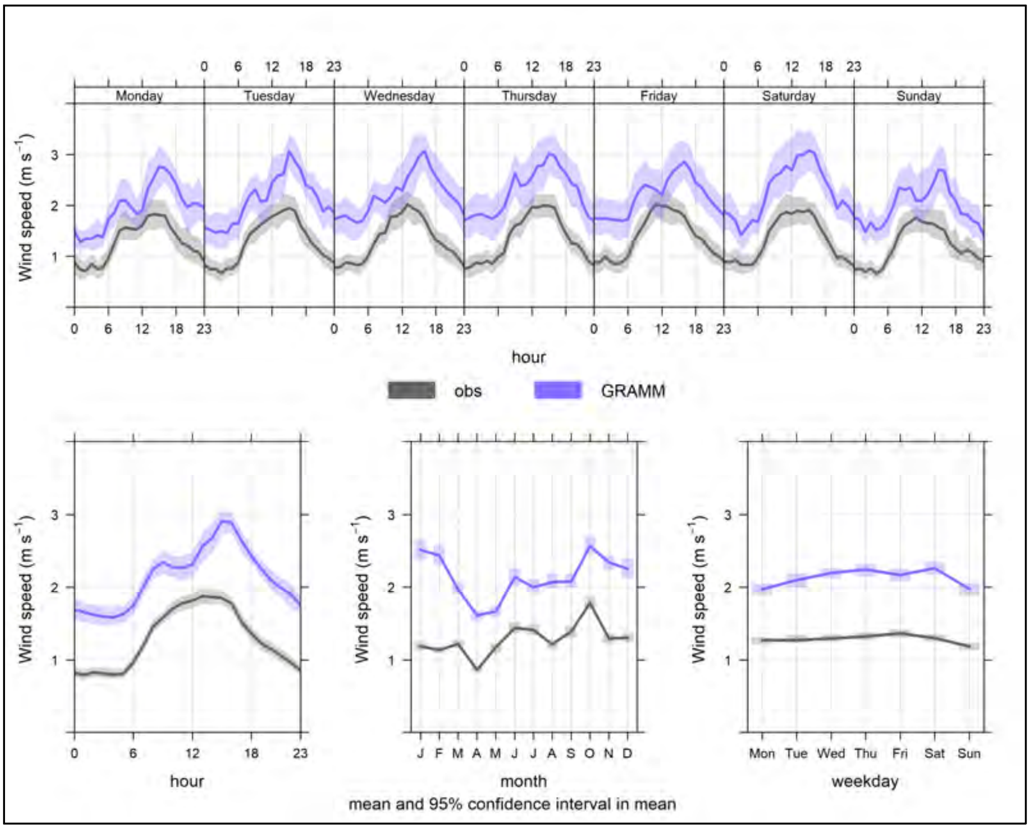


Figure F-8 **Openair `timeVariation` plot of observed vs predicted wind speeds at OEH Earlwood (2016)**

F.4.3 Wind direction

Annual and seasonal wind roses for the measured and predicted winds in 2016 for OEH Randwick and OEH Earlwood are provided in Figure F-9 to Figure F-10.

The measured and predicted winds for the two sites reflect the discussion above regarding the weighting factors used in the MtO process. There is a good agreement of the prominent wind directions at OEH Randwick between the observed and predicted results.

There is a fair level of agreement between the observed and predicted dominant winds at the OEH Earlwood site with prominent winds from the western and north-eastern directions reflected in both cases.

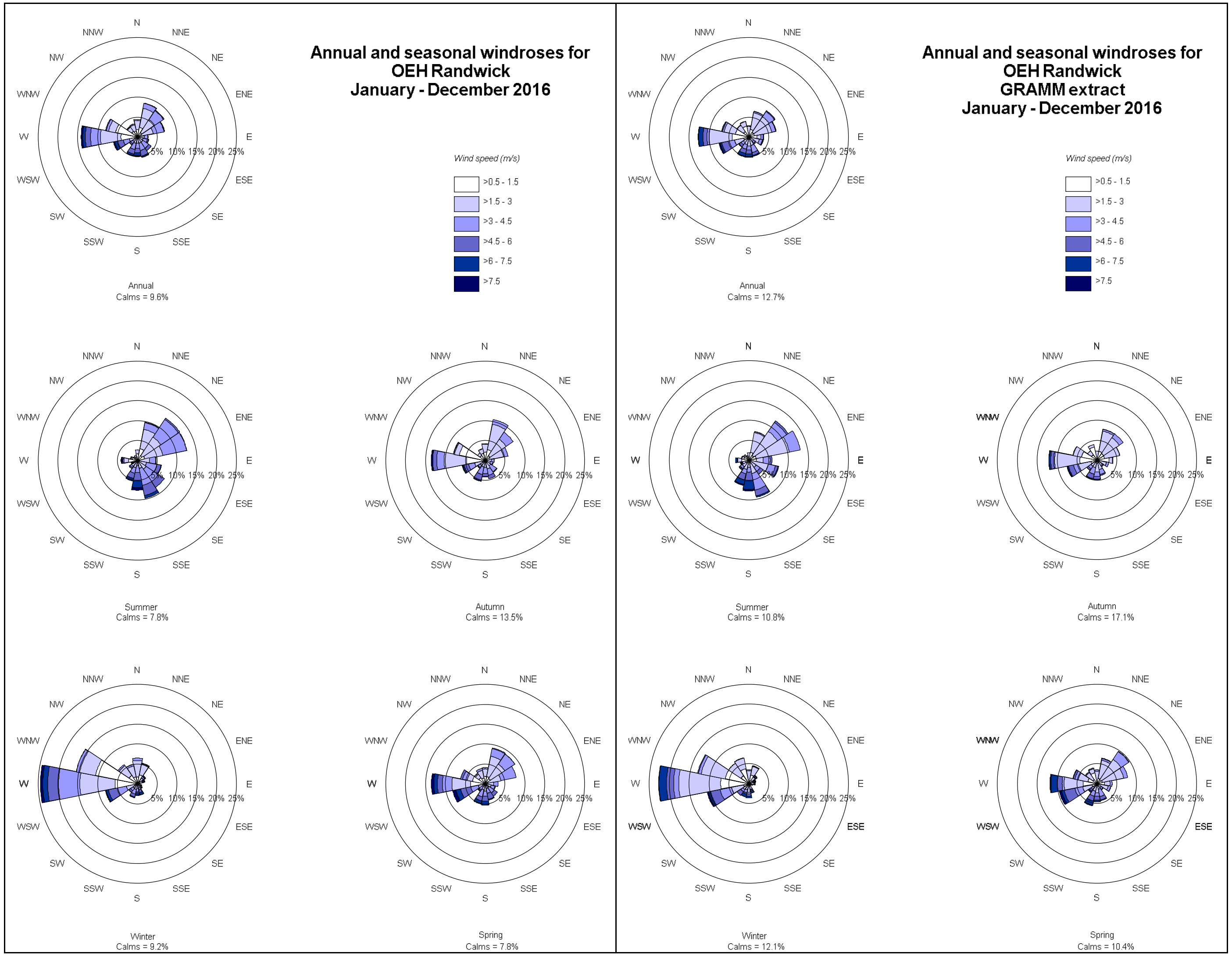


Figure F-9 Annual and seasonal wind roses for observed and predicted winds at OEH Randwick (2016)

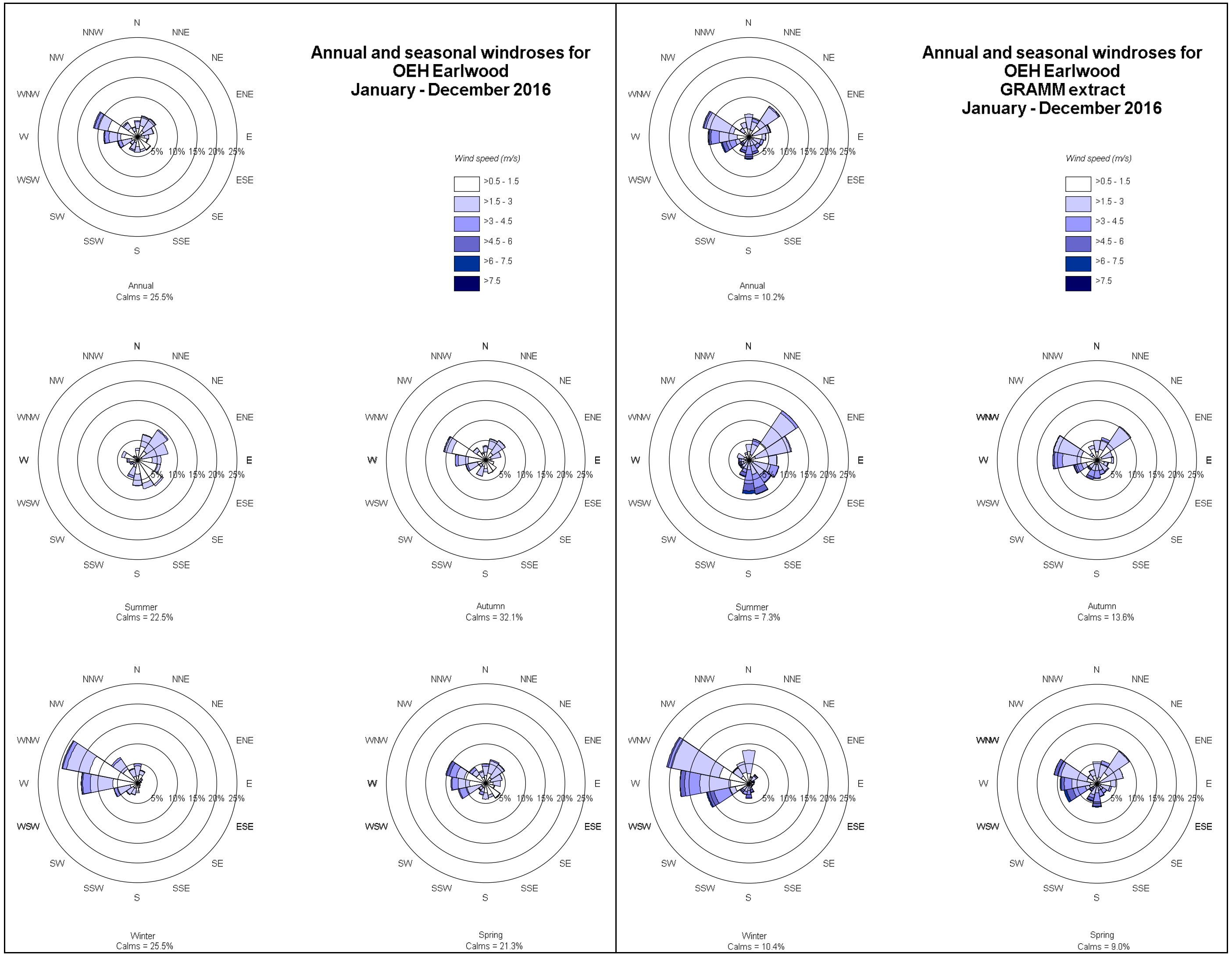


Figure F-10 Annual and seasonal wind roses for observed and predicted winds at OEH Earlwood (2016)

Annexure G - Ventilation outlet parameters

Annexure G – Ventilation outlet parameters

This Annexure provides the following parameters for all ventilation outlets in the various scenarios:

- Outlet locations and dimensions
- Air flows and temperatures for the expected traffic scenarios
- Emissions for the expected traffic scenarios
- In-stack concentrations for the expected traffic scenarios
- Parameters for the regulatory worst case scenarios

G.1 Outlet locations and dimensions

The locations and dimensions of the existing/other ventilation outlets included in the assessment are given in Table G-1. The locations and dimensions of the project outlets are given in Table G-2.

Table G-1 Ventilation outlet locations and dimensions – existing/other outlets

Ventilation outlet	Tunnel project	Location	Traffic direction	Number of sub-outlets	Code	Outlet locations (MGA94)		Ground elevation	Outlet height above ground elevation (m)	Outlet/sub-outlet diameter[b] (m)
						X	Y	Z[a]		
A	M5 East	Turrella	EB/WB	1	M5E1	328204	6244290	2.6	35.0	7.33
B	New M5	Arncliffe	EB	4	ARN1	329459	6243267	1.8	35.0	4.51
					ARN2	329470	6243275	0.8	35.0	4.51
					ARN3	329463	6243261	1.8	35.0	4.51
					ARN4	329474	6243269	0.8	35.0	4.51
C	New M5	SPI	EB	4	SPI1	331340	6245650	5.0	20.0	5.60
					SPI2	331346	6245655	4.7	20.0	5.60
					SPI3	331334	6245656	5.3	20.0	5.60
					SPI4	331340	6245662	5.3	20.0	5.60
D	M4-M5 Link	SPI	SB	4	SPI5	331765	6245940	13.1	22.0	9.00
					SPI6	331775	6245933	13.5	22.0	9.00
					SPI7	331755	6245925	10.7	22.0	9.00
					SPI8	331765	6245918	10.7	22.0	9.00

(a) Taken from GRAMM terrain file.
(b) Effective circular diameter.

Table G-2 Ventilation outlet locations and dimensions – project outlets

Ventilation outlet	Tunnel project	Location	Traffic direction	Number of sub-outlets	Code	Outlet locations (MGA94) X	Outlet locations (MGA94) Y	Ground elevation Z[(a)]	Outlet height above ground elevation (m)	Outlet/sub-outlet diameter[(b)] (m)
E	F6 Extension (Stage 1)	Arncliffe	NB	4	ARN5	329479	6243276	1.2	35.0	4.51
					ARN6	329475	6243281	1.2	35.0	4.51
					ARN7	329485	6243291	1.2	35.0	4.51
					ARN8	329489	6243286	1.2	35.0	4.51
F	F6 Extension (Stage 1)	Rockdale	SB	4	ROC1	328558	6240595	3.2	35.0	6.25
					ROC2	328567	6240597	3.2	35.0	6.25
					ROC3	328570	6240588	3.4	35.0	6.25
					ROC4	328580	6240591	3.4	35.0	6.25
G	F6 Extension (Stage 2)	Rockdale	NB	4	ROC5	328896	6240783	2.8	35.0	6.25
					ROC6	328920	6240771	3.2	35.0	6.25
					ROC7	328920	6240771	3.1	35.0	6.25
					ROC8	328930	6240761	3.1	35.0	6.25

(a) Taken from GRAMM terrain file.
(b) Effective circular diameter.

G.2 Air flows and temperatures - expected traffic scenarios

Table G-3 Ventilation air flows and temperatures: 2016-BY

Ventilation outlet	Tunnel project	Location	GRAL source group	Time period(s) (hour start)	No. of outlets/sub-outlets	Air flow per outlet/sub-outlet (m^3/s)	Exit velocity (m/s)	Outlet temp. (ºC)
A	M5 East	Turrella	A-1	Hours 00 to 04, 20 to 23	1	500	11.9	28.5
			A-2	Hours 05 to 21	1	850	20.1	30.0

Table G-4 Ventilation air flows and temperatures: 2026-DM

Ventilation outlet	Tunnel project	Location	GRAL source group	Time period(s) (hour start)*	No. of outlets/sub-outlets	Air flow per outlet/sub-outlet (m^3/s)	Exit velocity (m/s)	Outlet temp. (ºC)
A	M5 East	Turrella	A-1	Hours 00 to 04, 20 to 23	1	500	11.9	28.5
			A-2	Hours 05 to 21	1	850	20.1	30.0
B	New M5	Arncliffe	Outlet is not required for this scenario					
C	SPI	EB	C-1	Hours 00 to 06, 18 to 23	3	115	4.7	25.3
			C-2	Hours 15-17	4	108	4.4	25.3
			C-3	Hours 07-14	4	126	5.1	25.3
D	M4-M5 Link	SPI	D-1	Hours 00 to 06, 18 to 23	2	270	4.3	25.3
			D-2	Hours 07-17	3	220	3.5	25.3

* For any hours of the day not listed, the air flow = 0.

Table G-5 Ventilation air flows and temperatures: 2026-DS

Ventilation outlet	Tunnel project	Location	GRAL source group	Time period(s) (hour start)*	No. of outlets/sub-outlets	Air flow per outlet/sub-outlet (m^3/s)	Exit velocity (m/s)	Outlet temp. (ºC)
A	M5 East	Turrella	A-1	Hours 00 to 04, 20 to 23	1	500	11.9	28.5
			A-2	Hours 05 to 21	1	850	20.1	30.0
B	New M5	Arncliffe	B-1	Hours 09 to 14	2	60	3.8	25.3
			B-2	Hours 07 to 08	3	78	4.9	25.3
C	SPI	EB	C-1	Hours 00 to 06, 18 to 23	4	138	5.6	25.3
			C-2	Hours 07 to 17	4	181	7.4	25.3
D	M4-M5 Link	SPI	D-1	Hours 00 to 06, 18 to 23	2	210	3.3	25.3
			D-2	Hours 15 to 17	2	240	3.8	25.3
			D-3	Hours 07 to 14	2	253	4.0	25.3
E	F6 Extension (Stage 1)	Arncliffe	E-1	Hours 09 to 14	2	60	3.8	25.3
			E-2	Hours 07 to 08	3	78	4.9	25.3
F	F6 Extension (Stage 1)	Rockdale	F-1	Hours 00 to 08, 18 to 23	3	112	3.6	25.3
			F-2	Hours 09 to 14	4	120	3.9	25.3
			F-3	Hours 15 to 17	5	135	4.4	25.3

* For any hours of the day not listed, the air flow = 0.

Table G-6 Ventilation air flows and temperatures: 2036-DM

Ventilation outlet	Tunnel project	Location	GRAL source group	Time period(s) (hour start)*	No. of outlets/sub-outlets	Air flow per outlet/sub-	Exit velocity (m/s)	Outlet temp. (ºC)
A	M5 East	Turrella	A-1	Hours 00 to 04, 20 to 23	1	500	11.9	28.5
			A-2	Hours 05 to 21	1	850	20.1	30.0
B	New M5	Arncliffe	Outlet is not required for this scenario					
C	SPI	EB	C-1	Hours 00 to 06, 18 to 23	4	91	3.7	25.3
			C-2	Hours 15 to 17	4	113	4.6	25.3
			C-3	Hours 07 to 14	4	136	5.5	25.3
D	M4-M5 Link	SPI	D-1	Hours 00 to 06, 18 to 23	2	283	4.4	25.3
			D-2	Hours 07 to 17	3	232	3.6	25.3

* For any hours of the day not listed, the air flow = 0.

Table G-7 Ventilation air flows and temperatures: 2036-DS

Ventilation outlet	Tunnel project	Location	GRAL source group	Time period(s) (hour start)*	No. of outlets/sub-outlets	Air flow per outlet/sub-outlet (m^3/s)	Exit velocity (m/s)	Outlet temp. (ºC)
A	M5 East	Turrella	A-1	Hours 00 to 04, 20 to 23	1	500	11.9	28.5
			A-2	Hours 05 to 21	1	850	20.1	30.0
B	New M5	Arncliffe	B-1	Hours 09 to 14	3	58	3.6	25.3
			B-2	Hours 07 to 08	4	76	4.8	25.3
C	SPI	EB	C-1	Hours 00 to 06, 18 to 23	4	144	5.8	25.3
			C-2	Hours 07 to 17	4	181	7.4	25.3
D	M4-M5 Link	SPI	D-1	Hours 00 to 06, 18 to 23	2	218	3.4	25.3
			D-2	Hours 07 to 17	2	253	4.0	25.3
E	F6 Extension (Stage 1)	Arncliffe	E-1	Hours 09 to 14	3	58	3.7	25.3
			E-2	Hours 07 to 08	4	76	4.8	25.3
F	F6 Extension (Stage 1)	Rockdale	F-1	Hours 00 to 08, 18 to 23	3	117	3.8	25.3
			F-2	Hours 09 to 14	4	128	4.2	25.3
			F-3	Hours 15 to 17	4	138	4.5	25.3

* For any hours of the day not listed, the air flow = 0.

Table G-8 Ventilation air flows and temperatures: 2036-DSC

Ventilation outlet	Tunnel project	Location	GRAL source group	Time period(s) (hour start)*	No. of outlets/sub-outlets	Air flow per outlet/sub-outlet (m^3/s)	Exit velocity (m/s)	Outlet temp. (ºC)
A	M5 East	Turrella	A-1	Hours 00 to 04, 20 to 23	1	500	11.9	28.5
			A-2	Hours 05 to 21	1	850	20.1	30.0
B	New M5	Arncliffe	B-1	Hours 15 to 17	2	75	4.7	25.3
			B-2	Hours 09 to 14	3	88	5.5	25.3
			B-3	Hours 07 to 08	4	105	6.6	25.3
C	SPI	EB	C-1	Hours 00 to 06, 18 to 23	4	165	6.7	25.3
			C-2	Hours 07 to 17	4	181	7.4	25.3
D	M4-M5 Link	SPI	D-1	Hours 00 to 06, 18 to 23	2	250	3.9	25.3
			D-2	Hours 15 to 17	2	275	4.3	25.3
			D-3	Hours 07 to 14	2	300	4.7	25.3
E	F6 Extension (Stage 1)	Arncliffe	E-1	Hours 15 to 17	2	75	4.7	25.3
			E-2	Hours 09 to 14	3	88	5.5	25.3
			E-3	Hours 07 to 08	4	105	6.6	25.3
F	F6 Extension (Stage 1)	Rockdale	F-1	Hours 00 to 08, 18 to 23	4	113	3.7	25.3
			F-2	Hours 09 to 14	4	155	5.1	25.3
			F-3	Hours 15 to 17	4	183	5.9	25.3
G	F6 Extension (Stage 2)	Rockdale	G-1	Hours 00 to 06, 15 to 23	4	113	3.7	25.3
			G-2	Hours 09 to 14	4	156	5.1	25.3
			G-3	Hours 07 to 08	4	188	6.1	25.3

* For any hours of the day not listed, the air flow = 0.

G.3 Emissions - expected traffic scenarios

The diurnal emission profiles for each ventilation outlet and pollutant are presented in the following sections. The emission rate for each hour of the day represents the total from the outlet. The average emission rate for each GRAL source group (see Section 8.4.6) is also provided, with up to three source groups being defined for each outlet.

NB(1): Where a ventilation facility was sub-divided into several outlets, the emission rate for each source group was divided by the number of outlets, as provided in Table G-3 to Table G-8.

NB(2): The average emission rates for source groups are used in conjunction with emission modulation factors in GRAL (not shown). This approach results in exactly the same hourly emission profiles as those shown in the tables.

NB(3): The same presentational format has been used for each ventilation outlet, and where a particular outlet is not relevant to a scenario the corresponding table contains no values.

G.3.1 Outlet A (M5 East: Turrella)

Table G-9 Outlet A, 2016-BY

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	1.349	4.529	0.032	0.016	0.095
01	1.159	3.441	0.029	0.014	0.081
02	1.095	2.987	0.028	0.013	0.077
03	1.455	3.605	0.033	0.015	0.102
04	2.782	5.417	0.068	0.033	0.195
05	4.733	9.000	0.108	0.065	0.332
06	5.610	13.431	0.142	0.094	0.394
07	6.045	14.467	0.166	0.112	0.424
08	7.047	17.340	0.205	0.129	0.494
09	7.158	16.961	0.216	0.140	0.502
10	7.227	15.977	0.218	0.138	0.507
11	7.610	16.727	0.228	0.140	0.534
12	7.967	18.019	0.253	0.156	0.559
13	7.693	17.851	0.241	0.147	0.540
14	7.154	17.448	0.211	0.132	0.502
15	6.469	16.921	0.175	0.111	0.454
16	5.905	17.139	0.150	0.096	0.414
17	5.163	16.135	0.118	0.077	0.362
18	4.473	15.313	0.093	0.062	0.314
19	3.629	12.976	0.073	0.051	0.255
20	2.884	11.300	0.059	0.041	0.202
21	2.418	9.822	0.050	0.034	0.170
22	1.878	7.229	0.039	0.024	0.132
23	1.620	5.924	0.035	0.019	0.114
Average emission rates by source group used in GRAL **(kg/h)**					
A-1	***5.831***	***17.040***	***0.135***	***0.069***	***0.409***
A-2	***21.004***	***54.387***	***0.573***	***0.365***	***1.474***
A-3	***-***	***-***	***-***	***-***	***-***

Table G-10 Outlet A, 2026-DM

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.546	1.232	0.016	0.007	0.020
01	0.469	0.936	0.014	0.006	0.017
02	0.443	0.813	0.014	0.006	0.016
03	0.589	0.981	0.016	0.007	0.022
04	1.126	1.474	0.033	0.015	0.041
05	1.915	2.448	0.053	0.029	0.070
06	2.270	3.654	0.070	0.042	0.083
07	2.446	3.936	0.081	0.050	0.090
08	2.851	4.717	0.101	0.058	0.105
09	2.896	4.614	0.106	0.063	0.106
10	2.924	4.346	0.107	0.062	0.107
11	3.079	4.550	0.112	0.063	0.113
12	3.223	4.902	0.124	0.069	0.118
13	3.113	4.856	0.118	0.066	0.114
14	2.895	4.747	0.104	0.059	0.106
15	2.617	4.603	0.086	0.049	0.096
16	2.389	4.663	0.073	0.043	0.088
17	2.089	4.390	0.058	0.034	0.077
18	1.810	4.166	0.045	0.028	0.067
19	1.469	3.530	0.036	0.023	0.054
20	1.167	3.074	0.029	0.018	0.043
21	0.979	2.672	0.024	0.015	0.036
22	0.760	1.967	0.019	0.011	0.028
23	0.655	1.612	0.017	0.008	0.024
Average emission rates by source group used in GRAL **(kg/h)**					
A-1	***2.359***	***4.636***	***0.066***	***0.031***	***0.087***
A-2	***8.498***	***14.796***	***0.281***	***0.163***	***0.312***
A-3	***-***	***-***	***-***	***-***	***-***

Table G-11 Outlet A, 2026-DS

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.553	1.254	0.016	0.007	0.020
01	0.475	0.953	0.015	0.007	0.018
02	0.449	0.827	0.014	0.006	0.017
03	0.597	0.999	0.017	0.007	0.022
04	1.141	1.500	0.034	0.015	0.042
05	1.941	2.493	0.054	0.030	0.072
06	2.301	3.720	0.071	0.043	0.085
07	2.479	4.007	0.082	0.051	0.092
08	2.890	4.803	0.102	0.059	0.107
09	2.936	4.698	0.108	0.063	0.108
10	2.964	4.425	0.108	0.063	0.109
11	3.121	4.633	0.114	0.064	0.115
12	3.267	4.991	0.126	0.070	0.121
13	3.155	4.944	0.120	0.067	0.116
14	2.934	4.833	0.105	0.060	0.108
15	2.653	4.687	0.087	0.050	0.098
16	2.422	4.747	0.075	0.043	0.089
17	2.118	4.469	0.059	0.035	0.078
18	1.835	4.241	0.046	0.028	0.068
19	1.489	3.594	0.036	0.023	0.055
20	1.183	3.130	0.029	0.019	0.044
21	0.992	2.720	0.025	0.015	0.037
22	0.770	2.002	0.019	0.011	0.028
23	0.664	1.641	0.017	0.008	0.025
Average emission rates by source group used in GRAL **(kg/h)**					
A-1	***2.391***	***4.720***	***0.067***	***0.031***	***0.088***
A-2	***8.614***	***15.064***	***0.285***	***0.166***	***0.318***
A-3	***-***	***-***	***-***	***-***	***-***

Table G-12 Outlet A, 2036-DM

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.627	1.050	0.017	0.008	0.018
01	0.539	0.798	0.016	0.007	0.015
02	0.509	0.692	0.015	0.006	0.015
03	0.676	0.836	0.018	0.007	0.019
04	1.293	1.256	0.037	0.016	0.037
05	2.200	2.086	0.059	0.032	0.063
06	2.608	3.113	0.078	0.046	0.075
07	2.810	3.353	0.091	0.054	0.080
08	3.276	4.019	0.113	0.063	0.094
09	3.328	3.931	0.119	0.068	0.095
10	3.360	3.703	0.119	0.068	0.096
11	3.538	3.877	0.125	0.068	0.101
12	3.704	4.176	0.139	0.076	0.106
13	3.577	4.138	0.132	0.072	0.102
14	3.326	4.044	0.116	0.064	0.095
15	3.008	3.922	0.096	0.054	0.086
16	2.746	3.972	0.082	0.047	0.079
17	2.401	3.740	0.065	0.038	0.069
18	2.080	3.549	0.051	0.030	0.060
19	1.687	3.008	0.040	0.025	0.048
20	1.341	2.619	0.032	0.020	0.038
21	1.124	2.276	0.027	0.017	0.032
22	0.873	1.676	0.021	0.012	0.025
23	0.753	1.373	0.019	0.009	0.022
Average emission rates by source group used in GRAL **(kg/h)**					
A-1	***2.711***	***3.949***	***0.074***	***0.034***	***0.078***
A-2	***9.765***	***12.606***	***0.315***	***0.178***	***0.280***
A-3	-	-	-	-	-

Table G-13 Outlet A, 2036-DS

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.636	1.152	0.019	0.009	0.018
01	0.546	0.876	0.017	0.008	0.015
02	0.516	0.760	0.016	0.007	0.014
03	0.686	0.917	0.020	0.008	0.019
04	1.311	1.378	0.040	0.018	0.036
05	2.231	2.290	0.064	0.035	0.062
06	2.644	3.417	0.084	0.050	0.074
07	2.849	3.681	0.098	0.059	0.079
08	3.321	4.412	0.121	0.068	0.092
09	3.373	4.316	0.128	0.074	0.094
10	3.406	4.065	0.129	0.073	0.095
11	3.586	4.256	0.135	0.074	0.100
12	3.755	4.585	0.150	0.082	0.104
13	3.626	4.542	0.143	0.078	0.101
14	3.372	4.440	0.125	0.070	0.094
15	3.049	4.306	0.104	0.059	0.085
16	2.783	4.361	0.089	0.051	0.077
17	2.434	4.106	0.070	0.041	0.068
18	2.108	3.896	0.055	0.033	0.059
19	1.711	3.302	0.043	0.027	0.048
20	1.359	2.875	0.035	0.022	0.038
21	1.140	2.499	0.029	0.018	0.032
22	0.885	1.839	0.023	0.013	0.025
23	0.763	1.507	0.021	0.010	0.021
Average emission rates by source group used in GRAL **(kg/h)**					
A-1	***2.748***	***4.336***	***0.080***	***0.037***	***0.076***
A-2	***9.899***	***13.839***	***0.339***	***0.194***	***0.275***
A-3	-	-	-	-	-

Table G-14 Outlet A, 2036-DSC

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.587	1.050	0.017	0.008	0.016
01	0.505	0.798	0.016	0.007	0.014
02	0.477	0.692	0.015	0.006	0.013
03	0.633	0.836	0.018	0.007	0.017
04	1.211	1.256	0.037	0.016	0.033
05	2.060	2.086	0.059	0.032	0.057
06	2.442	3.113	0.078	0.046	0.067
07	2.631	3.353	0.091	0.054	0.073
08	3.068	4.019	0.113	0.063	0.085
09	3.116	3.931	0.119	0.068	0.086
10	3.146	3.703	0.119	0.068	0.087
11	3.313	3.877	0.125	0.068	0.091
12	3.468	4.176	0.139	0.076	0.096
13	3.349	4.138	0.132	0.072	0.092
14	3.114	4.044	0.116	0.064	0.086
15	2.816	3.922	0.096	0.054	0.078
16	2.571	3.972	0.082	0.047	0.071
17	2.248	3.740	0.065	0.038	0.062
18	1.947	3.549	0.051	0.030	0.054
19	1.580	3.008	0.040	0.025	0.044
20	1.256	2.619	0.032	0.020	0.035
21	1.053	2.276	0.027	0.017	0.029
22	0.817	1.676	0.021	0.012	0.023
23	0.705	1.373	0.019	0.009	0.019
Average emission rates by source group used in GRAL **(kg/h)**					
A-1	***2.538***	***3.949***	***0.074***	***0.034***	***0.070***
A-2	***9.143***	***12.606***	***0.315***	***0.178***	***0.252***
A-3	-	-	-	-	-

G.3.2 Outlet B (New M5: Arncliffe)

Table G-15 Outlet B, 2016-BY

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-
Average emission rates by source group used in GRAL **(kg/h)**					
B-1	-	-	-	-	-
B-2	-	-	-	-	-
B-3	-	-	-	-	-

Table G-16 Outlet B, 2026-DM

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-
Average emission rates by source group used in GRAL **(kg/h)**					
B-1	-	-	-	-	-
B-2	-	-	-	-	-
B-3	-	-	-	-	-

Table G-17 Outlet B, 2026-DS

Hour start	NO_X (g/s)	CO (g/s)		PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.000	0.000	0.000	0.000	0.000	0.000
01	0.000	0.000	0.000	0.000	0.000	0.000
02	0.000	0.000	0.000	0.000	0.000	0.000
03	0.000	0.000	0.000	0.000	0.000	0.000
04	0.000	0.000	0.000	0.000	0.000	0.000
05	0.000	0.000	0.000	0.000	0.000	0.000
06	0.000	0.000	0.000	0.000	0.000	0.000
07	0.341	0.443	0.090	0.060	0.022	0.341
08	0.341	0.443	0.090	0.060	0.022	0.341
09	0.140	0.148	0.032	0.021	0.009	0.140
10	0.140	0.148	0.032	0.021	0.009	0.140
11	0.140	0.148	0.032	0.021	0.009	0.140
12	0.140	0.148	0.032	0.021	0.009	0.140
13	0.140	0.148	0.032	0.021	0.009	0.140
14	0.140	0.148	0.032	0.021	0.009	0.140
15	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000
21	0.000	0.000	0.000	0.000	0.000	0.000
22	0.000	0.000	0.000	0.000	0.000	0.000
23	0.000	0.000	0.000	0.000	0.000	0.000
	Average emission rates by source group used in GRAL **(kg/h)**					
B-1	***0.505***	***0.534***	***0.112***	***0.077***	***0.034***	***0.505***
B-2	***1.229***	***1.596***	***0.312***	***0.215***	***0.083***	***1.229***
B-3	**-**	**-**	**-**	**-**	**-**	**-**

Table G-18 Outlet B, 2036-DM

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-
Average emission rates by source group used in GRAL **(kg/h)**					
B-1	-	-	-	-	-
B-2	-	-	-	-	-
B-3	-	-	-	-	-

Table G-19 Outlet B, 2036-DS

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.000	0.000	0.000	0.000	0.000
01	0.000	0.000	0.000	0.000	0.000
02	0.000	0.000	0.000	0.000	0.000
03	0.000	0.000	0.000	0.000	0.000
04	0.000	0.000	0.000	0.000	0.000
05	0.000	0.000	0.000	0.000	0.000
06	0.000	0.000	0.000	0.000	0.000
07	0.483	0.620	0.138	0.092	0.031
08	0.483	0.620	0.138	0.092	0.031
09	0.203	0.213	0.050	0.033	0.013
10	0.203	0.213	0.050	0.033	0.013
11	0.203	0.213	0.050	0.033	0.013
12	0.203	0.213	0.050	0.033	0.013
13	0.203	0.213	0.050	0.033	0.013
14	0.203	0.213	0.050	0.033	0.013
15	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000
21	0.000	0.000	0.000	0.000	0.000
22	0.000	0.000	0.000	0.000	0.000
23	0.000	0.000	0.000	0.000	0.000
Average emission rates by source group used in GRAL **(kg/h)**					
B-1	***0.732***	***0.766***	***0.181***	***0.120***	***0.047***
B-2	***1.739***	***2.231***	***0.498***	***0.331***	***0.111***
B-3	-	-	-	-	-

Table G-20 Outlet B, 2036-DSC

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.000	0.000	0.000	0.000	0.000
01	0.000	0.000	0.000	0.000	0.000
02	0.000	0.000	0.000	0.000	0.000
03	0.000	0.000	0.000	0.000	0.000
04	0.000	0.000	0.000	0.000	0.000
05	0.000	0.000	0.000	0.000	0.000
06	0.000	0.000	0.000	0.000	0.000
07	0.687	0.856	0.193	0.128	0.044
08	0.687	0.856	0.193	0.128	0.044
09	0.318	0.338	0.079	0.053	0.020
10	0.318	0.338	0.079	0.053	0.020
11	0.318	0.338	0.079	0.053	0.020
12	0.318	0.338	0.079	0.053	0.020
13	0.318	0.338	0.079	0.053	0.020
14	0.318	0.338	0.079	0.053	0.020
15	0.113	0.178	0.037	0.025	0.007
16	0.113	0.178	0.037	0.025	0.007
17	0.113	0.178	0.037	0.025	0.007
18	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000
21	0.000	0.000	0.000	0.000	0.000
22	0.000	0.000	0.000	0.000	0.000
23	0.000	0.000	0.000	0.000	0.000
Average emission rates by source group used in GRAL **(kg/h)**					
B-1	***0.407***	***0.640***	***0.133***	***0.088***	***0.026***
B-2	***1.144***	***1.218***	***0.286***	***0.190***	***0.073***
B-3	***2.473***	***3.080***	***0.693***	***0.461***	***0.158***

G.3.3 Outlet C (New M5: SPI)

Table G-21 Outlet C, 2016-BY

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-
Average emission rates by source group used in GRAL **(kg/h)**					
C-1	-	-	-	-	-
C-2	-	-	-	-	-
C-3	-	-	-	-	-

Table G-22 Outlet C, 2026-DM

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.269	0.524	0.059	0.041	0.018
01	0.269	0.525	0.059	0.041	0.018
02	0.269	0.525	0.059	0.041	0.018
03	0.269	0.525	0.059	0.041	0.018
04	0.269	0.525	0.059	0.041	0.018
05	0.269	0.525	0.059	0.041	0.018
06	0.269	0.525	0.059	0.041	0.018
07	2.081	3.118	0.388	0.268	0.141
08	2.081	3.118	0.388	0.268	0.141
09	1.257	1.445	0.198	0.137	0.085
10	1.257	1.445	0.198	0.137	0.085
11	1.257	1.444	0.198	0.137	0.085
12	1.257	1.445	0.198	0.137	0.085
13	1.257	1.444	0.198	0.137	0.085
14	1.257	1.444	0.198	0.137	0.085
15	0.552	1.000	0.115	0.079	0.037
16	0.552	1.001	0.115	0.079	0.037
17	0.552	1.001	0.115	0.079	0.037
18	0.268	0.524	0.059	0.041	0.018
19	0.269	0.524	0.059	0.041	0.018
20	0.269	0.524	0.059	0.041	0.018
21	0.269	0.524	0.059	0.041	0.018
22	0.269	0.524	0.059	0.041	0.018
23	0.269	0.524	0.059	0.041	0.018
Average emission rates by source group used in GRAL **(kg/h)**					
C-1	***0.967***	***1.888***	***0.212***	***0.147***	***0.065***
C-2	***1.988***	***3.602***	***0.413***	***0.286***	***0.135***
C-3	***5.266***	***6.706***	***0.882***	***0.610***	***0.356***

Table G-23 Outlet C, 2026-DS

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.423	0.875	0.097	0.064	0.027
01	0.424	0.875	0.097	0.064	0.027
02	0.424	0.875	0.097	0.064	0.027
03	0.424	0.875	0.097	0.064	0.027
04	0.424	0.875	0.097	0.064	0.027
05	0.424	0.875	0.097	0.064	0.027
06	0.424	0.875	0.097	0.064	0.027
07	2.324	3.714	0.409	0.272	0.148
08	2.324	3.713	0.409	0.272	0.148
09	1.785	2.261	0.281	0.187	0.114
10	1.785	2.261	0.281	0.187	0.114
11	1.785	2.261	0.281	0.187	0.114
12	1.785	2.260	0.281	0.187	0.114
13	1.785	2.260	0.281	0.187	0.114
14	1.785	2.260	0.281	0.187	0.114
15	0.872	1.618	0.186	0.124	0.056
16	0.872	1.618	0.186	0.124	0.056
17	0.872	1.617	0.186	0.124	0.056
18	0.423	0.875	0.097	0.064	0.027
19	0.423	0.875	0.097	0.064	0.027
20	0.423	0.875	0.097	0.064	0.027
21	0.423	0.875	0.097	0.064	0.027
22	0.423	0.875	0.097	0.064	0.027
23	0.423	0.875	0.097	0.064	0.027
Average emission rates by source group used in GRAL **(kg/h)**					
C-1	***1.525***	***3.151***	***0.335***	***0.231***	***0.103***
C-2	***5.882***	***8.457***	***0.000***	***0.666***	***0.398***
C-3	-	-	-	-	-

Table G-24 Outlet C, 2036-DM

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.276	0.531	0.071	0.047	0.018
01	0.277	0.531	0.071	0.047	0.018
02	0.277	0.531	0.071	0.047	0.018
03	0.277	0.531	0.071	0.047	0.018
04	0.277	0.531	0.071	0.047	0.018
05	0.277	0.531	0.071	0.047	0.018
06	0.277	0.531	0.071	0.047	0.018
07	2.436	3.371	0.498	0.331	0.156
08	2.436	3.371	0.498	0.331	0.156
09	1.379	1.602	0.250	0.166	0.088
10	1.379	1.602	0.250	0.166	0.088
11	1.379	1.602	0.250	0.166	0.088
12	1.379	1.602	0.250	0.166	0.088
13	1.379	1.602	0.250	0.166	0.088
14	1.379	1.602	0.250	0.166	0.088
15	0.568	0.969	0.133	0.088	0.036
16	0.568	0.969	0.133	0.088	0.036
17	0.568	0.969	0.133	0.088	0.036
18	0.276	0.531	0.071	0.047	0.018
19	0.276	0.531	0.071	0.047	0.018
20	0.276	0.531	0.071	0.047	0.018
21	0.276	0.531	0.071	0.047	0.018
22	0.276	0.531	0.071	0.047	0.018
23	0.276	0.531	0.071	0.047	0.018
Average emission rates by source group used in GRAL **(kg/h)**					
C-1	***0.995***	***1.911***	***0.255***	***0.169***	***0.064***
C-2	***2.044***	***3.490***	***0.478***	***0.318***	***0.131***
C-3	***5.916***	***7.359***	***1.122***	***0.745***	***0.378***

Table G-25 Outlet C, 2036-DS

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.404	0.821	0.104	0.069	0.026
01	0.404	0.821	0.104	0.069	0.026
02	0.404	0.821	0.104	0.069	0.026
03	0.404	0.821	0.104	0.069	0.026
04	0.404	0.821	0.104	0.069	0.026
05	0.404	0.821	0.104	0.069	0.026
06	0.404	0.821	0.104	0.069	0.026
07	2.633	4.046	0.511	0.340	0.168
08	2.633	4.046	0.511	0.339	0.168
09	1.859	2.337	0.316	0.210	0.119
10	1.859	2.337	0.316	0.210	0.119
11	1.859	2.337	0.316	0.210	0.119
12	1.859	2.337	0.316	0.210	0.119
13	1.859	2.337	0.316	0.210	0.119
14	1.859	2.337	0.316	0.210	0.119
15	0.859	1.543	0.203	0.135	0.055
16	0.859	1.543	0.203	0.135	0.055
17	0.859	1.543	0.203	0.135	0.055
18	0.404	0.821	0.104	0.069	0.026
19	0.404	0.821	0.104	0.069	0.026
20	0.404	0.821	0.104	0.069	0.026
21	0.404	0.821	0.104	0.069	0.026
22	0.404	0.821	0.104	0.069	0.026
23	0.404	0.821	0.104	0.069	0.026
Average emission rates by source group used in GRAL **(kg/h)**					
C-1	***1.454***	***2.956***	***0.375***	***0.249***	***0.093***
C-2	***6.217***	***8.753***	***1.154***	***0.767***	***0.397***
C-3	-	-	-	-	-

Table G-26 Outlet C, 2036-DSC

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.559	1.046	0.134	0.089	0.036
01	0.559	1.047	0.134	0.089	0.036
02	0.559	1.047	0.134	0.089	0.036
03	0.559	1.047	0.134	0.089	0.036
04	0.559	1.047	0.134	0.089	0.036
05	0.559	1.047	0.134	0.089	0.036
06	0.559	1.047	0.134	0.089	0.036
07	2.863	4.251	0.531	0.353	0.183
08	2.863	4.251	0.531	0.353	0.183
09	1.812	2.462	0.308	0.205	0.116
10	1.812	2.462	0.308	0.205	0.116
11	1.812	2.462	0.308	0.205	0.116
12	1.812	2.462	0.308	0.205	0.116
13	1.812	2.462	0.308	0.205	0.116
14	1.812	2.462	0.308	0.205	0.116
15	1.061	1.925	0.233	0.155	0.068
16	1.061	1.925	0.233	0.155	0.068
17	1.061	1.925	0.233	0.155	0.068
18	0.559	1.046	0.134	0.089	0.036
19	0.559	1.046	0.134	0.089	0.036
20	0.559	1.046	0.134	0.089	0.036
21	0.559	1.046	0.134	0.089	0.036
22	0.559	1.046	0.134	0.089	0.036
23	0.559	1.046	0.134	0.089	0.036
Average emission rates by source group used in GRAL **(kg/h)**					
C-1	***2.013***	***3.768***	***0.482***	***0.320***	***0.129***
C-2	***6.474***	***9.506***	***1.182***	***0.785***	***0.413***
C-3	-	-	-	-	-

G.3.4 Outlet D (M4-M5 Link: SPI)

Table G-27 Outlet D, 2016-BY

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-
Average emission rates by source group used in GRAL **(kg/h)**					
D-1	-	-	-	-	-
D-2	-	-	-	-	-
D-3	-	-	-	-	-

Table G-28 Outlet D, 2026-DM

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.902	1.711	0.160	0.111	0.061
01	0.906	1.717	0.161	0.111	0.061
02	0.906	1.717	0.161	0.111	0.061
03	0.906	1.716	0.161	0.111	0.061
04	0.905	1.716	0.161	0.111	0.061
05	0.905	1.716	0.161	0.111	0.061
06	0.905	1.716	0.161	0.111	0.061
07	2.211	3.955	0.395	0.273	0.150
08	2.211	3.954	0.395	0.273	0.150
09	2.375	3.560	0.374	0.258	0.161
10	2.375	3.559	0.374	0.258	0.161
11	2.375	3.559	0.374	0.258	0.161
12	2.374	3.559	0.373	0.258	0.161
13	2.374	3.558	0.373	0.258	0.161
14	2.374	3.558	0.373	0.258	0.161
15	1.815	3.445	0.333	0.230	0.123
16	1.815	3.445	0.333	0.230	0.123
17	1.814	3.444	0.333	0.230	0.123
18	0.903	1.712	0.160	0.111	0.061
19	0.903	1.712	0.160	0.111	0.061
20	0.903	1.711	0.160	0.111	0.061
21	0.903	1.711	0.160	0.111	0.061
22	0.903	1.711	0.160	0.111	0.061
23	0.903	1.711	0.160	0.111	0.061
Average emission rates by source group used in GRAL **(kg/h)**					
D-1	***3.254***	***6.169***	***0.577***	***0.399***	***0.220***
D-2	***7.891***	***12.958***	***1.319***	***0.911***	***0.534***
D-3	-	-	-	-	-

Table G-29 Outlet D, 2026-DS

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.627	1.172	0.114	0.076	0.040
01	0.629	1.176	0.114	0.076	0.040
02	0.629	1.176	0.114	0.076	0.040
03	0.629	1.176	0.114	0.076	0.040
04	0.629	1.176	0.114	0.076	0.040
05	0.629	1.176	0.114	0.076	0.040
06	0.629	1.176	0.114	0.076	0.040
07	1.313	2.331	0.240	0.160	0.084
08	1.313	2.330	0.240	0.160	0.084
09	1.501	2.206	0.240	0.159	0.096
10	1.501	2.205	0.240	0.159	0.096
11	1.501	2.205	0.240	0.159	0.096
12	1.500	2.205	0.240	0.159	0.096
13	1.500	2.205	0.240	0.159	0.096
14	1.500	2.204	0.240	0.159	0.096
15	1.177	2.250	0.223	0.148	0.075
16	1.177	2.249	0.223	0.148	0.075
17	1.177	2.249	0.223	0.148	0.075
18	0.628	1.173	0.114	0.076	0.040
19	0.627	1.173	0.114	0.076	0.040
20	0.627	1.172	0.114	0.076	0.040
21	0.627	1.172	0.114	0.076	0.040
22	0.627	1.172	0.114	0.076	0.040
23	0.627	1.172	0.114	0.076	0.040
Average emission rates by source group used in GRAL **(kg/h)**					
D-1	***2.261***	***4.226***	***0.394***	***0.272***	***0.153***
D-2	***4.237***	***8.097***	***0.771***	***0.533***	***0.287***
D-3	***5.233***	***8.051***	***0.831***	***0.574***	***0.354***

Table G-30 Outlet D, 2036-DM

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.956	1.640	0.185	0.123	0.061
01	0.960	1.646	0.186	0.123	0.061
02	0.959	1.646	0.186	0.123	0.061
03	0.959	1.645	0.186	0.123	0.061
04	0.959	1.645	0.186	0.123	0.061
05	0.959	1.645	0.185	0.123	0.061
06	0.959	1.645	0.185	0.123	0.061
07	2.276	3.799	0.442	0.294	0.145
08	2.325	3.861	0.445	0.296	0.148
09	2.357	3.422	0.420	0.279	0.151
10	2.357	3.422	0.420	0.279	0.150
11	2.357	3.421	0.420	0.279	0.150
12	2.356	3.421	0.420	0.279	0.150
13	2.356	3.421	0.420	0.279	0.150
14	2.356	3.420	0.420	0.279	0.150
15	2.039	3.506	0.418	0.278	0.130
16	2.039	3.506	0.418	0.278	0.130
17	2.039	3.506	0.418	0.278	0.130
18	0.957	1.641	0.185	0.123	0.061
19	0.957	1.641	0.185	0.123	0.061
20	0.957	1.641	0.185	0.123	0.061
21	0.957	1.641	0.185	0.123	0.061
22	0.957	1.641	0.185	0.123	0.061
23	0.956	1.641	0.185	0.123	0.061
Average emission rates by source group used in GRAL **(kg/h)**					
D-1	***3.448***	***5.914***	***0.667***	***0.443***	***0.220***
D-2	***8.135***	***12.667***	***1.525***	***1.014***	***0.519***
D-3	-	-	-	-	-

Table G-31 Outlet D, 2036-DS

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.647	1.079	0.122	0.081	0.041
01	0.650	1.083	0.123	0.081	0.041
02	0.650	1.083	0.123	0.081	0.041
03	0.649	1.083	0.123	0.081	0.041
04	0.649	1.083	0.123	0.081	0.041
05	0.649	1.083	0.123	0.081	0.041
06	0.649	1.082	0.123	0.081	0.041
07	1.323	2.288	0.261	0.173	0.085
08	1.358	2.327	0.263	0.175	0.087
09	1.399	1.995	0.244	0.162	0.089
10	1.398	1.994	0.244	0.162	0.089
11	1.398	1.994	0.244	0.162	0.089
12	1.398	1.994	0.244	0.162	0.089
13	1.398	1.994	0.244	0.162	0.089
14	1.398	1.993	0.244	0.162	0.089
15	1.246	2.207	0.256	0.170	0.080
16	1.246	2.207	0.256	0.170	0.080
17	1.245	2.207	0.256	0.170	0.080
18	0.648	1.080	0.122	0.081	0.041
19	0.648	1.080	0.122	0.081	0.041
20	0.648	1.080	0.122	0.081	0.041
21	0.648	1.080	0.122	0.081	0.041
22	0.647	1.079	0.122	0.081	0.041
23	0.647	1.079	0.122	0.081	0.041
Average emission rates by source group used in GRAL **(kg/h)**					
D-1	***2.334***	***3.892***	***0.440***	***0.293***	***0.149***
D-2	***4.846***	***7.593***	***0.902***	***0.599***	***0.309***
D-3	-	-	-	-	-

Table G-32 Outlet D, 2036-DSC

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.844	1.419	0.158	0.105	0.054
01	0.847	1.424	0.159	0.105	0.054
02	0.847	1.424	0.159	0.105	0.054
03	0.847	1.424	0.159	0.105	0.054
04	0.847	1.424	0.159	0.105	0.054
05	0.847	1.424	0.159	0.105	0.054
06	0.847	1.423	0.159	0.105	0.054
07	2.048	3.415	0.391	0.260	0.131
08	2.067	3.438	0.391	0.260	0.132
09	2.025	2.917	0.351	0.233	0.129
10	2.025	2.917	0.351	0.233	0.129
11	2.024	2.916	0.351	0.233	0.129
12	2.024	2.916	0.351	0.233	0.129
13	2.024	2.916	0.351	0.233	0.129
14	2.024	2.915	0.351	0.233	0.129
15	1.691	2.986	0.343	0.228	0.108
16	1.691	2.986	0.343	0.228	0.108
17	1.690	2.985	0.343	0.228	0.108
18	0.845	1.420	0.158	0.105	0.054
19	0.845	1.420	0.158	0.105	0.054
20	0.844	1.420	0.158	0.105	0.054
21	0.844	1.419	0.158	0.105	0.054
22	0.844	1.419	0.158	0.105	0.054
23	0.844	1.419	0.158	0.105	0.054
Average emission rates by source group used in GRAL **(kg/h)**					
D-1	***3.044***	***5.117***	***0.570***	***0.379***	***0.194***
D-2	***6.086***	***10.748***	***1.234***	***0.820***	***0.389***
D-3	***7.318***	***10.957***	***1.300***	***0.864***	***0.467***

G.3.5 Outlet E (F6 Extension – Stage 1: Arncliffe)

Table G-33 Outlet E, 2016-BY

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-
Average emission rates by source group used in GRAL **(kg/h)**					
E-1	-	-	-	-	-
E-2	-	-	-	-	-
E-3	-	-	-	-	-

Table G-34 Outlet E, 2026-DM

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-
Average emission rates by source group used in GRAL **(kg/h)**					
E-1	-	-	-	-	-
E-2	-	-	-	-	-
E-3	-	-	-	-	-

Table G-35 Outlet E, 2026-DS

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.000	0.000	0.000	0.000	0.000
01	0.000	0.000	0.000	0.000	0.000
02	0.000	0.000	0.000	0.000	0.000
03	0.000	0.000	0.000	0.000	0.000
04	0.000	0.000	0.000	0.000	0.000
05	0.000	0.000	0.000	0.000	0.000
06	0.000	0.000	0.000	0.000	0.000
07	0.162	0.269	0.049	0.033	0.010
08	0.162	0.269	0.049	0.033	0.010
09	0.084	0.112	0.022	0.014	0.005
10	0.084	0.112	0.022	0.014	0.005
11	0.084	0.112	0.022	0.014	0.005
12	0.084	0.112	0.022	0.014	0.005
13	0.084	0.112	0.022	0.014	0.005
14	0.084	0.112	0.022	0.014	0.005
15	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000
21	0.000	0.000	0.000	0.000	0.000
22	0.000	0.000	0.000	0.000	0.000
23	0.000	0.000	0.000	0.000	0.000
Average emission rates by source group used in GRAL **(kg/h)**					
E-1	***0.304***	***0.402***	***0.075***	***0.052***	***0.021***
E-2	***0.582***	***0.968***	***0.170***	***0.118***	***0.039***
E-3	***0.000***	***0.000***	***0.000***	***0.000***	***0.000***

Table G-36 Outlet E, 2036-DM

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-
Average emission rates by source group used in GRAL **(kg/h)**					
E-1	-	-	-	-	-
E-2	-	-	-	-	-
E-3	-	-	-	-	-

Table G-37 Outlet E, 2036-DS

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.000	0.000	0.000	0.000	0.000
01	0.000	0.000	0.000	0.000	0.000
02	0.000	0.000	0.000	0.000	0.000
03	0.000	0.000	0.000	0.000	0.000
04	0.000	0.000	0.000	0.000	0.000
05	0.000	0.000	0.000	0.000	0.000
06	0.000	0.000	0.000	0.000	0.000
07	0.228	0.369	0.077	0.051	0.015
08	0.229	0.369	0.077	0.051	0.015
09	0.121	0.158	0.034	0.023	0.008
10	0.121	0.158	0.034	0.023	0.008
11	0.121	0.158	0.034	0.023	0.008
12	0.121	0.159	0.034	0.023	0.008
13	0.121	0.159	0.034	0.023	0.008
14	0.121	0.159	0.034	0.023	0.008
15	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000
21	0.000	0.000	0.000	0.000	0.000
22	0.000	0.000	0.000	0.000	0.000
23	0.000	0.000	0.000	0.000	0.000
Average emission rates by source group used in GRAL **(kg/h)**					
E-1	***0.437***	***0.571***	***0.123***	***0.082***	***0.028***
E-2	***0.823***	***1.329***	***0.276***	***0.184***	***0.053***
E-3	-	-	-	-	-

Table G-38 Outlet E, 2036-DSC

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.000	0.000	0.000	0.000	0.000
01	0.000	0.000	0.000	0.000	0.000
02	0.000	0.000	0.000	0.000	0.000
03	0.000	0.000	0.000	0.000	0.000
04	0.000	0.000	0.000	0.000	0.000
05	0.000	0.000	0.000	0.000	0.000
06	0.000	0.000	0.000	0.000	0.000
07	0.345	0.586	0.108	0.072	0.022
08	0.345	0.586	0.108	0.072	0.022
09	0.162	0.237	0.045	0.030	0.010
10	0.162	0.237	0.045	0.030	0.010
11	0.162	0.237	0.045	0.030	0.010
12	0.162	0.237	0.045	0.030	0.010
13	0.162	0.237	0.045	0.030	0.010
14	0.162	0.237	0.045	0.030	0.010
15	0.067	0.122	0.022	0.015	0.004
16	0.067	0.122	0.022	0.015	0.004
17	0.067	0.122	0.022	0.015	0.004
18	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000
21	0.000	0.000	0.000	0.000	0.000
22	0.000	0.000	0.000	0.000	0.000
23	0.000	0.000	0.000	0.000	0.000
Average emission rates by source group used in GRAL **(kg/h)**					
E-1	***0.243***	***0.437***	***0.079***	***0.052***	***0.015***
E-2	***0.583***	***0.853***	***0.160***	***0.107***	***0.037***
E-3	***1.241***	***2.111***	***0.388***	***0.258***	***0.079***

G.3.6 Outlet F (F6 Extension – Stage 1: Rockdale)

Table G-39 Outlet F, 2016-BY

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-
Average emission rates by source group used in GRAL **(kg/h)**					
F-1	-	-	-	-	-
F-2	-	-	-	-	-
F-3	-	-	-	-	-

Table G-40 Outlet F, 2026-DM

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-
Average emission rates by source group used in GRAL **(kg/h)**					
F-1	-	-	-	-	-
F-2	-	-	-	-	-
F-3	-	-	-	-	-

Table G-41 Outlet F, 2026-DS

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.397	0.913	0.085	0.056	0.025
01	0.396	0.912	0.085	0.056	0.025
02	0.396	0.912	0.085	0.056	0.025
03	0.396	0.912	0.085	0.056	0.025
04	0.396	0.912	0.085	0.056	0.025
05	0.396	0.912	0.085	0.056	0.025
06	0.396	0.912	0.085	0.056	0.025
07	0.920	1.434	0.163	0.108	0.059
08	0.919	1.433	0.162	0.108	0.059
09	1.524	2.332	0.258	0.171	0.097
10	1.524	2.332	0.257	0.171	0.097
11	1.524	2.332	0.258	0.171	0.097
12	1.524	2.332	0.258	0.171	0.097
13	1.524	2.332	0.258	0.171	0.097
14	1.524	2.332	0.258	0.171	0.097
15	1.818	3.425	0.362	0.240	0.116
16	1.818	3.425	0.362	0.240	0.116
17	1.819	3.425	0.362	0.240	0.116
18	0.410	0.935	0.088	0.059	0.026
19	0.397	0.913	0.085	0.056	0.025
20	0.397	0.913	0.085	0.056	0.025
21	0.397	0.913	0.085	0.056	0.025
22	0.397	0.913	0.085	0.056	0.025
23	0.397	0.913	0.085	0.056	0.025
Average emission rates by source group used in GRAL **(kg/h)**					
F-1	***1.682***	***3.540***	***0.343***	***0.228***	***0.107***
F-2	***5.486***	***8.394***	***0.927***	***0.616***	***0.350***
F-3	***6.547***	***12.331***	***1.303***	***0.866***	***0.418***

Table G-42 Outlet F, 2036-DM

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-
Average emission rates by source group used in GRAL **(kg/h)**					
F-1	-	-	-	-	-
F-2	-	-	-	-	-
F-3	-	-	-	-	-

Table G-43 Outlet F, 2036-DS

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.397	0.900	0.094	0.063	0.025
01	0.397	0.899	0.094	0.063	0.025
02	0.397	0.899	0.094	0.063	0.025
03	0.397	0.899	0.094	0.063	0.025
04	0.397	0.899	0.094	0.063	0.025
05	0.397	0.899	0.094	0.063	0.025
06	0.397	0.899	0.094	0.063	0.025
07	0.990	1.623	0.197	0.131	0.063
08	1.007	1.641	0.198	0.132	0.064
09	1.588	2.467	0.301	0.200	0.101
10	1.588	2.468	0.301	0.200	0.101
11	1.588	2.468	0.301	0.200	0.101
12	1.588	2.468	0.301	0.200	0.101
13	1.588	2.468	0.301	0.200	0.101
14	1.588	2.468	0.301	0.200	0.101
15	1.916	3.410	0.424	0.282	0.122
16	1.916	3.410	0.424	0.282	0.122
17	1.916	3.410	0.424	0.282	0.122
18	0.405	0.911	0.097	0.064	0.026
19	0.397	0.900	0.094	0.063	0.025
20	0.397	0.900	0.094	0.063	0.025
21	0.397	0.900	0.094	0.063	0.025
22	0.397	0.900	0.094	0.063	0.025
23	0.397	0.900	0.094	0.063	0.025
Average emission rates by source group used in GRAL **(kg/h)**					
F-1	***1.720***	***3.592***	***0.390***	***0.259***	***0.110***
F-2	***5.716***	***8.883***	***1.085***	***0.721***	***0.365***
F-3	***6.898***	***12.275***	***1.525***	***1.014***	***0.440***

Table G-44 Outlet F, 2036-DSC

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.484	0.952	0.117	0.078	0.031
01	0.483	0.949	0.116	0.077	0.031
02	0.483	0.949	0.116	0.077	0.031
03	0.483	0.949	0.116	0.077	0.031
04	0.483	0.950	0.116	0.077	0.031
05	0.483	0.950	0.116	0.077	0.031
06	0.483	0.950	0.116	0.077	0.031
07	1.072	1.686	0.228	0.152	0.068
08	1.095	1.712	0.230	0.153	0.070
09	1.766	2.574	0.352	0.234	0.113
10	1.716	2.544	0.347	0.231	0.110
11	1.716	2.543	0.347	0.231	0.110
12	1.716	2.544	0.347	0.231	0.110
13	1.716	2.543	0.347	0.231	0.110
14	1.716	2.544	0.347	0.231	0.110
15	2.393	4.522	0.579	0.385	0.153
16	2.393	4.522	0.579	0.385	0.153
17	2.393	4.522	0.579	0.385	0.153
18	0.489	0.960	0.118	0.079	0.031
19	0.484	0.952	0.117	0.078	0.031
20	0.484	0.952	0.117	0.078	0.031
21	0.484	0.952	0.117	0.078	0.031
22	0.484	0.952	0.117	0.078	0.031
23	0.484	0.952	0.117	0.078	0.031
Average emission rates by source group used in GRAL **(kg/h)**					
F-1	***2.030***	***3.784***	***0.474***	***0.315***	***0.130***
F-2	***6.208***	***9.175***	***1.253***	***0.833***	***0.396***
F-3	***8.616***	***16.279***	***2.084***	***1.385***	***0.550***

G.3.7 Outlet G (F6 Extension – Stage 2: Rockdale)

Table G-45 Outlet G, 2016-BY

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-
Average emission rates by source group used in GRAL **(kg/h)**					
G-1	-	-	-	-	-
G-2	-	-	-	-	-
G-3	-	-	-	-	-

Table G-46 Outlet G, 2026-DM

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-
Average emission rates by source group used in GRAL **(kg/h)**					
G-1	-	-	-	-	-
G-2	-	-	-	-	-
G-3	-	-	-	-	-

Table G-47 Outlet G, 2026-DS

Hour start	*NO_X (g/s)*	*CO (g/s)*	*PM_{10} (g/s)*	*$PM_{2.5}$ (g/s)*	*THC (g/s)*
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-
Average emission rates by source group used in GRAL ***(kg/h)***					
G-1	-	-	-	-	-
G-2	-	-	-	-	-
G-3	-	-	-	-	-

Table G-48 Outlet G, 2036-DM

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-
Average emission rates by source group used in GRAL **(kg/h)**					
G-1	-	-	-	-	-
G-2	-	-	-	-	-
G-3	-	-	-	-	-

Table G-49 Outlet G, 2036-DS

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-
Average emission rates by source group used in GRAL **(kg/h)**					
G-1	-	-	-	-	-
G-2	-	-	-	-	-
G-3	-	-	-	-	-

Table G-50 Outlet G, 2036-DSC

Hour start	NO_X (g/s)	CO (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	THC (g/s)
00	0.138	0.241	0.033	0.022	0.009
01	0.138	0.242	0.033	0.022	0.009
02	0.138	0.242	0.033	0.022	0.009
03	0.138	0.242	0.033	0.022	0.009
04	0.138	0.242	0.033	0.022	0.009
05	0.138	0.242	0.033	0.022	0.009
06	0.138	0.242	0.033	0.022	0.009
07	0.667	1.156	0.163	0.109	0.043
08	0.667	1.156	0.163	0.109	0.043
09	0.422	0.632	0.091	0.060	0.027
10	0.422	0.632	0.091	0.060	0.027
11	0.422	0.632	0.091	0.060	0.027
12	0.422	0.632	0.091	0.060	0.027
13	0.422	0.632	0.091	0.060	0.027
14	0.422	0.632	0.091	0.060	0.027
15	0.251	0.479	0.063	0.042	0.016
16	0.251	0.479	0.063	0.042	0.016
17	0.251	0.479	0.063	0.042	0.016
18	0.138	0.242	0.033	0.022	0.009
19	0.138	0.241	0.033	0.022	0.009
20	0.138	0.241	0.033	0.022	0.009
21	0.138	0.241	0.033	0.022	0.009
22	0.138	0.241	0.033	0.022	0.009
23	0.138	0.241	0.033	0.022	0.009
Average emission rates by source group used in GRAL **(kg/h)**					
G-1	***0.574***	***1.030***	***0.139***	***0.092***	***0.037***
G-2	***1.519***	***2.276***	***0.327***	***0.218***	***0.097***
G-3	***2.403***	***4.162***	***0.588***	***0.391***	***0.153***

G.4 In-stack concentrations - expected traffic scenarios

The diurnal profiles for the concentrations of pollutants in each ventilation outlet are presented in the following sections.

G.4.1 Outlet A (M5 East: Turrella)

Table G-51 Outlet A, 2016-BY

Hour start	NO_X (mg/m³)	CO (mg/m³)	$PM_{2.5}$ (mg/m³)	PM_{10} (mg/m³)	THC (mg/m³)
00	2.698	9.058	0.064	0.032	0.189
01	2.319	6.883	0.058	0.029	0.163
02	2.190	5.974	0.055	0.025	0.154
03	2.910	7.211	0.066	0.030	0.204
04	5.564	10.834	0.135	0.067	0.390
05	5.568	10.588	0.127	0.077	0.391
06	6.600	15.801	0.167	0.111	0.463
07	7.111	17.020	0.195	0.131	0.499
08	8.290	20.401	0.241	0.152	0.582
09	8.421	19.955	0.254	0.165	0.591
10	8.503	18.797	0.256	0.163	0.597
11	8.952	19.678	0.268	0.165	0.628
12	9.373	21.199	0.298	0.183	0.658
13	9.050	21.002	0.284	0.173	0.635
14	8.417	20.527	0.249	0.156	0.591
15	7.610	19.907	0.206	0.130	0.534
16	6.947	20.164	0.176	0.113	0.487
17	6.074	18.983	0.138	0.091	0.426
18	5.263	18.015	0.109	0.073	0.369
19	4.270	15.266	0.086	0.060	0.300
20	3.393	13.295	0.069	0.049	0.238
21	2.845	11.555	0.059	0.040	0.200
22	3.755	14.458	0.077	0.048	0.264
23	3.239	11.848	0.070	0.037	0.227

Table G-52 Outlet A, 2026-DM

Hour start	NO_X (mg/m³)	CO (mg/m³)	$PM_{2.5}$ (mg/m³)	PM_{10} (mg/m³)	THC (mg/m³)
00	1.092	2.464	0.031	0.014	0.040
01	0.938	1.872	0.029	0.013	0.034
02	0.886	1.625	0.027	0.011	0.033
03	1.177	1.962	0.033	0.014	0.043
04	2.251	2.947	0.066	0.030	0.083
05	2.253	2.880	0.063	0.034	0.083
06	2.670	4.299	0.082	0.049	0.098
07	2.877	4.630	0.096	0.059	0.106
08	3.354	5.550	0.118	0.068	0.123
09	3.407	5.429	0.125	0.074	0.125
10	3.440	5.114	0.126	0.073	0.126
11	3.622	5.353	0.132	0.074	0.133
12	3.792	5.767	0.146	0.082	0.139
13	3.662	5.713	0.139	0.077	0.135
14	3.406	5.584	0.122	0.069	0.125
15	3.079	5.416	0.101	0.058	0.113
16	2.811	5.485	0.086	0.050	0.103
17	2.458	5.164	0.068	0.040	0.090
18	2.129	4.901	0.053	0.033	0.078
19	1.728	4.153	0.042	0.027	0.063
20	1.373	3.617	0.034	0.022	0.050
21	1.151	3.143	0.029	0.018	0.042
22	1.519	3.933	0.038	0.021	0.056
23	1.311	3.223	0.034	0.017	0.048

Table G-53 Outlet A, 2026-DS

Hour start	NO_X (mg/m³)	CO (mg/m³)	$PM_{2.5}$ (mg/m³)	PM_{10} (mg/m³)	THC (mg/m³)
00	1.107	2.509	0.032	0.015	0.041
01	0.951	1.906	0.029	0.013	0.035
02	0.898	1.655	0.028	0.011	0.033
03	1.193	1.997	0.033	0.014	0.044
04	2.282	3.001	0.067	0.030	0.084
05	2.284	2.933	0.063	0.035	0.084
06	2.707	4.376	0.083	0.050	0.100
07	2.917	4.714	0.097	0.060	0.108
08	3.400	5.650	0.120	0.069	0.126
09	3.454	5.527	0.127	0.075	0.127
10	3.487	5.206	0.127	0.074	0.129
11	3.672	5.450	0.134	0.075	0.136
12	3.844	5.872	0.148	0.083	0.142
13	3.712	5.817	0.141	0.079	0.137
14	3.452	5.686	0.124	0.070	0.127
15	3.121	5.514	0.103	0.059	0.115
16	2.849	5.585	0.088	0.051	0.105
17	2.491	5.258	0.069	0.041	0.092
18	2.158	4.990	0.054	0.033	0.080
19	1.751	4.228	0.043	0.027	0.065
20	1.392	3.682	0.035	0.022	0.051
21	1.167	3.200	0.029	0.018	0.043
22	1.540	4.005	0.038	0.022	0.057
23	1.328	3.282	0.035	0.017	0.049

Table G-54 Outlet A, 2036-DM

Hour start	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	1.255	2.099	0.035	0.016	0.036
01	1.078	1.595	0.032	0.014	0.031
02	1.018	1.385	0.030	0.012	0.029
03	1.353	1.671	0.036	0.015	0.039
04	2.587	2.511	0.074	0.033	0.074
05	2.589	2.454	0.070	0.037	0.074
06	3.068	3.662	0.092	0.054	0.088
07	3.306	3.945	0.107	0.064	0.095
08	3.855	4.728	0.132	0.074	0.110
09	3.915	4.625	0.140	0.080	0.112
10	3.953	4.357	0.140	0.079	0.113
11	4.162	4.561	0.147	0.080	0.119
12	4.358	4.913	0.164	0.089	0.125
13	4.208	4.868	0.156	0.084	0.120
14	3.913	4.758	0.137	0.076	0.112
15	3.538	4.614	0.113	0.063	0.101
16	3.230	4.673	0.097	0.055	0.092
17	2.824	4.400	0.076	0.044	0.081
18	2.447	4.175	0.060	0.036	0.070
19	1.985	3.538	0.047	0.029	0.057
20	1.578	3.081	0.038	0.024	0.045
21	1.323	2.678	0.032	0.019	0.038
22	1.746	3.351	0.042	0.023	0.050
23	1.506	2.746	0.038	0.018	0.043

Table G-55 Outlet A, 2036-DS

Hour start	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	1.272	2.305	0.038	0.017	0.035
01	1.093	1.751	0.035	0.015	0.030
02	1.032	1.520	0.033	0.013	0.029
03	1.371	1.835	0.039	0.016	0.038
04	2.622	2.757	0.080	0.035	0.073
05	2.624	2.694	0.075	0.041	0.073
06	3.111	4.021	0.099	0.059	0.087
07	3.352	4.331	0.115	0.070	0.093
08	3.907	5.191	0.143	0.080	0.109
09	3.969	5.077	0.151	0.087	0.110
10	4.007	4.783	0.152	0.086	0.112
11	4.219	5.007	0.159	0.087	0.117
12	4.417	5.394	0.176	0.097	0.123
13	4.266	5.344	0.168	0.092	0.119
14	3.967	5.223	0.147	0.082	0.110
15	3.587	5.065	0.122	0.069	0.100
16	3.274	5.131	0.104	0.060	0.091
17	2.863	4.830	0.082	0.048	0.080
18	2.480	4.584	0.064	0.039	0.069
19	2.012	3.884	0.051	0.032	0.056
20	1.599	3.383	0.041	0.026	0.045
21	1.341	2.940	0.035	0.021	0.037
22	1.770	3.679	0.046	0.025	0.049
23	1.527	3.015	0.041	0.020	0.042

Table G-56 Outlet A, 2036-DSC

Hour start	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	1.175	2.099	0.035	0.016	0.032
01	1.009	1.595	0.032	0.014	0.028
02	0.953	1.385	0.030	0.012	0.026
03	1.267	1.671	0.036	0.015	0.035
04	2.422	2.511	0.074	0.033	0.067
05	2.424	2.454	0.070	0.037	0.067
06	2.873	3.662	0.092	0.054	0.079
07	3.096	3.945	0.107	0.064	0.085
08	3.609	4.728	0.132	0.074	0.100
09	3.666	4.625	0.140	0.080	0.101
10	3.701	4.357	0.140	0.079	0.102
11	3.897	4.561	0.147	0.080	0.108
12	4.080	4.913	0.164	0.089	0.113
13	3.940	4.868	0.156	0.084	0.109
14	3.664	4.758	0.137	0.076	0.101
15	3.313	4.614	0.113	0.063	0.091
16	3.024	4.673	0.097	0.055	0.083
17	2.644	4.400	0.076	0.044	0.073
18	2.291	4.175	0.060	0.036	0.063
19	1.859	3.538	0.047	0.029	0.051
20	1.477	3.081	0.038	0.024	0.041
21	1.239	2.678	0.032	0.019	0.034
22	1.635	3.351	0.042	0.023	0.045
23	1.410	2.746	0.038	0.018	0.039

G.4.2 Outlet B (New M5: Arncliffe)

Table G-57 Outlet B, 2016-BY

Hour start	NO_X (mg/m³)	CO (mg/m³)	$PM_{2.5}$ (mg/m³)	PM_{10} (mg/m³)	THC (mg/m³)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-

Table G-58 Outlet B, 2026-DM

Hour start	NO_X (mg/m³)	CO (mg/m³)	$PM_{2.5}$ (mg/m³)	PM_{10} (mg/m³)	THC (mg/m³)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-

Table G-59 Outlet B, 2026-DS

Hour start	NO_X (mg/m³)	CO (mg/m³)	$PM_{2.5}$ (mg/m³)	PM_{10} (mg/m³)	THC (mg/m³)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	1.453	1.887	0.383	0.254	0.093
08	1.453	1.887	0.383	0.254	0.093
09	1.168	1.237	0.268	0.178	0.075
10	1.168	1.237	0.268	0.178	0.075
11	1.169	1.237	0.268	0.178	0.075
12	1.169	1.237	0.269	0.178	0.075
13	1.169	1.237	0.269	0.178	0.075
14	1.169	1.237	0.269	0.178	0.075
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-

Table G-60 Outlet B, 2036-DM

Hour start	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-

Table G-61 Outlet B, 2036-DS

Hour start	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	1.584	2.032	0.453	0.301	0.101
08	1.584	2.032	0.453	0.301	0.101
09	1.161	1.215	0.287	0.191	0.074
10	1.161	1.216	0.287	0.191	0.074
11	1.162	1.216	0.287	0.191	0.074
12	1.162	1.216	0.287	0.191	0.074
13	1.162	1.216	0.287	0.191	0.074
14	1.162	1.216	0.287	0.191	0.074
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-

Table G-62 Outlet B, 2036-DSC

Hour start	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	1.635	2.037	0.458	0.305	0.104
08	1.636	2.037	0.458	0.305	0.104
09	1.199	1.276	0.300	0.199	0.077
10	1.199	1.276	0.300	0.199	0.077
11	1.199	1.277	0.300	0.199	0.077
12	1.199	1.277	0.300	0.199	0.077
13	1.199	1.277	0.300	0.199	0.077
14	1.199	1.277	0.300	0.199	0.077
15	0.754	1.185	0.246	0.163	0.048
16	0.754	1.185	0.246	0.163	0.048
17	0.754	1.185	0.246	0.163	0.048
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-

G.4.3 Outlet C (New M5: SPI)

Table G-63 Outlet C, 2016-BY

Hour start	NO_X (mg/m³)	CO (mg/m³)	$PM_{2.5}$ (mg/m³)	PM_{10} (mg/m³)	THC (mg/m³)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-

Table G-64 Outlet C, 2026-DM

Hour start	NO_X (mg/m³)	CO (mg/m³)	$PM_{2.5}$ (mg/m³)	PM_{10} (mg/m³)	THC (mg/m³)
00	0.778	1.520	0.171	0.118	0.053
01	0.779	1.520	0.171	0.118	0.053
02	0.779	1.520	0.171	0.118	0.053
03	0.779	1.520	0.171	0.118	0.053
04	0.779	1.520	0.171	0.118	0.053
05	0.779	1.520	0.171	0.118	0.053
06	0.779	1.520	0.171	0.118	0.053
07	4.122	6.173	0.767	0.530	0.279
08	4.121	6.173	0.767	0.530	0.279
09	2.488	2.861	0.391	0.270	0.168
10	2.488	2.861	0.391	0.270	0.168
11	2.488	2.860	0.391	0.270	0.168
12	2.488	2.860	0.391	0.270	0.168
13	2.488	2.860	0.391	0.270	0.168
14	2.488	2.860	0.391	0.270	0.168
15	1.284	2.327	0.267	0.184	0.087
16	1.284	2.327	0.267	0.184	0.087
17	1.284	2.327	0.267	0.184	0.087
18	0.777	1.518	0.170	0.118	0.053
19	0.778	1.520	0.171	0.118	0.053
20	0.778	1.520	0.171	0.118	0.053
21	0.778	1.520	0.171	0.118	0.053
22	0.778	1.520	0.171	0.118	0.053
23	0.778	1.520	0.171	0.118	0.053

Table G-65 Outlet C, 2026-DS

Hour start	NO_X (mg/m³)	CO (mg/m³)	$PM_{2.5}$ (mg/m³)	PM_{10} (mg/m³)	THC (mg/m³)
00	0.770	1.591	0.176	0.117	0.049
01	0.770	1.592	0.176	0.117	0.049
02	0.770	1.592	0.176	0.117	0.049
03	0.770	1.592	0.176	0.117	0.049
04	0.770	1.592	0.176	0.117	0.049
05	0.770	1.592	0.176	0.117	0.049
06	0.770	1.592	0.176	0.117	0.049
07	3.205	5.122	0.565	0.375	0.205
08	3.205	5.122	0.565	0.375	0.205
09	2.462	3.118	0.387	0.257	0.157
10	2.462	3.118	0.387	0.257	0.157
11	2.462	3.118	0.387	0.257	0.157
12	2.462	3.118	0.387	0.257	0.157
13	2.462	3.118	0.387	0.257	0.157
14	2.462	3.118	0.387	0.257	0.157
15	1.203	2.231	0.256	0.170	0.077
16	1.203	2.231	0.256	0.170	0.077
17	1.203	2.231	0.256	0.170	0.077
18	0.770	1.591	0.176	0.117	0.049
19	0.770	1.591	0.176	0.117	0.049
20	0.770	1.591	0.176	0.117	0.049
21	0.770	1.591	0.176	0.117	0.049
22	0.770	1.591	0.176	0.117	0.049
23	0.770	1.591	0.176	0.117	0.049

Table G-66 Outlet C, 2036-DM

Hour start	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	0.757	1.454	0.194	0.129	0.048
01	0.758	1.455	0.194	0.129	0.048
02	0.758	1.455	0.194	0.129	0.048
03	0.758	1.455	0.194	0.129	0.048
04	0.758	1.455	0.194	0.129	0.048
05	0.758	1.455	0.194	0.129	0.048
06	0.758	1.455	0.194	0.129	0.048
07	4.470	6.185	0.913	0.607	0.285
08	4.470	6.185	0.913	0.607	0.285
09	2.531	2.939	0.458	0.304	0.162
10	2.531	2.939	0.458	0.304	0.162
11	2.531	2.939	0.458	0.304	0.162
12	2.530	2.939	0.458	0.304	0.162
13	2.530	2.939	0.458	0.304	0.162
14	2.530	2.939	0.458	0.304	0.162
15	1.262	2.154	0.295	0.196	0.081
16	1.262	2.154	0.295	0.196	0.081
17	1.262	2.154	0.295	0.196	0.081
18	0.757	1.454	0.193	0.129	0.048
19	0.757	1.454	0.194	0.129	0.048
20	0.757	1.454	0.194	0.129	0.048
21	0.757	1.454	0.194	0.129	0.048
22	0.757	1.454	0.194	0.129	0.048
23	0.757	1.454	0.194	0.129	0.048

Table G-67 Outlet C, 2036-DS

Hour start	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	0.702	1.428	0.181	0.120	0.045
01	0.703	1.429	0.181	0.120	0.045
02	0.703	1.429	0.181	0.120	0.045
03	0.703	1.429	0.181	0.120	0.045
04	0.703	1.428	0.181	0.120	0.045
05	0.703	1.428	0.181	0.120	0.045
06	0.703	1.428	0.181	0.120	0.045
07	3.632	5.580	0.705	0.468	0.232
08	3.632	5.580	0.705	0.468	0.232
09	2.565	3.224	0.436	0.290	0.164
10	2.565	3.224	0.436	0.290	0.164
11	2.564	3.224	0.436	0.290	0.164
12	2.564	3.224	0.436	0.290	0.164
13	2.564	3.223	0.436	0.290	0.164
14	2.564	3.223	0.436	0.290	0.164
15	1.185	2.129	0.280	0.186	0.076
16	1.185	2.129	0.280	0.186	0.076
17	1.184	2.129	0.280	0.186	0.076
18	0.702	1.428	0.181	0.120	0.045
19	0.702	1.428	0.181	0.120	0.045
20	0.702	1.428	0.181	0.120	0.045
21	0.702	1.428	0.181	0.120	0.045
22	0.702	1.428	0.181	0.120	0.045
23	0.702	1.428	0.181	0.120	0.045

Table G-68 Outlet C, 2036-DSC

Hour start	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	0.847	1.585	0.203	0.135	0.054
01	0.848	1.586	0.203	0.135	0.054
02	0.848	1.586	0.203	0.135	0.054
03	0.848	1.586	0.203	0.135	0.054
04	0.848	1.586	0.203	0.135	0.054
05	0.847	1.586	0.203	0.135	0.054
06	0.847	1.586	0.203	0.135	0.054
07	3.949	5.863	0.733	0.487	0.252
08	3.949	5.863	0.733	0.487	0.252
09	2.500	3.396	0.425	0.282	0.160
10	2.499	3.396	0.425	0.282	0.160
11	2.499	3.396	0.425	0.282	0.160
12	2.499	3.396	0.425	0.282	0.160
13	2.499	3.396	0.425	0.282	0.160
14	2.499	3.395	0.425	0.282	0.160
15	1.464	2.655	0.322	0.214	0.093
16	1.464	2.655	0.322	0.214	0.093
17	1.464	2.655	0.322	0.214	0.093
18	0.847	1.585	0.203	0.135	0.054
19	0.847	1.585	0.203	0.135	0.054
20	0.847	1.585	0.203	0.135	0.054
21	0.848	1.586	0.203	0.135	0.054
22	0.848	1.586	0.203	0.135	0.054
23	0.848	1.586	0.203	0.135	0.054

G.4.4 Outlet D (M4-M5 Link: SPI)

Table G-69 Outlet D, 2016-BY

Hour start	NO_X (mg/m³)	CO (mg/m³)	$PM_{2.5}$ (mg/m³)	PM_{10} (mg/m³)	THC (mg/m³)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-

Table G-70 Outlet D, 2026-DM

Hour start	NO_X (mg/m³)	CO (mg/m³)	$PM_{2.5}$ (mg/m³)	PM_{10} (mg/m³)	THC (mg/m³)
00	1.671	3.168	0.296	0.205	0.113
01	1.677	3.179	0.298	0.206	0.113
02	1.677	3.179	0.298	0.206	0.113
03	1.677	3.178	0.297	0.206	0.113
04	1.677	3.178	0.297	0.206	0.113
05	1.676	3.177	0.297	0.206	0.113
06	1.676	3.177	0.297	0.205	0.113
07	3.350	5.992	0.599	0.414	0.227
08	3.350	5.991	0.599	0.414	0.227
09	3.598	5.393	0.566	0.391	0.244
10	3.598	5.393	0.566	0.391	0.243
11	3.598	5.392	0.566	0.391	0.243
12	3.597	5.392	0.566	0.391	0.243
13	3.597	5.391	0.566	0.391	0.243
14	3.597	5.391	0.566	0.391	0.243
15	2.750	5.220	0.504	0.349	0.186
16	2.749	5.219	0.504	0.349	0.186
17	2.749	5.219	0.504	0.349	0.186
18	1.672	3.170	0.297	0.205	0.113
19	1.672	3.170	0.297	0.205	0.113
20	1.672	3.169	0.297	0.205	0.113
21	1.672	3.169	0.296	0.205	0.113
22	1.672	3.169	0.296	0.205	0.113
23	1.671	3.168	0.296	0.205	0.113

Table G-71 Outlet D, 2026-DS

Hour start	NO_X (mg/m³)	CO (mg/m³)	$PM_{2.5}$ (mg/m³)	PM_{10} (mg/m³)	THC (mg/m³)
00	1.493	2.790	0.271	0.180	0.095
01	1.499	2.800	0.272	0.181	0.096
02	1.498	2.800	0.272	0.181	0.096
03	1.498	2.800	0.272	0.181	0.096
04	1.498	2.799	0.272	0.181	0.096
05	1.498	2.799	0.272	0.180	0.096
06	1.498	2.799	0.272	0.180	0.096
07	2.600	4.615	0.475	0.316	0.166
08	2.600	4.614	0.475	0.316	0.166
09	2.972	4.368	0.475	0.316	0.190
10	2.972	4.367	0.475	0.316	0.190
11	2.971	4.367	0.475	0.316	0.190
12	2.971	4.366	0.475	0.316	0.190
13	2.971	4.366	0.475	0.316	0.190
14	2.970	4.365	0.475	0.316	0.190
15	2.452	4.687	0.464	0.308	0.157
16	2.452	4.686	0.464	0.308	0.157
17	2.452	4.685	0.464	0.308	0.157
18	1.494	2.792	0.271	0.180	0.095
19	1.494	2.792	0.271	0.180	0.095
20	1.494	2.791	0.271	0.180	0.095
21	1.494	2.791	0.271	0.180	0.095
22	1.493	2.791	0.271	0.180	0.095
23	1.493	2.790	0.271	0.180	0.095

Table G-72 Outlet D, 2036-DM

Hour start	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	1.693	2.903	0.327	0.217	0.108
01	1.698	2.913	0.328	0.218	0.108
02	1.698	2.912	0.328	0.218	0.108
03	1.698	2.912	0.328	0.218	0.108
04	1.698	2.912	0.328	0.218	0.108
05	1.698	2.911	0.328	0.218	0.108
06	1.697	2.911	0.328	0.218	0.108
07	3.275	5.466	0.637	0.423	0.209
08	3.345	5.555	0.641	0.426	0.214
09	3.392	4.923	0.604	0.401	0.217
10	3.391	4.923	0.604	0.401	0.217
11	3.391	4.923	0.604	0.401	0.217
12	3.391	4.922	0.604	0.401	0.216
13	3.390	4.922	0.604	0.401	0.216
14	3.390	4.921	0.604	0.401	0.216
15	2.934	5.045	0.602	0.400	0.187
16	2.934	5.044	0.602	0.400	0.187
17	2.933	5.044	0.602	0.400	0.187
18	1.694	2.905	0.327	0.218	0.108
19	1.694	2.905	0.327	0.218	0.108
20	1.693	2.904	0.327	0.218	0.108
21	1.693	2.904	0.327	0.218	0.108
22	1.693	2.904	0.327	0.218	0.108
23	1.693	2.904	0.327	0.218	0.108

Table G-73 Outlet D, 2036-DS

Hour start	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	1.488	2.481	0.281	0.187	0.095
01	1.493	2.490	0.282	0.187	0.095
02	1.493	2.489	0.282	0.187	0.095
03	1.493	2.489	0.282	0.187	0.095
04	1.493	2.489	0.282	0.187	0.095
05	1.493	2.489	0.282	0.187	0.095
06	1.492	2.488	0.282	0.187	0.095
07	2.621	4.530	0.516	0.343	0.167
08	2.690	4.608	0.521	0.346	0.172
09	2.769	3.950	0.484	0.321	0.177
10	2.769	3.949	0.483	0.321	0.177
11	2.769	3.949	0.483	0.321	0.177
12	2.768	3.948	0.483	0.321	0.177
13	2.768	3.948	0.483	0.321	0.177
14	2.768	3.947	0.483	0.321	0.177
15	2.467	4.371	0.507	0.337	0.158
16	2.467	4.370	0.507	0.337	0.157
17	2.466	4.370	0.507	0.337	0.157
18	1.489	2.483	0.281	0.187	0.095
19	1.489	2.482	0.281	0.187	0.095
20	1.489	2.482	0.281	0.187	0.095
21	1.489	2.482	0.281	0.187	0.095
22	1.488	2.481	0.281	0.187	0.095
23	1.488	2.481	0.281	0.187	0.095

Table G-74 Outlet D, 2036-DSC

Hour start	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	1.688	2.838	0.316	0.210	0.108
01	1.694	2.848	0.317	0.211	0.108
02	1.694	2.848	0.317	0.211	0.108
03	1.694	2.848	0.317	0.211	0.108
04	1.694	2.847	0.317	0.211	0.108
05	1.694	2.847	0.317	0.211	0.108
06	1.693	2.847	0.317	0.211	0.108
07	3.413	5.691	0.652	0.433	0.218
08	3.446	5.730	0.652	0.433	0.220
09	3.375	4.862	0.586	0.389	0.215
10	3.375	4.861	0.585	0.389	0.215
11	3.374	4.861	0.585	0.389	0.215
12	3.374	4.860	0.585	0.389	0.215
13	3.373	4.860	0.585	0.389	0.215
14	3.373	4.859	0.585	0.389	0.215
15	3.074	5.429	0.623	0.414	0.196
16	3.074	5.428	0.623	0.414	0.196
17	3.074	5.427	0.623	0.414	0.196
18	1.689	2.840	0.316	0.210	0.108
19	1.689	2.840	0.316	0.210	0.108
20	1.689	2.839	0.316	0.210	0.108
21	1.689	2.839	0.316	0.210	0.108
22	1.689	2.839	0.316	0.210	0.108
23	1.688	2.838	0.316	0.210	0.108

G.4.5 Outlet E (F6 Extension – Stage 1: Arncliffe)

Table G-75 Outlet E, 2016-BY

Hour start	NO_X (mg/m³)	CO (mg/m³)	$PM_{2.5}$ (mg/m³)	PM_{10} (mg/m³)	THC (mg/m³)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-

Table G-76 Outlet E, 2026-DM

Hour start	NO_X (mg/m³)	CO (mg/m³)	$PM_{2.5}$ (mg/m³)	PM_{10} (mg/m³)	THC (mg/m³)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-

Table G-77 Outlet E, 2026-DS

Hour start	NO_X (mg/m³)	CO (mg/m³)	$PM_{2.5}$ (mg/m³)	PM_{10} (mg/m³)	THC (mg/m³)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	0.688	1.144	0.209	0.139	0.044
08	0.688	1.144	0.209	0.139	0.044
09	0.703	0.930	0.181	0.120	0.045
10	0.703	0.930	0.181	0.120	0.045
11	0.704	0.930	0.181	0.120	0.045
12	0.704	0.931	0.181	0.120	0.045
13	0.704	0.931	0.181	0.120	0.045
14	0.704	0.931	0.181	0.120	0.045
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-

Table G-78 Outlet E, 2036-DM

Hour start	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-

Table G-79 Outlet E, 2036-DS

Hour start	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	0.749	1.210	0.252	0.167	0.048
08	0.749	1.211	0.252	0.167	0.048
09	0.693	0.905	0.195	0.130	0.044
10	0.693	0.905	0.195	0.130	0.044
11	0.693	0.906	0.195	0.130	0.044
12	0.693	0.906	0.195	0.130	0.044
13	0.694	0.906	0.195	0.130	0.044
14	0.694	0.906	0.195	0.130	0.044
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-

Table G-80 Outlet E, 2036-DSC

Hour start	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	0.821	1.396	0.257	0.170	0.052
08	0.821	1.396	0.257	0.171	0.052
09	0.610	0.893	0.168	0.112	0.039
10	0.611	0.893	0.168	0.112	0.039
11	0.611	0.894	0.168	0.112	0.039
12	0.611	0.894	0.168	0.112	0.039
13	0.611	0.894	0.168	0.112	0.039
14	0.611	0.894	0.168	0.112	0.039
15	0.449	0.810	0.146	0.097	0.029
16	0.449	0.810	0.146	0.097	0.029
17	0.449	0.810	0.146	0.097	0.029
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-

G.4.6 Outlet F (F6 Extension – Stage 1: Rockdale)

Table G-81 Outlet F, 2016-BY

Hour start	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-

Table G-82 Outlet F, 2026-DM

Hour start	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-

Table G-83 Outlet F, 2026-DS

Hour start	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	1.185	2.726	0.253	0.168	0.076
01	1.183	2.721	0.253	0.168	0.076
02	1.183	2.722	0.253	0.168	0.076
03	1.183	2.722	0.253	0.168	0.076
04	1.183	2.722	0.253	0.168	0.076
05	1.183	2.722	0.253	0.168	0.076
06	1.183	2.722	0.253	0.168	0.076
07	2.746	4.280	0.485	0.322	0.175
08	2.744	4.278	0.485	0.322	0.175
09	3.175	4.858	0.536	0.357	0.203
10	3.175	4.858	0.536	0.356	0.203
11	3.175	4.858	0.536	0.357	0.203
12	3.175	4.858	0.536	0.357	0.203
13	3.175	4.858	0.536	0.357	0.203
14	3.175	4.858	0.536	0.357	0.203
15	3.368	6.343	0.670	0.445	0.215
16	3.368	6.343	0.670	0.445	0.215
17	3.368	6.343	0.670	0.445	0.215
18	1.225	2.792	0.264	0.175	0.078
19	1.185	2.725	0.253	0.168	0.076
20	1.185	2.725	0.253	0.168	0.076
21	1.185	2.725	0.253	0.168	0.076
22	1.185	2.726	0.253	0.168	0.076
23	1.186	2.726	0.253	0.168	0.076

Table G-84 Outlet F, 2036-DM

Hour start	NO_X (mg/m³)	CO (mg/m³)	$PM_{2.5}$ (mg/m³)	PM_{10} (mg/m³)	THC (mg/m³)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-

Table G-85 Outlet F, 2036-DS

Hour start	NO_X (mg/m³)	CO (mg/m³)	$PM_{2.5}$ (mg/m³)	PM_{10} (mg/m³)	THC (mg/m³)
00	1.136	2.572	0.270	0.179	0.073
01	1.133	2.568	0.269	0.179	0.072
02	1.133	2.568	0.269	0.179	0.072
03	1.133	2.568	0.269	0.179	0.072
04	1.133	2.568	0.269	0.179	0.072
05	1.133	2.568	0.269	0.179	0.072
06	1.134	2.569	0.269	0.179	0.072
07	2.827	4.636	0.563	0.374	0.181
08	2.878	4.690	0.566	0.376	0.184
09	3.114	4.838	0.591	0.393	0.199
10	3.113	4.838	0.591	0.393	0.199
11	3.114	4.838	0.591	0.393	0.199
12	3.114	4.838	0.591	0.393	0.199
13	3.113	4.838	0.591	0.393	0.199
14	3.114	4.838	0.591	0.393	0.199
15	3.484	6.200	0.770	0.512	0.222
16	3.483	6.199	0.770	0.512	0.222
17	3.483	6.199	0.770	0.512	0.222
18	1.158	2.603	0.276	0.184	0.074
19	1.135	2.571	0.270	0.179	0.072
20	1.135	2.571	0.270	0.179	0.072
21	1.135	2.571	0.270	0.179	0.072
22	1.135	2.571	0.270	0.179	0.072
23	1.135	2.571	0.270	0.179	0.072

Table G-86 Outlet F, 2036-DSC

Hour start	NO_X (mg/m³)	CO (mg/m³)	$PM_{2.5}$ (mg/m³)	PM_{10} (mg/m³)	THC (mg/m³)
00	1.076	2.115	0.260	0.173	0.069
01	1.073	2.110	0.259	0.172	0.068
02	1.073	2.110	0.259	0.172	0.069
03	1.073	2.110	0.259	0.172	0.069
04	1.073	2.110	0.259	0.172	0.069
05	1.073	2.111	0.259	0.172	0.069
06	1.073	2.111	0.259	0.172	0.069
07	2.381	3.748	0.508	0.337	0.152
08	2.434	3.805	0.510	0.339	0.155
09	2.849	4.151	0.567	0.377	0.182
10	2.768	4.102	0.560	0.372	0.177
11	2.768	4.102	0.560	0.372	0.177
12	2.768	4.103	0.560	0.372	0.177
13	2.767	4.102	0.560	0.372	0.177
14	2.768	4.103	0.560	0.372	0.177
15	3.279	6.194	0.793	0.527	0.209
16	3.279	6.195	0.793	0.527	0.209
17	3.278	6.194	0.793	0.527	0.209
18	1.087	2.133	0.263	0.175	0.069
19	1.076	2.114	0.259	0.172	0.069
20	1.076	2.115	0.259	0.172	0.069
21	1.076	2.115	0.259	0.172	0.069
22	1.076	2.115	0.259	0.172	0.069
23	1.076	2.115	0.260	0.172	0.069

G.4.7 Outlet G (F6 Extension – Stage 2: Rockdale)

Table G-87 Outlet G, 2016-BY

Hour start	NO_X (mg/m³)	CO (mg/m³)	$PM_{2.5}$ (mg/m³)	PM_{10} (mg/m³)	THC (mg/m³)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-

Table G-88 Outlet G, 2026-DM

Hour start	NO_X (mg/m³)	CO (mg/m³)	$PM_{2.5}$ (mg/m³)	PM_{10} (mg/m³)	THC (mg/m³)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-

Table G-89 Outlet G, 2026-DS

Hour start	NO_X (mg/m³)	CO (mg/m³)	$PM_{2.5}$ (mg/m³)	PM_{10} (mg/m³)	THC (mg/m³)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-

Table G-90 Outlet G, 2036-DM

Hour start	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-

Table G-91 Outlet G, 2036-DS

Hour start	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	-	-	-	-	-
01	-	-	-	-	-
02	-	-	-	-	-
03	-	-	-	-	-
04	-	-	-	-	-
05	-	-	-	-	-
06	-	-	-	-	-
07	-	-	-	-	-
08	-	-	-	-	-
09	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
12	-	-	-	-	-
13	-	-	-	-	-
14	-	-	-	-	-
15	-	-	-	-	-
16	-	-	-	-	-
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	-	-	-	-	-
21	-	-	-	-	-
22	-	-	-	-	-
23	-	-	-	-	-

Table G-92 Outlet G, 2036-DSC

Hour start	NO_X (mg/m^3)	CO (mg/m^3)	$PM_{2.5}$ (mg/m^3)	PM_{10} (mg/m^3)	THC (mg/m^3)
00	0.307	0.537	0.074	0.049	0.020
01	0.307	0.537	0.074	0.049	0.020
02	0.307	0.537	0.074	0.049	0.020
03	0.307	0.537	0.074	0.049	0.020
04	0.307	0.537	0.074	0.049	0.020
05	0.307	0.537	0.074	0.049	0.020
06	0.307	0.537	0.074	0.049	0.020
07	0.890	1.542	0.218	0.145	0.057
08	0.890	1.542	0.218	0.145	0.057
09	0.675	1.012	0.146	0.097	0.043
10	0.675	1.012	0.146	0.097	0.043
11	0.675	1.012	0.146	0.097	0.043
12	0.675	1.012	0.146	0.097	0.043
13	0.675	1.012	0.146	0.097	0.043
14	0.675	1.012	0.146	0.097	0.043
15	0.558	1.065	0.139	0.092	0.036
16	0.558	1.065	0.139	0.092	0.036
17	0.558	1.065	0.139	0.092	0.036
18	0.307	0.537	0.074	0.049	0.020
19	0.307	0.537	0.074	0.049	0.020
20	0.307	0.537	0.074	0.049	0.020
21	0.307	0.537	0.074	0.049	0.020
22	0.307	0.537	0.074	0.049	0.020
23	0.307	0.537	0.074	0.049	0.020

G.5 Parameters for regulatory worst case scenarios

Table G-93 Ventilation outlet assumptions for regulatory worst case (RWC-2026-DS scenario - only used for NO_2 assessment)

Ventilation outlet	Number of outlets/ sub-outlets built	CSA per outlet/ sub-outlet (m^2)	Exit velocity per outlet/ sub-outlet (m/s)	Temp. (^0C)	Emission rate (kg/hour)				
					PM_{10}	$PM_{2.5}$	NO_X	CO	VOC/THC
Exiting and other outlets									
A (M5 East: Turrella)	1	42.2	11.8	25.0	1.980	1.980	36.000	72.000	7.200
B (New M5: Arncliffe)	4	16.0	3.8	25.0	0.238	0.238	4.320	8.640	0.864
C (New M5L SPI)	4	24.6	5.6	25.0	0.545	0.545	9.900	19.800	1.980
D (M4-M4 Link: SPI)	4	63.6	3.3	25.0	0.832	0.832	15.120	30.240	3.024
Project outlets									
E (F6 Extension – Stage 1: Arncliffe)	4	16.0	3.8	25.0	0.238	0.238	4.320	8.640	0.864
F (F6 Extension – Stage 1: Rockdale)	4	30.7	6.3	25.0	0.332	0.332	6.033	12.066	1.207
G (F6 Extension – Stage 2: Rockdale)	*Not applicable to scenario*								

Table G-94 Ventilation outlet assumptions for regulatory worst case (RWC-2036-DS scenario - only used for NO_2 assessment)

Ventilation outlet	Number of outlets/ sub-outlets built	CSA per outlet/ sub-outlet (m^2)	Exit velocity per outlet/ sub-outlet (m/s)	Temp. (^0C)	Emission rate (kg/hour)				
					PM_{10}	$PM_{2.5}$	NO_X	CO	VOC/THC
Exiting and other outlets									
A (M5 East: Turrella)	1	42.2	11.8	25.0	1.980	1.980	36.000	72.000	7.200
B (New M5: Arncliffe)	4	16.0	2.7	25.0	0.168	0.168	3.060	6.120	0.612
C (New M5L SPI)	4	24.6	5.8	25.0	0.569	0.569	10.350	20.700	2.070
D (M4-M4 Link: SPI)	4	63.6	3.4	25.0	0.861	0.861	15.660	31.320	3.132
Project outlets									
E (F6 Extension – Stage 1: Arncliffe)	4	16.0	3.6	25.0	0.231	0.231	4.200	8.400	0.840
F (F6 Extension – Stage 1: Rockdale)	4	30.7	6.3	25.0	0.347	0.347	6.303	12.607	1.261
G (F6 Extension – Stage 2: Rockdale)	*Not applicable to scenario*								

Table G-95 Ventilation outlet assumptions for regulatory worst case (RWC-2036-DSC scenario – used for all pollutants)

Ventilation outlet	Number of outlets/ sub-outlets built	CSA per outlet/ sub-outlet (m^2)	Exit velocity per outlet/ sub-outlet (m/s)	Temp. (^0C)	Emission rate (kg/hour)				
					PM_{10}	$PM_{2.5}$	NO_X	CO	VOC/THC
Exiting and other outlets									
A (M5 East: Turrella)	1	42.2	11.8	25.0	1.980	1.980	36.000	72.000	7.200
B (New M5: Arncliffe)	4	16.0	4.7	25.0	0.297	0.297	5.400	10.800	1.080
C (New M5L SPI)	4	24.6	6.7	25.0	0.653	0.653	11.880	23.760	2.376
D (M4-M4 Link: SPI)	4	63.6	3.9	25.0	0.990	0.990	18.000	36.000	3.600
Project outlets									
E (F6 Extension – Stage 1: Arncliffe)	4	16.0	4.8	25.0	0.297	0.297	5.400	10.800	1.080
F (F6 Extension – Stage 1: Rockdale)	4	30.7	6.3	25.0	0.446	0.446	8.104	16.209	1.621
G (F6 Extension – Stage 2: Rockdale)	4	30.7	6.3	25.0	0.446	0.446	8.104	16.209	1.621

Annexure H - Dispersion model evaluation

Annexure H - Dispersion model evaluation

H.1 GRAL optimisation study

Manansala et al. (2017) examined the performance of the GRAMM-GRAL system in an urban area of Sydney. The main objectives of the study were to assess the performance of GRAMM (version: July 2016) and GRAL (version: August 2016) against meteorological measurements and air quality measurements respectively. GRAMM and GRAL were also compared against other models that are commonly used in Australia: CALMET version 6.334 for meteorology, and CAL3QHCR version 2.0 for dispersion. The study provided recommendations regarding the configuration and application of GRAMM and GRAL to the assessment urban road networks/projects in Australia.

The study area was located near Parramatta Road in Western Sydney, where the terrain was relatively flat and there were few large buildings. The dispersion modelling part of the study involved the analysis of monitoring data and model predictions for an overall period of four months (November 2016 to February 2017). Measurements from both near-road[1] and background continuous monitoring stations, as well as multiple passive sampling locations, were used in the assessment. The evaluation of GRAL and CAL3QHCR focussed on the dispersion of oxides of nitrogen (NO_X) from surface roads.

The study took advantage of the two existing air pollution monitoring stations that were established for the WestConnex M4 East project:

- Concord Oval (near-road), adjacent to Parramatta Road. The average weekday traffic volume on Parramatta Road near this location was around 80,000 vehicles per day.
- St Lukes Park (background), around 180 metres from the nearest heavily trafficked road (Gipps Street, with around 26,000 vehicles per day). The station was approximately 450 metres to the north-east of the Concord Oval station.

The continuous monitoring data were analysed as 1-hour averages.

Ogawa passive samplers were used to measure fortnightly-average NO_X and NO_2 concentrations simultaneously at 17 locations, including co-location with the continuous analysers for calibration. The Ogawa samplers were deployed over two periods (i.e. two rounds of sampling). A third round of sampling was included at Concord Oval and St Lukes Park only, the reason for this being to increase the number of data points available for sampler calibration.

All the main roads in the dispersion model domain were included in the models. Traffic volumes by lane and by hour at specific junctions, and for the whole dispersion model evaluation period, were obtained from the Sydney Coordinated Adaptive Traffic System (SCATS). Traffic surveys were also carried out at seven locations (four video camera sites and three automatic tube count sites) to obtain additional data on traffic composition. Average traffic speeds between specific node points on the network were estimated using the Google Maps Distance Matrix application programming interface (API).

The study showed that the combination of GRAMM and GRAL is capable of giving good average predictions which reflect the spatial distribution of concentrations near roads with reasonable accuracy. The model chain gives results that are at least as good as those produced by other models that are currently in use in Australia. For example, Figure H-1 compares the performance of GRAL and CAL3QHCR with respect to the prediction of two-week average NO_X concentrations at the passive sampling locations. The slight overestimation of GRAM is desirable in an air quality assessment context. As with all air pollution models, the prediction of short-term (1-hour) concentrations remains a challenge. This is not surprising given the complexity of the processes involved.

Another challenge for the study was the treatment of short-term average NO_2 concentrations. This was because of the need to simulate several complex processes, including adequate representation of background concentrations, quantification of primary NO_2 (which is especially uncertain), and the short-

[1] The stations affected by roads are referred to here as 'near-road'. The term 'roadside' has not been used as this has a specific meaning in terms of distance from the road.

term chemical formation of NO_2 through its reaction with ozone. The latter point was particularly important for this study; the time scales for atmospheric mixing and chemical reactions are very similar, which makes this task difficult.

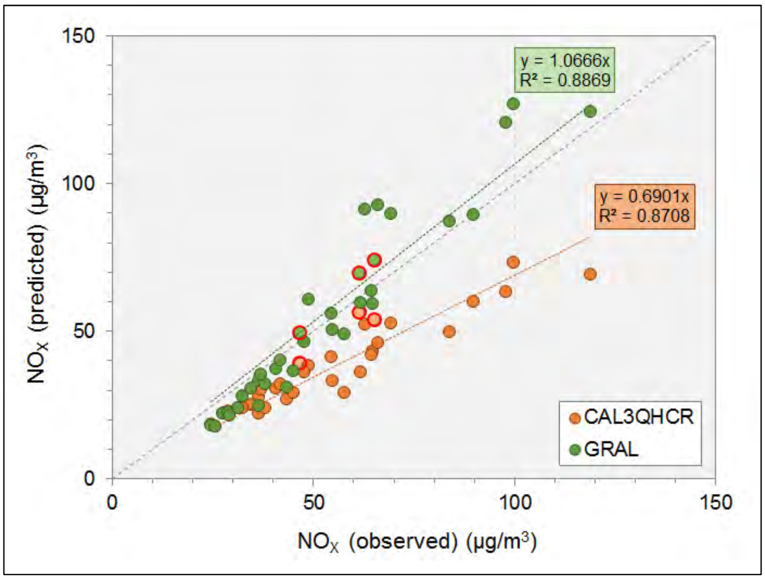


Figure H-1 Model evaluation at passive sampling locations (red circles show Concord Oval) (Manansala et al., 2017)

H.2 Evaluation for WestConnex projects

The performance of the GRAMM-GRAL system was also evaluated in the air quality assessments for the WestConnex M4 East, New M4 and M4-M5 Link projects. The most comprehensive of these evaluations was reported for the M4-M5 Link assessment (Pacific Environment, 2017). The evaluation involved comparing the predicted and measured concentrations at multiple air quality monitoring stations in 2015. The monitoring stations considered in the evaluation included a mixture of background and near-road stations.

The emphasis was on NO_X and NO_2, as the road traffic increment for CO and PM_{10} tends to be small relative to the background. $PM_{2.5}$ was not assessed as there were insufficient measurements to provide a detailed characterisation of background concentrations.

In order to cover different characteristics of the data, three statistical metrics were used: the annual mean concentration, the maximum short-term concentration (one hour or 24-hour, depending on the pollutant), and the 98th percentile[2] short-term concentration.

The results can be summarised as follows:

- For annual mean concentrations of all pollutants, there was, broadly speaking, a reasonably good agreement between the measured concentrations and those predicted by GRAL. An example of the results is shown in Figure H-2. However, there was a general overestimation of concentrations, and this was attributed to GRAL itself
- Maximum and 98th percentile concentrations are inherently difficult to predict, and there was a clear tendency towards the overestimation of these
- A more detailed temporal assessment of NO_X revealed a pronounced overestimation of concentrations at night-time and during peak traffic periods, although the seasonal variation in concentrations was, on average, well reproduced

[2] The selection of the 98th percentile was arbitrary. The intention of using this statistic was to provide an indication of the performance of GRAL at high concentrations, but with the most extreme values excluded.

- For annual mean and maximum 1-hour NO_2 the model with empirical NO_X-to-NO_2 conversion methods gave more realistic predictions than the ozone limiting method.

Overall, the results supported the application of GRAL in the assessment, along with the empirical conversion methods for NO_2, noting that the results tend to be quite conservative. The results suggested that the estimated concentrations ought to be conservative for most of the modelling domain.

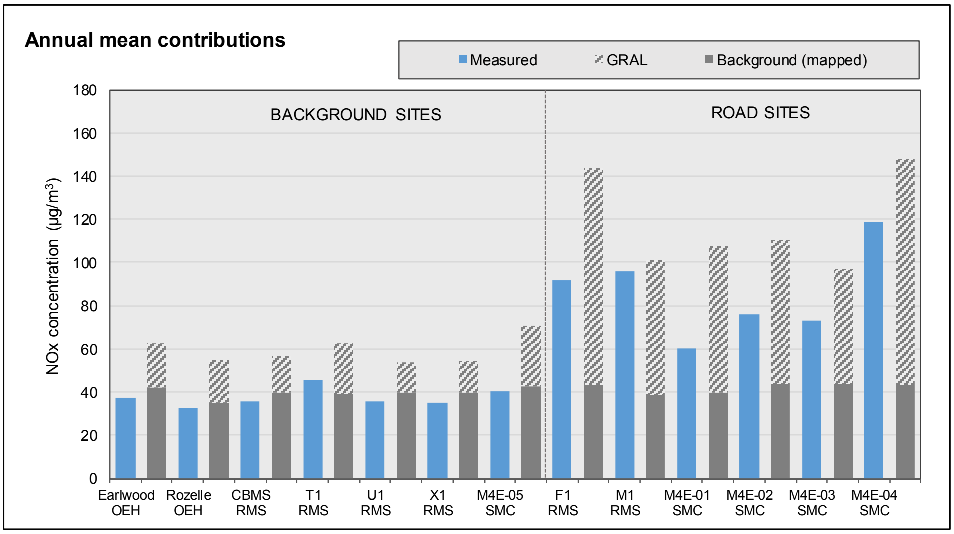


Figure H-2 Comparison between measured and predicted annual mean NO_X concentrations (Pacific Environment, 2017)

H.3 Project-specific evaluation

H.3.1 Approach

A similar model evaluation approach to that conducted for the WestConnex projects was also conducted for the F6 Extension – Stage 1, based on the monitoring data and model predictions for the 2016 base year. The characteristics of the background and near-road monitoring stations inside the GRAL domain are summarised in Table H-1, and for those located near roads the approximate two-way traffic volumes are also given. In total, 13 stations were located inside the GRAL domain. Of these, seven had data for all months of 2016 and four had partial data. The 11 stations with data for 2016 were therefore the only ones used in the evaluation. The performance of GRAL was not investigated at the two project-specific monitoring stations, as no data from these were available for the 2016 base year.

GRAL was configured to predict hourly concentrations of NO_X, NO_2, CO and PM_{10} at the 11 stations. For PM_{10}, daily average concentrations were also calculated.

A number of different approaches were used to account for the background contribution to the predicted concentrations, and to compare the effects of different assumptions:

- For annual mean NO_X and PM_{10}, a background concentration map was used (see Annexure D).
- For short-term metrics the contemporaneous method was used, based on both ‘average’ and ‘maximum’ synthetic background profiles. The average synthetic background profiles were constructed in a similar way to those described in Annexure D, but to enable a more direct comparison with the monitoring data, they were calculated using an average value for each hour of the year across several monitoring stations rather than the maximum value used in the assessment (where an element of conservatism was required for short-term concentrations).
- NO_2 was calculated using the empirical methods described in Annexure E. The ozone limiting method (OLM, see Annexure E) was also applied for comparison, as this is widely used in NSW.

In the following sections, the results of the evaluation are presented by pollutant.

Table H-1 Characteristics of monitoring stations in the GRAL domain

Station code	Organisation (project)	Station name	Location	Station type	Nearest busy road(s) (road stations only)			Monitoring data for 2016
					Road(s)	Distance to kerb (m)	Traffic vol. (approx. vpd)	
M01	OEH (-)	Earlwood[(a)]	Beaman Park	Background	-	-	-	Jan-Dec
M02	RMS (M5 East tunnel)	M5E:CBMS	Gipps Street, Bardwell Valley	Background	-	-	-	Jan-Dec[(b)]
M03		M5E:T1	Thompson Street, Turrella	Background	-	-	-	Jan-Dec
M04		M5E:U1	Jackson Place, Undercliffe	Background	-	-	-	Jan-Dec
M05		M5E:X1	Wavell Parade, Earlwood	Background	-	-	-	Jan-Dec
M06		M5E:M1	M5 East tunnel off-ramp	Peak (near-road)	Off-ramp, M5 East tunnel	~8	~20,000	Jan-Dec
M07	SMC (New M5 Motorway)	New M5:01	St Peters Public School, Church St, St Peters	Background	-	-	-	Jan-Dec
M08		New M5:02	Princes Highway, St Peters	Peak (near-road)	Princes Highway Campbell Street	~5 ~20	~35,000 ~5,000	Jan-Apr
M09		New M5:03	West Botany Street, Arncliffe	Peak (near-road)	West Botany Street On-ramp, M5 East tunnel	~11 ~35	~32,000 ~30,000	Jan-Jun
M10		New M5:04	Bestic Street, Rockdale	Background	-	-	-	Jan-Sep
M11		New M5:07	Canal Road, St Peters	Peak (near-road)	Canal Road	~5	~45,000	Jan-Apr
M12	RMS (F6 Extension - Stage 1)	F6:01	Kings Road	Background	-	-	-	None[(c)]
M13		F6:02	Tancred Avenue	Peak (near-road)	General Holmes Drive	~7		None[(c)]

(a) CO was not measured at this station.

(b) The CBMS station had no valid NO_X and NO_2 data in 2016.

(c) Monitoring commenced in November 2017.

H.3.2 Results for NOx

Figure H-3 and Figure H-4 show examples of the modelled 1-hour mean NO_X concentrations for a background station (New M5:01, St Peters Public School) and a near-road station (M5E:M1, M5 East tunnel off-ramp), along with the measured NO_X concentrations at these stations. The modelled concentration includes both the background contribution and the GRAL prediction. At the near-road station there was a larger modelled contribution from GRAL.

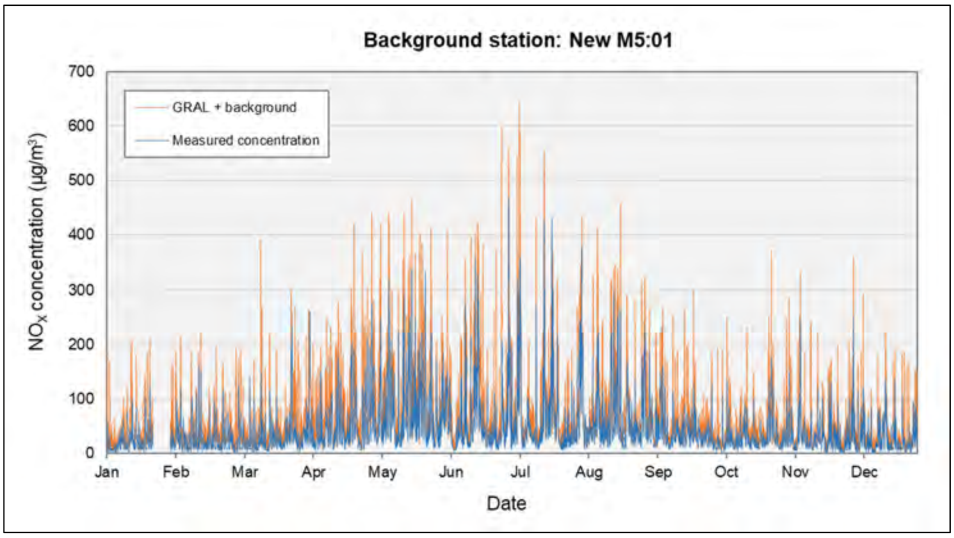


Figure H-3 Measured 1-hour mean NO_X concentrations and GRAL predictions (including background) for the New M5:01 (St Peters Public School) background monitoring station

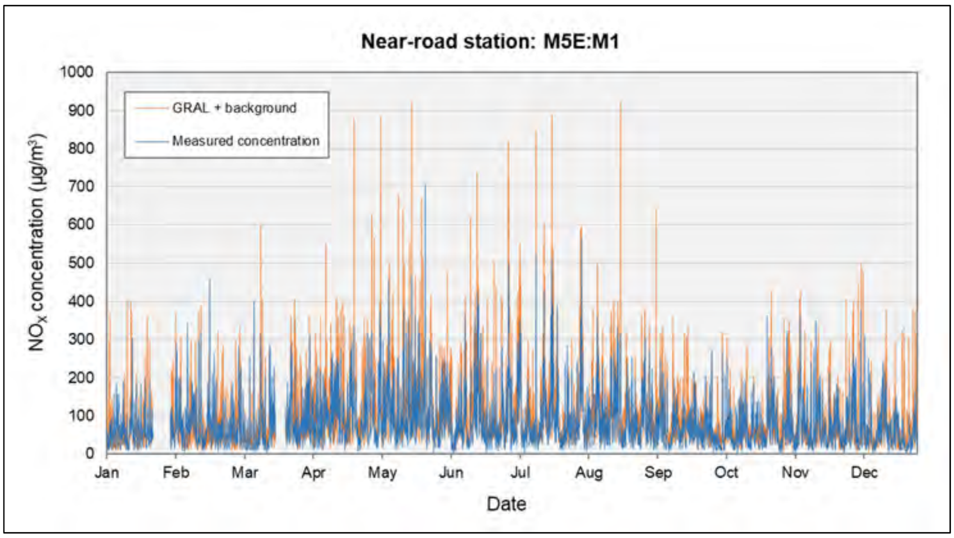
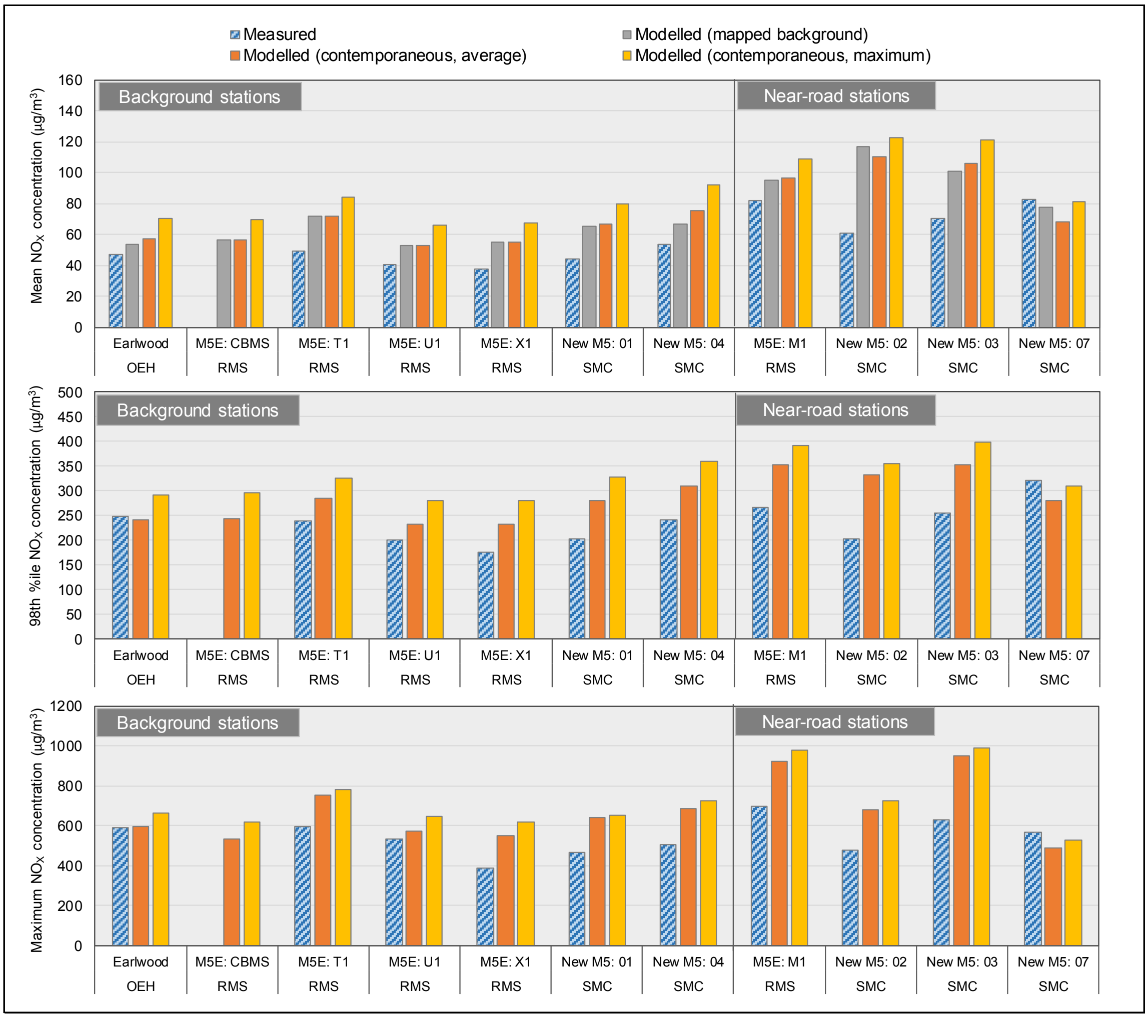


Figure H-4 Measured 1-hour mean NO_X concentrations and GRAL predictions (including background) for the M5E: M1 (M5 East tunnel off-ramp) monitoring station

In Figure H-5 the measured and predicted NO_X concentrations are compared for each of the monitoring stations. The tabulated results, including the predicted/observed ratios, are also provided. The mapped background concentration (as an annual mean) was only used in conjunction with the mean GRAL prediction. However, it should be noted that, for several stations, monitoring data were only available from April to December of 2016, whereas the mapped background was for the full year. This will have contributed to differences between the predictions and the observations. Figure H-6 shows the background concentrations and GRAL contributions separately for mean NO_X.



Statistical metric (based on 1-hour concentrations)	Station type	Org.	Station	Measured concentration (µg/m³)	Predicted concentration (µg/m³): GRAL + mapped background	Predicted concentration (µg/m³): GRAL + contemporaneous background 'Average' approach	Predicted concentration (µg/m³): GRAL + contemporaneous background 'Maximum' approach	Predicted/measured: GRAL + mapped background	Predicted/measured: GRAL + contemporaneous background 'Average' approach	Predicted/measured: GRAL + contemporaneous background 'Maximum' approach
Mean concentration	Background	OEH	Earlwood	47.0	53.9	57.0	70.2	1.1	1.2	1.5
		RMS	M5E: CBMS	-	56.8	56.8	69.7	-	-	-
		RMS	M5E: T1	49.2	71.8	71.8	84.4	1.5	1.5	1.7
		RMS	M5E: U1	40.2	53.1	53.1	65.9	1.3	1.3	1.6
		RMS	M5E: X1	37.3	55.1	54.8	67.4	1.5	1.5	1.8
		SMC	New M5: 01	44.1	65.3	66.7	79.7	1.5	1.5	1.8
		SMC	New M5: 04	53.5	66.4	75.6	92.0	1.2	1.4	1.7
	Near-road	RMS	M5E: M1	81.7	94.9	96.3	108.9	1.2	1.2	1.3
		SMC	New M5: 02	60.6	116.5	110.1	122.8	1.9	1.8	2.0
		SMC	New M5: 03	70.3	100.9	105.7	121.3	1.4	1.5	1.7
		SMC	New M5: 07	82.6	77.4	68.3	80.9	0.9	0.8	1.0
98th percentile concentration	Background	OEH	Earlwood	248.3	-	241.1	291.8	-	1.0	1.2
		RMS	M5E: CBMS	-	-	242.7	296.4	-	-	-
		RMS	M5E: T1	239.9	-	285.7	326.6	-	1.2	1.4
		RMS	M5E: U1	201.3	-	233.1	280.3	-	1.2	1.4
		RMS	M5E: X1	175.5	-	231.7	279.9	-	1.3	1.6
		SMC	New M5: 01	203.1	-	281.4	327.6	-	1.4	1.6
		SMC	New M5: 04	241.5	-	309.0	360.2	-	1.3	1.5
	Near-road	RMS	M5E: M1	267.6	-	352.6	392.1	-	1.3	1.5
		SMC	New M5: 02	203.2	-	331.7	354.4	-	1.6	1.7
		SMC	New M5: 03	255.6	-	354.2	398.1	-	1.4	1.6
		SMC	New M5: 07	320.9	-	279.3	308.9	-	0.9	1.0
Maximum concentration	Background	OEH	Earlwood	589.0	-	593.1	661.3	-	1.0	1.1
		RMS	M5E: CBMS	-	-	532.9	620.2	-	-	-
		RMS	M5E: T1	596.7	-	755.5	782.9	-	1.3	1.3
		RMS	M5E: U1	533.8	-	575.6	643.8	-	1.1	1.2
		RMS	M5E: X1	386.4	-	552.6	620.8	-	1.4	1.6
		SMC	New M5: 01	468.4	-	643.1	653.7	-	1.4	1.4
		SMC	New M5: 04	507.7	-	688.0	727.8	-	1.4	1.4
	Near-road	RMS	M5E: M1	696.3	-	921.9	980.7	-	1.3	1.4
		SMC	New M5: 02	476.1	-	680.6	724.8	-	1.4	1.5
		SMC	New M5: 03	627.7	-	950.5	990.3	-	1.5	1.6
		SMC	New M5: 07	569.5	-	486.6	530.8	-	0.9	0.9

Figure H-5 Comparison between measured and predicted total NO_X concentrations

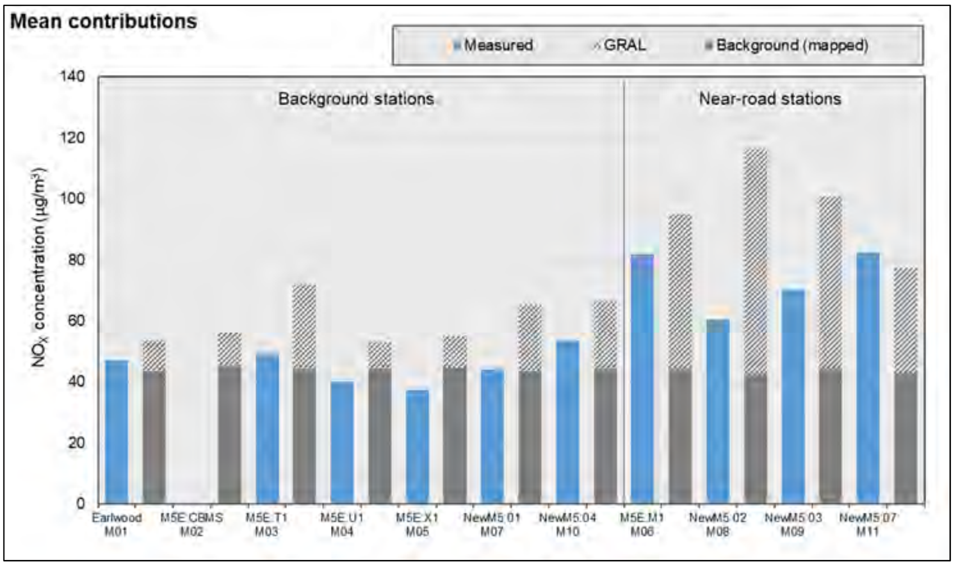


Figure H-6 Contributions to modelled mean NO_X concentrations

At the **background** stations NO_X concentrations were overestimated, as would be expected. For the purpose of the air quality assessment it was assumed that the measured background stations were not influenced by road transport sources, and therefore in principle the concentrations predicted by GRAL at these stations should have been zero. In practice, dispersion models will often give non-zero values at background stations, and this was also the case here. This overestimation of mean NO_X at the background stations was around 7-23 µg/m^3, or 15-48 per cent, based on the mapped background. The bulk of the overestimation was due mainly to the GRAL prediction (see Figure H-6). Using the 'average' synthetic profile the 98th percentile and maximum concentrations were overestimated by up to around 40 per cent, and using the 'maximum' synthetic profile the overestimation was up to around 60 per cent.

At the **near-road** stations the mean NO_X concentration was overestimated by up to 90 per cent based on the mapped background. The contemporaneous approaches gave broadly similar results to the mapped background approach. The synthetic profiles also resulted in the overestimation of 98th percentile and maximum NO_X concentration. It is worth noting that, for some of the near-road stations included in the assessment, the measured NO_X increment above the background was not very pronounced.

The inference from these results is that NO_X concentrations across the domain were probably overestimated.

Because there is generally a stronger road traffic signal for NO_X than for other criteria pollutants, the model performance at the four near-road stations was also examined in more detail using the '*timeVariation*' function in the Openair software (Carslaw, 2015). Figure H-7 to Figure H-10 show the results from the *timeVariation* function for the predicted ('GRAL') and monitored ('MON') hourly NO_X concentrations at the four near-road stations included in the evaluation. The hours with low numbers of values (typically less than 20) associated with, for example, periods of instrument calibration, have been removed from the datasets.

The variation of a pollutant by time of day and day of week can reveal useful information concerning the likely sources. For example, road vehicle emissions tend to follow regular patterns both on a daily and weekly basis. The *timeVariation* function produces four plots: day of the week variation, mean hour of day variation, a combined hour of day – day of week plot, and a monthly plot. Also shown on the plots is the 95 per cent confidence interval in the mean. For model evaluation it is important to consider the difference between observations and modelled values over these different time scales (Carslaw, 2015).

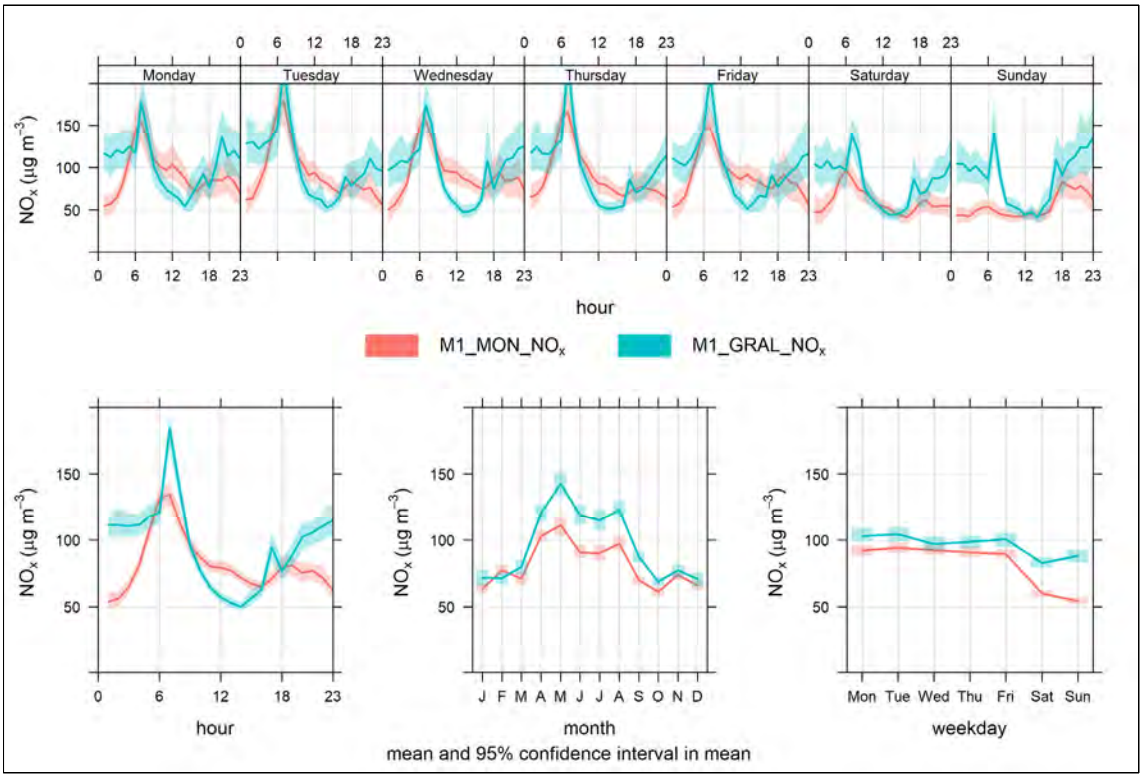


Figure H-7 Time variation of measured and predicted total NOX concentrations at the M5E:M1 (M5 East tunnel off-ramp) near-road monitoring station

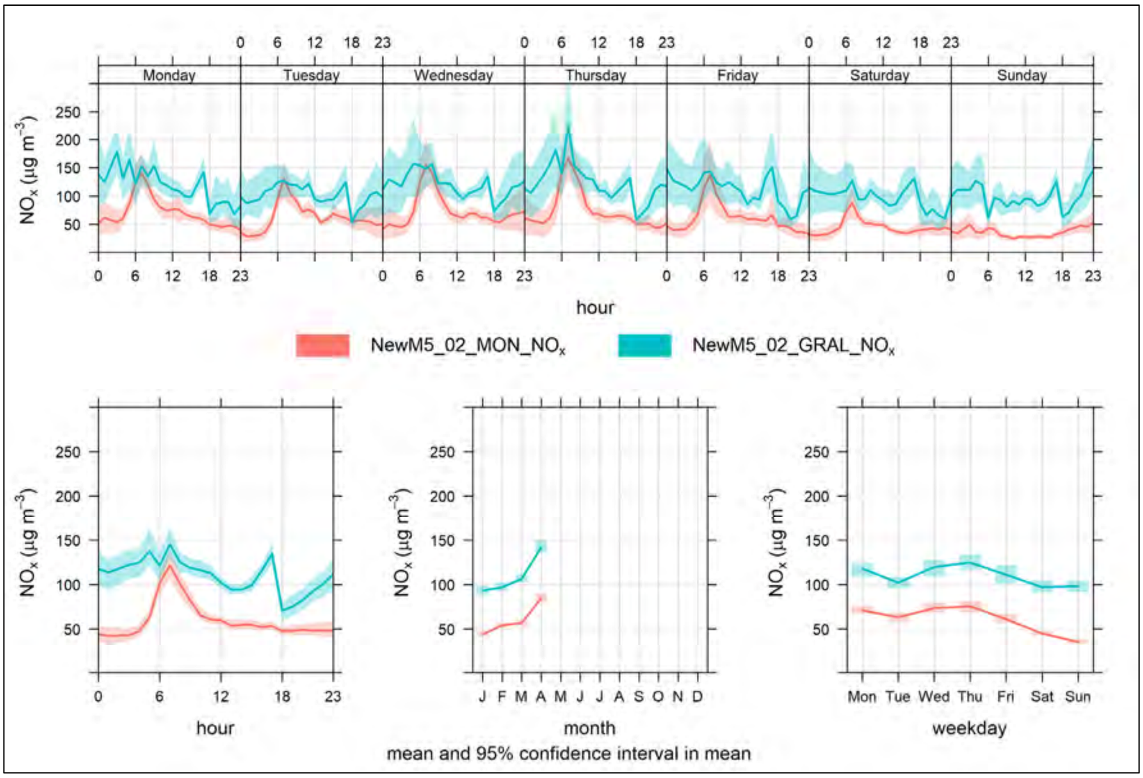


Figure H-8 Time variation of measured and predicted total NOX concentrations at the New M5:02 (Princes Highway) near-road monitoring station

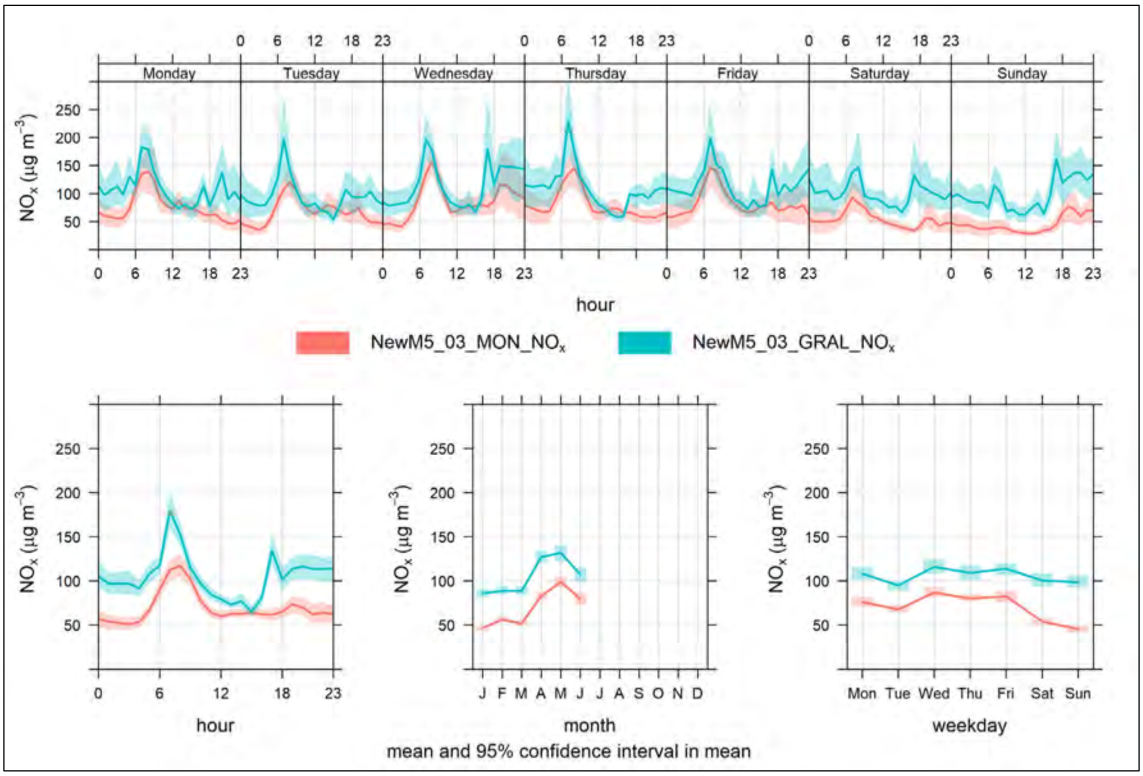


Figure H-9 Time variation of measured and predicted total NO_X concentrations at the New M5:03 (West Botany Street) near-road monitoring station

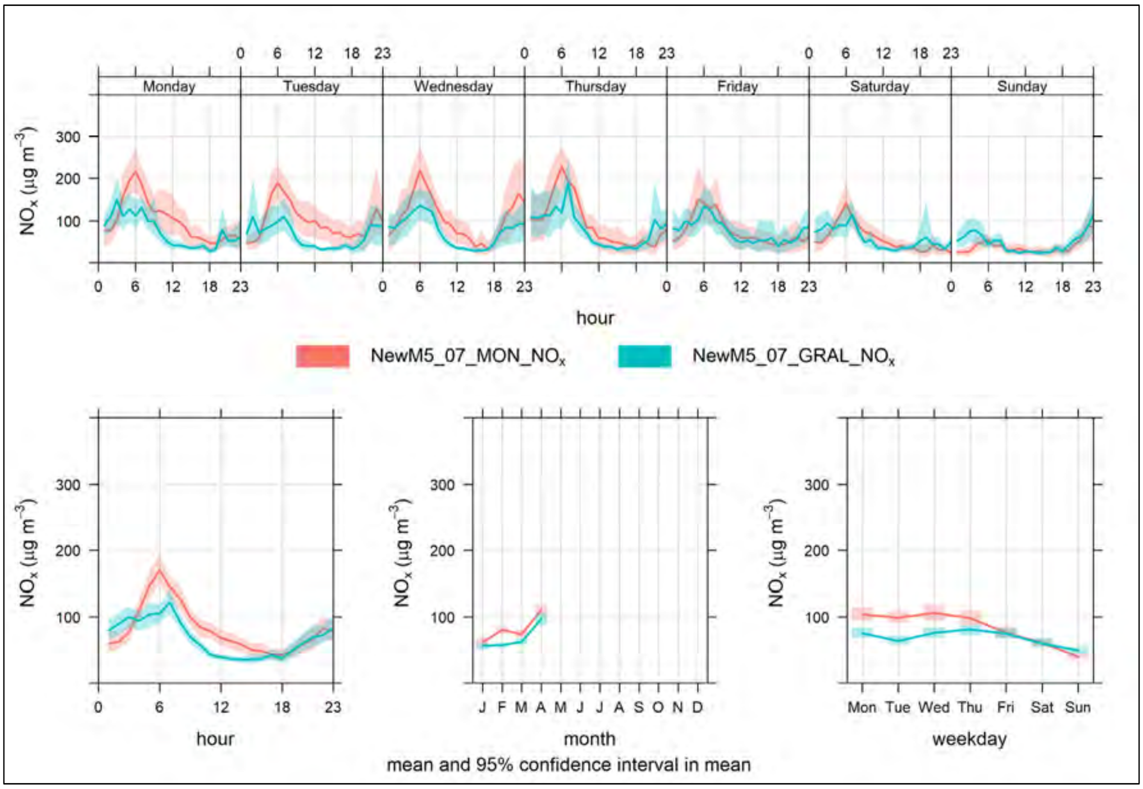


Figure H-10 Time variation of measured and predicted total NO_X concentrations at the New M5:07 (Canal Road) near-road monitoring station

The plots show the following:

- The average diurnal pattern was reasonably well reproduced at the Canal Road station. At the other three stations there were some pronounced differences between the predictions and the observations. For example, there was a marked overestimation of NO_X concentrations at these stations during the night-time period. The inter-peak concentrations were reasonably well reproduced, although there was still a marked overestimation at the Princes Highway station.
- The seasonal pattern in NO_X was well reproduced, although there was a consistent overestimation of the monthly average concentration at three of the four stations (again, the pattern at the Canal Road station matched closely to the observations).
- At some stations the overestimation was larger at the weekend than on weekdays. This is likely to be due in large part to the assumption of weekday traffic volumes on every day of the year in the modelling.

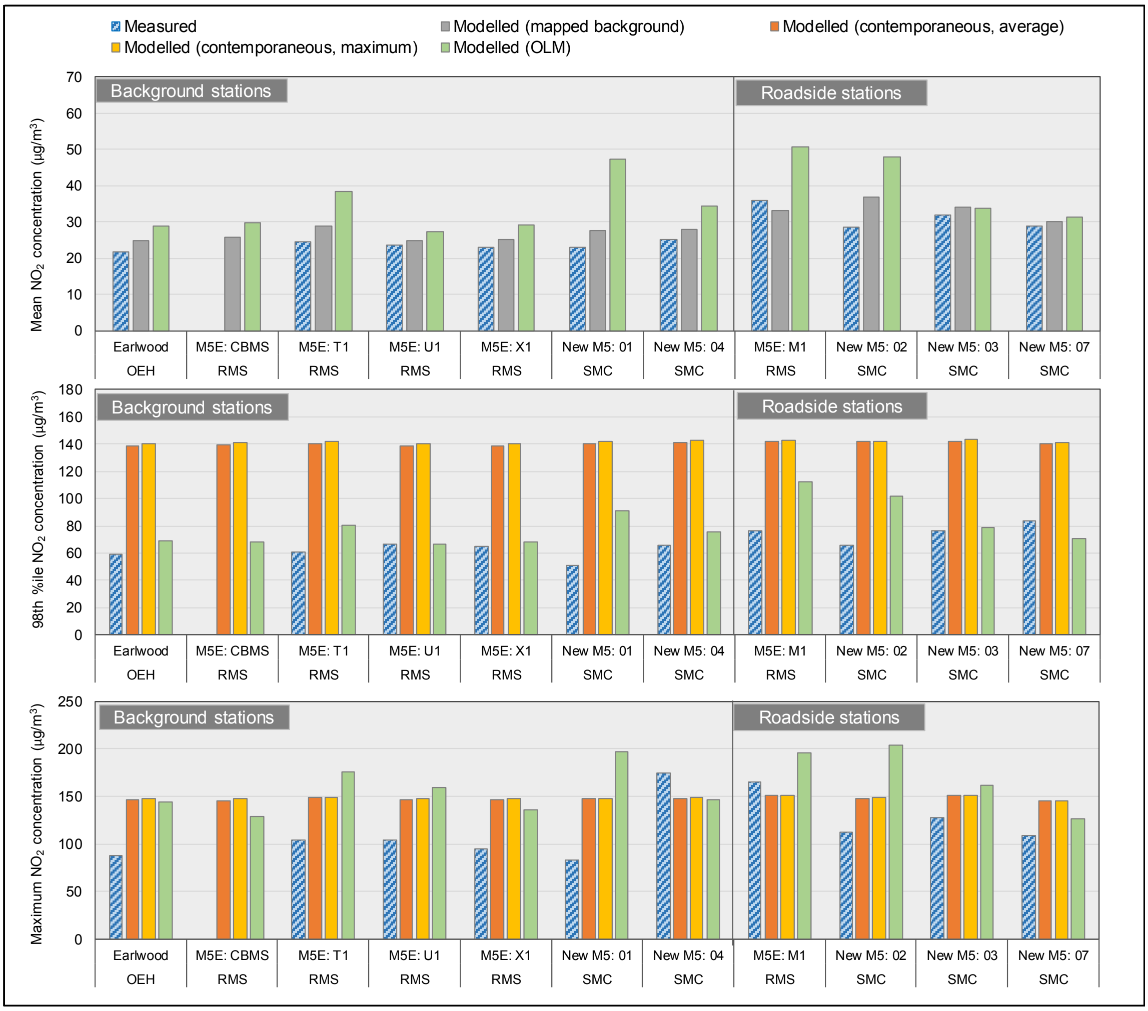
Overall, the results for NO_X confirm that the estimated total annual mean and short-term NO_X concentrations ought to be quite conservative for most of the modelling domain and time periods. The selected approaches should introduce a clear margin of safety into the F6 Extension – Stage 1 assessment.

H.3.3 Results for NO_2

Figure H-11 shows the measured and predicted NO_2 concentrations. NO_2 concentrations calculated using the OLM for converting NO_X to NO_2 are shown for comparison with the empirical methods used in the assessment. The mean NO_2 values were obtained using a background map for NO_X. The OLM calculations were contemporaneous, based on the synthetic (average) background profiles for NO_2 and O_3, and the *f*-NO_2 value of 0.16 recommended by NSW EPA.

At the **background** stations, the predicted mean NO_2 concentrations based on the background maps for NO_X were slightly higher (5-20 per cent) than the measured values. When the OLM was used to determine NO_2 for each hour of the year, the predicted mean concentration was generally higher than that obtained using the mapped background. For the 98th percentile, the OLM gave results that were much closer to the measurements than the empirical method. The latter is designed to give a conservative estimate for the maximum NO_2 concentration for each hour of the year, so that the overall maximum for the year is not underestimated. This means that the whole distribution is skewed towards high values. Although this is useful for determining the maximum value during a year, it is clearly not well suited to the estimation of other NO_2 statistics such as means and percentiles. In fact, for the background stations the empirical method and the OLM gave broadly similar maximum concentrations.

For the **near-road** stations, the mapped background approach and empirical conversion method resulted in mean NO_2 predictions that were quite close to the measurements (ranging from a 7 per cent under-prediction to a 30 per cent over-prediction). The OLM gave substantially higher mean predictions at three of the four stations. As at the background stations, the empirical background methods for 1-hour NO_2 over-predicted the 98th percentile concentration (again, the OLM gave a better result for this metric). For the maximum NO_2 concentration at the near-road stations, the empirical conversion methods gave results that were reasonably close to the measurements.



Statistical metric (based on 1-hour concentrations)	Station type	Org.	Station	Measured concentration (µg/m³)	Predicted concentration (µg/m³)			Predicted/measured		
					GRAL + mapped background	GRAL + contemporaneous background		GRAL + mapped background	GRAL + contemporaneous background	
						'Average' approach	'Maximum' approach		'Average' approach	'Maximum' approach
Mean concentration	Background	OEH	Earlwood	21.8	24.9	-	-	1.1	-	-
		RMS	M5E: CBMS	-	25.6	-	-	-	-	-
		RMS	M5E: T1	24.5	28.9	-	-	1.2	-	-
		RMS	M5E: U1	23.5	24.8	-	-	1.1	-	-
		RMS	M5E: X1	23.0	25.2	-	-	1.1	-	-
		SMC	New M5: 01	22.9	27.6	-	-	1.2	-	-
		SMC	New M5: 04	25.1	27.8	-	-	1.1	-	-
	Near-road	RMS	M5E: M1	35.8	33.2	-	-	0.9	-	-
		SMC	New M5: 02	28.6	36.8	-	-	1.3	-	-
		SMC	New M5: 03	32.0	34.2	-	-	1.1	-	-
		SMC	New M5: 07	29.0	30.0	-	-	1.0	-	-
98th percentile concentration	Background	OEH	Earlwood	59.5	-	139.0	140.6	-	2.3	2.4
		RMS	M5E: CBMS	-	-	139.0	140.7	-	-	-
		RMS	M5E: T1	61.1	-	140.4	141.5	-	2.3	2.3
		RMS	M5E: U1	66.7	-	138.7	140.2	-	2.1	2.1
		RMS	M5E: X1	64.5	-	138.6	140.2	-	2.1	2.2
		SMC	New M5: 01	51.1	-	140.3	141.6	-	2.7	2.8
		SMC	New M5: 04	65.8	-	141.1	142.4	-	2.1	2.2
	Near-road	RMS	M5E: M1	76.7	-	142.2	143.1	-	1.9	1.9
		SMC	New M5: 02	65.7	-	141.7	142.2	-	2.2	2.2
		SMC	New M5: 03	76.7	-	142.2	143.2	-	1.9	1.9
		SMC	New M5: 07	83.4	-	140.2	141.1	-	1.7	1.7
Maximum concentration	Background	OEH	Earlwood	88.3	-	146.7	147.6	-	1.7	1.7
		RMS	M5E: CBMS	-	-	145.7	147.1	-	-	-
		RMS	M5E: T1	104.4	-	148.8	149.1	-	1.4	1.4
		RMS	M5E: U1	103.7	-	146.4	147.4	-	1.4	1.4
		RMS	M5E: X1	94.7	-	146.1	147.1	-	1.5	1.6
		SMC	New M5: 01	83.5	-	147.4	147.5	-	1.8	1.8
		SMC	New M5: 04	174.6	-	148.0	148.5	-	0.8	0.9
	Near-road	RMS	M5E: M1	165.0	-	150.6	151.2	-	0.9	0.9
		SMC	New M5: 02	112.5	-	147.9	148.5	-	1.3	1.3
		SMC	New M5: 03	128.1	-	150.9	151.3	-	1.2	1.2
		SMC	New M5: 07	109.0	-	145.0	145.7	-	1.3	1.3

Figure H-11 Comparison between measured and predicted total NO_2 concentrations

H.3.4 Results for CO

Figure H-12 and Figure H-13 show examples of the 1-hour mean CO concentrations predicted by GRAL for the background and near-road stations. The GRAL predictions include the background contribution. The GRAL concentration was, however, generally much lower than the measured background. The concentration profiles at the background and near-road stations were quite similar, indicating a small road traffic influence on CO.

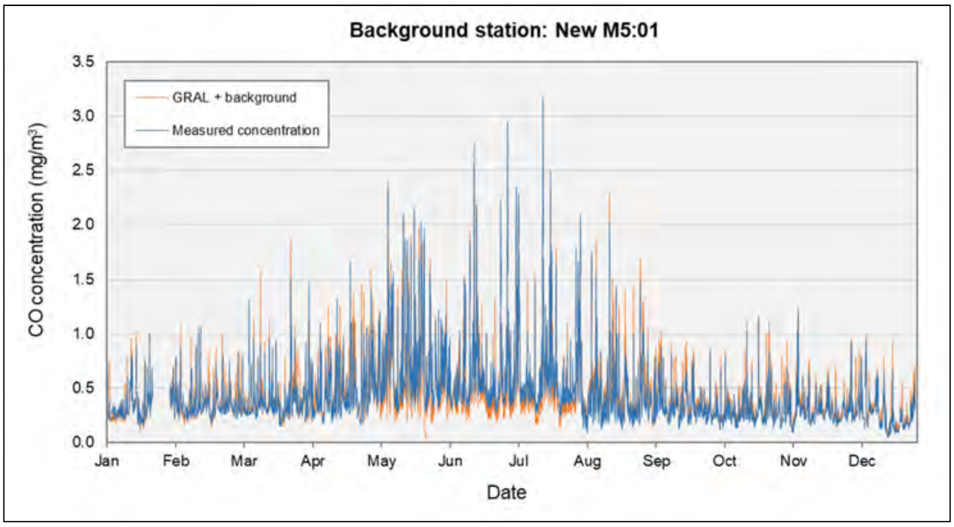


Figure H-12 Measured 1-hour mean CO concentrations and GRAL predictions (including background) for the New M5:01 (St Peters Public School) background monitoring station

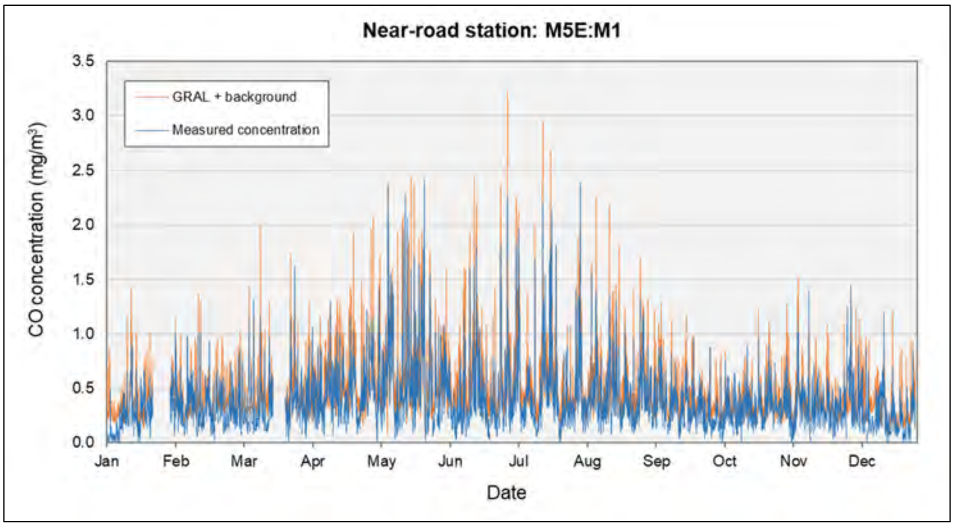
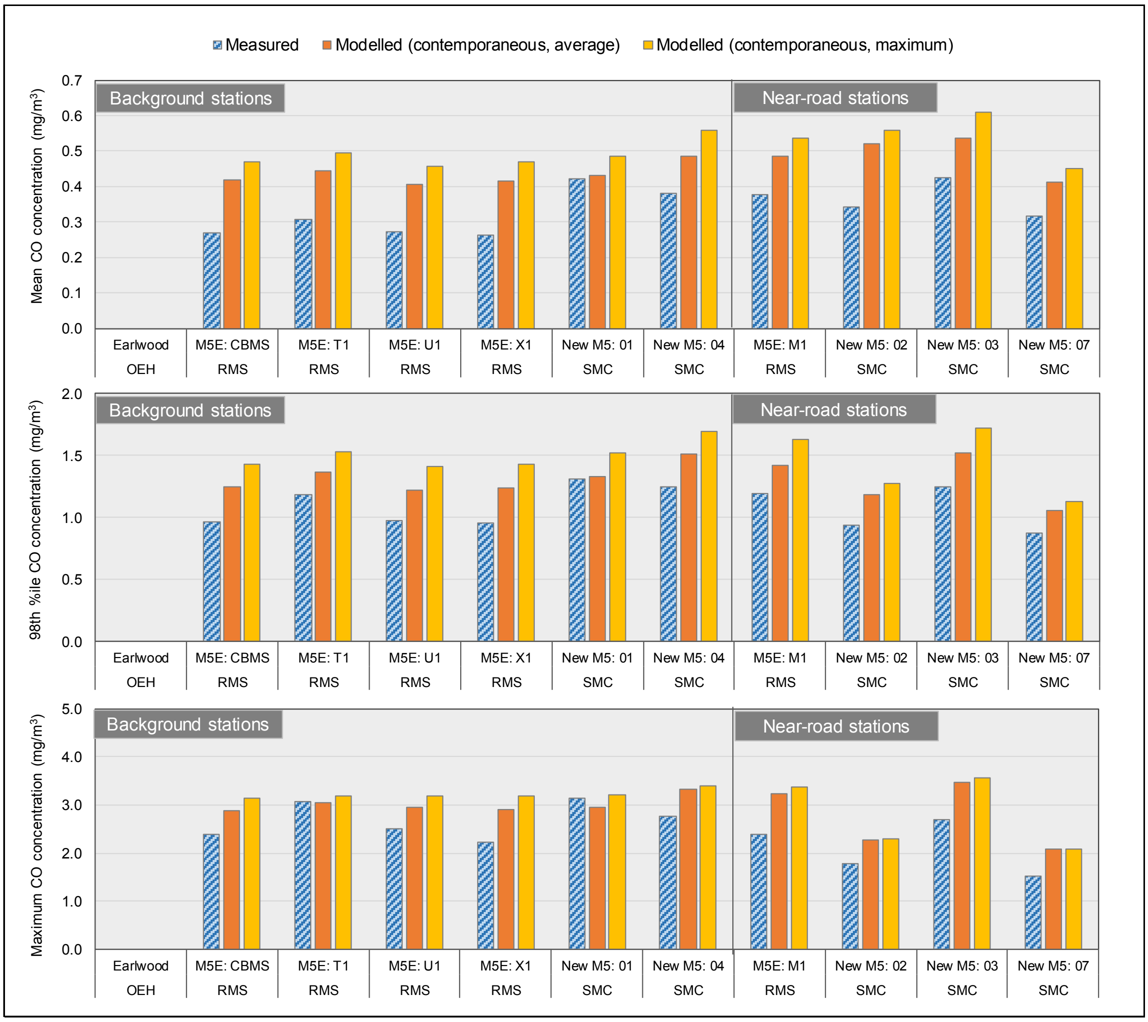


Figure H-13 Measured 1-hour mean CO concentrations and GRAL predictions (including background) for the M5E:M1 (M5 East tunnel off-ramp) monitoring station

The statistics for the measured and predicted total CO concentrations are compared in Figure H-14. For mean concentrations the predictions based on the average synthetic profile generally showed a good agreement with the measurements. CO concentrations were systematically overestimated, and typically by 30-40 per cent. This is not surprising given the strong influence of the background. In Figure H-15 the background and GRAL contributions to the mean CO concentration are shown separately. The background here is simply an average for the synthetic CO profile. At the near-road stations the background contributed 70-85 per cent of the total CO concentration.



Statistical metric (based on 1-hour concentrations)	Station type	Org.	Station	Measured concentration (µg/m³)	Predicted concentration (µg/m³): GRAL + mapped background	Predicted concentration (µg/m³): GRAL + contemporaneous background, 'Average' approach	Predicted concentration (µg/m³): GRAL + contemporaneous background, 'Maximum' approach	Predicted/measured: GRAL + mapped background	Predicted/measured: GRAL + contemporaneous background, 'Average' approach	Predicted/measured: GRAL + contemporaneous background, 'Maximum' approach
Mean concentration	Background	OEH	Earlwood	-	-	-	-	-	-	-
		RMS	M5E: CBMS	0.3	-	0.4	0.5	-	1.5	1.7
		RMS	M5E: T1	0.3	-	0.4	0.5	-	1.4	1.6
		RMS	M5E: U1	0.3	-	0.4	0.5	-	1.5	1.7
		RMS	M5E: X1	0.3	-	0.4	0.5	-	1.6	1.8
		SMC	New M5: 01	0.4	-	0.4	0.5	-	1.0	1.2
		SMC	New M5: 04	0.4	-	0.5	0.6	-	1.3	1.5
	Near-road	RMS	M5E: M1	0.4	-	0.5	0.5	-	1.3	1.4
		SMC	New M5: 02	0.3	-	0.5	0.6	-	1.5	1.6
		SMC	New M5: 03	0.4	-	0.5	0.6	-	1.3	1.4
		SMC	New M5: 07	0.3	-	0.4	0.5	-	1.3	1.4
98th percentile concentration	Background	OEH	Earlwood	-	-	-	-	-	-	-
		RMS	M5E: CBMS	1.0	-	1.2	1.4	-	1.3	1.5
		RMS	M5E: T1	1.2	-	1.4	1.5	-	1.2	1.3
		RMS	M5E: U1	1.0	-	1.2	1.4	-	1.3	1.5
		RMS	M5E: X1	1.0	-	1.2	1.4	-	1.3	1.5
		SMC	New M5: 01	1.3	-	1.3	1.5	-	1.0	1.2
		SMC	New M5: 04	1.2	-	1.5	1.7	-	1.2	1.4
	Near-road	RMS	M5E: M1	1.2	-	1.4	1.6	-	1.2	1.4
		SMC	New M5: 02	0.9	-	1.2	1.3	-	1.3	1.4
		SMC	New M5: 03	1.2	-	1.5	1.7	-	1.2	1.4
		SMC	New M5: 07	0.9	-	1.1	1.1	-	1.2	1.3
Maximum concentration	Background	OEH	Earlwood	-	-	-	-	-	-	-
		RMS	M5E: CBMS	2.4	-	2.9	3.1	-	1.2	1.3
		RMS	M5E: T1	3.1	-	3.0	3.2	-	1.0	1.0
		RMS	M5E: U1	2.5	-	3.0	3.2	-	1.2	1.3
		RMS	M5E: X1	2.2	-	2.9	3.2	-	1.3	1.4
		SMC	New M5: 01	3.1	-	2.9	3.2	-	0.9	1.0
		SMC	New M5: 04	2.8	-	3.3	3.4	-	1.2	1.2
	Near-road	RMS	M5E: M1	2.4	-	3.2	3.4	-	1.4	1.4
		SMC	New M5: 02	1.8	-	2.3	2.3	-	1.3	1.3
		SMC	New M5: 03	2.7	-	3.5	3.6	-	1.3	1.3
		SMC	New M5: 07	1.5	-	2.1	2.1	-	1.4	1.4

Figure H-14 Comparison between measured and predicted total CO concentrations

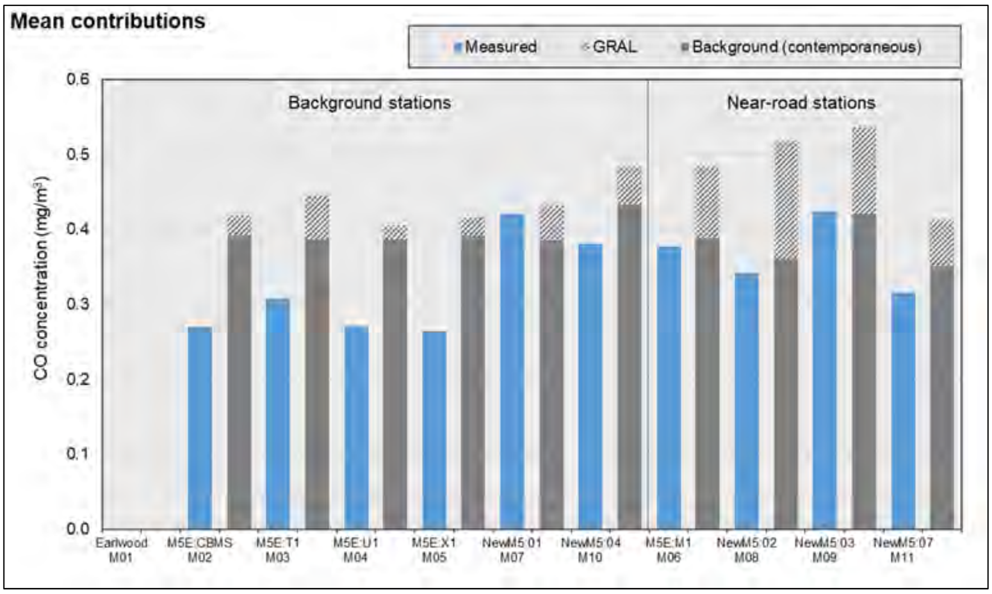


Figure H-15 **Contributions to modelled mean CO concentrations**

H.3.5 Results for PM_{10}

Figure H-16 compares the measured 24-hour mean PM_{10} concentrations with those predicted by GRAL for the background station, and Figure H-17 shows the results for the near-road station. Unsurprisingly, given the large background contribution, there was a good agreement between the model predictions and the measurements.

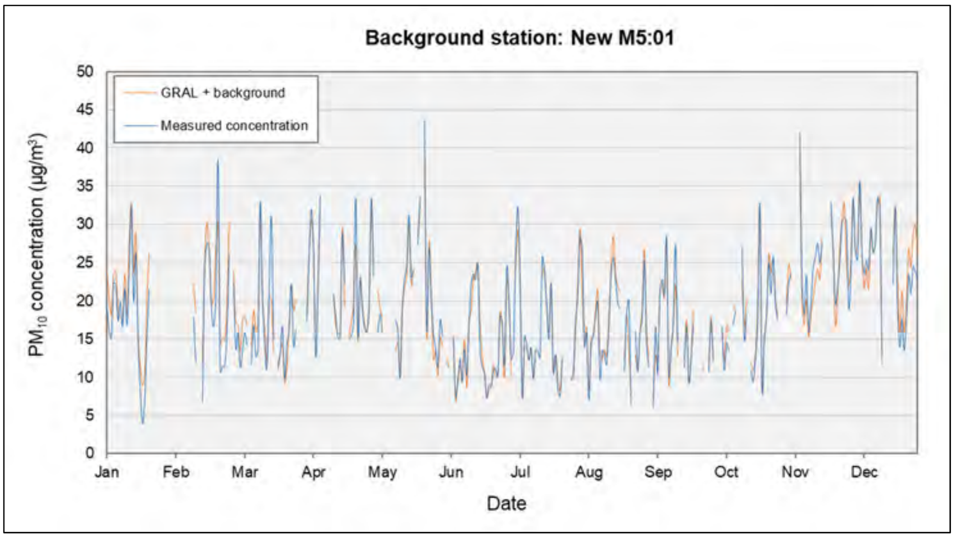


Figure H-16 **Measured 24-hour mean PM_{10} concentrations and GRAL predictions (including background) for the New M5:01 (St Peters Public School) background monitoring station**

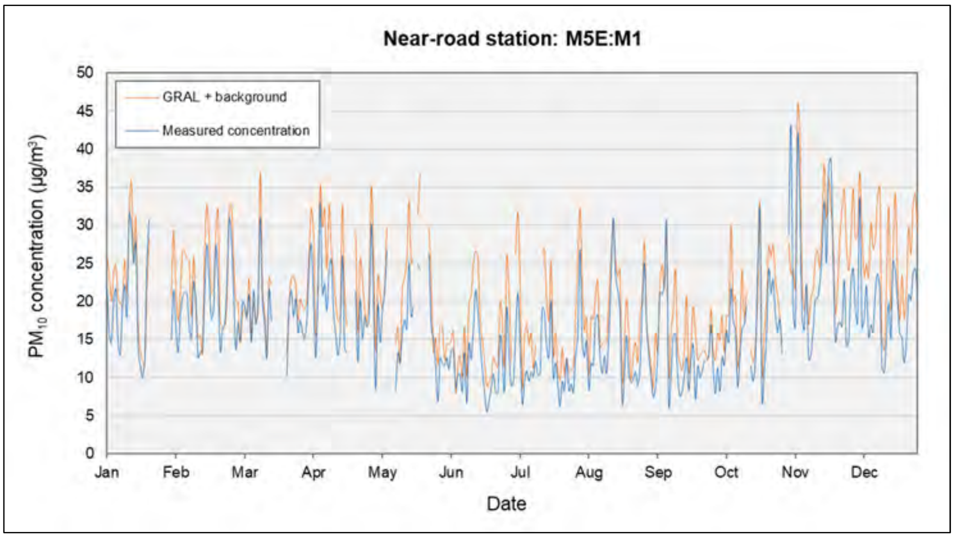
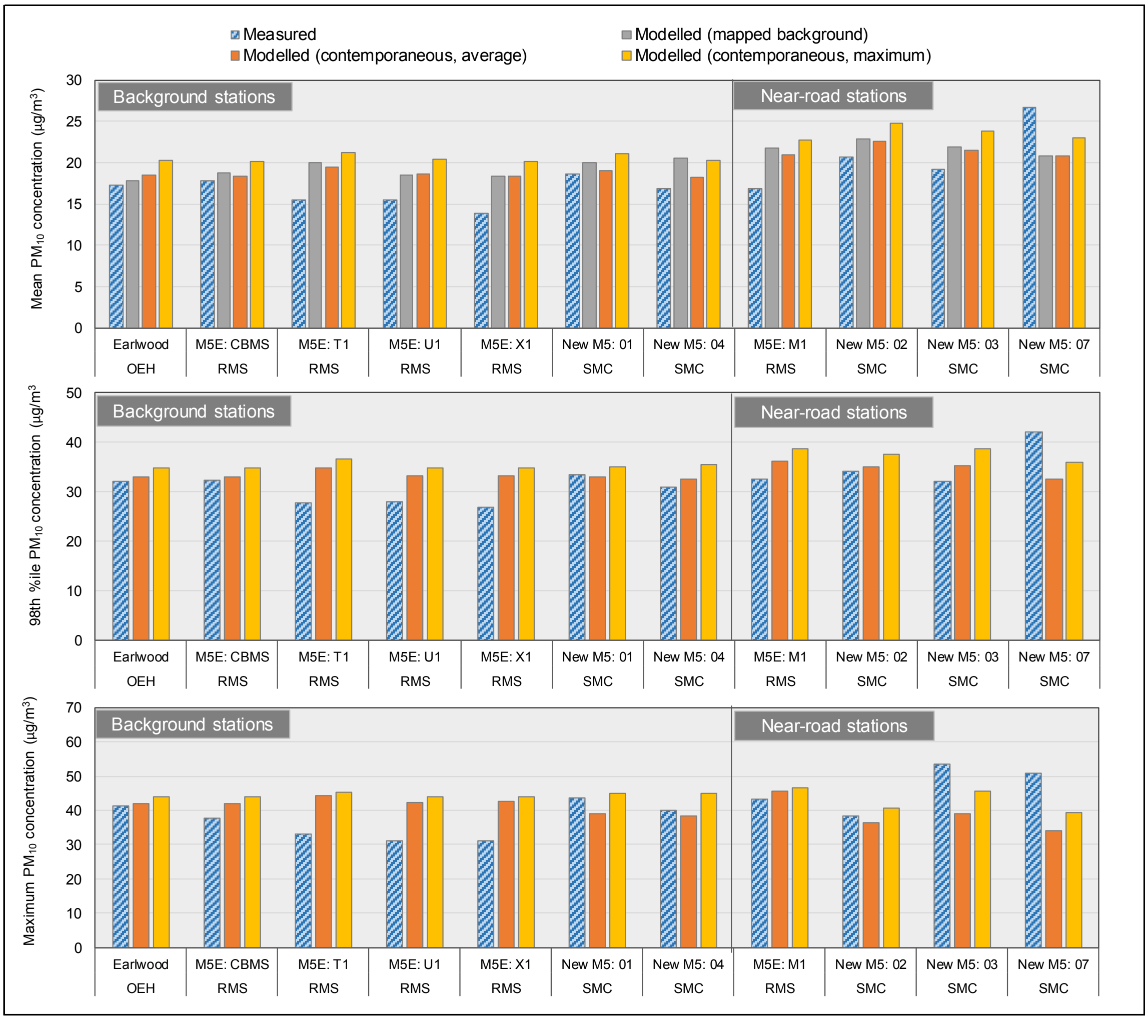


Figure H-17 **Measured 24-hour mean PM_{10} concentrations and GRAL predictions (including background) for the M5E:M1 (M5 East tunnel off-ramp) monitoring station**

The summary plots and statistics for the PM_{10} comparisons are provided in Figure H-18. As with NO_X, calculations based on the contemporaneous background approaches are also included for comparison with the mapped background approach. In Figure H-19 the background and GRAL contributions to the mean PM_{10} concentration are shown separately, and the large background contribution (between 82 and 97 per cent) at all stations is clear. This explains the generally small over-prediction at both background and near-road sites.

In general, the results suggest that the use of GRAL and the background mapping approach should give good (and slightly conservative) estimates of PM_{10} concentrations.



Statistical metric (based on 1-hour concentrations)	Station type	Org.	Station	Measured concentration (µg/m³)	Predicted concentration (µg/m³) GRAL + mapped background	GRAL + contemporaneous background 'Average' approach	GRAL + contemporaneous background 'Maximum' approach	Predicted/measured GRAL + mapped background	GRAL + contemporaneous background 'Average' approach	GRAL + contemporaneous background 'Maximum' approach
Mean concentration	Background	OEH	Earlwood	17.3	17.7	18.5	20.3	1.0	1.1	1.2
		RMS	M5E: CBMS	17.7	18.8	18.4	20.1	1.1	1.0	1.1
		RMS	M5E: T1	15.5	19.9	19.5	21.2	1.3	1.3	1.4
		RMS	M5E: U1	15.5	18.5	18.6	20.3	1.2	1.2	1.3
		RMS	M5E: X1	13.8	18.4	18.4	20.1	1.3	1.3	1.5
		SMC	New M5: 01	18.6	19.9	19.1	21.0	1.1	1.0	1.1
		SMC	New M5: 04	16.9	20.6	18.2	20.2	1.2	1.1	1.2
	Near-road	RMS	M5E: M1	16.9	21.7	21.0	22.8	1.3	1.2	1.3
		SMC	New M5: 02	20.7	22.8	22.6	24.8	1.1	1.1	1.2
		SMC	New M5: 03	19.2	21.9	21.5	23.8	1.1	1.1	1.2
		SMC	New M5: 07	26.6	20.7	20.8	22.9	0.8	0.8	0.9
98th percentile concentration	Background	OEH	Earlwood	32.0	-	33.0	34.8	-	1.0	1.1
		RMS	M5E: CBMS	32.4	-	33.0	34.8	-	1.0	1.1
		RMS	M5E: T1	27.7	-	34.9	36.6	-	1.3	1.3
		RMS	M5E: U1	27.9	-	33.3	34.9	-	1.2	1.2
		RMS	M5E: X1	26.9	-	33.2	34.8	-	1.2	1.3
		SMC	New M5: 01	33.6	-	33.0	35.1	-	1.0	1.0
		SMC	New M5: 04	31.0	-	32.6	35.5	-	1.1	1.1
	Near-road	RMS	M5E: M1	32.6	-	36.3	38.8	-	1.1	1.2
		SMC	New M5: 02	34.1	-	35.1	37.6	-	1.0	1.1
		SMC	New M5: 03	32.1	-	35.4	38.8	-	1.1	1.2
		SMC	New M5: 07	42.2	-	32.5	36.1	-	0.8	0.9
Maximum concentration	Background	OEH	Earlwood	41.2	-	42.0	43.9	-	1.0	1.1
		RMS	M5E: CBMS	37.8	-	42.0	43.8	-	1.1	1.2
		RMS	M5E: T1	33.1	-	44.2	45.2	-	1.3	1.4
		RMS	M5E: U1	31.1	-	42.5	44.0	-	1.4	1.4
		RMS	M5E: X1	31.1	-	42.5	43.9	-	1.4	1.4
		SMC	New M5: 01	43.6	-	39.2	45.0	-	0.9	1.0
		SMC	New M5: 04	40.0	-	38.4	44.9	-	1.0	1.1
	Near-road	RMS	M5E: M1	43.1	-	45.7	46.6	-	1.1	1.1
		SMC	New M5: 02	38.3	-	36.3	40.7	-	0.9	1.1
		SMC	New M5: 03	53.4	-	39.0	45.6	-	0.7	0.9
		SMC	New M5: 07	50.7	-	34.1	39.5	-	0.7	0.8

Figure H-18 Comparison between measured and predicted total PM_{10} concentrations

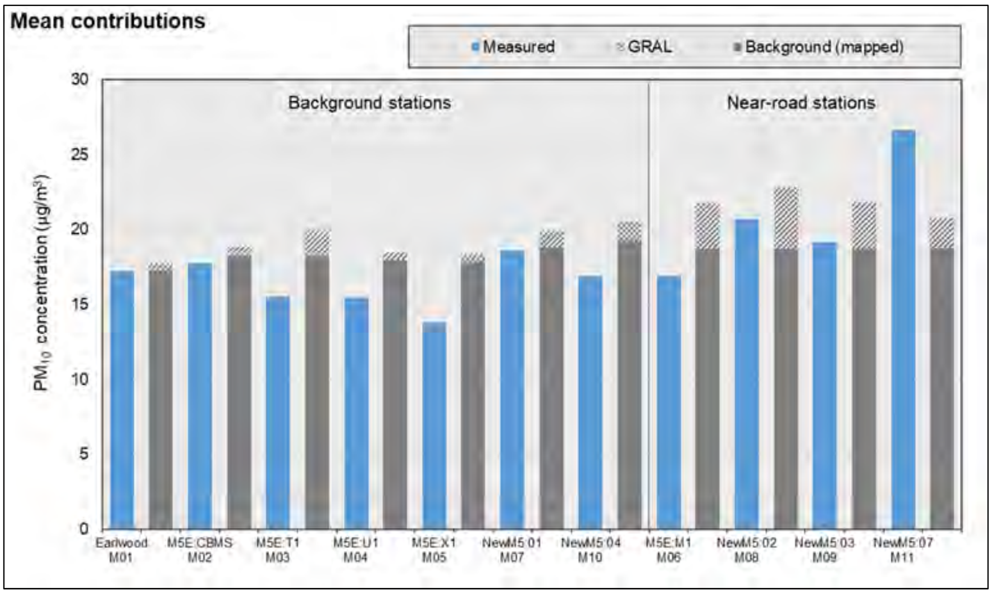


Figure H-19 Contributions to modelled mean PM_{10} concentrations

Annexure I - Dispersion modelling results – all sources

Annexure I - Dispersion modelling results - all sources

This Annexure provides all results of the dispersion modelling for the **expected traffic** scenarios. The following notes apply:

- Data are not presented for the 2016-BY scenario, as this scenario was designed primarily for model evaluation.
- For community receptors the Figures presented in the main body of the report have not been duplicated. The results for these receptors have been tabulated.
- In the Tables any grey shading indicates where no value was obtained. For example, where the top ten increases in concentration are ranked, there may have been fewer than ten receptors that actually had an increase in concentration.
- For short-term air quality criteria, such as the maximum 1-hour NO_2 concentrations, the contour plots should be viewed as indicative. This is a consequence of the difficulties associated with the prediction of short-term concentrations.

> **NB:** Contour plots for just the ventilation outlet contributions in the expected traffic scenarios are provided in Annexure J

I.1 Carbon monoxide (maximum 1-hour mean)

Table I-1 Maximum 1-hour mean CO concentration at community receptors

Receptor	Maximum 1-hour CO concentration (mg/m^3)						Change relative to Do Minimum (mg/m^3)			Change relative to Do Minimum (%)		
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
CR01	-	3.20	3.16	3.15	3.17	3.18	-0.04	0.02	0.03	-1.3%	0.7%	0.9%
CR02	-	3.27	3.21	3.17	3.22	3.20	-0.06	0.05	0.03	-2.0%	1.6%	1.0%
CR03	-	3.24	3.21	3.20	3.20	3.17	-0.03	0.00	-0.03	-1.0%	0.0%	-1.0%
CR04	-	3.32	3.31	3.27	3.26	3.20	-0.01	-0.01	-0.07	-0.3%	-0.3%	-2.1%
CR05	-	3.17	3.18	3.17	3.18	3.15	0.01	0.01	-0.02	0.3%	0.2%	-0.7%
CR06	-	3.24	3.24	3.23	3.24	3.24	-0.01	0.01	0.01	-0.2%	0.3%	0.2%
CR07	-	3.21	3.18	3.21	3.17	3.16	-0.02	-0.04	-0.05	-0.7%	-1.3%	-1.7%
CR08	-	3.20	3.21	3.17	3.17	3.17	0.01	0.00	0.00	0.5%	0.1%	0.0%
CR09	-	3.19	3.29	3.19	3.21	3.17	0.10	0.02	-0.02	3.0%	0.6%	-0.5%
CR10	-	3.19	3.21	3.19	3.15	3.21	0.02	-0.04	0.02	0.5%	-1.2%	0.6%
CR11	-	3.19	3.17	3.18	3.17	3.17	-0.02	-0.01	0.00	-0.7%	-0.2%	-0.1%
CR12	-	3.21	3.21	3.19	3.23	3.22	0.01	0.04	0.03	0.2%	1.1%	1.0%
CR13	-	3.22	3.23	3.19	3.28	3.19	0.01	0.09	0.00	0.4%	2.9%	0.0%
CR14	-	3.16	3.17	3.20	3.13	3.18	0.01	-0.06	-0.01	0.3%	-1.9%	-0.5%
CR15	-	3.25	3.21	3.18	3.20	3.21	-0.05	0.02	0.03	-1.5%	0.8%	1.0%
CR16	-	3.15	3.19	3.14	3.16	3.16	0.03	0.02	0.01	1.0%	0.5%	0.5%
CR17	-	3.32	3.20	3.22	3.19	3.18	-0.13	-0.03	-0.04	-3.8%	-0.8%	-1.2%
CR18	-	3.14	3.15	3.19	3.17	3.17	0.01	-0.02	-0.01	0.2%	-0.5%	-0.4%
CR19	-	3.18	3.20	3.19	3.15	3.18	0.02	-0.04	-0.01	0.7%	-1.1%	-0.2%
CR20	-	3.23	3.19	3.23	3.23	3.17	-0.05	0.00	-0.06	-1.5%	0.0%	-1.8%
CR21	-	3.15	3.15	3.15	3.16	3.14	0.00	0.02	0.00	0.0%	0.5%	-0.1%
CR22	-	3.19	3.14	3.16	3.15	3.14	-0.05	0.00	-0.02	-1.6%	-0.1%	-0.5%
CR23	-	3.18	3.16	3.17	3.15	3.16	-0.01	-0.02	-0.01	-0.4%	-0.5%	-0.3%
CR24	-	3.15	3.21	3.17	3.14	3.22	0.07	-0.03	0.05	2.1%	-1.1%	1.4%
CR25	-	3.20	3.20	3.15	3.15	3.16	-0.01	0.00	0.01	-0.2%	0.1%	0.3%
CR26	-	3.22	3.17	3.14	3.15	3.16	-0.05	0.01	0.02	-1.6%	0.4%	0.5%
CR27	-	3.21	3.31	3.18	3.27	3.18	0.10	0.09	0.00	3.0%	2.8%	0.0%
CR28	-	3.20	3.28	3.20	3.22	3.26	0.09	0.03	0.07	2.7%	0.8%	2.1%
CR29	-	3.35	3.20	3.19	3.20	3.20	-0.15	0.01	0.01	-4.4%	0.2%	0.3%
CR30	-	3.26	3.32	3.29	3.18	3.19	0.05	-0.11	-0.11	1.6%	-3.4%	-3.2%

Table I-2 Maximum 1-hour mean CO concentration at community receptors, ranked by concentration

Rank		Ranking by concentration (mg/m^3)					
		2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1		-	3.35	3.32	3.29	3.28	3.26
2		-	3.32	3.31	3.27	3.27	3.24
3		-	3.32	3.31	3.23	3.26	3.22
4		-	3.27	3.29	3.23	3.24	3.22
5		-	3.26	3.28	3.22	3.23	3.21
6		-	3.25	3.24	3.21	3.23	3.21
7		-	3.24	3.23	3.20	3.22	3.20
8		-	3.24	3.21	3.20	3.22	3.20
9		-	3.23	3.21	3.20	3.21	3.20
10		-	3.22	3.21	3.19	3.20	3.19

Table I-3 Maximum 1-hour mean CO concentration at community receptors, ranked by increase and by decrease in concentration

Rank		Ranking by increase in concentration relative to Do Minimum (mg/m^3)				Ranking by decrease in concentration relative to Do Minimum (mg/m^3)		
		2026-DS	2036-DS	2036-DSC		2026-DS	2036-DS	2036-DSC
1		0.10	0.09	0.07		-0.15	-0.11	-0.11
2		0.10	0.09	0.05		-0.13	-0.06	-0.07
3		0.09	0.05	0.03		-0.06	-0.04	-0.06
4		0.07	0.04	0.03		-0.05	-0.04	-0.05
5		0.05	0.03	0.03		-0.05	-0.04	-0.04
6		0.03	0.02	0.03		-0.05	-0.03	-0.03
7		0.02	0.02	0.02		-0.05	-0.03	-0.02
8		0.02	0.02	0.02		-0.04	-0.02	-0.02
9		0.01	0.02	0.01		-0.03	-0.02	-0.02
10		0.01	0.02	0.01		-0.02	-0.01	-0.01

Table I-4 Maximum 1-hour mean CO concentration at community receptors, ranked by percentage increase and by decrease in concentration

Rank		Ranking by % increase in concentration relative to Do Minimum				Ranking by % decrease in concentration relative to Do Minimum		
		2026-DS	2036-DS	2036-DSC		2026-DS	2036-DS	2036-DSC
1		3.0%	2.9%	2.1%		-4.4%	-3.4%	-3.2%
2		3.0%	2.8%	1.4%		-3.8%	-1.9%	-2.1%
3		2.7%	1.6%	1.0%		-2.0%	-1.3%	-1.8%
4		2.1%	1.1%	1.0%		-1.6%	-1.2%	-1.7%
5		1.6%	0.8%	1.0%		-1.6%	-1.1%	-1.2%
6		1.0%	0.8%	0.9%		-1.5%	-1.1%	-1.0%
7		0.7%	0.7%	0.6%		-1.5%	-0.8%	-0.7%
8		0.5%	0.6%	0.5%		-1.3%	-0.5%	-0.5%
9		0.5%	0.5%	0.5%		-1.0%	-0.5%	-0.5%
10		0.4%	0.5%	0.3%		-0.7%	-0.3%	-0.5%

Table I-5 **Maximum 1-hour mean CO concentration at RWR receptors, ranked by concentration**

Rank		Ranking by concentration (mg/m³)					
		2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1		-	5.3	5.3	5.0	4.7	4.8
2		-	5.1	5.3	5.0	4.6	4.6
3		-	5.0	5.1	4.9	4.5	4.6
4		-	5.0	5.0	4.9	4.5	4.6
5		-	5.0	5.0	4.8	4.5	4.5
6		-	5.0	5.0	4.7	4.5	4.5
7		-	5.0	5.0	4.7	4.5	4.5
8		-	5.0	5.0	4.7	4.5	4.4
9		-	4.9	4.9	4.7	4.5	4.4
10		-	4.9	4.9	4.7	4.5	4.4

Table I-6 **Maximum 1-hour mean CO concentration at RWR receptors, ranked by increase and by decrease in concentration**

Rank		Ranking by increase in concentration relative to Do Minimum (mg/m³)				Ranking by decrease in concentration relative to Do Minimum (mg/m³)		
		2026-DS	2036-DS	2036-DSC		2026-DS	2036-DS	2036-DSC
1		0.5	0.3	0.4		-0.9	-0.6	-0.7
2		0.5	0.3	0.3		-0.7	-0.6	-0.6
3		0.4	0.3	0.3		-0.7	-0.5	-0.5
4		0.4	0.3	0.3		-0.6	-0.5	-0.5
5		0.4	0.3	0.3		-0.6	-0.5	-0.5
6		0.4	0.3	0.3		-0.6	-0.5	-0.5
7		0.4	0.3	0.3		-0.6	-0.5	-0.5
8		0.4	0.3	0.3		-0.6	-0.4	-0.5
9		0.4	0.3	0.3		-0.5	-0.4	-0.5
10		0.4	0.3	0.3		-0.5	-0.4	-0.5

Table I-7 **Maximum 1-hour mean CO concentration at RWR receptors, ranked by percentage increase and by decrease in concentration**

Rank		Ranking by % increase in concentration relative to Do Minimum				Ranking by % decrease in concentration relative to Do Minimum		
		2026-DS	2036-DS	2036-DSC		2026-DS	2036-DS	2036-DSC
1		12.2%	9.4%	10.1%		-16.9%	-12.6%	-15.8%
2		10.9%	8.6%	8.4%		-13.8%	-12.4%	-13.8%
3		10.5%	8.5%	8.2%		-13.5%	-10.8%	-13.7%
4		10.5%	8.3%	7.6%		-13.5%	-10.6%	-13.5%
5		10.3%	8.2%	7.6%		-13.4%	-10.6%	-13.0%
6		10.3%	8.0%	7.3%		-12.3%	-10.5%	-13.0%
7		9.7%	7.8%	7.2%		-12.3%	-10.3%	-13.0%
8		9.6%	7.7%	7.1%		-12.2%	-9.9%	-12.9%
9		9.5%	7.7%	7.1%		-12.1%	-9.7%	-12.6%
10		9.0%	7.6%	7.0%		-12.0%	-9.7%	-12.2%

I.2 Carbon monoxide (maximum rolling 8-hour mean)

Table I-8 Maximum rolling 8-hour mean CO concentration at community receptors

Receptor	Maximum 8-hour CO concentration (mg/m^3)						Change relative to Do Minimum (mg/m^3)			Change relative to Do Minimum (%)		
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
CR01	-	2.43	2.42	2.42	2.41	2.41	-0.01	-0.01	0.00	-0.3%	-0.4%	-0.2%
CR02	-	2.47	2.46	2.43	2.45	2.44	-0.01	0.02	0.00	-0.6%	0.9%	0.1%
CR03	-	2.45	2.46	2.44	2.43	2.41	0.01	0.00	-0.02	0.4%	-0.1%	-1.0%
CR04	-	2.59	2.56	2.52	2.55	2.50	-0.03	0.03	-0.02	-1.2%	1.1%	-1.0%
CR05	-	2.43	2.44	2.42	2.42	2.43	0.01	0.00	0.01	0.2%	-0.1%	0.3%
CR06	-	2.56	2.57	2.51	2.53	2.50	0.01	0.02	-0.01	0.3%	0.7%	-0.4%
CR07	-	2.44	2.43	2.46	2.42	2.42	-0.01	-0.04	-0.04	-0.4%	-1.8%	-1.6%
CR08	-	2.47	2.48	2.46	2.45	2.45	0.01	-0.01	-0.01	0.4%	-0.2%	-0.5%
CR09	-	2.47	2.48	2.45	2.45	2.42	0.02	-0.01	-0.03	0.6%	-0.2%	-1.3%
CR10	-	2.44	2.43	2.43	2.42	2.42	-0.01	-0.01	0.00	-0.4%	-0.5%	-0.2%
CR11	-	2.49	2.50	2.45	2.48	2.45	0.02	0.03	0.00	0.8%	1.1%	0.0%
CR12	-	2.45	2.47	2.45	2.46	2.44	0.03	0.02	0.00	1.1%	0.7%	-0.1%
CR13	-	2.44	2.44	2.42	2.45	2.41	0.00	0.04	-0.01	-0.1%	1.6%	-0.2%
CR14	-	2.46	2.46	2.44	2.44	2.43	0.00	0.00	-0.01	-0.1%	-0.1%	-0.5%
CR15	-	2.50	2.48	2.46	2.48	2.48	-0.02	0.01	0.01	-0.9%	0.6%	0.6%
CR16	-	2.41	2.41	2.40	2.40	2.39	0.00	0.00	-0.01	0.2%	-0.1%	-0.5%
CR17	-	2.51	2.51	2.47	2.47	2.45	0.00	-0.01	-0.02	0.1%	-0.3%	-1.0%
CR18	-	2.42	2.41	2.41	2.41	2.42	0.00	0.00	0.01	-0.1%	0.0%	0.5%
CR19	-	2.45	2.46	2.45	2.43	2.44	0.01	-0.02	-0.01	0.3%	-0.7%	-0.3%
CR20	-	2.50	2.48	2.47	2.48	2.47	-0.02	0.01	-0.01	-0.7%	0.4%	-0.2%
CR21	-	2.44	2.44	2.42	2.42	2.42	0.00	0.00	-0.01	0.2%	-0.2%	-0.3%
CR22	-	2.44	2.41	2.41	2.42	2.41	-0.03	0.00	0.00	-1.4%	0.1%	-0.1%
CR23	-	2.48	2.49	2.44	2.46	2.47	0.01	0.02	0.03	0.5%	0.9%	1.2%
CR24	-	2.48	2.48	2.45	2.46	2.49	0.00	0.01	0.03	0.1%	0.5%	1.4%
CR25	-	2.52	2.50	2.45	2.51	2.45	-0.02	0.07	0.00	-0.7%	2.7%	0.2%
CR26	-	2.50	2.49	2.46	2.46	2.47	-0.02	0.01	0.01	-0.6%	0.2%	0.4%
CR27	-	2.59	2.58	2.51	2.57	2.52	-0.01	0.06	0.01	-0.3%	2.4%	0.3%
CR28	-	2.56	2.58	2.53	2.49	2.53	0.02	-0.04	0.00	0.8%	-1.5%	0.0%
CR29	-	2.53	2.50	2.50	2.49	2.46	-0.03	-0.01	-0.04	-1.3%	-0.5%	-1.8%
CR30	-	2.50	2.51	2.50	2.47	2.48	0.01	-0.03	-0.02	0.3%	-1.2%	-0.7%

Table I-9 Maximum rolling 8-hour mean CO concentration at community receptors, ranked by concentration

Rank	Ranking by concentration (mg/m³)					
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1	-	2.59	2.58	2.53	2.57	2.53
2	-	2.59	2.58	2.52	2.55	2.52
3	-	2.56	2.57	2.51	2.53	2.50
4	-	2.56	2.56	2.51	2.51	2.50
5	-	2.53	2.51	2.50	2.49	2.49
6	-	2.52	2.51	2.50	2.49	2.48
7	-	2.51	2.50	2.47	2.48	2.48
8	-	2.50	2.50	2.47	2.48	2.47
9	-	2.50	2.50	2.46	2.48	2.47
10	-	2.50	2.49	2.46	2.47	2.47

Table I-10 Maximum rolling 8-hour mean CO concentration at community receptors, ranked by increase and by decrease in concentration

Rank	Ranking by increase in concentration relative to Do Minimum (mg/m³)			Ranking by decrease in concentration relative to Do Minimum (mg/m³)		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	0.03	0.07	0.03	-0.03	-0.04	-0.04
2	0.02	0.06	0.03	-0.03	-0.04	-0.04
3	0.02	0.04	0.01	-0.03	-0.03	-0.03
4	0.02	0.03	0.01	-0.02	-0.02	-0.02
5	0.01	0.03	0.01	-0.02	-0.01	-0.02
6	0.01	0.02	0.01	-0.02	-0.01	-0.02
7	0.01	0.02	0.01	-0.02	-0.01	-0.02
8	0.01	0.02	0.00	-0.01	-0.01	-0.01
9	0.01	0.02	0.00	-0.01	-0.01	-0.01
10	0.01	0.01	0.00	-0.01	-0.01	-0.01

Table I-11 Maximum rolling 8-hour mean CO concentration at community receptors, ranked by percentage increase and by decrease in concentration

Rank	Ranking by % increase in concentration relative to Do Minimum			Ranking by % decrease in concentration relative to Do Minimum		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	1.1%	2.7%	1.4%	-1.4%	-1.8%	-1.8%
2	0.8%	2.4%	1.2%	-1.3%	-1.5%	-1.6%
3	0.8%	1.6%	0.6%	-1.2%	-1.2%	-1.3%
4	0.6%	1.1%	0.5%	-0.9%	-0.7%	-1.0%
5	0.5%	1.1%	0.4%	-0.7%	-0.5%	-1.0%
6	0.4%	0.9%	0.3%	-0.7%	-0.5%	-1.0%
7	0.4%	0.9%	0.3%	-0.6%	-0.4%	-0.7%
8	0.3%	0.7%	0.2%	-0.6%	-0.3%	-0.5%
9	0.3%	0.7%	0.1%	-0.4%	-0.2%	-0.5%
10	0.3%	0.6%	0.0%	-0.4%	-0.2%	-0.5%

Table I-12 Maximum rolling 8-hour mean CO concentration at RWR receptors, ranked by concentration

Rank	Ranking by concentration (mg/m³)					
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1	-	3.7	3.7	3.5	3.3	3.3
2	-	3.5	3.7	3.4	3.2	3.2
3	-	3.5	3.5	3.4	3.1	3.2
4	-	3.5	3.5	3.4	3.1	3.2
5	-	3.5	3.5	3.4	3.1	3.2
6	-	3.5	3.5	3.3	3.1	3.1
7	-	3.5	3.4	3.3	3.1	3.1
8	-	3.5	3.4	3.3	3.1	3.1
9	-	3.4	3.4	3.3	3.1	3.1
10	-	3.4	3.4	3.3	3.1	3.1

Table I-13 Maximum rolling 8-hour mean CO concentration at RWR receptors, ranked by increase and by decrease in concentration

Rank	Ranking by increase in concentration relative to Do Minimum (mg/m³)			Ranking by decrease in concentration relative to Do Minimum (mg/m³)		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	0.3	0.2	0.3	-0.6	-0.4	-0.5
2	0.3	0.2	0.2	-0.5	-0.4	-0.4
3	0.3	0.2	0.2	-0.5	-0.3	-0.4
4	0.3	0.2	0.2	-0.4	-0.3	-0.4
5	0.3	0.2	0.2	-0.4	-0.3	-0.4
6	0.3	0.2	0.2	-0.4	-0.3	-0.4
7	0.3	0.2	0.2	-0.4	-0.3	-0.4
8	0.3	0.2	0.2	-0.4	-0.3	-0.4
9	0.3	0.2	0.2	-0.4	-0.3	-0.4
10	0.2	0.2	0.2	-0.4	-0.3	-0.4

Table I-14 Maximum rolling 8-hour mean CO concentration at RWR receptors, ranked by percentage increase and by decrease in concentration

Rank	Ranking by % increase in concentration relative to Do Minimum			Ranking by % decrease in concentration relative to Do Minimum		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	12.2%	9.4%	10.1%	-16.9%	-12.6%	-15.8%
2	10.9%	8.6%	8.4%	-13.8%	-12.4%	-13.8%
3	10.5%	8.5%	8.2%	-13.5%	-10.8%	-13.7%
4	10.5%	8.3%	7.6%	-13.5%	-10.6%	-13.5%
5	10.3%	8.2%	7.6%	-13.4%	-10.6%	-13.0%
6	10.3%	8.0%	7.3%	-12.3%	-10.5%	-13.0%
7	9.7%	7.8%	7.2%	-12.3%	-10.3%	-13.0%
8	9.6%	7.7%	7.1%	-12.2%	-9.9%	-12.9%
9	9.5%	7.7%	7.1%	-12.1%	-9.7%	-12.6%
10	9.0%	7.6%	7.0%	-12.0%	-9.7%	-12.2%

I.3 Nitrogen dioxide (annual mean)

Table I-15 Annual mean NO_2 concentration at community receptors

Receptor	Annual mean NO_2 concentration (mg/m^3)						Change relative to Do Minimum (mg/m^3)			Change relative to Do Minimum (%)		
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
CR01	-	24.5	24.4	24.4	24.3	24.1	-0.1	-0.1	-0.2	-0.2%	-0.4%	-1.0%
CR02	-	25.5	25.7	25.3	25.4	24.6	0.2	0.2	-0.6	0.8%	0.6%	-2.5%
CR03	-	24.6	24.8	24.3	24.6	24.2	0.2	0.3	-0.1	0.7%	1.1%	-0.5%
CR04	-	28.1	28.4	27.5	27.9	26.6	0.3	0.3	-0.9	1.0%	1.3%	-3.2%
CR05	-	25.2	25.1	25.1	25.1	24.9	-0.1	0.1	-0.1	-0.2%	0.4%	-0.5%
CR06	-	26.8	27.2	26.3	26.7	26.0	0.4	0.4	-0.3	1.6%	1.5%	-1.1%
CR07	-	25.6	25.7	25.3	25.6	25.2	0.1	0.3	0.0	0.4%	1.1%	-0.1%
CR08	-	25.3	25.3	25.0	25.2	25.2	0.0	0.2	0.2	0.2%	0.9%	0.8%
CR09	-	25.8	26.0	25.8	25.7	25.6	0.2	0.0	-0.2	0.8%	-0.1%	-0.6%
CR10	-	25.5	25.4	25.0	25.2	24.8	-0.1	0.2	-0.2	-0.5%	0.7%	-0.6%
CR11	-	25.4	25.3	25.6	25.0	25.2	0.0	-0.6	-0.4	-0.2%	-2.3%	-1.5%
CR12	-	25.1	25.0	25.1	24.9	24.9	-0.2	-0.2	-0.2	-0.6%	-0.9%	-0.6%
CR13	-	25.7	25.6	25.3	25.4	25.3	-0.2	0.1	-0.1	-0.7%	0.4%	-0.3%
CR14	-	25.2	25.2	24.9	24.9	25.0	0.0	-0.1	0.0	0.0%	-0.2%	0.2%
CR15	-	27.5	27.4	27.0	26.9	26.8	-0.1	-0.2	-0.2	-0.5%	-0.6%	-0.9%
CR16	-	24.4	24.4	24.3	24.3	24.3	-0.1	-0.1	-0.1	-0.2%	-0.3%	-0.2%
CR17	-	27.3	26.9	26.7	26.5	26.2	-0.4	-0.2	-0.5	-1.5%	-0.7%	-1.7%
CR18	-	24.5	24.4	24.3	24.3	24.2	-0.1	0.0	-0.1	-0.3%	0.0%	-0.3%
CR19	-	25.1	25.0	24.9	24.9	24.8	-0.1	0.0	-0.1	-0.5%	-0.1%	-0.4%
CR20	-	25.4	25.1	25.3	25.1	25.0	-0.3	-0.2	-0.3	-1.3%	-0.9%	-1.1%
CR21	-	25.3	25.2	25.1	24.9	24.8	-0.1	-0.2	-0.3	-0.3%	-0.9%	-1.2%
CR22	-	24.1	23.8	23.7	23.7	23.7	-0.2	0.0	0.0	-0.9%	0.0%	-0.1%
CR23	-	25.6	25.7	25.7	25.5	25.4	0.1	-0.2	-0.4	0.3%	-0.7%	-1.4%
CR24	-	26.8	26.6	26.4	26.6	26.7	-0.2	0.2	0.3	-0.7%	0.8%	1.1%
CR25	-	25.9	25.8	25.3	25.5	25.4	-0.1	0.2	0.1	-0.3%	0.8%	0.6%
CR26	-	24.8	24.8	24.6	24.6	24.8	0.1	0.0	0.2	0.2%	0.1%	0.7%
CR27	-	27.2	27.2	26.9	26.8	26.7	0.0	-0.1	-0.2	-0.1%	-0.3%	-0.8%
CR28	-	27.6	27.2	27.2	27.3	27.3	-0.4	0.2	0.2	-1.4%	0.7%	0.6%
CR29	-	26.3	26.0	26.3	26.4	25.9	-0.4	0.1	-0.3	-1.4%	0.4%	-1.3%
CR30	-	27.0	27.0	27.1	27.2	27.1	0.0	0.1	0.0	0.2%	0.3%	0.1%

Table I-16 Annual mean NO_2 concentration at community receptors, ranked by concentration

Rank		Ranking by concentration (µg/m³)					
		2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1		-	28.1	28.4	27.5	27.9	27.3
2		-	27.6	27.4	27.2	27.3	27.1
3		-	27.5	27.2	27.1	27.2	26.8
4		-	27.3	27.2	27.0	26.9	26.7
5		-	27.2	27.2	26.9	26.8	26.7
6		-	27.0	27.0	26.7	26.7	26.6
7		-	26.8	26.9	26.4	26.6	26.2
8		-	26.8	26.6	26.3	26.5	26.0
9		-	26.3	26.0	26.3	26.4	25.9
10		-	25.9	26.0	25.8	25.7	25.6

Table I-17 Annual mean NO_2 concentration at community receptors, ranked by increase and by decrease in concentration

Rank		Ranking by increase in concentration relative to Do Minimum (µg/m³)				Ranking by decrease in concentration relative to Do Minimum (µg/m³)		
		2026-DS	2036-DS	2036-DSC		2026-DS	2036-DS	2036-DSC
1		0.44	0.38	0.30		-0.41	-0.59	-0.88
2		0.28	0.34	0.20		-0.38	-0.23	-0.63
3		0.22	0.29	0.17		-0.36	-0.22	-0.45
4		0.20	0.28	0.17		-0.32	-0.22	-0.39
5		0.17	0.22	0.14		-0.21	-0.19	-0.37
6		0.09	0.21	0.04		-0.19	-0.19	-0.34
7		0.08	0.20	0.02		-0.17	-0.16	-0.30
8		0.06	0.18			-0.16	-0.09	-0.28
9		0.05	0.18			-0.14	-0.09	-0.28
10		0.05	0.16			-0.14	-0.07	-0.24

Table I-18 Annual mean NO_2 concentration at community receptors, ranked by percentage increase and by decrease in concentration

Rank		Ranking by % increase in concentration relative to Do Minimum				Ranking by % decrease in concentration relative to Do Minimum		
		2026-DS	2036-DS	2036-DSC		2026-DS	2036-DS	2036-DSC
1		1.6%	1.5%	1.1%		-1.5%	-2.3%	-3.2%
2		1.0%	1.3%	0.8%		-1.4%	-0.9%	-2.5%
3		0.8%	1.1%	0.7%		-1.4%	-0.9%	-1.7%
4		0.8%	1.1%	0.6%		-1.3%	-0.9%	-1.5%
5		0.7%	0.9%	0.6%		-0.9%	-0.7%	-1.4%
6		0.4%	0.8%	0.2%		-0.7%	-0.7%	-1.3%
7		0.3%	0.8%	0.1%		-0.7%	-0.6%	-1.2%
8		0.2%	0.7%			-0.6%	-0.4%	-1.1%
9		0.2%	0.7%			-0.5%	-0.3%	-1.1%
10		0.2%	0.6%			-0.5%	-0.3%	-1.0%

Table I-19 Annual mean NO_2 concentration at RWR receptors, ranked by concentration

Rank	Ranking by concentration (µg/m³)					
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1	-	42.5	40.7	44.8	42.7	46.8
2	-	38.4	38.5	40.4	40.1	43.4
3	-	37.6	37.1	37.4	37.6	42.4
4	-	37.0	36.3	37.0	37.0	39.7
5	-	36.0	35.5	36.3	36.0	38.5
6	-	36.0	35.4	36.2	35.2	38.2
7	-	35.7	35.2	35.1	34.9	37.8
8	-	35.6	35.1	35.1	34.7	37.5
9	-	35.6	35.0	35.0	34.6	37.3
10	-	35.5	34.9	35.0	34.5	37.2

Table I-20 Annual mean NO_2 concentration at RWR receptors, ranked by increase and by decrease in concentration

Rank	Ranking by increase in concentration relative to Do Minimum (µg/m³)			Ranking by decrease in concentration relative to Do Minimum (µg/m³)		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	1.6	1.4	5.3	-2.0	-2.2	-1.7
2	1.6	1.4	4.5	-1.8	-1.8	-1.6
3	1.5	1.3	4.5	-1.7	-1.5	-1.6
4	1.5	1.3	4.1	-1.7	-1.5	-1.6
5	1.5	1.3	3.9	-1.6	-1.5	-1.5
6	1.4	1.3	3.9	-1.6	-1.5	-1.5
7	1.4	1.2	3.8	-1.6	-1.4	-1.4
8	1.4	1.2	3.7	-1.6	-1.4	-1.3
9	1.4	1.2	3.6	-1.5	-1.4	-1.3
10	1.4	1.2	3.6	-1.5	-1.4	-1.3

Table I-21 Annual mean NO_2 concentration at RWR receptors, ranked by percentage increase and by decrease in concentration

Rank	Ranking by % increase in concentration relative to Do Minimum			Ranking by % decrease in concentration relative to Do Minimum		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	5.5%	5.0%	14.6%	-6.1%	-5.5%	-6.1%
2	5.3%	4.8%	14.4%	-5.3%	-5.0%	-5.8%
3	5.3%	4.5%	14.4%	-5.0%	-4.9%	-5.8%
4	5.1%	4.5%	13.6%	-4.9%	-4.8%	-5.7%
5	4.9%	4.5%	13.3%	-4.9%	-4.8%	-5.5%
6	4.8%	4.4%	13.2%	-4.8%	-4.8%	-5.3%
7	4.7%	4.4%	12.9%	-4.8%	-4.7%	-5.3%
8	4.7%	4.4%	12.8%	-4.8%	-4.6%	-5.0%
9	4.6%	4.2%	12.2%	-4.8%	-4.6%	-5.0%
10	4.6%	4.2%	12.2%	-4.7%	-4.6%	-4.8%

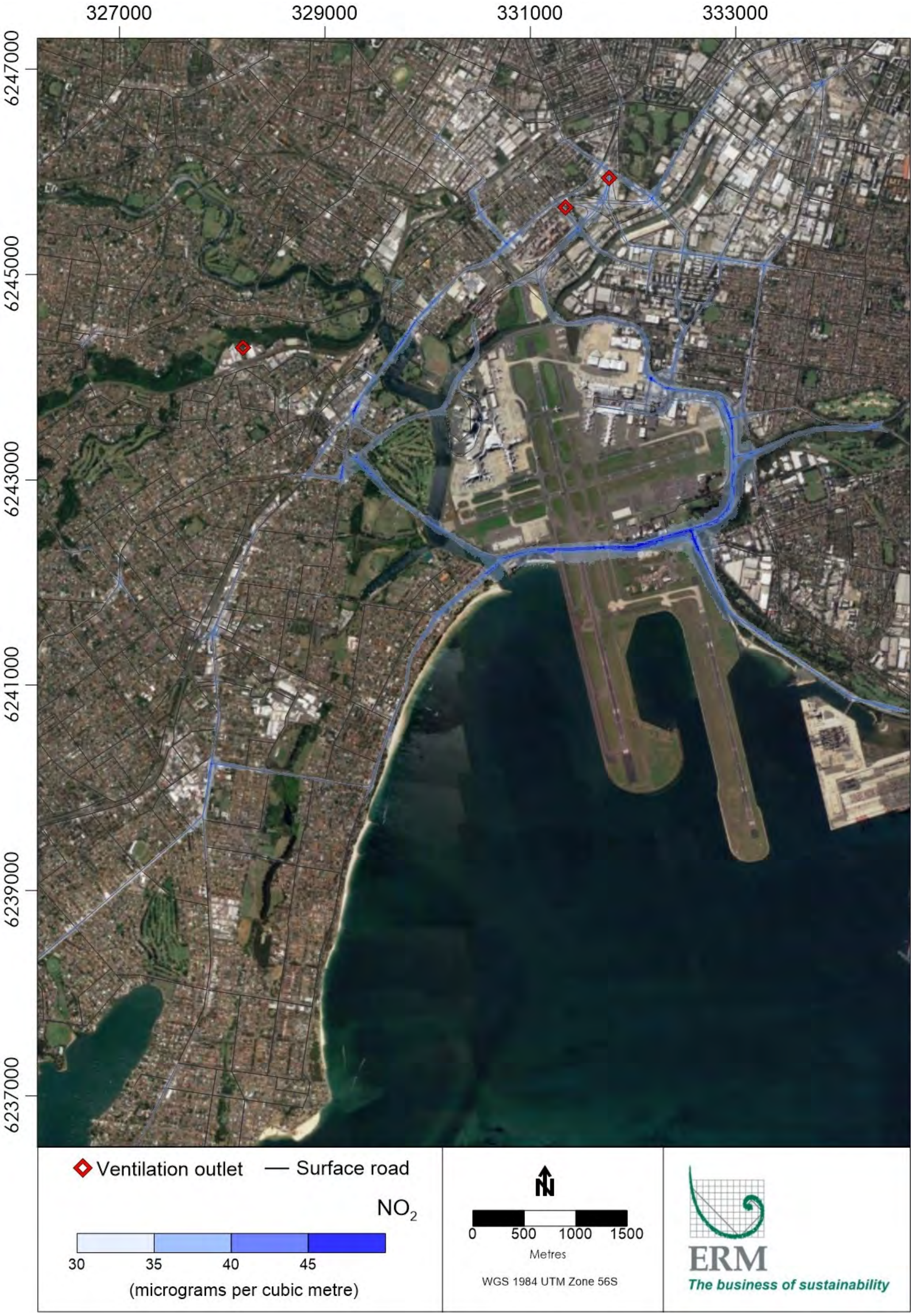


Figure I-1 **Contour plot of annual mean NO_2 concentration in the 2026 Do Minimum scenario (all sources, 2026-DM)**

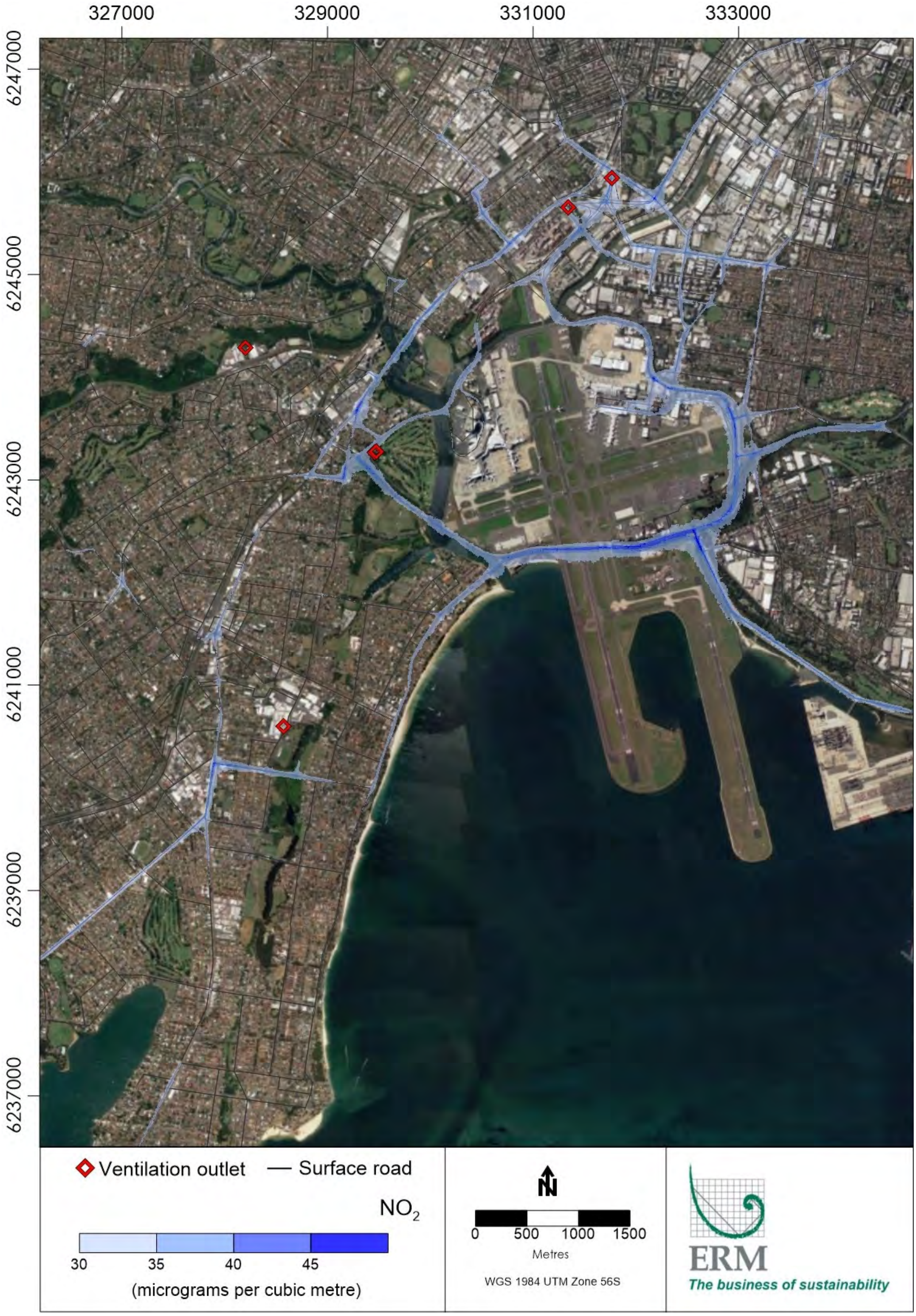


Figure I-2 Contour plot of annual mean NO_2 concentration in the 2026 Do Something scenario (all sources, 2026-DS)

Figure I-3 **Contour plot of change in annual mean NO_2 concentration in the 2026 Do something scenario (all sources, 2026-DS minus 2026-DM)**

Figure I-4 **Contour plot of annual mean NO_2 concentration in the 2036 Do Minimum scenario (all sources, 2036-DM)**

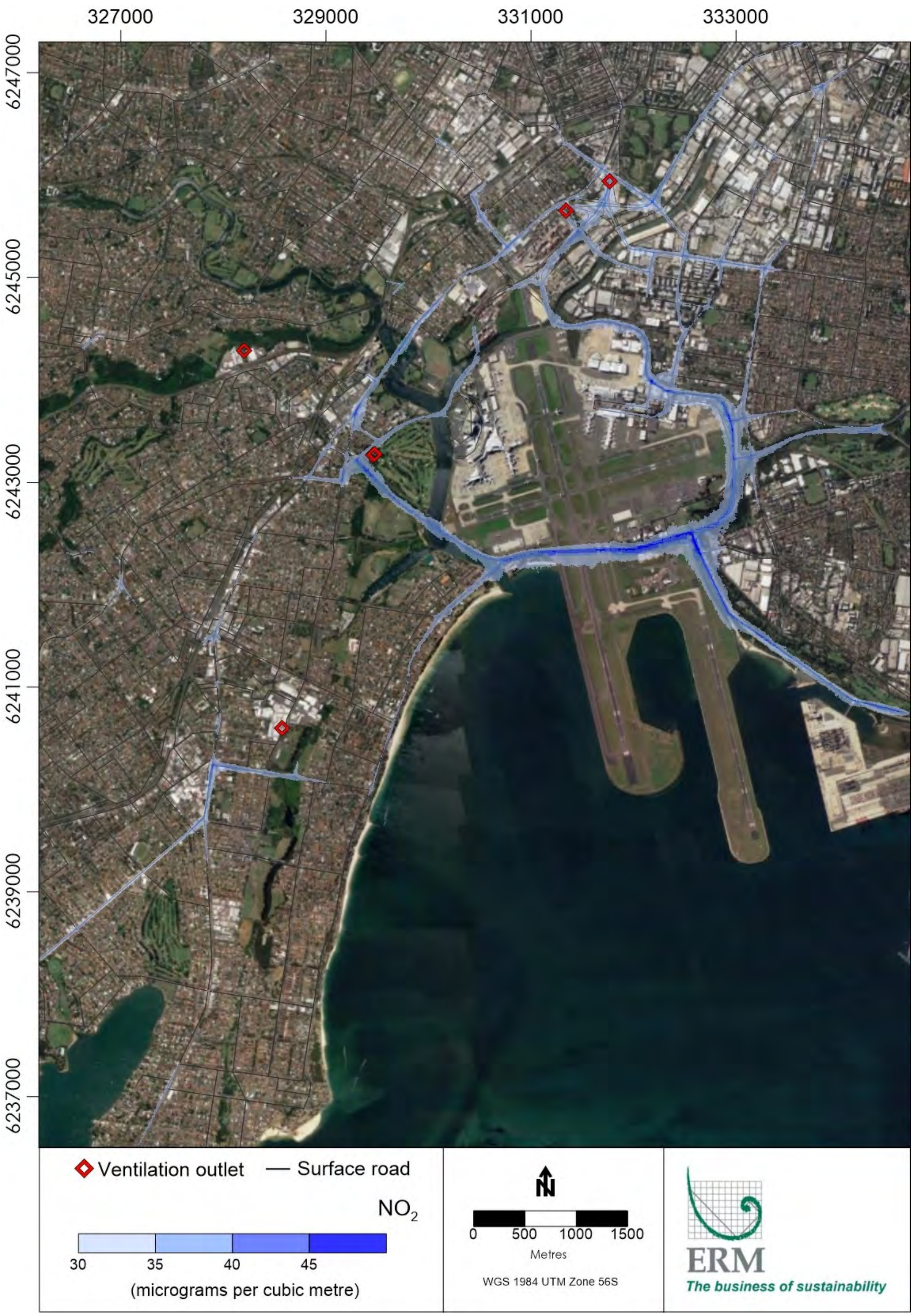


Figure I-5 **Contour plot of annual mean NO_2 concentration in the 2036 Do Something scenario (all sources, 2036-DS))**

Figure I-6 **Contour plot of change in annual mean NO_2 concentration in the 2036 Do Something scenario (all sources, 2036-DS minus 2036-DM)**

Figure I-7 **Contour plot of annual mean NO_2 concentration in the 2036 cumulative scenario (all sources, 2036-DSC)**

Figure I-8 Contour plot of change in annual mean NO_2 concentration in the 2036 cumulative scenario (all sources, 2036-DSC minus 2036-DM)

I.4 Nitrogen dioxide (maximum 1-hour mean)

Table I-22 Maximum 1-hour mean NO_2 concentration at community receptors

Receptor	Maximum 1-hour NO_2 concentration (mg/m³)						Change relative to Do Minimum (mg/m³)			Change relative to Do Minimum (%)		
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
CR01	-	187.2	186.6	186.3	186.2	188.0	-0.5	0.0	1.7	-0.3%	0.0%	0.9%
CR02	-	187.0	186.8	187.7	186.9	186.2	-0.2	-0.8	-1.5	-0.1%	-0.4%	-0.8%
CR03	-	187.8	187.8	187.6	187.1	186.2	0.0	-0.6	-1.4	0.0%	-0.3%	-0.8%
CR04	-	190.8	192.1	191.5	191.2	189.8	1.3	-0.3	-1.7	0.7%	-0.2%	-0.9%
CR05	-	186.3	186.6	187.0	187.8	186.7	0.3	0.8	-0.3	0.2%	0.4%	-0.2%
CR06	-	189.1	190.3	189.5	187.9	189.5	1.1	-1.6	0.1	0.6%	-0.8%	0.0%
CR07	-	187.3	187.7	187.7	187.6	186.8	0.4	-0.1	-0.9	0.2%	-0.1%	-0.5%
CR08	-	189.9	189.4	187.7	188.1	187.6	-0.5	0.5	0.0	-0.3%	0.3%	0.0%
CR09	-	186.4	187.5	186.2	186.7	186.5	1.2	0.4	0.2	0.6%	0.2%	0.1%
CR10	-	187.0	187.0	186.4	187.5	186.3	0.0	1.1	-0.1	0.0%	0.6%	-0.1%
CR11	-	189.6	188.9	191.2	189.0	189.5	-0.7	-2.3	-1.7	-0.4%	-1.2%	-0.9%
CR12	-	187.9	190.2	192.0	188.1	189.4	2.3	-3.9	-2.5	1.2%	-2.0%	-1.3%
CR13	-	187.2	186.9	187.7	188.2	187.2	-0.3	0.5	-0.4	-0.1%	0.3%	-0.2%
CR14	-	188.1	187.6	188.3	187.6	188.9	-0.5	-0.7	0.6	-0.3%	-0.4%	0.3%
CR15	-	190.0	191.3	189.8	189.3	189.0	1.3	-0.5	-0.8	0.7%	-0.2%	-0.4%
CR16	-	187.7	187.2	187.9	186.5	186.5	-0.5	-1.4	-1.4	-0.3%	-0.7%	-0.8%
CR17	-	189.4	188.3	187.5	191.0	187.8	-1.1	3.4	0.3	-0.6%	1.8%	0.2%
CR18	-	189.0	186.4	186.9	186.9	189.0	-2.6	0.0	2.1	-1.4%	0.0%	1.2%
CR19	-	187.9	188.0	189.6	190.5	189.0	0.1	0.8	-0.6	0.0%	0.4%	-0.3%
CR20	-	188.8	189.6	188.6	189.8	190.2	0.8	1.2	1.5	0.4%	0.6%	0.8%
CR21	-	188.4	189.9	189.1	187.7	187.0	1.5	-1.4	-2.1	0.8%	-0.8%	-1.1%
CR22	-	188.6	188.4	194.3	188.2	188.3	-0.2	-6.1	-6.0	-0.1%	-3.2%	-3.1%
CR23	-	188.8	189.1	189.4	190.5	188.5	0.2	1.1	-0.9	0.1%	0.6%	-0.5%
CR24	-	189.4	190.7	189.3	190.5	189.8	1.3	1.2	0.5	0.7%	0.6%	0.3%
CR25	-	191.5	190.2	188.7	188.4	187.9	-1.4	-0.2	-0.8	-0.7%	-0.1%	-0.4%
CR26	-	189.7	189.2	189.9	189.2	189.4	-0.5	-0.7	-0.5	-0.3%	-0.4%	-0.3%
CR27	-	193.0	197.1	196.9	190.9	191.7	4.1	-6.0	-5.2	2.1%	-3.0%	-2.6%
CR28	-	194.8	192.3	193.9	194.2	193.9	-2.5	0.3	0.0	-1.3%	0.1%	0.0%
CR29	-	193.4	192.2	194.8	193.1	194.0	-1.2	-1.7	-0.8	-0.6%	-0.9%	-0.4%
CR30	-	192.1	193.8	196.7	197.2	196.1	1.6	0.5	-0.6	0.9%	0.3%	-0.3%

Table I-23 Maximum 1-hour mean NO_2 concentration at community receptors, ranked by concentration

Rank		Ranking by concentration (µg/m³)					
		2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1		-	194.8	197.1	196.9	197.2	196.1
2		-	193.4	193.8	196.7	194.2	194.0
3		-	193.0	192.3	194.8	193.1	193.9
4		-	192.1	192.2	194.3	191.2	191.7
5		-	191.5	192.1	193.9	191.0	190.2
6		-	190.8	191.3	192.0	190.9	189.8
7		-	190.0	190.7	191.5	190.5	189.8
8		-	189.9	190.3	191.2	190.5	189.5
9		-	189.7	190.2	189.9	190.5	189.5
10		-	189.6	190.2	189.8	189.8	189.4

Table I-24 Maximum 1-hour mean NO_2 concentration at community receptors, ranked by increase and by decrease in concentration

Rank		Ranking by increase in concentration relative to Do Minimum (µg/m³)				Ranking by decrease in concentration relative to Do Minimum (µg/m³)		
		2026-DS	2036-DS	2036-DSC		2026-DS	2036-DS	2036-DSC
1		4.1	3.4	2.1		-2.6	-6.1	-6.0
2		2.3	1.2	1.7		-2.5	-6.0	-5.2
3		1.6	1.2	1.5		-1.4	-3.9	-2.5
4		1.5	1.1	0.6		-1.2	-2.3	-2.1
5		1.3	1.1	0.5		-1.1	-1.7	-1.7
6		1.3	0.8	0.3		-0.7	-1.6	-1.7
7		1.3	0.8	0.2		-0.5	-1.4	-1.5
8		1.2	0.5	0.1		-0.5	-1.4	-1.4
9		1.1	0.5	0.0		-0.5	-0.8	-1.4
10		0.8	0.5			-0.5	-0.7	-0.9

Table I-25 Maximum 1-hour mean NO_2 concentration at community receptors, ranked by percentage increase and by decrease in concentration

Rank		Ranking by % increase in concentration relative to Do Minimum				Ranking by % decrease in concentration relative to Do Minimum		
		2026-DS	2036-DS	2036-DSC		2026-DS	2036-DS	2036-DSC
1		2.1%	1.8%	1.2%		-1.4%	-3.2%	-3.1%
2		1.2%	0.6%	0.9%		-1.3%	-3.0%	-2.6%
3		0.9%	0.6%	0.8%		-0.7%	-2.0%	-1.3%
4		0.8%	0.6%	0.3%		-0.6%	-1.2%	-1.1%
5		0.7%	0.6%	0.3%		-0.6%	-0.9%	-0.9%
6		0.7%	0.4%	0.2%		-0.4%	-0.8%	-0.9%
7		0.7%	0.4%	0.1%		-0.3%	-0.8%	-0.8%
8		0.6%	0.3%	0.0%		-0.3%	-0.7%	-0.8%
9		0.6%	0.3%	0.0%		-0.3%	-0.4%	-0.8%
10		0.4%	0.3%			-0.3%	-0.4%	-0.5%

Table I-26 Maximum 1-hour mean NO_2 concentration at RWR receptors, ranked by concentration

Rank	Ranking by concentration (µg/m³)					
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1	-	348.5	307.9	375.1	334.9	321.5
2	-	292.9	282.0	269.5	259.4	267.0
3	-	279.2	274.3	267.8	252.5	262.3
4	-	277.1	272.9	264.4	249.8	256.5
5	-	268.7	264.3	262.4	248.5	247.0
6	-	259.2	258.5	260.8	247.6	247.0
7	-	253.8	256.6	255.1	247.1	241.1
8	-	252.2	253.6	254.2	243.0	238.8
9	-	250.4	250.6	253.4	236.5	238.1
10	-	250.2	249.4	250.4	233.3	237.2

Table I-27 Maximum 1-hour mean NO_2 concentration at RWR receptors, ranked by increase and by decrease in concentration

Rank	Ranking by increase in concentration relative to Do Minimum (µg/m³)			Ranking by decrease in concentration relative to Do Minimum (µg/m³)		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	34.9	16.5	42.2	-40.6	-40.3	-53.6
2	23.9	15.0	37.6	-37.2	-40.3	-41.1
3	23.3	9.9	28.0	-33.3	-36.4	-36.1
4	21.1	8.9	24.0	-32.6	-34.2	-33.6
5	20.8	8.6	18.2	-29.6	-33.9	-32.7
6	16.9	8.6	10.6	-28.8	-31.3	-31.1
7	16.4	8.3	10.1	-28.6	-30.2	-30.6
8	16.3	8.2	9.4	-27.4	-22.1	-28.2
9	15.3	8.1	9.1	-25.1	-21.4	-26.5
10	15.2	8.0	8.7	-25.0	-20.7	-21.9

Table I-28 Maximum 1-hour mean NO_2 concentration at RWR receptors, ranked by percentage increase and by decrease in concentration

Rank	Ranking by % increase in concentration relative to Do Minimum			Ranking by % decrease in concentration relative to Do Minimum		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	14.1%	7.5%	19.2%	-14.7%	-15.8%	-16.1%
2	10.8%	6.1%	17.2%	-13.2%	-14.4%	-14.4%
3	9.6%	4.6%	12.8%	-13.1%	-13.6%	-14.3%
4	9.5%	4.2%	11.0%	-12.2%	-13.3%	-13.6%
5	9.1%	4.1%	8.3%	-11.6%	-12.6%	-13.1%
6	7.8%	4.1%	4.9%	-11.2%	-12.1%	-11.8%
7	7.6%	4.1%	4.7%	-11.1%	-10.7%	-11.4%
8	7.4%	4.0%	4.6%	-10.4%	-9.2%	-10.8%
9	7.0%	3.9%	4.2%	-10.4%	-8.9%	-10.5%
10	6.9%	3.8%	4.2%	-10.2%	-8.8%	-9.1%

Figure I-9 **Contour plot of maximum 1-hour mean NO_2 concentration in the 2026 Do Minimum scenario (all sources, 2026-DM)**

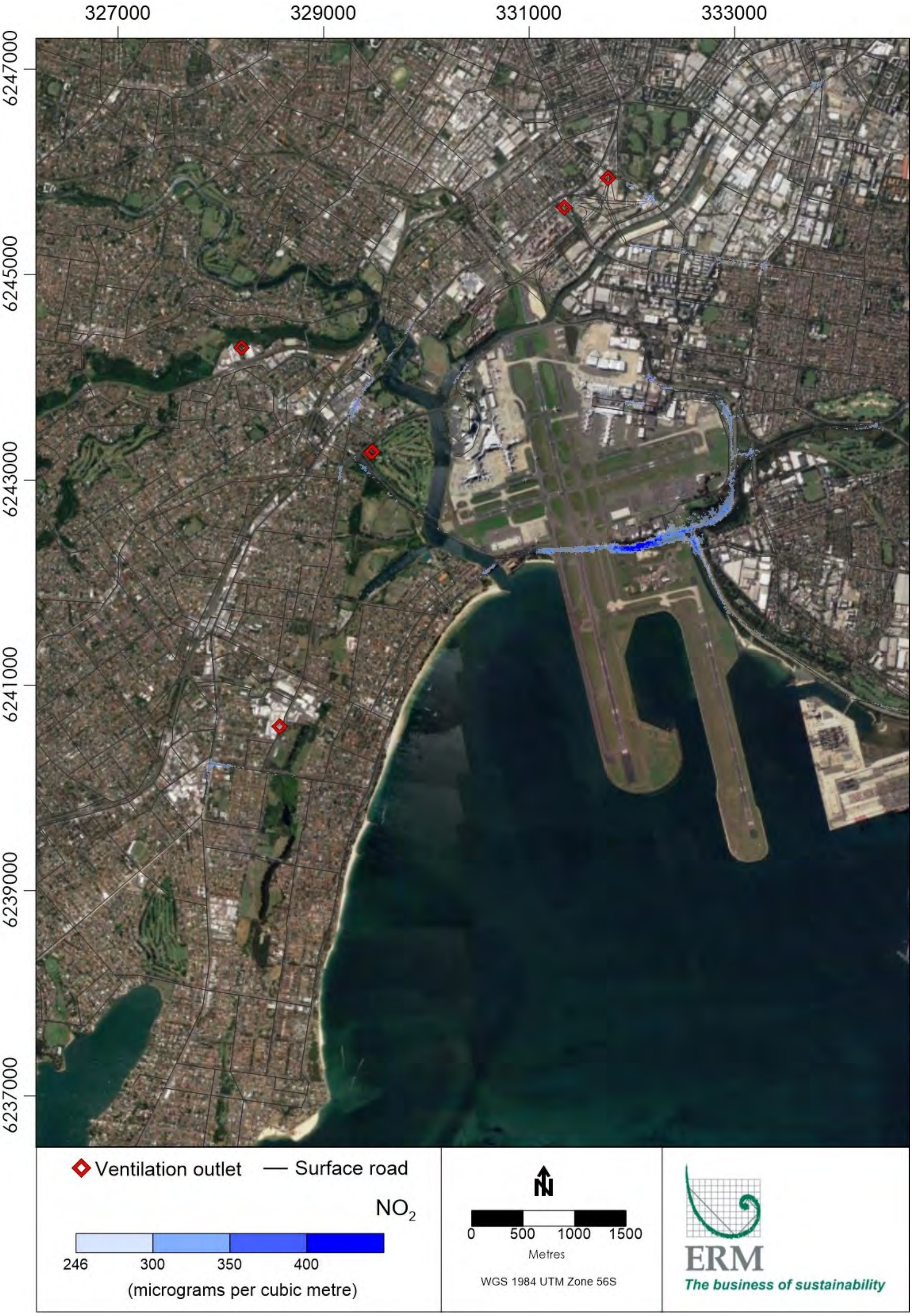


Figure I-10 **Contour plot of maximum 1-hour mean NO_2 concentration in the 2026 Do Something scenario (all sources, 2026-DS)**

Figure I-11 **Contour plot of change in maximum 1-hour mean NO_2 concentration in the 2026 Do Something scenario (all sources, 2026-DS minus 2026-DM)**

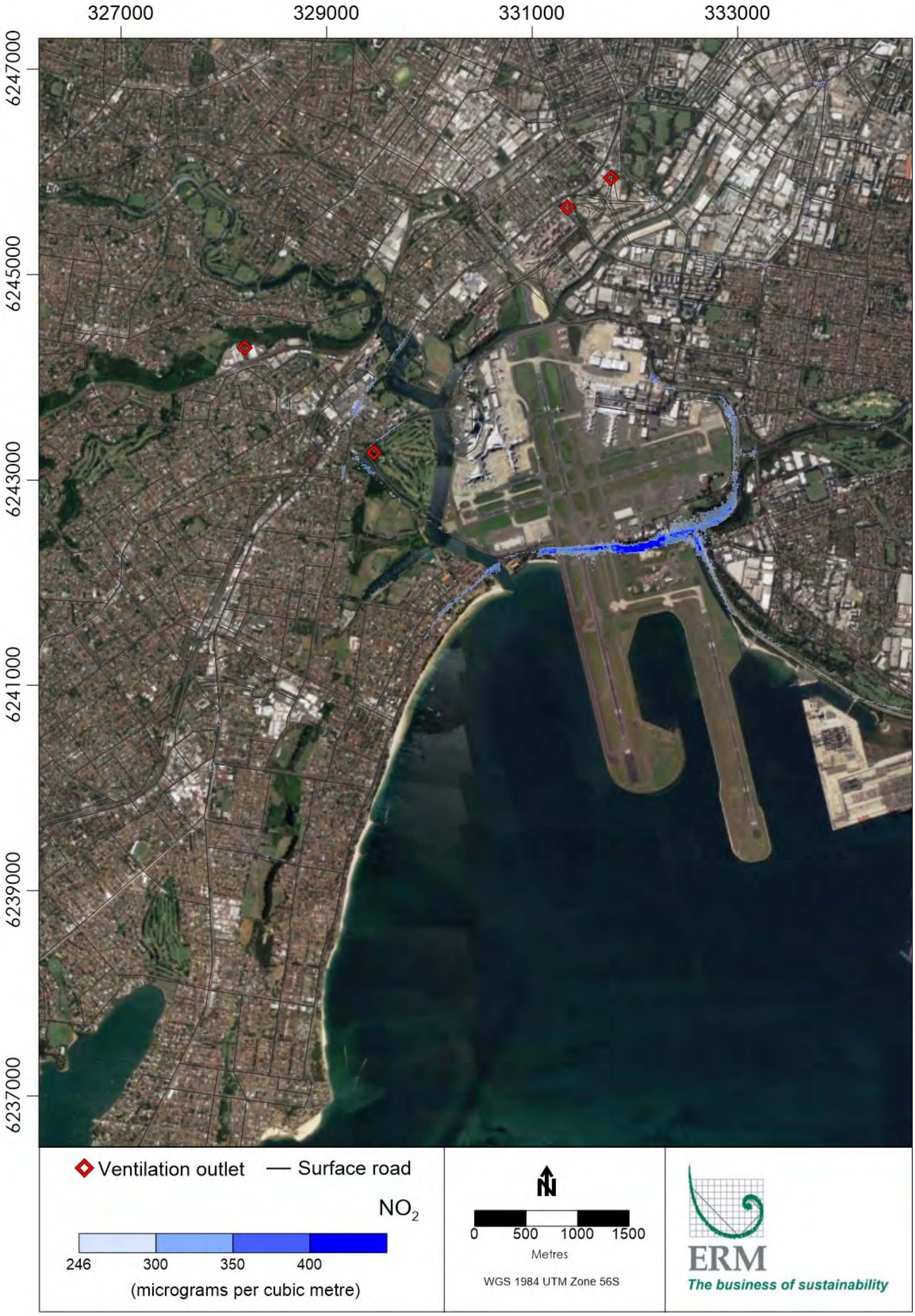


Figure I-12 **Contour plot of maximum 1-hour mean NO_2 concentration in the 2036 Do Minimum scenario (all sources, 2036-DM)**

Figure I-13 Contour plot of maximum 1-hour mean NO_2 concentration in the 2036 Do Something scenario (all sources, 2036-DS)

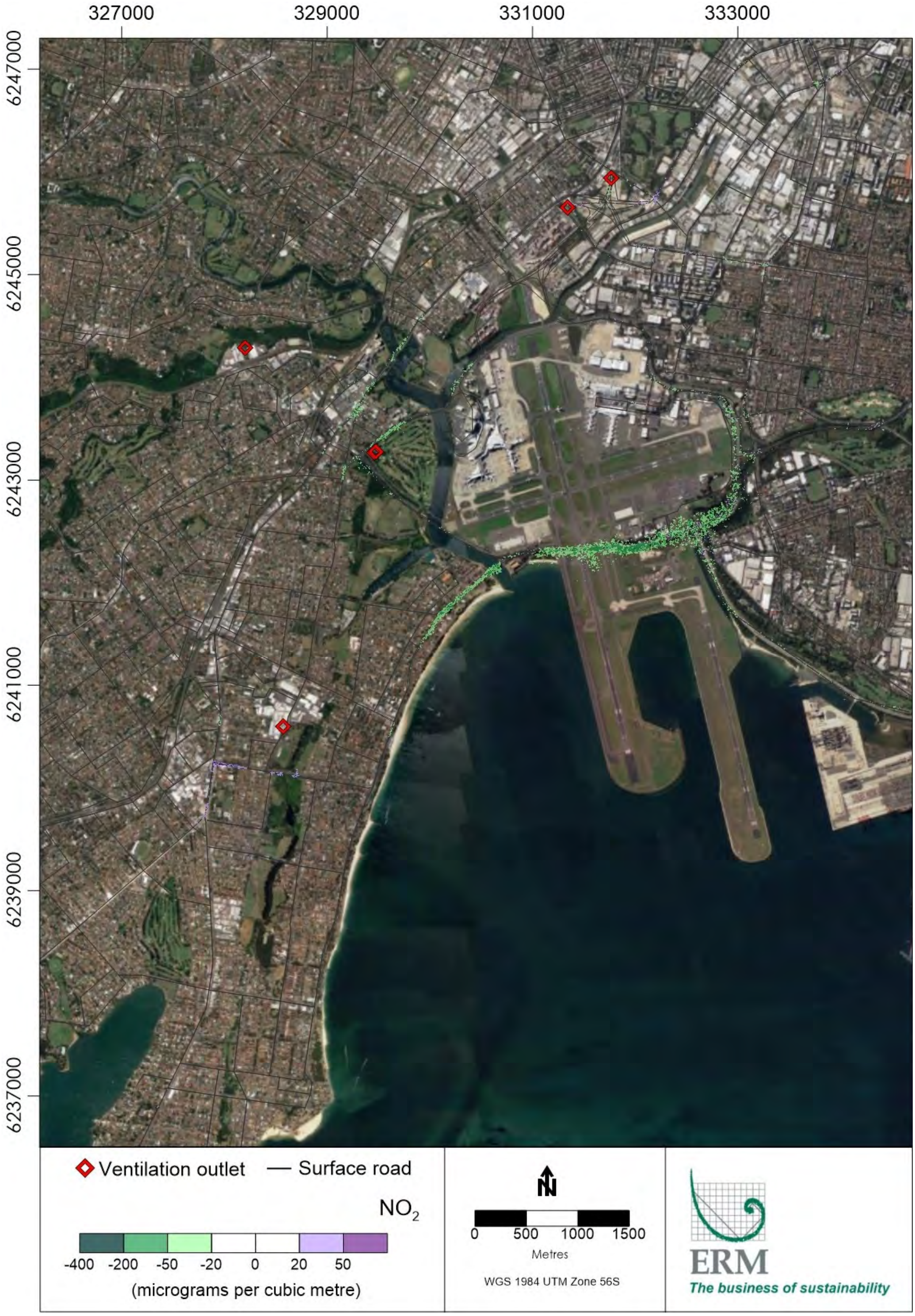


Figure I-14 **Contour plot of change in maximum 1-hour mean NO_2 concentration in the 2036 Do Something scenario (all sources, 2036-DS minus 2036-DM)**

Figure I-15 **Contour plot of maximum 1-hour mean NO_2 concentration in the 2036 cumulative scenario (all sources, 2036-DSC)**

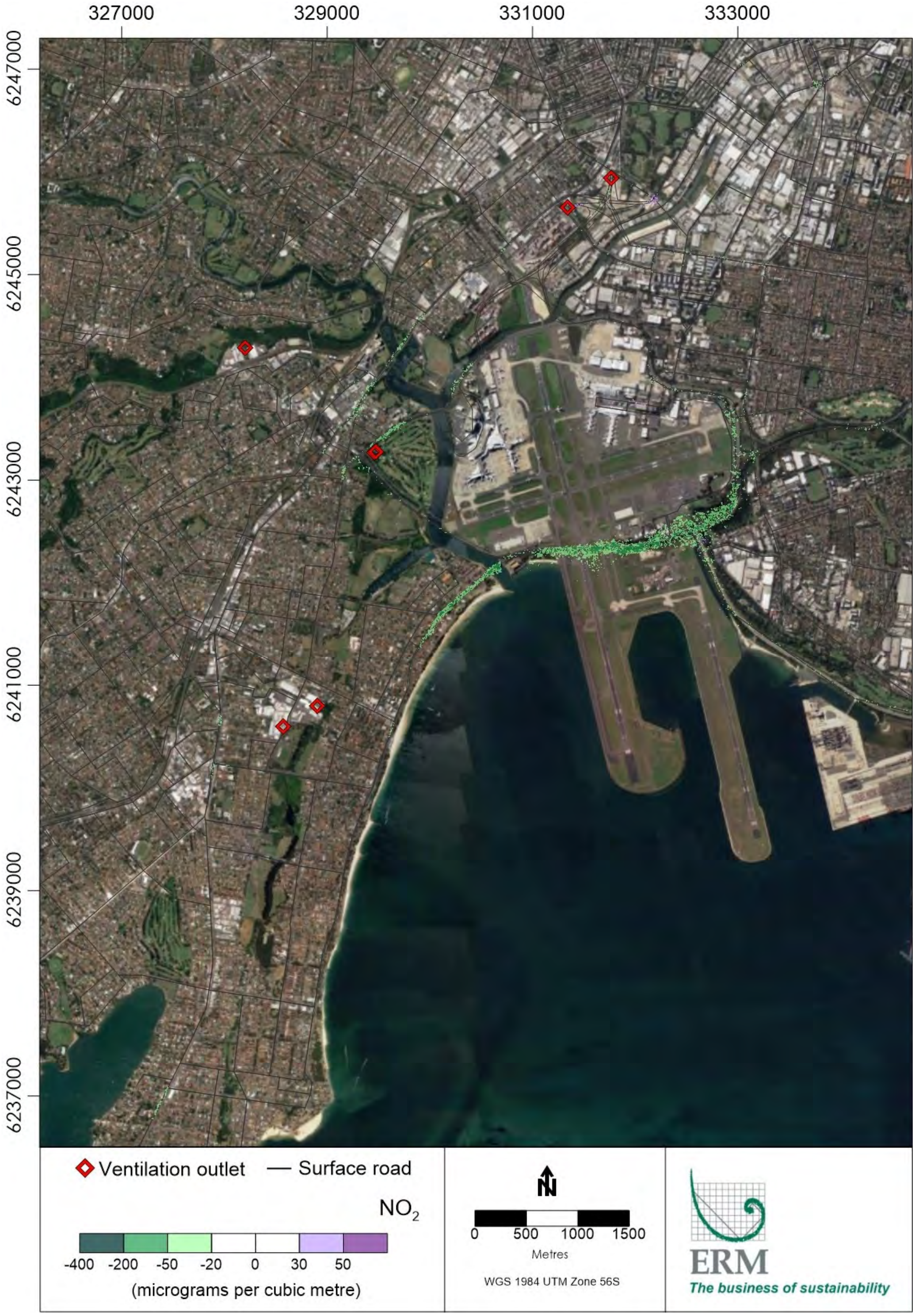


Figure I-16 Contour plot of change in maximum 1-hour mean NO_2 concentration in the 2036 cumulative scenario (all sources, 2036-DSC minus 2036-DM)

I.5 PM_{10} (annual mean)

Table I-29 Annual mean PM_{10} concentration at community receptors

Receptor	Annual mean PM_{10} concentration (µg/m³)						Change relative to Do Minimum (µg/m³)			Change relative to Do Minimum (%)		
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
CR01	-	19.7	19.8	19.8	19.8	19.7	0.1	0.0	-0.1	0.3%	0.2%	-0.4%
CR02	-	20.2	20.4	20.3	20.4	20.1	0.1	0.1	-0.3	0.6%	0.3%	-1.2%
CR03	-	19.9	19.9	19.9	20.0	19.9	0.0	0.1	0.0	0.2%	0.5%	-0.1%
CR04	-	21.1	21.1	21.1	21.3	20.9	0.0	0.2	-0.3	-0.2%	0.9%	-1.3%
CR05	-	19.8	19.8	19.9	19.9	19.9	0.0	-0.1	0.0	0.1%	-0.3%	-0.2%
CR06	-	20.6	20.7	20.6	20.8	20.6	0.1	0.2	0.0	0.5%	0.7%	-0.1%
CR07	-	20.0	20.1	20.1	20.2	20.2	0.1	0.1	0.1	0.3%	0.7%	0.4%
CR08	-	20.2	20.3	20.2	20.3	20.3	0.1	0.1	0.2	0.5%	0.6%	0.8%
CR09	-	20.2	20.2	20.2	20.2	20.2	0.0	0.0	0.0	0.2%	0.2%	-0.1%
CR10	-	19.9	19.9	19.9	19.9	19.9	0.0	0.0	0.0	0.1%	-0.2%	0.2%
CR11	-	20.5	20.3	20.5	20.5	20.5	-0.2	0.0	0.0	-0.8%	0.0%	0.2%
CR12	-	20.4	20.3	20.4	20.3	20.4	-0.1	-0.2	0.0	-0.5%	-0.7%	-0.2%
CR13	-	19.9	19.9	19.9	19.9	19.8	0.0	0.0	-0.1	0.0%	-0.2%	-0.5%
CR14	-	19.9	19.8	19.9	19.9	19.9	-0.1	0.0	0.0	-0.3%	0.1%	0.0%
CR15	-	20.1	20.0	20.2	20.1	20.2	-0.1	-0.1	0.0	-0.5%	-0.3%	-0.1%
CR16	-	19.2	19.2	19.2	19.2	19.2	0.0	0.0	0.0	-0.1%	0.1%	0.2%
CR17	-	20.5	20.3	20.6	20.5	20.4	-0.2	-0.1	-0.2	-1.1%	-0.6%	-0.8%
CR18	-	19.0	19.1	19.1	19.1	19.1	0.0	0.0	-0.1	0.2%	-0.2%	-0.3%
CR19	-	19.3	19.3	19.4	19.4	19.3	0.0	-0.1	-0.1	0.2%	-0.3%	-0.5%
CR20	-	20.3	20.3	20.5	20.4	20.4	-0.1	-0.1	-0.1	-0.3%	-0.4%	-0.5%
CR21	-	18.8	18.8	18.8	18.9	18.9	0.0	0.0	0.0	0.2%	0.3%	0.2%
CR22	-	18.6	18.6	18.7	18.6	18.6	0.0	-0.1	-0.1	-0.1%	-0.7%	-0.4%
CR23	-	19.6	19.6	19.7	19.7	19.6	0.1	-0.1	-0.1	0.3%	-0.3%	-0.4%
CR24	-	20.4	20.4	20.5	20.4	20.6	0.0	-0.1	0.2	-0.1%	-0.3%	0.7%
CR25	-	19.9	19.8	19.8	19.8	19.8	0.0	0.0	0.0	-0.2%	-0.2%	0.0%
CR26	-	19.6	19.6	19.7	19.8	19.7	0.0	0.1	0.0	0.0%	0.6%	-0.1%
CR27	-	20.7	20.9	20.8	20.8	21.0	0.2	0.0	0.2	0.9%	0.0%	0.8%
CR28	-	20.9	20.9	20.9	21.0	21.0	0.1	0.0	0.1	0.3%	0.2%	0.4%
CR29	-	20.5	20.4	20.8	20.7	20.7	0.0	-0.1	-0.1	-0.2%	-0.3%	-0.3%
CR30	-	21.0	21.1	21.4	21.3	21.2	0.1	-0.1	-0.2	0.6%	-0.4%	-0.8%

Table I-30 Annual mean PM_{10} concentration at community receptors, ranked by concentration

Rank	Ranking by concentration (µg/m³)					
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1	-	21.1	21.1	21.4	21.3	21.2
2	-	21.0	21.1	21.1	21.3	21.0
3	-	20.9	20.9	20.9	21.0	21.0
4	-	20.7	20.9	20.8	20.8	20.9
5	-	20.6	20.7	20.8	20.8	20.7
6	-	20.5	20.4	20.6	20.7	20.6
7	-	20.5	20.4	20.6	20.5	20.6
8	-	20.5	20.4	20.5	20.5	20.5
9	-	20.4	20.3	20.5	20.4	20.4
10	-	20.4	20.3	20.5	20.4	20.4

Table I-31 Annual mean PM_{10} concentration at community receptors, ranked by increase and by decrease in concentration

Rank	Ranking by increase in concentration relative to Do Minimum (µg/m³)			Ranking by decrease in concentration relative to Do Minimum (µg/m³)		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	0.20	0.18	0.16	-0.23	-0.15	-0.27
2	0.12	0.15	0.15	-0.16	-0.12	-0.25
3	0.11	0.14	0.15	-0.10	-0.12	-0.17
4	0.10	0.13	0.08	-0.09	-0.08	-0.16
5	0.10	0.11	0.07	-0.06	-0.07	-0.11
6	0.07	0.11	0.05	-0.06	-0.07	-0.10
7	0.06	0.06	0.04	-0.04	-0.06	-0.09
8	0.05	0.05	0.04	-0.04	-0.06	-0.09
9	0.05	0.04	0.03	-0.03	-0.06	-0.08
10	0.04	0.03	0.00	-0.02	-0.05	-0.07

Table I-32 Annual mean PM_{10} concentration at community receptors, ranked by percentage increase and by decrease in concentration

Rank	Ranking by % increase in concentration relative to Do Minimum			Ranking by % decrease in concentration relative to Do Minimum		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	0.9%	0.9%	0.8%	-1.1%	-0.7%	-1.3%
2	0.6%	0.7%	0.8%	-0.8%	-0.7%	-1.2%
3	0.6%	0.7%	0.7%	-0.5%	-0.6%	-0.8%
4	0.5%	0.6%	0.4%	-0.5%	-0.4%	-0.8%
5	0.5%	0.6%	0.4%	-0.3%	-0.4%	-0.5%
6	0.3%	0.5%	0.2%	-0.3%	-0.3%	-0.5%
7	0.3%	0.3%	0.2%	-0.2%	-0.3%	-0.5%
8	0.3%	0.3%	0.2%	-0.2%	-0.3%	-0.4%
9	0.3%	0.2%	0.2%	-0.2%	-0.3%	-0.4%
10	0.2%	0.2%	0.0%	-0.1%	-0.3%	-0.4%

Table I-33 Annual mean PM_{10} concentration at RWR receptors, ranked by concentration

Rank	Ranking by concentration (µg/m³)					
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1	-	30.29	29.51	31.81	30.92	30.69
2	-	26.31	25.77	26.61	26.20	25.84
3	-	25.11	24.55	25.45	25.43	25.20
4	-	24.55	24.43	25.15	24.99	24.75
5	-	24.55	24.06	25.02	24.68	24.70
6	-	24.54	23.77	24.91	24.68	24.67
7	-	24.04	23.76	24.83	24.36	24.36
8	-	23.90	23.76	24.78	24.31	24.28
9	-	23.86	23.73	24.35	24.04	24.04
10	-	23.83	23.69	24.09	23.95	23.94

Table I-34 Annual mean PM_{10} concentration at RWR receptors, ranked by increase and by decrease in concentration

Rank	Ranking by increase in concentration relative to Do Minimum (µg/m³)			Ranking by decrease in concentration relative to Do Minimum (µg/m³)		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	0.68	0.65	0.50	-0.78	-0.89	-1.12
2	0.57	0.64	0.48	-0.78	-0.88	-0.94
3	0.57	0.63	0.46	-0.71	-0.77	-0.91
4	0.54	0.62	0.46	-0.70	-0.72	-0.91
5	0.54	0.61	0.41	-0.68	-0.70	-0.89
6	0.53	0.59	0.38	-0.66	-0.67	-0.87
7	0.52	0.58	0.38	-0.61	-0.67	-0.81
8	0.51	0.57	0.38	-0.61	-0.65	-0.81
9	0.51	0.57	0.38	-0.61	-0.62	-0.78
10	0.51	0.56	0.37	-0.61	-0.59	-0.78

Table I-35 Annual mean PM_{10} concentration at RWR receptors, ranked by percentage increase and by decrease in concentration

Rank	Ranking by % increase in concentration relative to Do Minimum			Ranking by % decrease in concentration relative to Do Minimum		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	3.1%	3.0%	2.3%	-3.2%	-3.5%	-4.3%
2	2.7%	3.0%	2.3%	-3.0%	-3.2%	-4.3%
3	2.6%	2.9%	2.2%	-2.9%	-3.1%	-3.8%
4	2.5%	2.9%	2.0%	-2.8%	-3.0%	-3.8%
5	2.5%	2.8%	1.9%	-2.7%	-2.8%	-3.7%
6	2.4%	2.7%	1.8%	-2.6%	-2.8%	-3.7%
7	2.4%	2.7%	1.8%	-2.6%	-2.8%	-3.6%
8	2.4%	2.7%	1.8%	-2.6%	-2.6%	-3.6%
9	2.4%	2.6%	1.8%	-2.6%	-2.6%	-3.5%
10	2.4%	2.6%	1.8%	-2.6%	-2.6%	-3.4%

Figure I-16 **Contour plot of annual mean PM_{10} concentration in 2026 Do Minimum scenario (all sources, 2026-DM)**

Figure I-17 **Contour plot of annual mean PM_{10} concentration in 2026 Do Something scenario (all sources, 2026-DS**

Figure I-18 **Contour plot of change in annual mean PM_{10} concentration in 2026 Do something scenario (all sources, 2026-DS minus 2026-DM)**

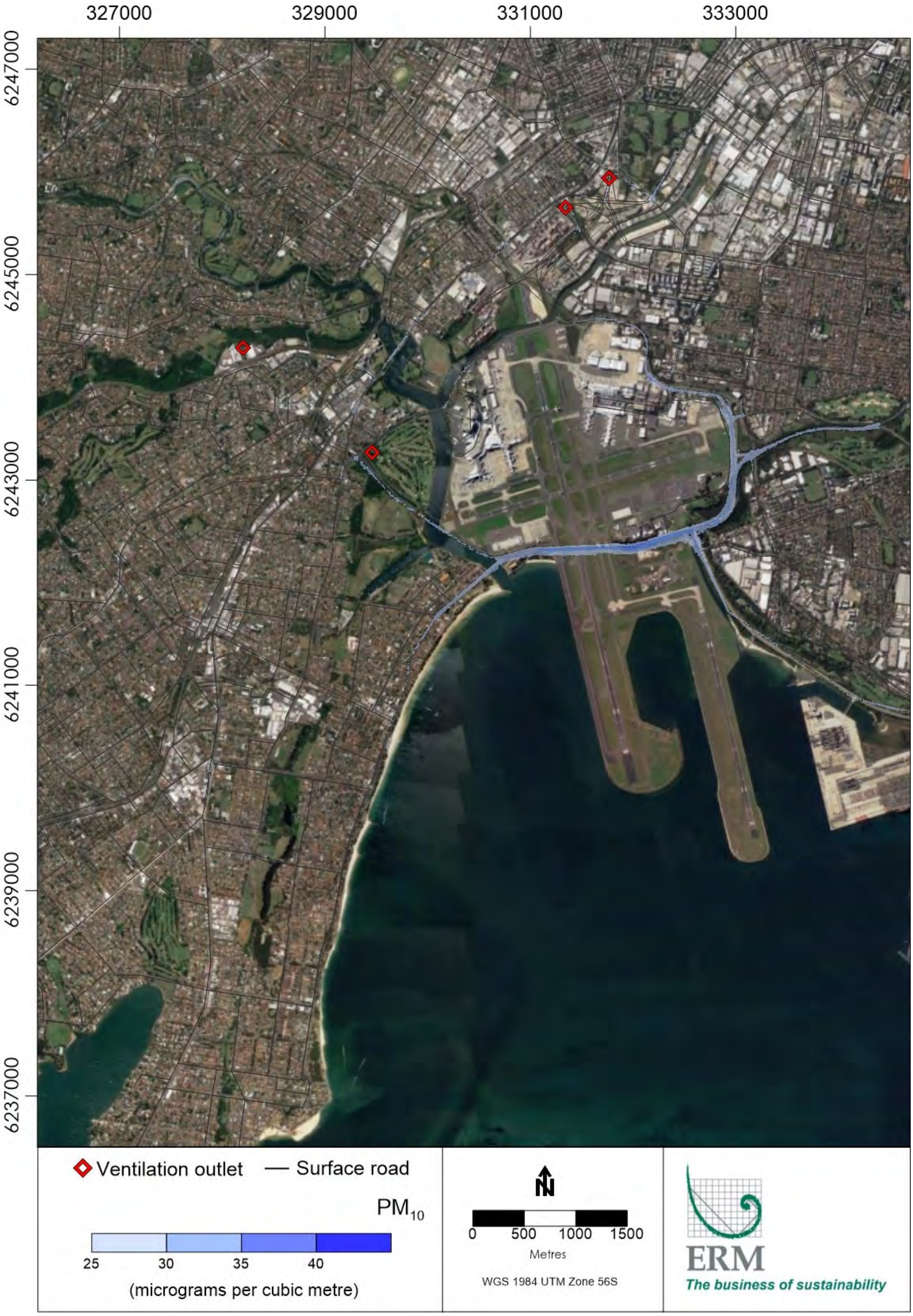


Figure I-19 **Contour plot of annual mean PM_{10} concentration in 2036 Do Minimum scenario (all sources, 2036-DM)**

Figure I-20 Contour plot of annual mean PM_{10} concentration in 2036 Do Something scenario (all sources, 2036-DS)

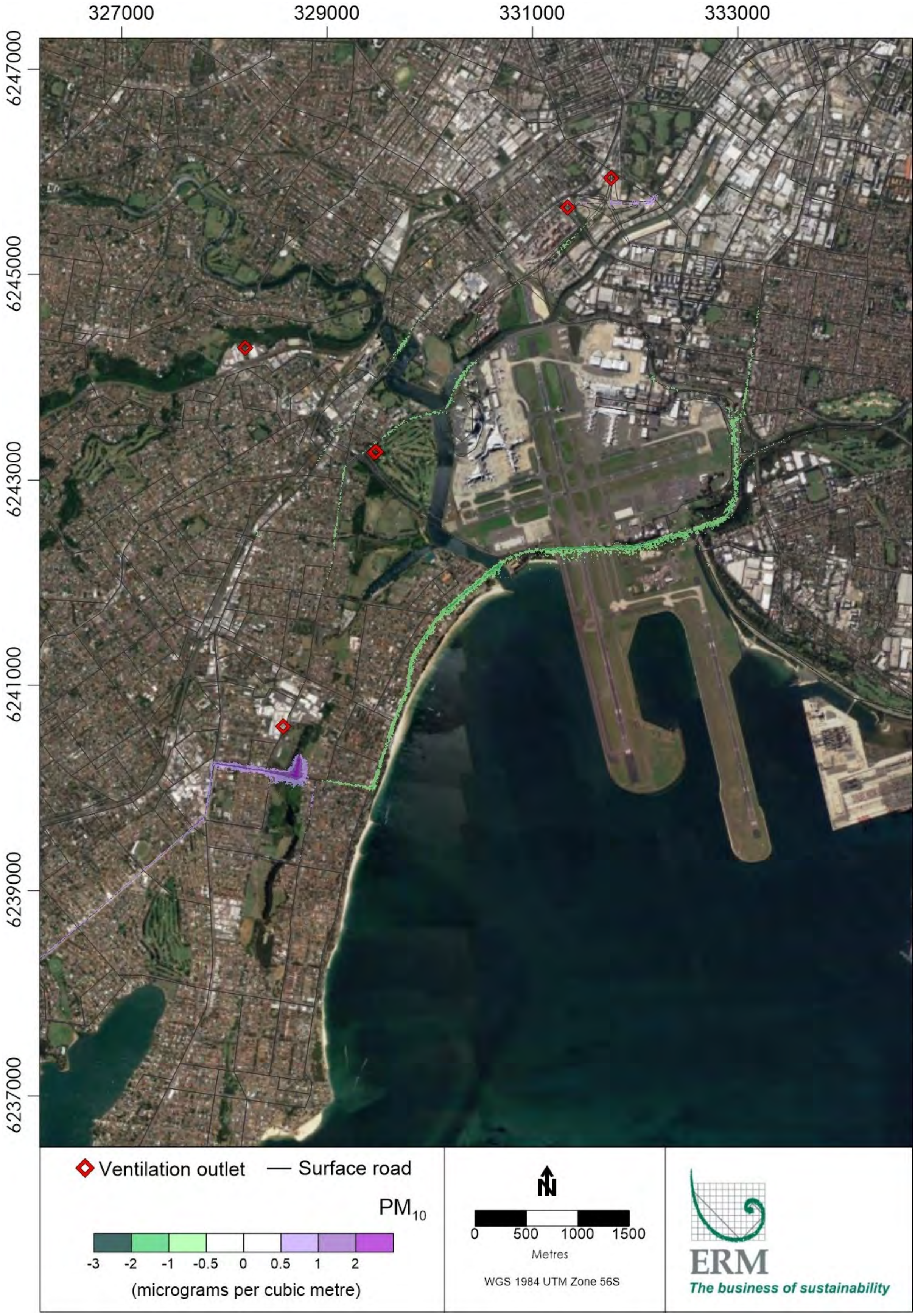


Figure I-21 Contour plot of change in annual mean PM_{10} concentration in 2036 Do Something scenario (all sources, 2036-DS minus 2036-DM)

Figure I-22 **Contour plot of annual mean PM_{10} concentration in 2036 cumulative scenario (all sources, 2036-DSC)**

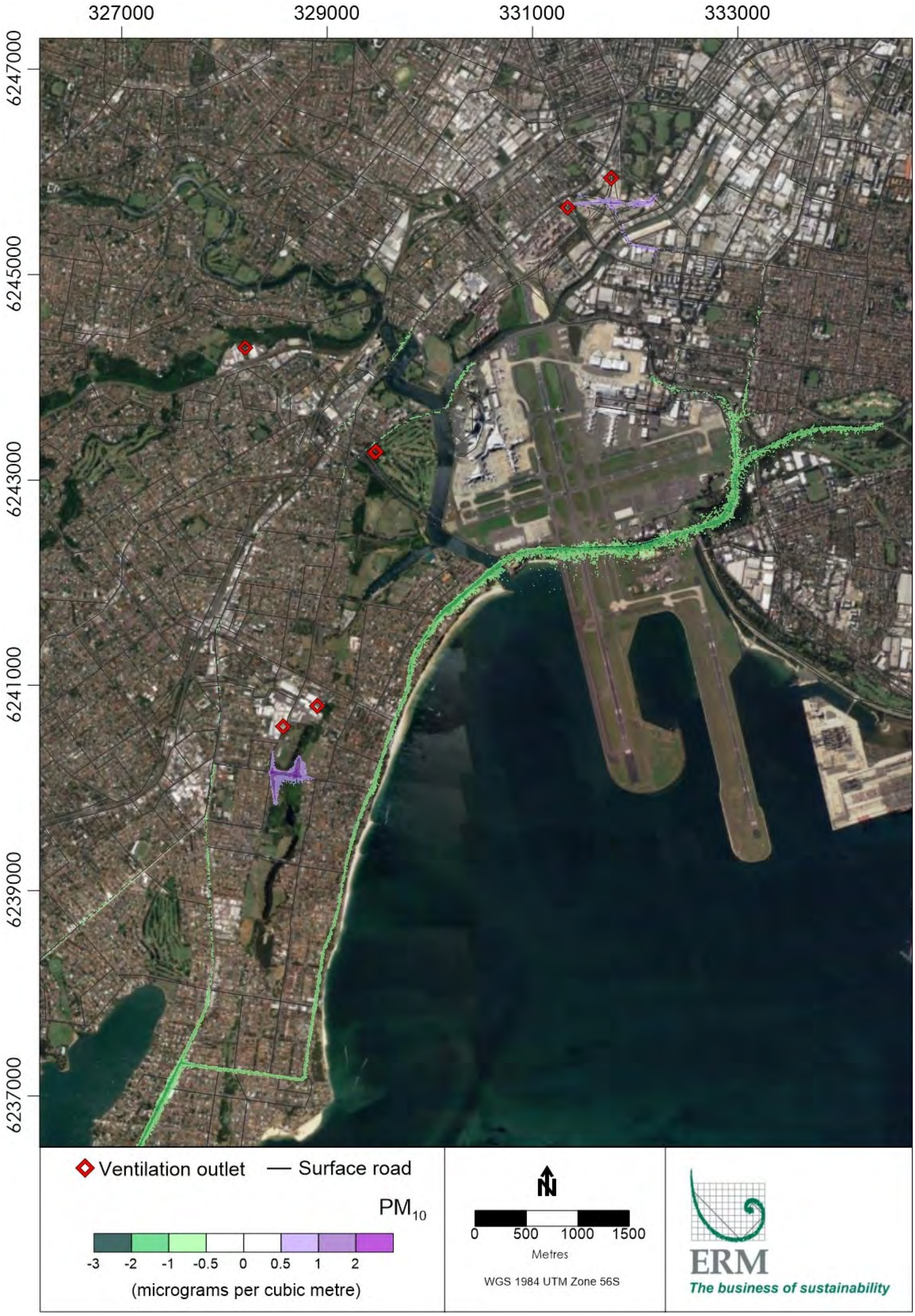


Figure I-23 Contour plot of change in annual mean PM_{10} concentration in 2036 cumulative scenario (all sources, 2036-DSC minus 2036-DM)

I.6 PM_{10} (maximum 24-hour mean)

Table I-36 Maximum 24-hour mean PM_{10} concentration at community receptors

Receptor	Maximum 24-hour PM_{10} concentration (µg/m³)						Change relative to Do Minimum (µg/m³)			Change relative to Do Minimum (%)		
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
CR01	-	43.9	44.0	43.9	43.9	44.2	0.2	0.0	0.3	0.4%	-0.1%	0.6%
CR02	-	43.8	44.0	44.0	44.2	43.8	0.1	0.2	-0.2	0.3%	0.5%	-0.4%
CR03	-	44.2	44.0	43.9	44.2	44.2	-0.3	0.2	0.2	-0.6%	0.5%	0.5%
CR04	-	46.4	46.0	46.0	46.3	45.4	-0.4	0.3	-0.6	-0.9%	0.6%	-1.4%
CR05	-	44.2	44.2	44.2	44.2	44.0	0.0	-0.1	-0.2	0.0%	-0.2%	-0.5%
CR06	-	45.2	45.4	45.4	45.2	45.8	0.2	-0.2	0.4	0.5%	-0.4%	0.8%
CR07	-	44.3	44.3	44.6	44.8	44.5	0.0	0.2	0.0	0.0%	0.4%	-0.1%
CR08	-	44.3	44.6	44.2	44.8	45.0	0.4	0.5	0.7	0.8%	1.2%	1.7%
CR09	-	44.2	44.5	44.2	44.5	44.2	0.2	0.3	0.0	0.6%	0.7%	0.0%
CR10	-	44.1	44.2	44.1	44.0	44.3	0.1	-0.1	0.2	0.2%	-0.3%	0.5%
CR11	-	44.7	44.7	44.6	44.6	45.1	0.0	0.0	0.5	0.1%	0.0%	1.2%
CR12	-	44.7	44.4	44.6	44.6	44.7	-0.3	0.0	0.1	-0.7%	0.0%	0.3%
CR13	-	44.3	44.3	44.3	44.5	44.4	-0.1	0.2	0.1	-0.1%	0.4%	0.2%
CR14	-	44.5	44.4	44.5	44.7	44.2	-0.1	0.2	-0.3	-0.2%	0.4%	-0.7%
CR15	-	45.2	44.9	45.3	45.3	45.5	-0.3	0.0	0.2	-0.6%	0.0%	0.4%
CR16	-	44.0	44.0	44.0	43.9	44.0	0.0	-0.2	0.0	0.0%	-0.3%	0.0%
CR17	-	45.5	45.2	45.6	45.4	45.2	-0.4	-0.2	-0.4	-0.8%	-0.4%	-0.8%
CR18	-	43.9	43.8	44.1	43.8	43.8	-0.2	-0.3	-0.2	-0.4%	-0.7%	-0.5%
CR19	-	43.9	44.0	44.1	43.9	44.0	0.1	-0.2	-0.1	0.2%	-0.4%	-0.1%
CR20	-	44.8	44.5	44.7	44.7	44.8	-0.3	0.0	0.2	-0.7%	0.1%	0.4%
CR21	-	44.5	44.4	44.8	45.2	44.5	-0.2	0.4	-0.3	-0.4%	0.9%	-0.6%
CR22	-	43.8	43.7	44.3	43.8	43.7	-0.1	-0.5	-0.6	-0.3%	-1.1%	-1.3%
CR23	-	44.2	44.3	44.9	44.7	44.6	0.1	-0.1	-0.3	0.3%	-0.3%	-0.7%
CR24	-	44.9	44.7	44.8	44.8	44.9	-0.2	0.0	0.2	-0.5%	0.1%	0.4%
CR25	-	44.8	45.4	44.7	44.3	45.0	0.6	-0.3	0.3	1.2%	-0.8%	0.7%
CR26	-	44.5	44.7	45.0	45.6	44.9	0.2	0.6	-0.1	0.5%	1.2%	-0.3%
CR27	-	47.4	48.0	47.1	47.4	47.7	0.6	0.3	0.6	1.3%	0.5%	1.2%
CR28	-	46.6	47.3	46.7	46.7	46.7	0.8	0.0	0.0	1.6%	0.1%	0.0%
CR29	-	45.6	45.7	46.3	45.4	46.3	0.1	-0.8	0.1	0.2%	-1.8%	0.1%
CR30	-	46.7	48.5	48.5	47.5	48.2	1.8	-1.0	-0.3	3.9%	-2.1%	-0.6%

Table I-37 Maximum 24-hour mean PM_{10} concentration at community receptors, ranked by concentration

Rank	Ranking by concentration (µg/m³)					
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1	-	47.4	48.5	48.5	47.5	48.2
2	-	46.7	48.0	47.1	47.4	47.7
3	-	46.6	47.3	46.7	46.7	46.7
4	-	46.4	46.0	46.3	46.3	46.3
5	-	45.6	45.7	46.0	45.6	45.8
6	-	45.5	45.4	45.6	45.4	45.5
7	-	45.2	45.4	45.4	45.4	45.4
8	-	45.2	45.2	45.3	45.3	45.2
9	-	44.9	44.9	45.0	45.2	45.1
10	-	44.8	44.7	44.9	45.2	45.0

Table I-38 Maximum 24-hour mean PM_{10} concentration at community receptors, ranked by increase and by decrease in concentration

Rank	Ranking by increase in concentration relative to Do Minimum (µg/m³)			Ranking by decrease in concentration relative to Do Minimum (µg/m³)		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	1.83	0.55	0.74	-0.41	-1.01	-0.62
2	0.76	0.52	0.56	-0.36	-0.84	-0.58
3	0.61	0.42	0.54	-0.33	-0.49	-0.37
4	0.56	0.30	0.38	-0.32	-0.35	-0.29
5	0.37	0.30	0.32	-0.27	-0.30	-0.29
6	0.24	0.25	0.27	-0.27	-0.19	-0.29
7	0.23	0.24	0.24	-0.23	-0.17	-0.28
8	0.21	0.22	0.23	-0.17	-0.15	-0.22
9	0.16	0.18	0.19	-0.16	-0.15	-0.20
10	0.15	0.17	0.18	-0.13	-0.14	-0.16

Table I-39 Maximum 24-hour mean PM_{10} concentration at community receptors, ranked by percentage increase and by decrease in concentration

Rank	Ranking by % increase in concentration relative to Do Minimum			Ranking by % decrease in concentration relative to Do Minimum		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	3.9%	1.2%	1.7%	-0.9%	-2.1%	-1.4%
2	1.6%	1.2%	1.2%	-0.8%	-1.8%	-1.3%
3	1.3%	0.9%	1.2%	-0.7%	-1.1%	-0.8%
4	1.2%	0.7%	0.8%	-0.7%	-0.8%	-0.7%
5	0.8%	0.6%	0.7%	-0.6%	-0.7%	-0.7%
6	0.6%	0.5%	0.6%	-0.6%	-0.4%	-0.6%
7	0.5%	0.5%	0.5%	-0.5%	-0.4%	-0.6%
8	0.5%	0.5%	0.5%	-0.4%	-0.4%	-0.5%
9	0.4%	0.4%	0.4%	-0.4%	-0.3%	-0.5%
10	0.3%	0.4%	0.4%	-0.3%	-0.3%	-0.4%

Table I-40 Maximum 24-hour mean PM_{10} concentration at RWR receptors, ranked by concentration

Rank	Ranking by concentration (µg/m³)					
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1	-	70.7	69.0	74.1	71.7	70.5
2	-	62.6	61.1	63.4	62.7	61.9
3	-	58.8	58.7	61.1	62.4	61.5
4	-	58.6	58.3	61.0	60.7	60.8
5	-	58.4	58.0	59.6	59.5	59.9
6	-	58.3	57.9	59.5	59.3	59.5
7	-	58.1	57.6	59.5	58.2	58.7
8	-	57.5	57.4	58.8	57.9	58.6
9	-	57.5	56.9	58.7	57.8	58.3
10	-	56.9	56.1	58.7	57.7	58.2

Table I-41 Maximum 24-hour mean PM_{10} concentration at RWR receptors, ranked by increase and by decrease in concentration

Rank	Ranking by increase in concentration relative to Do Minimum (µg/m³)			Ranking by decrease in concentration relative to Do Minimum (µg/m³)		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	2.0	2.6	3.5	-2.8	-2.9	-3.6
2	1.9	2.1	2.4	-2.7	-2.7	-3.4
3	1.9	2.1	2.3	-2.5	-2.6	-2.9
4	1.9	2.0	2.1	-2.5	-2.6	-2.9
5	1.8	1.9	2.1	-2.4	-2.6	-2.7
6	1.8	1.9	2.0	-2.4	-2.5	-2.7
7	1.8	1.9	2.0	-2.4	-2.5	-2.6
8	1.8	1.8	2.0	-2.4	-2.4	-2.6
9	1.8	1.8	1.8	-2.3	-2.4	-2.5
10	1.8	1.7	1.8	-2.3	-2.3	-2.5

Table I-42 Maximum 24-hour mean PM_{10} concentration at RWR receptors, ranked by percentage increase and by decrease in concentration

Rank	Ranking by % increase in concentration relative to Do Minimum			Ranking by % decrease in concentration relative to Do Minimum		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	4.0%	5.4%	5.4%	-5.3%	-5.4%	-6.3%
2	3.9%	4.5%	5.4%	-5.0%	-5.0%	-5.6%
3	3.8%	4.2%	5.4%	-4.9%	-4.9%	-5.3%
4	3.7%	4.0%	5.4%	-4.8%	-4.8%	-5.2%
5	3.7%	3.9%	5.4%	-4.8%	-4.8%	-5.1%
6	3.7%	3.8%	5.4%	-4.8%	-4.7%	-5.1%
7	3.7%	3.7%	5.4%	-4.7%	-4.4%	-4.9%
8	3.7%	3.7%	5.4%	-4.5%	-4.4%	-4.9%
9	3.6%	3.7%	5.4%	-4.5%	-4.3%	-4.8%
10	3.6%	3.5%	5.4%	-4.4%	-4.3%	-4.8%

Figure I-24 **Contour plot of maximum 24-hour mean PM_{10} concentration in 2026 Do Minimum scenario (all sources, 2026-DM)**

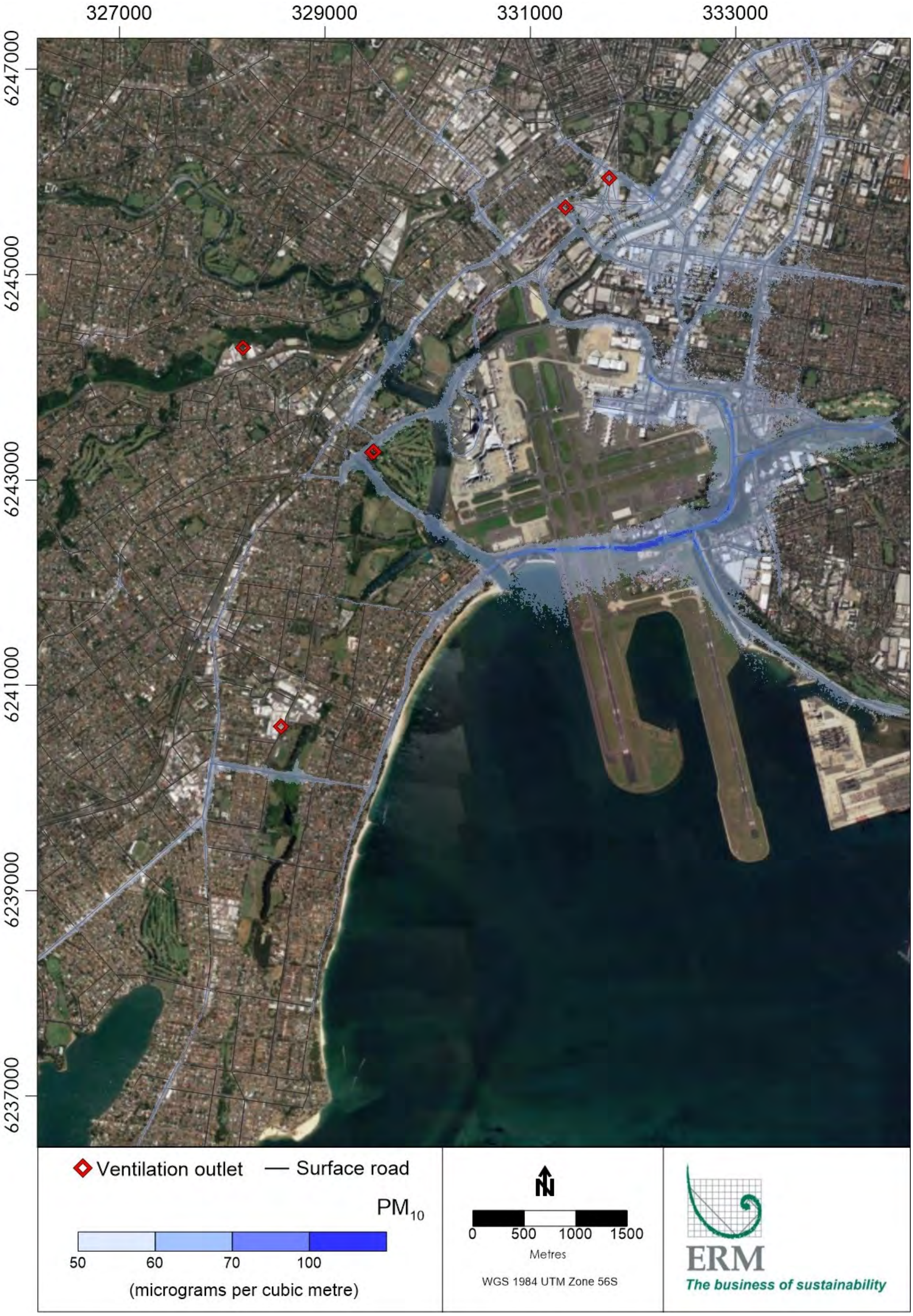


Figure I-25 **Contour plot of maximum 24-hour mean PM_{10} concentration in 2026 Do Something scenario (all sources, 2026-DS)**

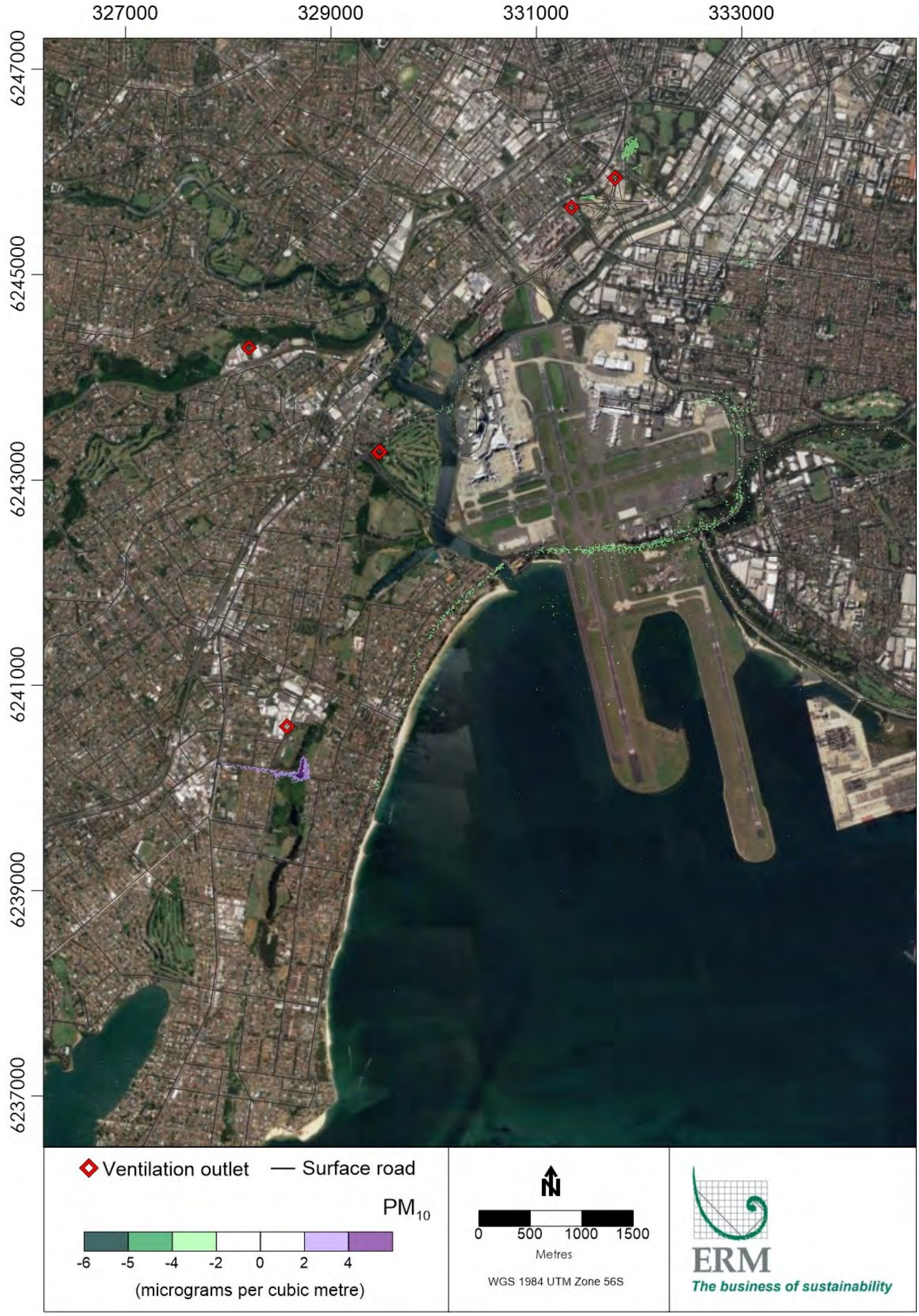


Figure I-26 **Contour plot of change in maximum 24-hour mean PM_{10} concentration in 2026 Do Something scenario (all sources, 2026-DS minus 2026-DM)**

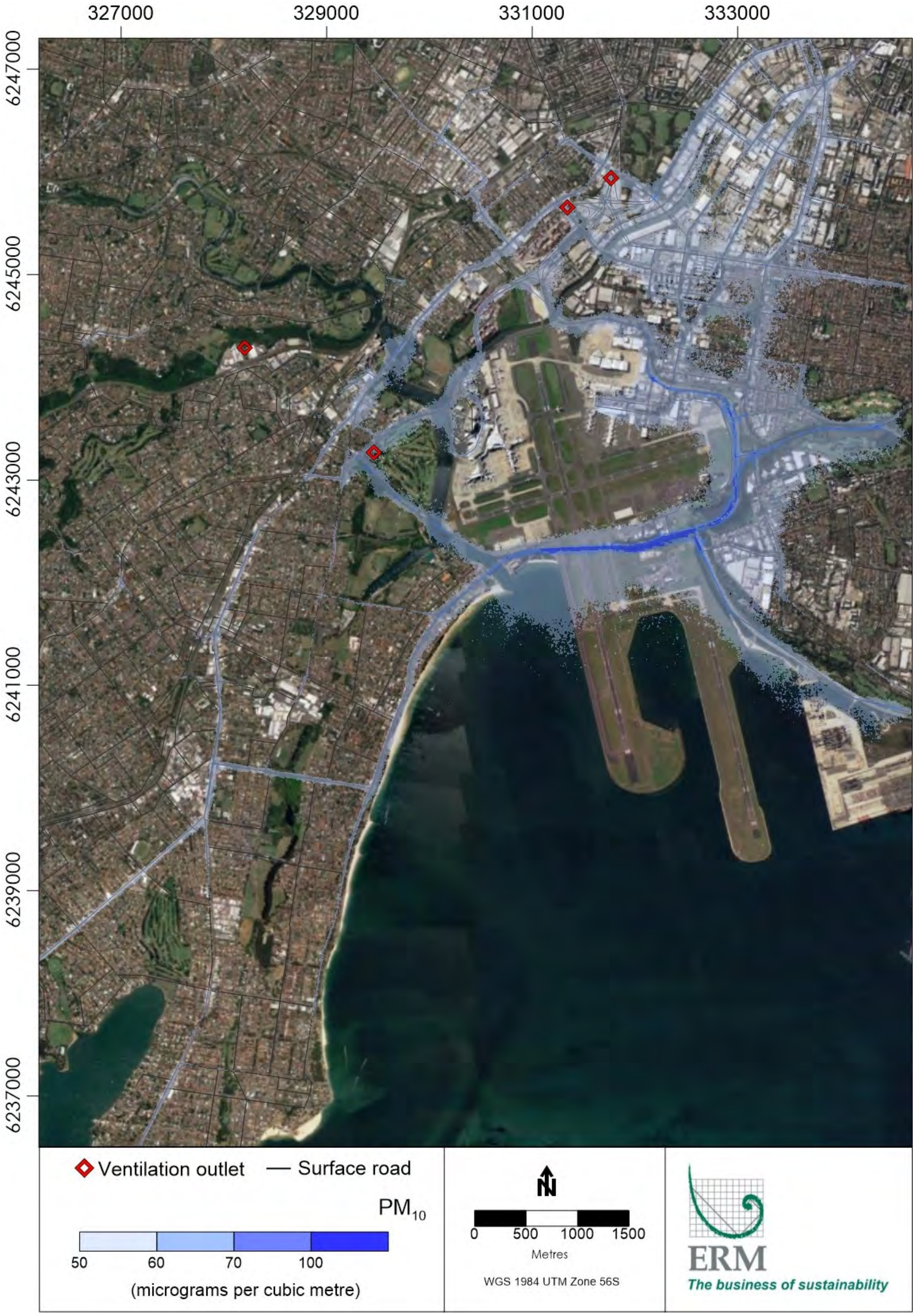


Figure I-27 **Contour plot of maximum 24-hour mean PM_{10} concentration in 2036 Do Minimum scenario (all sources, 2036-DM)**

Figure I-28 Contour plot of maximum 24-hour mean PM_{10} concentration in 20363 Do Something scenario (all sources, 2036-DS)

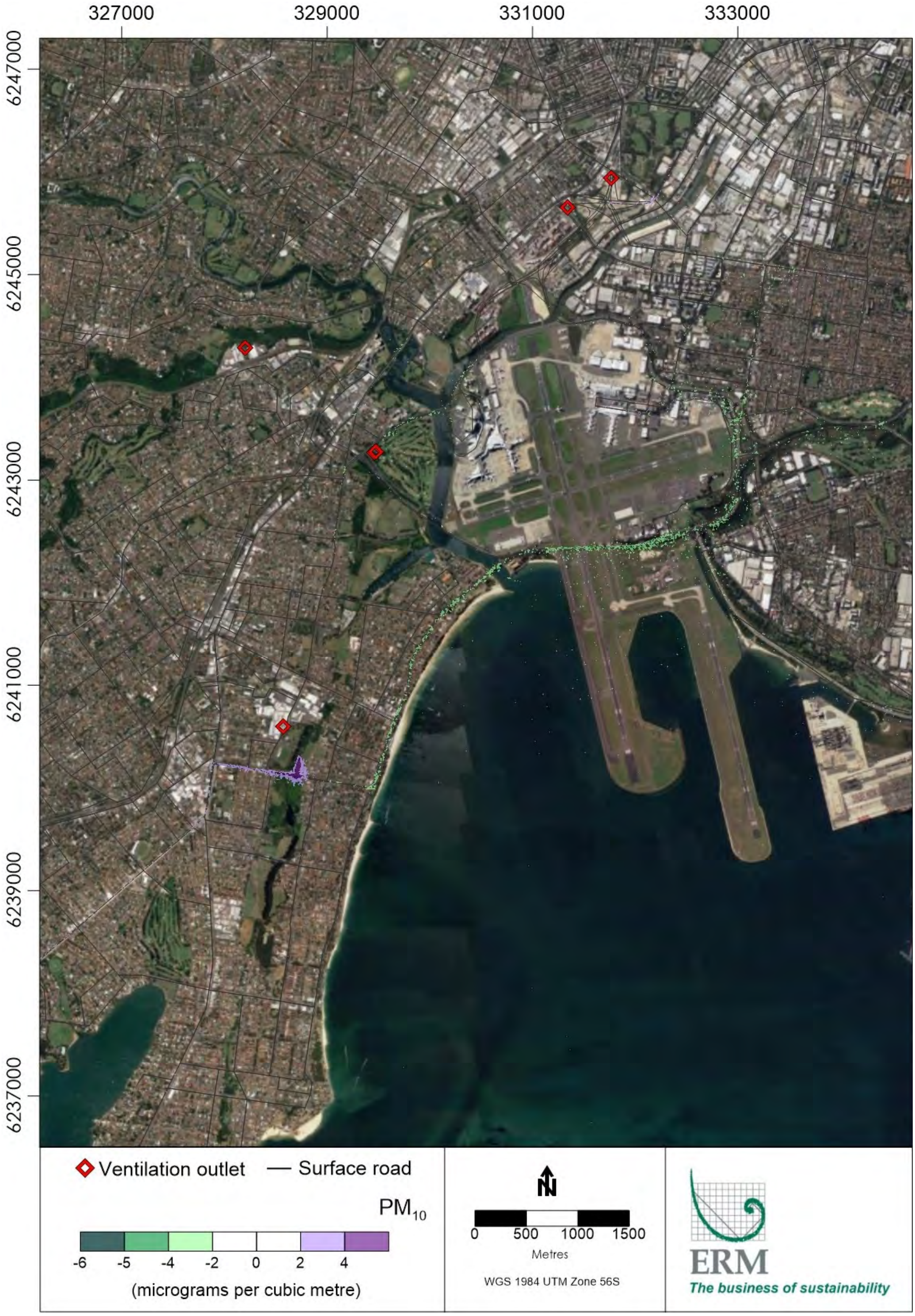


Figure I-29 **Contour plot of change in maximum 24-hour mean PM_{10} concentration in 2036 Do Something scenario (all sources, 2036-DS minus 2036-DM)**

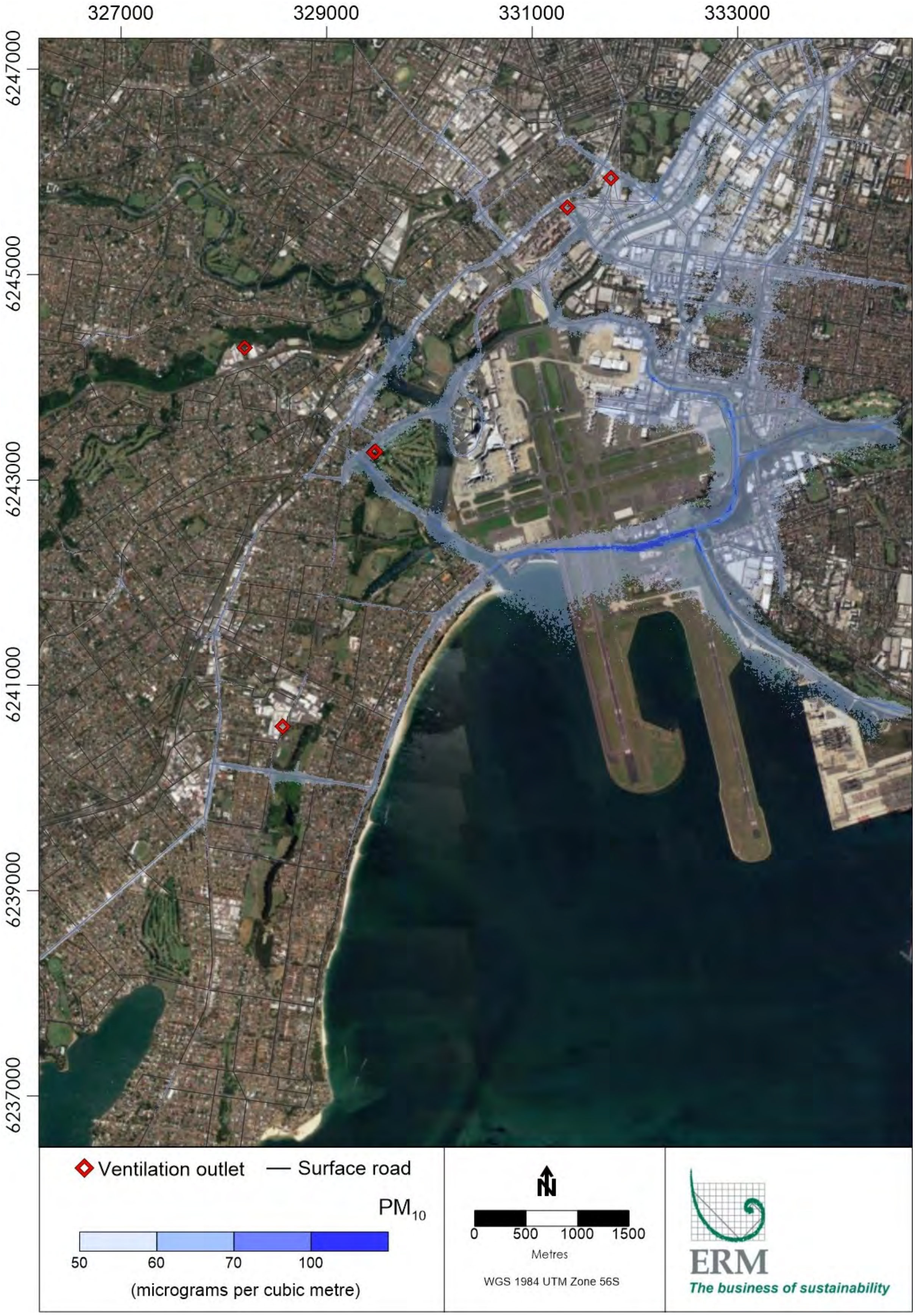


Figure I-30 Contour plot of maximum 24-hour mean PM_{10} concentration in 2036 cumulative scenario (all sources, 2036-DSC)

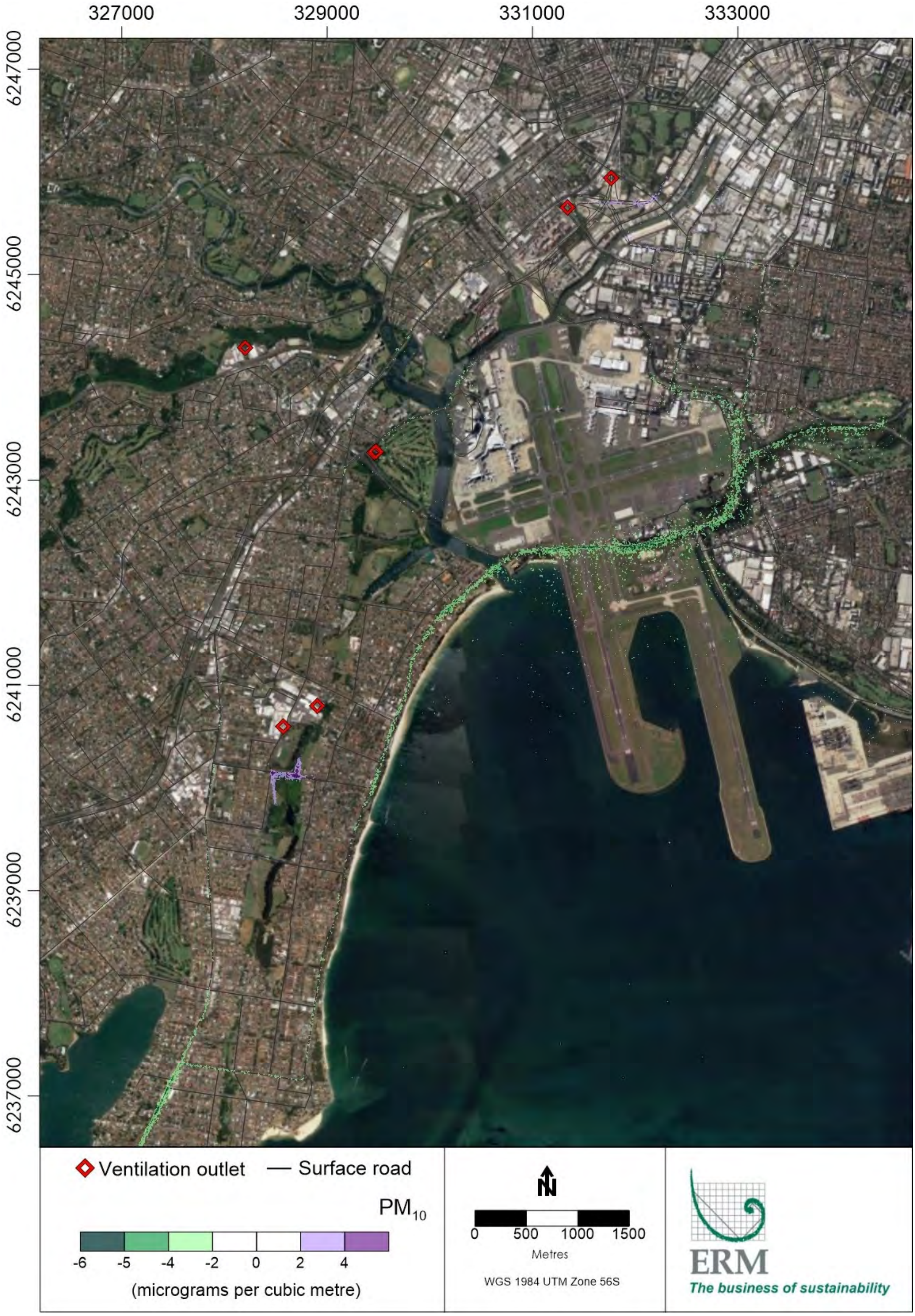


Figure I-31 **Contour plot of change in maximum 24-hour mean PM_{10} concentration in 2036 cumulative scenario (all sources, 2036-DSC minus 2036-DM)**

I.7 $PM_{2.5}$ (annual mean)

Table I-43 Annual mean $PM_{2.5}$ concentration at community receptors

Receptor	Annual mean $PM_{2.5}$ concentration (µg/m^3)						Change relative to Do Minimum (µg/m^3)			Change relative to Do Minimum (%)		
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
CR01	-	8.9	9.0	8.9	8.9	8.9	0.03	0.01	-0.01	0.3%	0.1%	-0.1%
CR02	-	9.3	9.4	9.4	9.4	9.2	0.06	0.00	-0.17	0.6%	0.0%	-1.8%
CR03	-	9.2	9.3	9.3	9.3	9.3	0.07	0.06	0.01	0.8%	0.6%	0.1%
CR04	-	9.9	10.0	10.0	10.1	9.8	0.14	0.10	-0.19	1.4%	1.0%	-1.9%
CR05	-	9.0	9.1	9.1	9.1	9.0	0.08	0.03	-0.02	0.9%	0.4%	-0.3%
CR06	-	9.7	9.8	9.7	9.8	9.7	0.17	0.14	-0.03	1.7%	1.5%	-0.3%
CR07	-	9.3	9.3	9.3	9.3	9.3	0.03	0.04	0.05	0.3%	0.4%	0.5%
CR08	-	9.7	9.7	9.7	9.7	9.8	-0.04	0.00	0.03	-0.4%	0.0%	0.3%
CR09	-	9.4	9.4	9.4	9.5	9.4	0.05	0.06	0.03	0.5%	0.7%	0.3%
CR10	-	9.2	9.2	9.3	9.2	9.2	0.00	-0.02	-0.02	0.0%	-0.2%	-0.2%
CR11	-	9.9	9.8	9.9	9.9	9.9	-0.04	-0.03	-0.02	-0.5%	-0.3%	-0.2%
CR12	-	9.8	9.8	9.9	9.9	9.8	-0.01	0.03	-0.03	-0.1%	0.3%	-0.3%
CR13	-	9.2	9.2	9.2	9.2	9.2	-0.01	-0.03	-0.02	-0.1%	-0.3%	-0.2%
CR14	-	9.4	9.4	9.4	9.4	9.4	0.00	-0.01	-0.03	0.0%	-0.1%	-0.3%
CR15	-	9.4	9.4	9.3	9.3	9.3	-0.05	0.04	-0.01	-0.5%	0.4%	-0.1%
CR16	-	8.8	8.8	8.8	8.8	8.8	0.03	-0.06	-0.02	0.3%	-0.7%	-0.2%
CR17	-	9.9	9.7	9.9	9.8	9.8	-0.14	-0.09	-0.01	-1.5%	-0.9%	-0.1%
CR18	-	8.8	8.8	8.9	8.8	8.8	0.00	-0.05	-0.03	0.0%	-0.5%	-0.3%
CR19	-	9.1	9.1	9.1	9.1	9.1	0.00	-0.05	-0.02	0.0%	-0.5%	-0.2%
CR20	-	9.9	9.8	9.9	9.8	9.8	-0.04	-0.02	-0.03	-0.4%	-0.2%	-0.3%
CR21	-	8.7	8.6	8.7	8.7	8.7	-0.06	0.03	-0.01	-0.7%	0.3%	-0.1%
CR22	-	8.6	8.6	8.6	8.6	8.6	-0.02	0.00	0.00	-0.2%	0.0%	0.0%
CR23	-	9.2	9.2	9.2	9.3	9.2	-0.01	0.08	0.00	-0.2%	0.9%	0.1%
CR24	-	9.7	9.6	9.7	9.6	9.8	-0.04	-0.06	0.09	-0.4%	-0.6%	0.9%
CR25	-	9.3	9.2	9.2	9.2	9.3	-0.05	0.00	0.03	-0.5%	0.0%	0.3%
CR26	-	9.2	9.2	9.3	9.2	9.3	0.00	-0.07	-0.02	0.0%	-0.7%	-0.2%
CR27	-	9.8	10.0	10.1	10.1	10.0	0.11	0.05	-0.08	1.1%	0.5%	-0.8%
CR28	-	10.2	10.1	10.3	10.2	10.1	-0.07	-0.03	-0.13	-0.7%	-0.3%	-1.2%
CR29	-	10.0	10.0	10.2	10.1	10.0	-0.03	-0.06	-0.13	-0.3%	-0.6%	-1.3%
CR30	-	10.5	10.5	10.7	10.5	10.6	0.03	-0.17	-0.14	0.3%	-1.6%	-1.3%

Table I-44 Annual mean $PM_{2.5}$ concentration at community receptors, ranked by concentration

Rank	Ranking by concentration (µg/m³)					
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1	-	10.5	10.5	10.7	10.5	10.6
2	-	10.2	10.1	10.3	10.2	10.1
3	-	10.0	10.0	10.2	10.1	10.0
4	-	9.9	10.0	10.1	10.1	10.0
5	-	9.9	10.0	10.0	10.1	9.9
6	-	9.9	9.8	9.9	9.9	9.8
7	-	9.9	9.8	9.9	9.9	9.8
8	-	9.8	9.8	9.9	9.8	9.8
9	-	9.8	9.8	9.9	9.8	9.8
10	-	9.7	9.7	9.7	9.8	9.8

Table I-45 Annual mean $PM_{2.5}$ concentration at community receptors, ranked by increase and by decrease in concentration

Rank	Ranking by increase in concentration relative to Do Minimum (µg/m³)			Ranking by decrease in concentration relative to Do Minimum (µg/m³)		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	0.17	0.14	0.09	-0.14	-0.17	-0.19
2	0.14	0.10	0.05	-0.07	-0.09	-0.17
3	0.11	0.08	0.03	-0.06	-0.07	-0.14
4	0.08	0.06	0.03	-0.05	-0.06	-0.13
5	0.07	0.06	0.03	-0.05	-0.06	-0.13
6	0.06	0.05	0.01	-0.04	-0.06	-0.08
7	0.05	0.04	0.00	-0.04	-0.05	-0.03
8	0.03	0.04	0.00	-0.04	-0.05	-0.03
9	0.03	0.03		-0.04	-0.03	-0.03
10	0.03	0.03		-0.03	-0.03	-0.03

Table I-46 Annual mean $PM_{2.5}$ concentration at community receptors, ranked by percentage increase and by decrease in concentration

Rank	Ranking by % increase in concentration relative to Do Minimum			Ranking by % decrease in concentration relative to Do Minimum		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	1.7%	1.5%	0.9%	-1.5%	-1.6%	-1.9%
2	1.4%	1.0%	0.5%	-0.7%	-0.9%	-1.8%
3	1.1%	0.9%	0.3%	-0.7%	-0.7%	-1.3%
4	0.9%	0.7%	0.3%	-0.5%	-0.7%	-1.3%
5	0.8%	0.6%	0.3%	-0.5%	-0.6%	-1.2%
6	0.6%	0.5%	0.1%	-0.5%	-0.6%	-0.8%
7	0.5%	0.4%	0.1%	-0.4%	-0.5%	-0.3%
8	0.3%	0.4%	0.0%	-0.4%	-0.5%	-0.3%
9	0.3%	0.4%		-0.4%	-0.3%	-0.3%
10	0.3%	0.3%		-0.3%	-0.3%	-0.3%

Table I-47 Annual mean $PM_{2.5}$ concentration at RWR receptors, ranked by concentration

Rank	Ranking by concentration (µg/m³)					
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1	-	16.09	15.60	17.09	16.26	16.09
2	-	13.63	13.36	13.81	13.37	13.24
3	-	12.68	12.68	13.08	12.93	12.99
4	-	12.67	12.30	12.97	12.75	12.79
5	-	12.48	12.28	12.83	12.73	12.75
6	-	12.36	12.19	12.68	12.41	12.37
7	-	12.30	12.08	12.61	12.32	12.33
8	-	12.30	12.07	12.55	12.25	12.23
9	-	12.26	12.06	12.53	12.21	12.17
10	-	12.13	12.00	12.38	12.12	12.13

Table I-48 Annual mean $PM_{2.5}$ concentration at RWR receptors, ranked by increase and by decrease in concentration

Rank	Ranking by increase in concentration relative to Do Minimum (µg/m³)			Ranking by decrease in concentration relative to Do Minimum (µg/m³)		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	0.44	0.39	0.37	-0.50	-0.83	-1.00
2	0.38	0.38	0.30	-0.41	-0.49	-0.57
3	0.37	0.35	0.29	-0.40	-0.46	-0.55
4	0.36	0.35	0.29	-0.39	-0.46	-0.54
5	0.35	0.34	0.27	-0.37	-0.45	-0.53
6	0.35	0.34	0.25	-0.37	-0.45	-0.53
7	0.34	0.34	0.25	-0.36	-0.45	-0.51
8	0.34	0.34	0.25	-0.36	-0.44	-0.51
9	0.33	0.34	0.24	-0.36	-0.44	-0.49
10	0.33	0.33	0.24	-0.35	-0.43	-0.48

Table I-49 Annual mean $PM_{2.5}$ concentration at RWR receptors, ranked by percentage increase and by decrease in concentration

Rank	Ranking by % increase in concentration relative to Do Minimum			Ranking by % decrease in concentration relative to Do Minimum		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	4.2%	3.8%	3.6%	-3.5%	-4.9%	-5.9%
2	3.6%	3.6%	2.9%	-3.4%	-4.0%	-5.3%
3	3.6%	3.4%	2.8%	-3.2%	-3.9%	-5.3%
4	3.4%	3.3%	2.8%	-3.2%	-3.9%	-4.9%
5	3.4%	3.3%	2.6%	-3.1%	-3.8%	-4.9%
6	3.4%	3.3%	2.5%	-3.1%	-3.8%	-4.7%
7	3.4%	3.3%	2.4%	-3.1%	-3.7%	-4.6%
8	3.3%	3.3%	2.4%	-3.1%	-3.7%	-4.6%
9	3.2%	3.3%	2.3%	-3.0%	-3.7%	-4.5%
10	3.2%	3.1%	2.3%	-3.0%	-3.5%	-4.5%

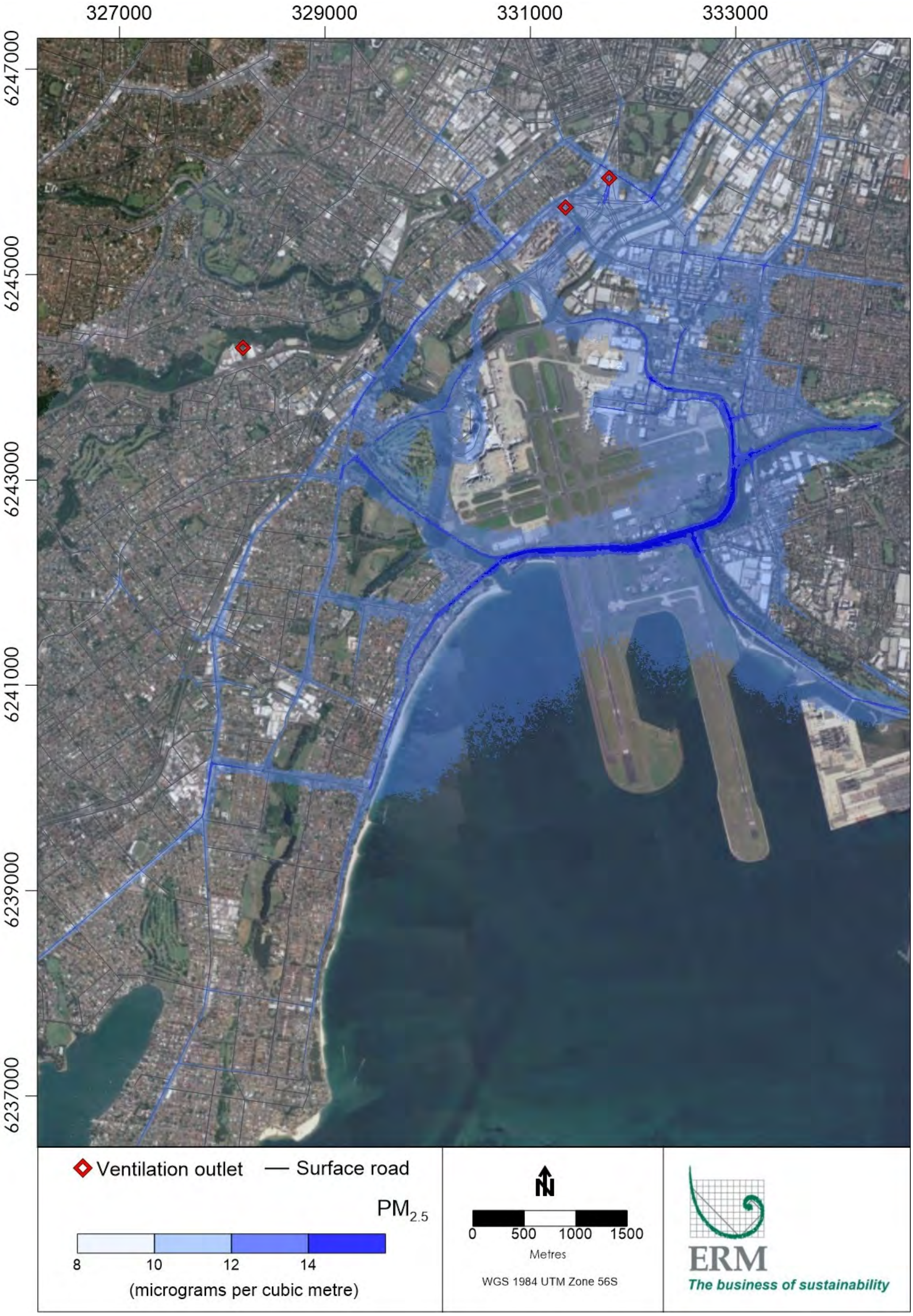


Figure I-32 **Contour plot of annual mean $PM_{2.5}$ concentration in 2026 Do Minimum scenario (all sources, 2026-DM)**

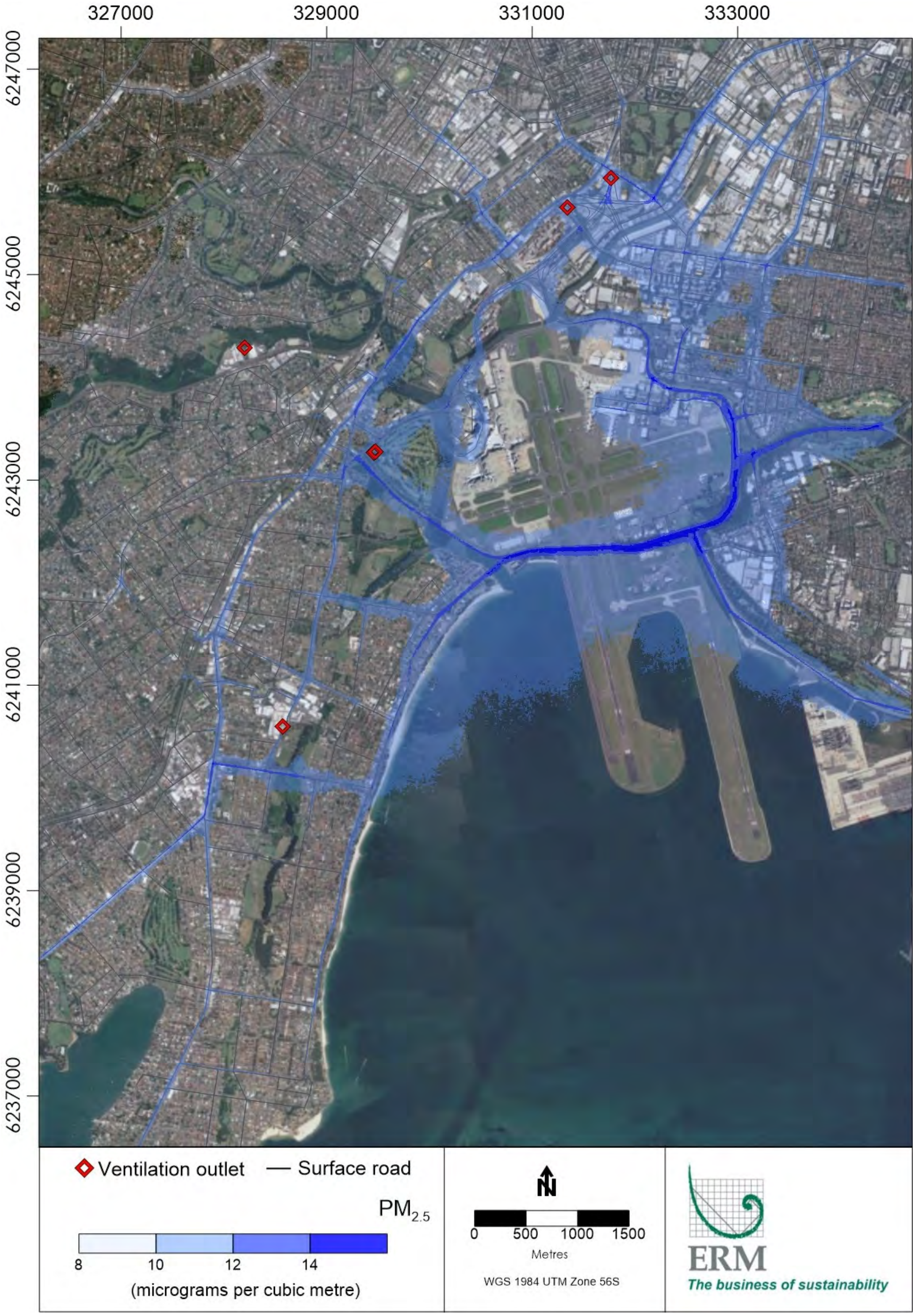


Figure I-33 **Contour plot of annual mean $PM_{2.5}$ concentration in 2026 Do Something scenario (all sources, 2026-DS)**

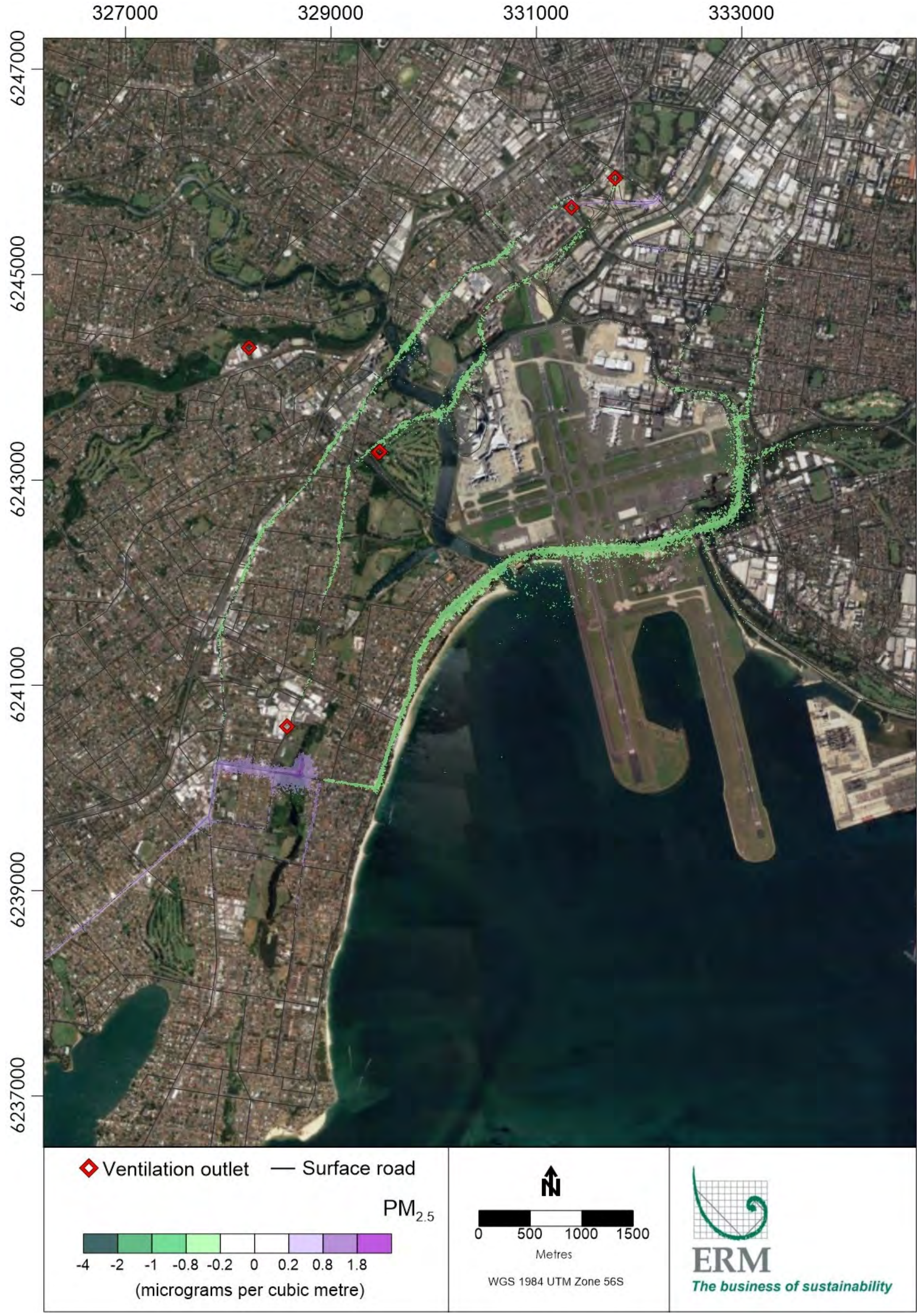


Figure I-34 **Contour plot of change in annual mean $PM_{2.5}$ concentration in 2026 Do Something scenario (all sources, 2026-DS minus 2026-DM)**

Figure I-35 **Contour plot of annual mean $PM_{2.5}$ concentration in 2036 Do Minimum scenario (all sources, 2036-DM)**

Figure I-36 **Contour plot of annual mean $PM_{2.5}$ concentration in 2036 Do Something scenario (all sources, 2036-DS)**

Figure I-37 **Contour plot of change in annual mean $PM_{2.5}$ concentration in 2036 Do Something scenario (all sources, 2036-DS minus 2036-DM)**

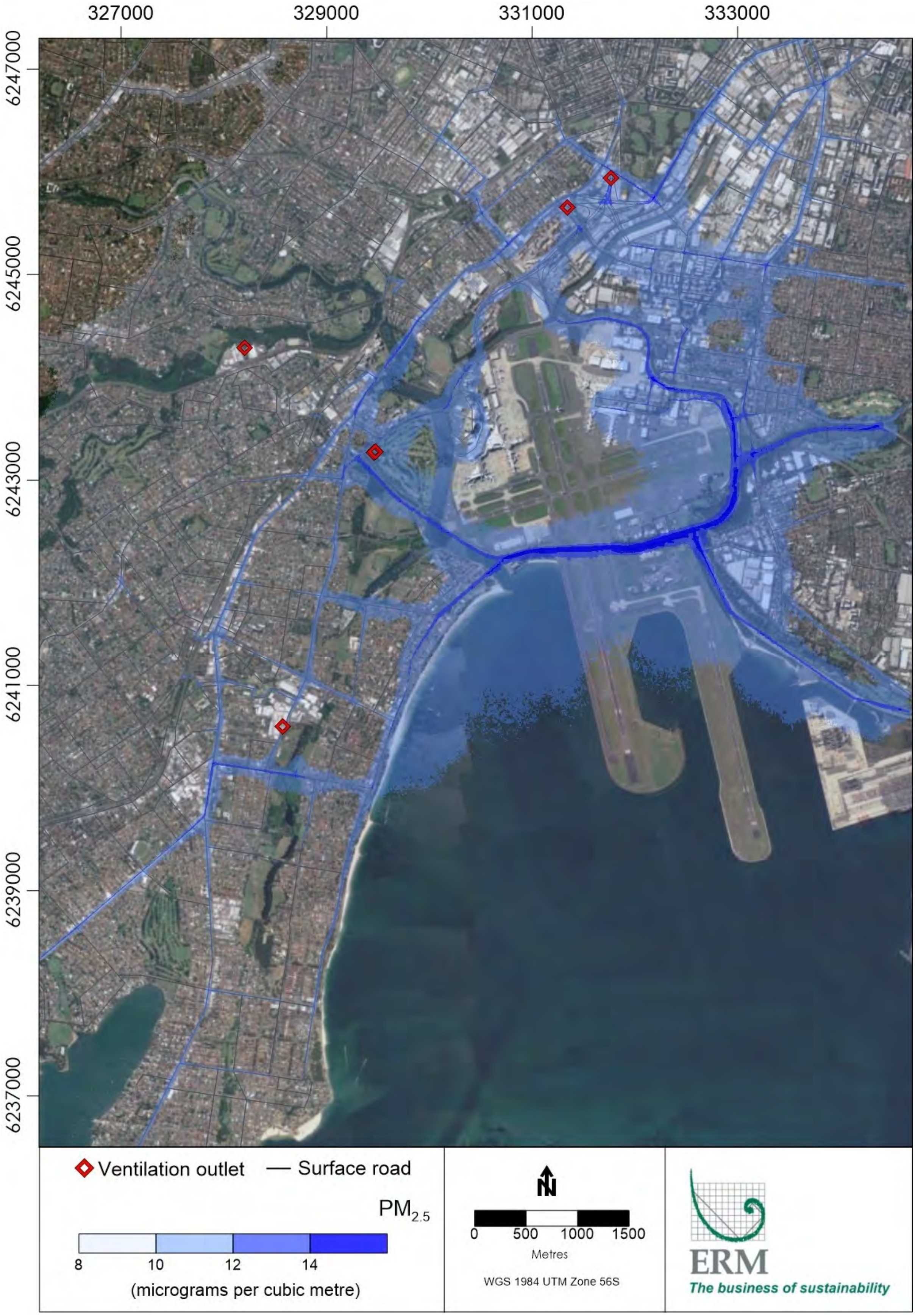


Figure I-38 Contour plot of annual mean $PM_{2.5}$ concentration in 2036 cumulative scenario (all sources, 2036-DSC)

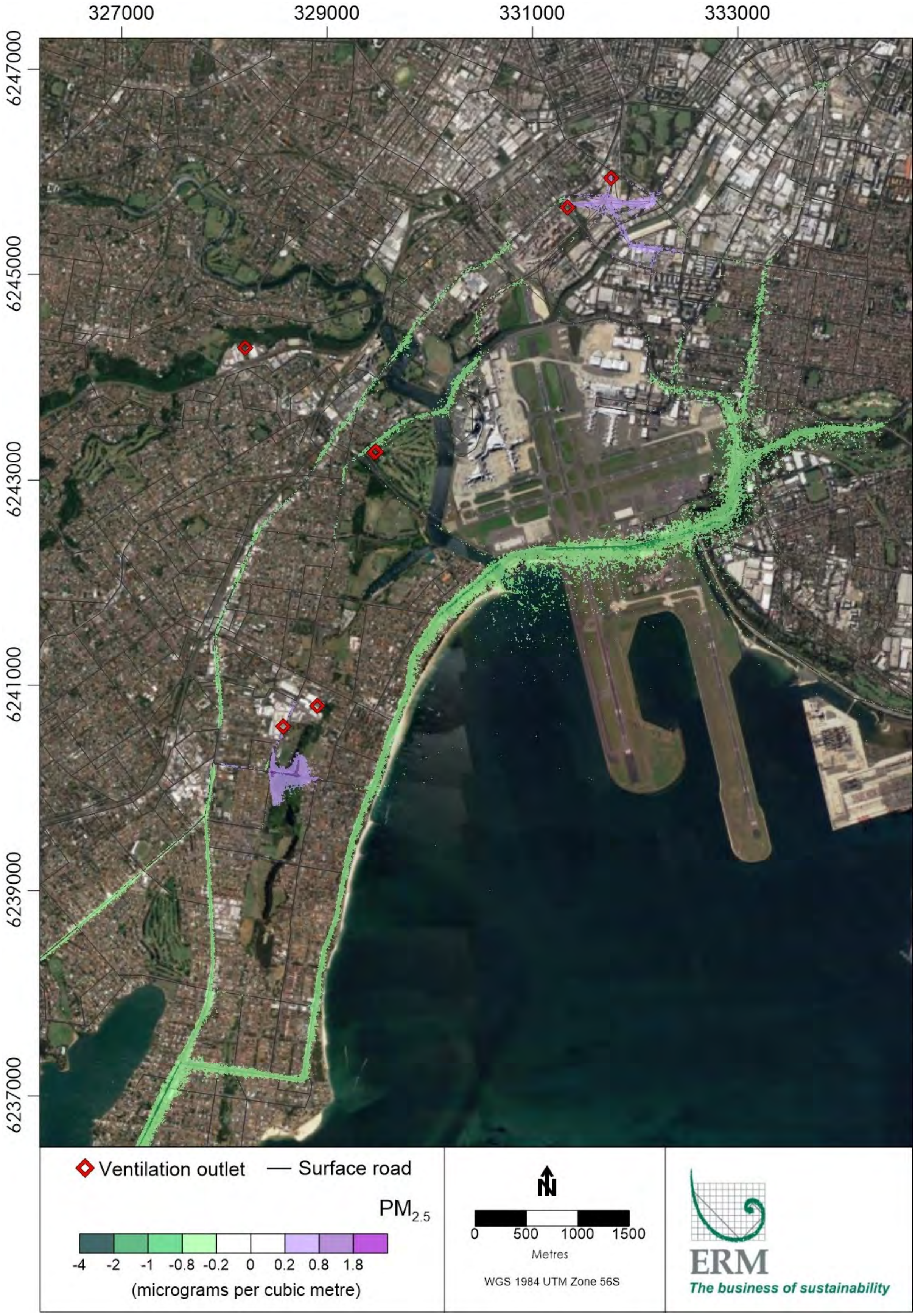


Figure I-39 Contour plot of change in annual mean $PM_{2.5}$ concentration in 2036 cumulative scenario (all sources, 2036-DSC minus 2036-DM)

I.8 $PM_{2.5}$ (maximum 24-hour mean)

Table I-50 Maximum 24-hour $PM_{2.5}$ concentration at community receptors

Receptor	Maximum 24-hour $PM_{2.5}$ concentration (µg/m^3)						Change relative to Do Minimum (µg/m^3)			Change relative to Do Minimum (%)		
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
CR01	-	23.1	23.2	23.1	23.0	23.1	0.1	-0.1	-0.1	0.6%	-0.5%	-0.3%
CR02	-	23.3	23.5	23.8	23.5	23.4	0.2	-0.2	-0.4	0.8%	-0.9%	-1.5%
CR03	-	23.2	23.2	23.2	23.2	23.3	0.0	0.1	0.1	0.2%	0.3%	0.5%
CR04	-	24.5	24.9	24.9	24.7	24.5	0.4	-0.2	-0.4	1.6%	-0.9%	-1.7%
CR05	-	23.5	23.4	23.4	23.4	23.3	-0.1	0.0	-0.2	-0.4%	-0.2%	-0.8%
CR06	-	24.3	24.4	23.9	24.7	24.2	0.1	0.8	0.3	0.4%	3.5%	1.4%
CR07	-	23.3	23.6	23.7	23.6	23.5	0.3	0.0	-0.1	1.1%	-0.1%	-0.6%
CR08	-	24.0	23.7	23.9	23.6	23.8	-0.3	-0.3	-0.1	-1.2%	-1.1%	-0.3%
CR09	-	23.5	23.6	23.6	23.4	23.4	0.0	-0.2	-0.2	0.1%	-1.0%	-0.8%
CR10	-	23.3	23.4	23.4	23.3	23.4	0.1	0.0	0.0	0.6%	0.0%	0.0%
CR11	-	23.9	23.8	23.9	24.0	23.8	-0.1	0.1	-0.1	-0.3%	0.5%	-0.3%
CR12	-	23.4	23.8	23.7	23.9	23.6	0.4	0.3	-0.1	1.5%	1.2%	-0.3%
CR13	-	23.6	23.6	23.6	23.6	23.7	0.0	0.0	0.0	0.0%	-0.1%	0.2%
CR14	-	23.3	23.4	23.4	23.3	23.6	0.1	-0.1	0.2	0.2%	-0.4%	1.0%
CR15	-	24.5	24.0	23.9	24.3	24.0	-0.5	0.4	0.1	-2.1%	1.7%	0.5%
CR16	-	23.2	23.1	23.1	22.9	23.1	-0.1	-0.1	0.0	-0.5%	-0.6%	0.0%
CR17	-	24.7	24.6	24.5	24.1	24.8	0.0	-0.4	0.4	-0.1%	-1.5%	1.6%
CR18	-	23.2	23.3	23.2	23.3	23.5	0.1	0.2	0.3	0.4%	0.7%	1.4%
CR19	-	23.4	23.4	23.7	23.4	23.6	-0.1	-0.4	-0.1	-0.3%	-1.5%	-0.3%
CR20	-	23.8	23.3	23.5	23.8	24.0	-0.4	0.2	0.4	-1.9%	1.1%	1.9%
CR21	-	23.8	23.4	23.5	23.8	23.8	-0.4	0.3	0.3	-1.6%	1.1%	1.4%
CR22	-	23.0	22.9	23.0	23.0	22.9	-0.1	-0.1	-0.2	-0.5%	-0.4%	-0.7%
CR23	-	23.8	23.7	23.4	23.6	23.6	-0.1	0.2	0.2	-0.3%	1.0%	1.0%
CR24	-	24.6	24.1	23.7	23.9	24.1	-0.5	0.2	0.4	-2.0%	0.8%	1.7%
CR25	-	24.4	23.9	24.0	23.8	24.1	-0.5	-0.2	0.1	-1.9%	-1.0%	0.4%
CR26	-	23.9	24.2	24.0	23.8	24.1	0.3	-0.2	0.1	1.2%	-1.0%	0.4%
CR27	-	25.5	25.4	26.1	26.3	26.0	-0.1	0.2	0.0	-0.4%	0.8%	-0.2%
CR28	-	25.6	25.4	26.1	25.7	25.2	-0.2	-0.4	-0.9	-0.7%	-1.4%	-3.3%
CR29	-	24.5	25.1	25.3	25.3	25.1	0.5	0.0	-0.2	2.2%	0.1%	-1.0%
CR30	-	25.8	26.0	27.0	26.4	26.1	0.2	-0.6	-0.9	0.6%	-2.3%	-3.2%

Table I-51 Maximum 24-hour $PM_{2.5}$ concentration at community receptors, ranked by concentration

Rank	Ranking by concentration (µg/m³)					
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1	-	25.8	26.0	27.0	26.4	26.1
2	-	25.6	25.4	26.1	26.3	26.0
3	-	25.5	25.4	26.1	25.7	25.2
4	-	24.7	25.1	25.3	25.3	25.1
5	-	24.6	24.9	24.9	24.7	24.8
6	-	24.5	24.6	24.5	24.7	24.5
7	-	24.5	24.4	24.0	24.3	24.2
8	-	24.5	24.2	24.0	24.1	24.1
9	-	24.4	24.1	23.9	24.0	24.1
10	-	24.3	24.0	23.9	23.9	24.1

Table I-52 Maximum 24-hour $PM_{2.5}$ concentration at community receptors, ranked by increase and by decrease in concentration

Rank	Ranking by increase in concentration relative to Do Minimum (µg/m³)			Ranking by decrease in concentration relative to Do Minimum (µg/m³)		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	0.53	0.83	0.45	-0.50	-0.61	-0.87
2	0.39	0.41	0.39	-0.49	-0.38	-0.87
3	0.36	0.27	0.39	-0.46	-0.36	-0.42
4	0.29	0.26	0.34	-0.45	-0.35	-0.35
5	0.26	0.25	0.33	-0.39	-0.27	-0.24
6	0.19	0.24	0.31	-0.28	-0.24	-0.19
7	0.16	0.20	0.24	-0.17	-0.24	-0.18
8	0.14	0.19	0.23	-0.13	-0.24	-0.17
9	0.13	0.16	0.12	-0.11	-0.22	-0.15
10	0.09	0.13	0.12	-0.10	-0.21	-0.08

Table I-53 Maximum 24-hour $PM_{2.5}$ concentration at community receptors, ranked by percentage increase and by decrease in concentration

Rank	Ranking by % increase in concentration relative to Do Minimum			Ranking by % decrease in concentration relative to Do Minimum		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	2.2%	3.5%	1.9%	-2.1%	-2.3%	-3.3%
2	1.6%	1.7%	1.7%	-2.0%	-1.5%	-3.2%
3	1.5%	1.2%	1.6%	-1.9%	-1.5%	-1.7%
4	1.2%	1.1%	1.4%	-1.9%	-1.4%	-1.5%
5	1.1%	1.1%	1.4%	-1.6%	-1.1%	-1.0%
6	0.8%	1.0%	1.4%	-1.2%	-1.0%	-0.8%
7	0.6%	0.8%	1.0%	-0.7%	-1.0%	-0.8%
8	0.6%	0.8%	1.0%	-0.5%	-1.0%	-0.7%
9	0.6%	0.7%	0.5%	-0.5%	-0.9%	-0.6%
10	0.4%	0.5%	0.5%	-0.4%	-0.9%	-0.3%

Table I-54 Maximum 24-hour $PM_{2.5}$ concentration at RWR receptors, ranked by concentration

Rank	Ranking by concentration (µg/m³)					
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1	-	39.1	39.0	42.0	39.8	38.3
2	-	34.5	33.8	35.1	34.1	34.1
3	-	32.0	31.9	34.0	34.0	34.0
4	-	32.0	31.9	33.5	33.3	33.0
5	-	31.9	31.5	32.9	32.9	32.8
6	-	31.9	31.2	32.5	32.6	32.5
7	-	31.8	31.0	32.4	32.0	32.2
8	-	31.4	30.9	32.3	31.9	31.6
9	-	31.4	30.8	32.3	31.8	31.6
10	-	31.2	30.8	32.0	31.7	31.3

Table I-55 Maximum 24-hour $PM_{2.5}$ concentration at RWR receptors, ranked by increase and by decrease in concentration

Rank	Ranking by increase in concentration relative to Do Minimum (µg/m³)			Ranking by decrease in concentration relative to Do Minimum (µg/m³)		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	1.5	1.3	1.5	-2.0	-2.2	-3.7
2	1.3	1.2	1.5	-1.5	-2.0	-2.1
3	1.3	1.2	1.4	-1.5	-2.0	-1.8
4	1.3	1.2	1.3	-1.5	-2.0	-1.8
5	1.3	1.2	1.3	-1.4	-1.9	-1.8
6	1.3	1.2	1.3	-1.4	-1.8	-1.7
7	1.2	1.2	1.3	-1.3	-1.8	-1.7
8	1.2	1.1	1.3	-1.3	-1.8	-1.7
9	1.1	1.1	1.3	-1.3	-1.6	-1.6
10	1.1	1.1	1.2	-1.3	-1.6	-1.6

Table I-56 Maximum 24-hour $PM_{2.5}$ concentration at RWR receptors, ranked by percentage increase and by decrease in concentration

Rank	Ranking by % increase in concentration relative to Do Minimum			Ranking by % decrease in concentration relative to Do Minimum		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	5.6%	4.9%	5.4%	-7.1%	-7.1%	-8.8%
2	5.0%	4.7%	5.1%	-5.1%	-6.7%	-7.5%
3	4.9%	4.6%	5.0%	-5.1%	-6.5%	-6.4%
4	4.8%	4.6%	4.9%	-5.0%	-6.2%	-6.2%
5	4.8%	4.6%	4.9%	-4.9%	-6.1%	-6.1%
6	4.8%	4.5%	4.9%	-4.8%	-6.1%	-6.0%
7	4.7%	4.3%	4.8%	-4.7%	-6.0%	-6.0%
8	4.5%	4.3%	4.6%	-4.7%	-5.8%	-6.0%
9	4.4%	4.3%	4.6%	-4.6%	-5.5%	-6.0%
10	4.4%	4.3%	4.5%	-4.5%	-5.2%	-5.9%

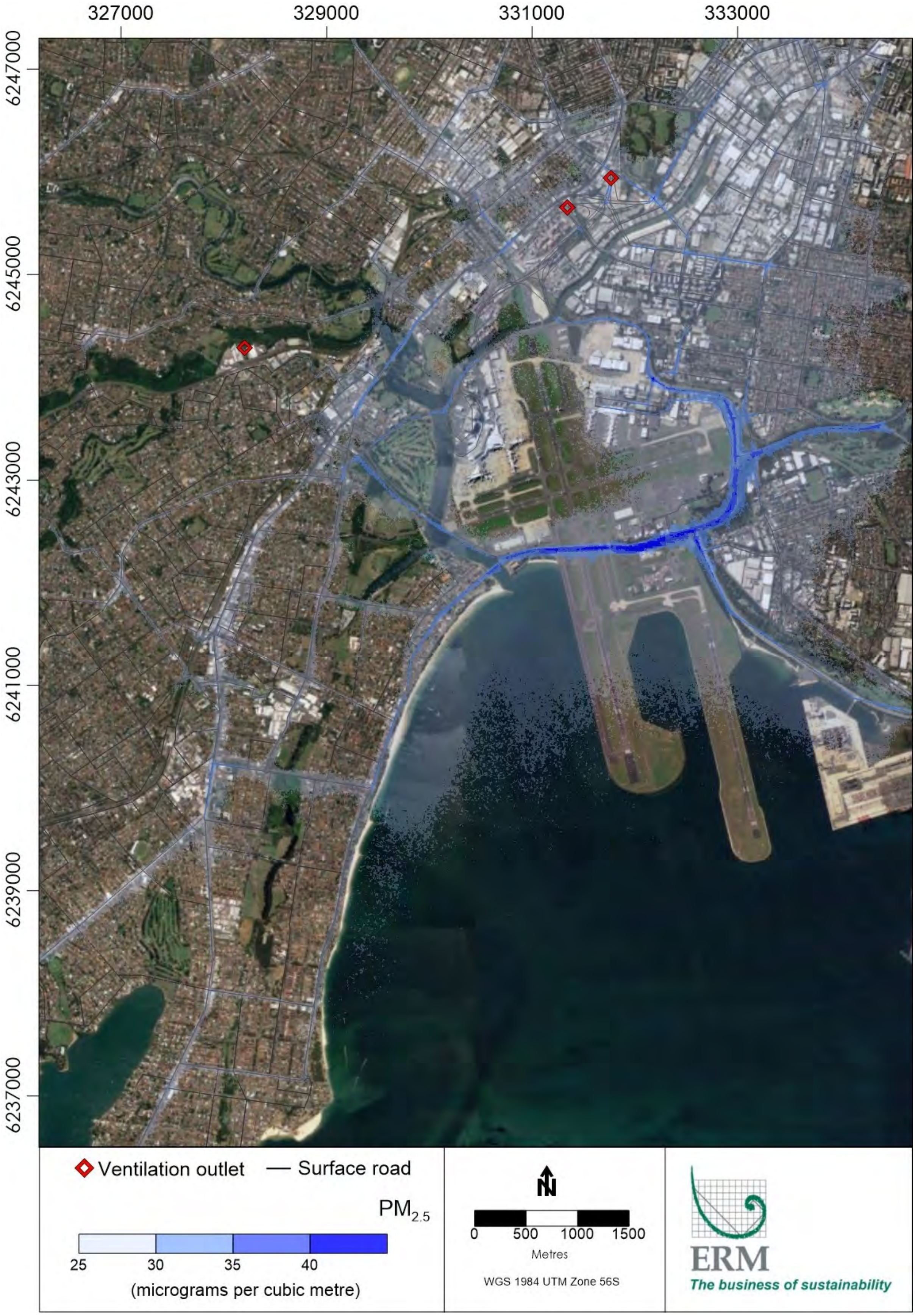


Figure I-40 **Contour plot of maximum 24-hour mean $PM_{2.5}$ concentration in 2026 Do Minimum scenario (all sources, 2026-DM)**

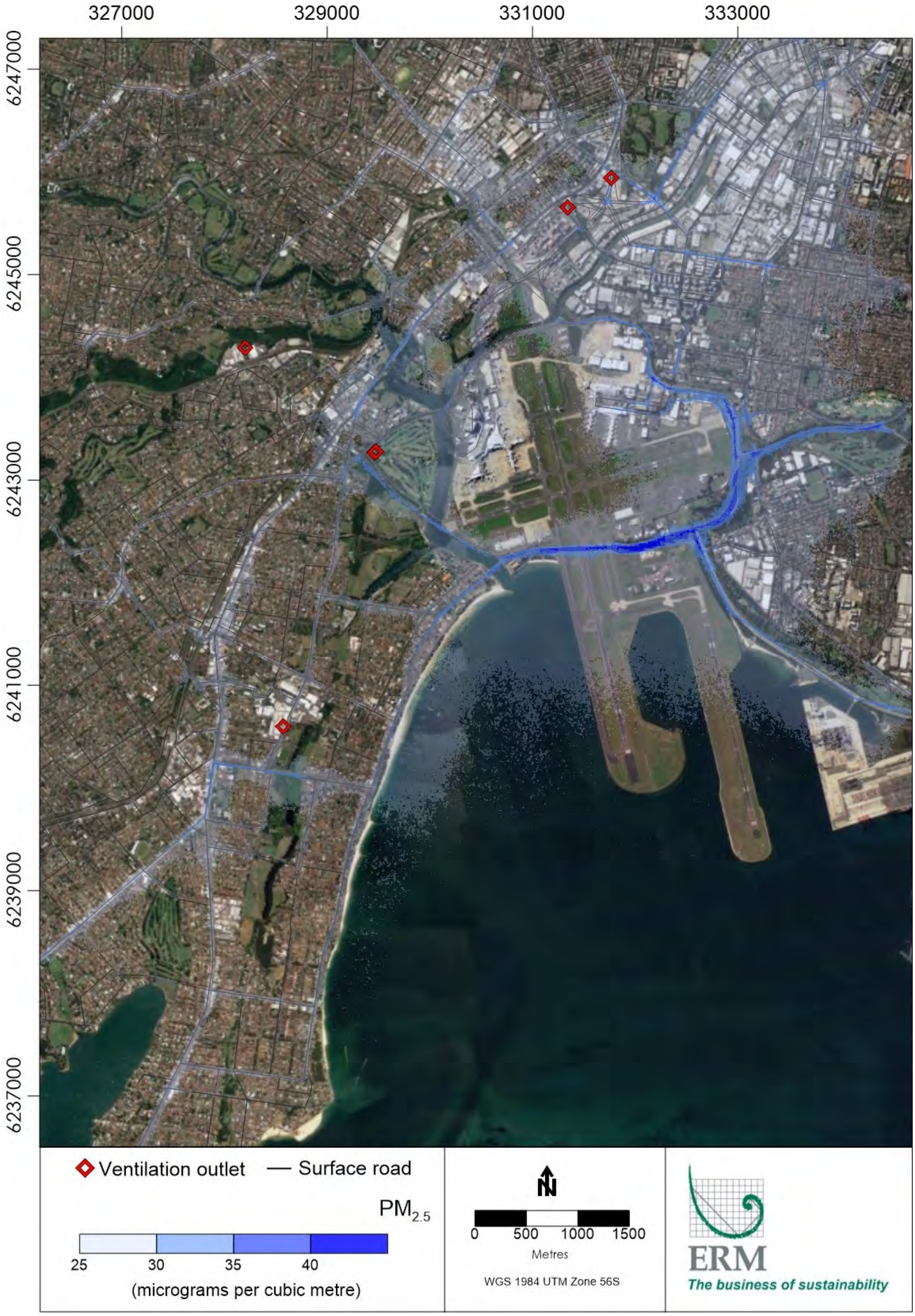


Figure I-41 **Contour plot of maximum 24-hour mean $PM_{2.5}$ concentration in 2026 Do Something scenario (all sources, 2026-DS)**

Figure I-42 **Contour plot of change in maximum 24-hour mean $PM_{2.5}$ concentration in 2026 Do Something scenario (all sources, 2026-DS minus 2026-DM)**

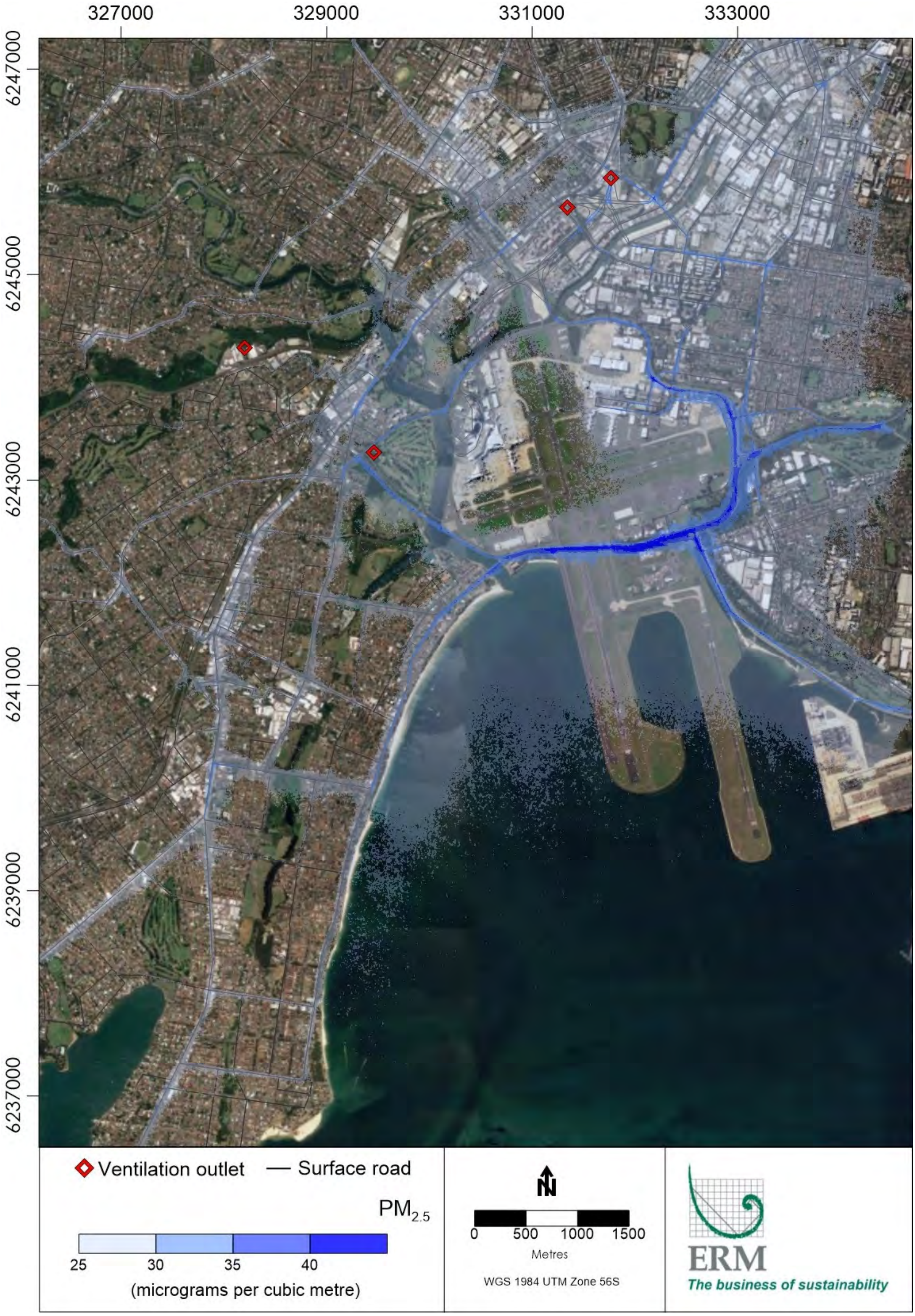


Figure I-43 **Contour plot of maximum 24-hour mean $PM_{2.5}$ concentration in 2036 Do Minimum scenario (all sources, 2036-DM)**

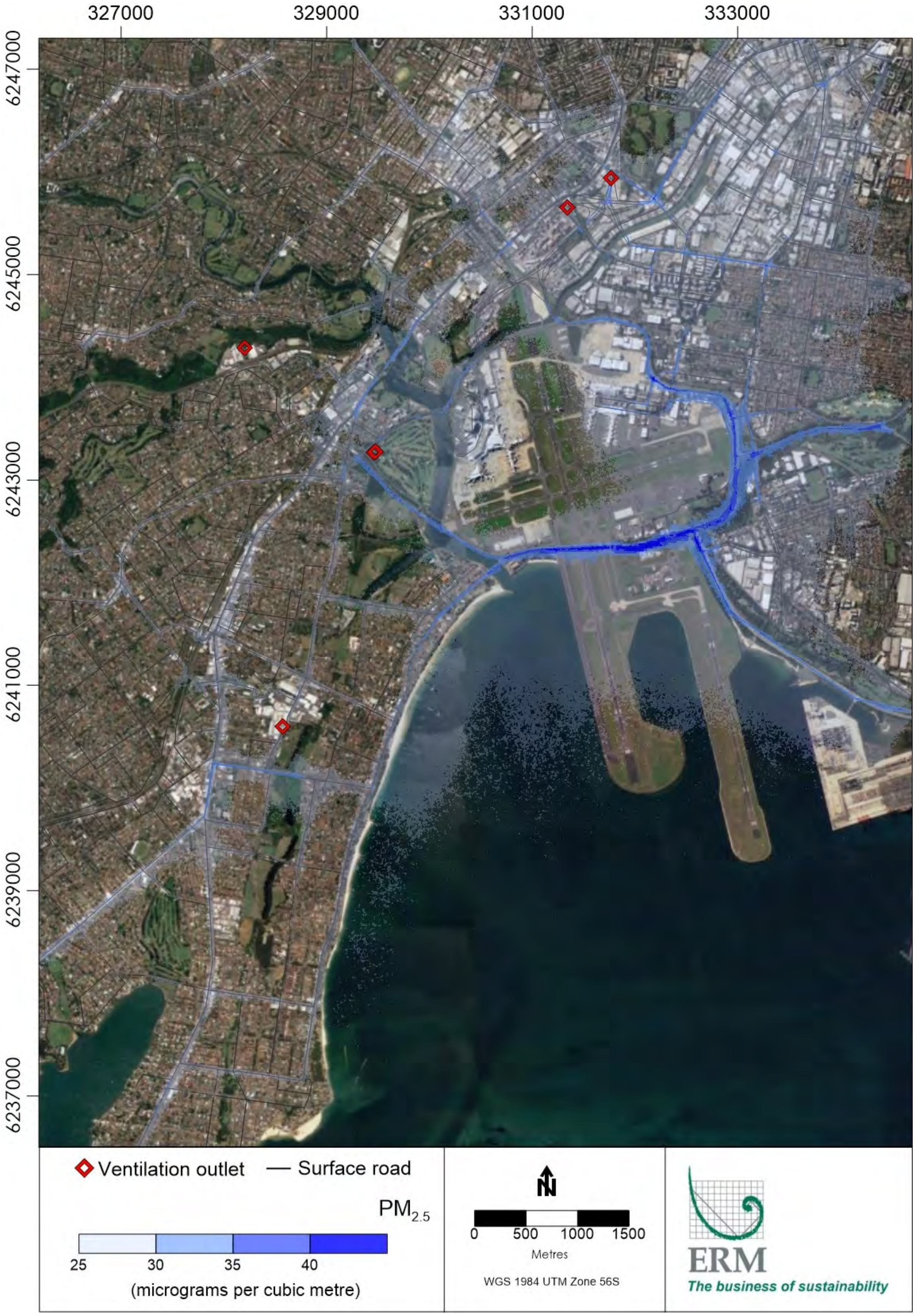


Figure I-44 **Contour plot of maximum 24-hour mean $PM_{2.5}$ concentration in 2036 Do Something scenario (all sources, 2036-DS)**

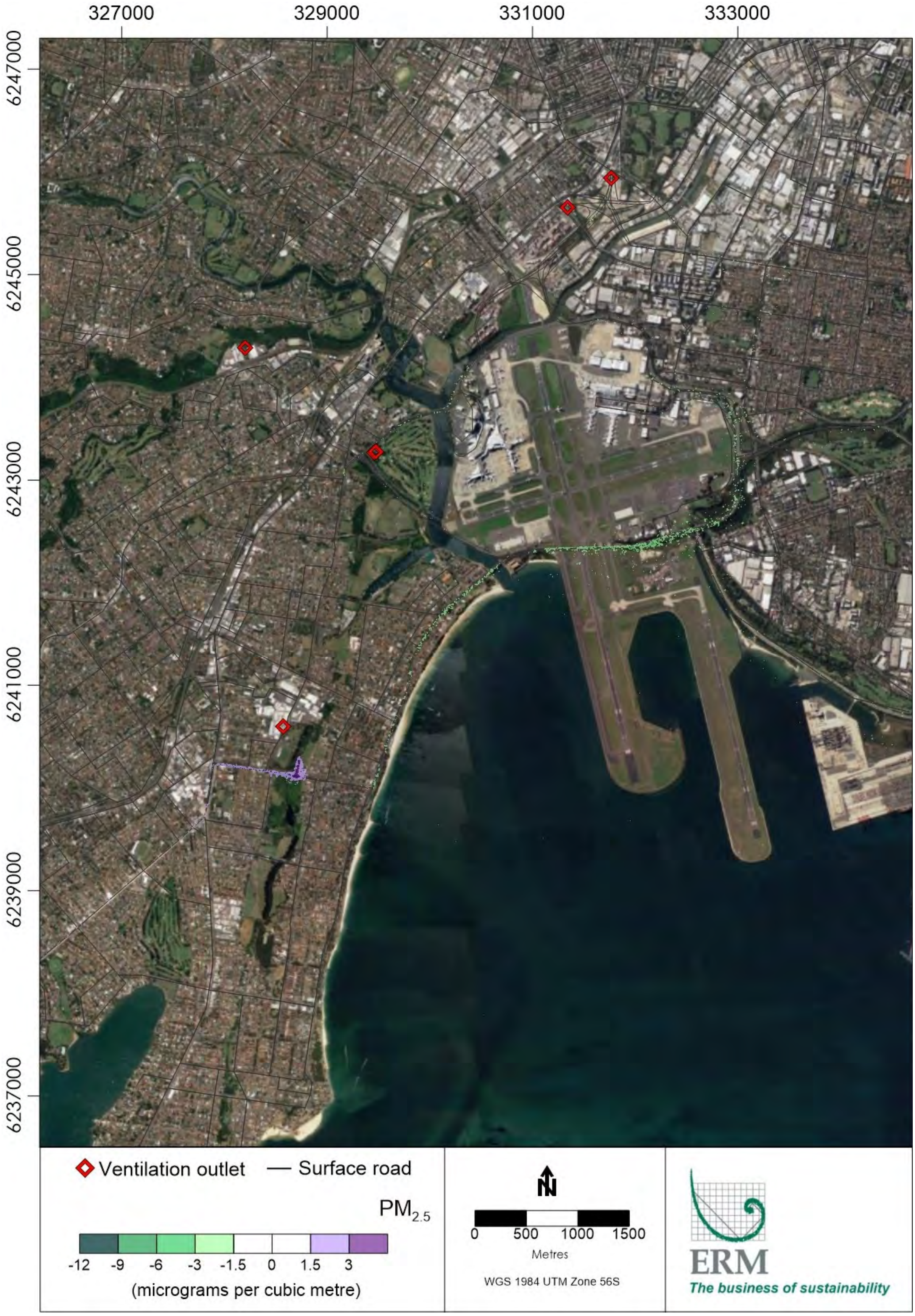


Figure I-45 Contour plot of change in maximum 24-hour mean $PM_{2.5}$ concentration in 2036 Do Something scenario (all sources, 2036-DS minus 2036-DM)

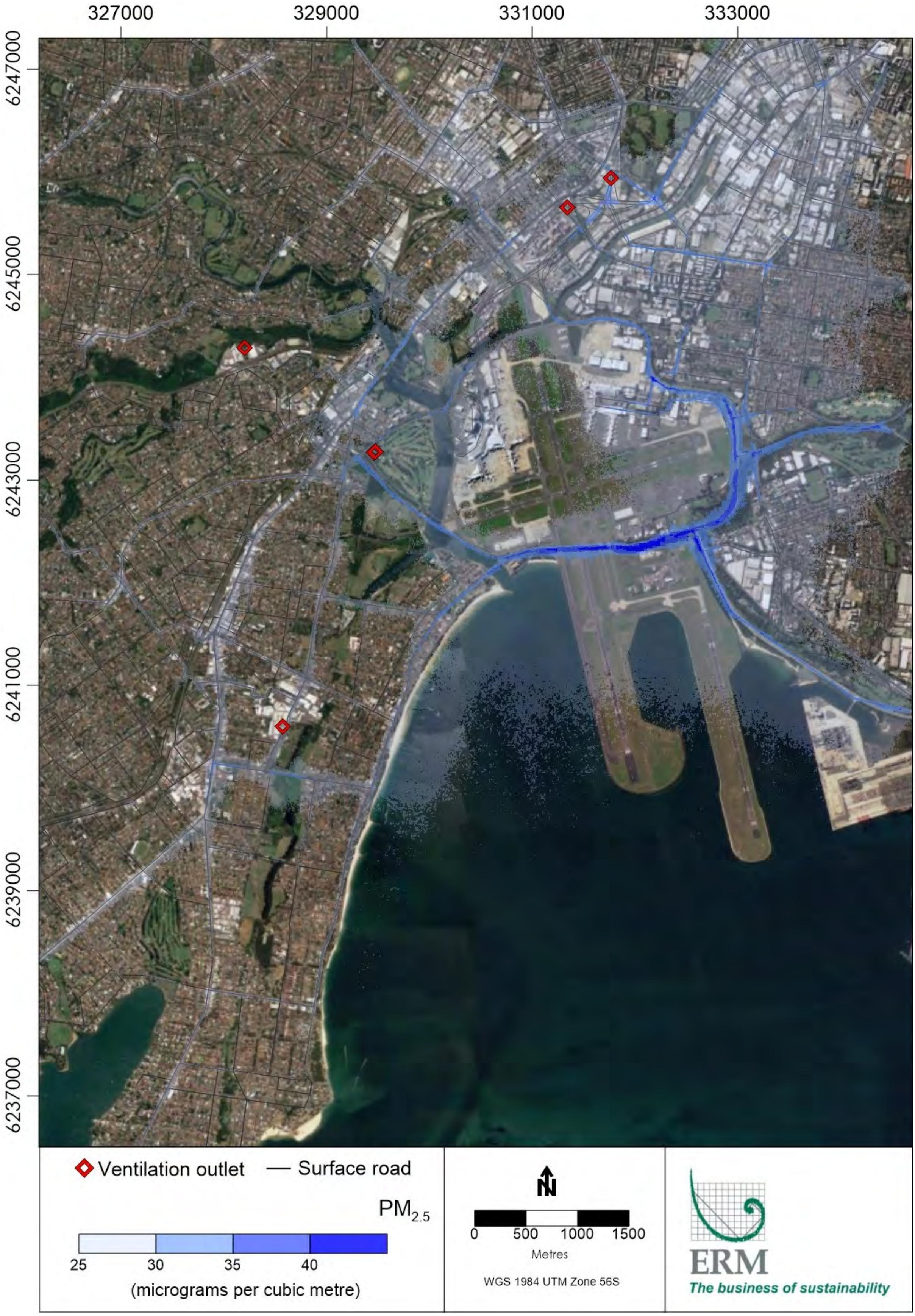


Figure I-46 **Contour plot of maximum 24-hour mean $PM_{2.5}$ concentration in 2036 cumulative scenario (all sources, 2036-DSC)**

Figure I-47 **Contour plot of change in maximum 24-hour mean $PM_{2.5}$ concentration in 2036 cumulative scenario (all sources, 2036-DSC minus 2036-DM)**

I.9 Air toxics: benzene (maximum 1-hour mean)

Table I-57 Maximum 1-hour mean benzene concentration (excluding background) at community receptors

Receptor	Maximum 1-hour benzene concentration (µg/m³)						Change relative to Do Minimum (µg/m³)		
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
CR01	-	1.2	1.2	0.9	0.8	0.7	0.0	-0.1	-0.2
CR02	-	2.1	2.0	1.4	1.4	1.1	-0.1	0.0	-0.3
CR03	-	1.5	1.7	1.1	1.2	1.0	0.2	0.1	-0.1
CR04	-	3.1	3.2	2.2	2.0	2.0	0.0	-0.2	-0.2
CR05	-	1.9	2.3	1.4	1.2	1.6	0.3	-0.2	0.2
CR06	-	2.6	3.4	1.6	1.8	2.4	0.7	0.3	0.8
CR07	-	1.8	2.1	1.3	1.4	1.1	0.3	0.1	-0.2
CR08	-	2.0	2.4	1.5	1.5	1.0	0.4	0.0	-0.4
CR09	-	3.2	2.7	1.8	1.8	2.1	-0.5	0.0	0.2
CR10	-	2.3	2.8	1.6	1.9	1.6	0.5	0.3	0.0
CR11	-	1.8	2.2	1.5	1.4	1.4	0.3	0.0	-0.1
CR12	-	2.2	1.7	1.5	1.2	1.1	-0.5	-0.2	-0.4
CR13	-	2.1	2.6	1.4	1.5	1.4	0.5	0.0	-0.1
CR14	-	1.1	1.3	0.8	0.7	0.9	0.2	-0.1	0.0
CR15	-	2.1	1.9	1.6	1.4	1.0	-0.2	-0.2	-0.6
CR16	-	1.0	0.9	0.6	0.6	1.1	-0.1	-0.1	0.5
CR17	-	3.0	2.7	1.9	1.5	1.5	-0.3	-0.5	-0.4
CR18	-	1.6	1.4	1.1	1.5	1.2	-0.2	0.4	0.1
CR19	-	3.4	4.1	2.0	2.5	2.4	0.7	0.4	0.3
CR20	-	2.7	2.3	1.6	1.4	1.3	-0.4	-0.1	-0.3
CR21	-	1.8	2.5	1.3	1.2	1.2	0.7	-0.1	-0.1
CR22	-	1.6	1.3	0.7	1.1	1.0	-0.3	0.3	0.2
CR23	-	2.6	3.3	1.3	1.6	1.5	0.7	0.3	0.2
CR24	-	2.6	2.1	1.8	1.7	1.3	-0.5	-0.2	-0.5
CR25	-	2.5	2.3	1.7	1.8	1.8	-0.2	0.1	0.1
CR26	-	3.9	3.0	2.3	2.0	2.2	-0.8	-0.2	-0.1
CR27	-	3.3	4.3	2.7	2.7	2.8	1.0	0.1	0.1
CR28	-	3.9	3.7	2.4	2.6	2.6	-0.2	0.2	0.2
CR29	-	2.5	2.4	2.2	2.1	1.9	-0.1	-0.1	-0.2
CR30	-	2.6	2.6	2.1	1.9	1.4	0.0	-0.3	-0.7

Table I-58 **Maximum 1-hour mean benzene concentration (excluding background) at community receptors, ranked by concentration**

Rank	Ranking by concentration (µg/m³)					
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1	-	3.9	4.3	2.7	2.7	2.8
2	-	3.9	4.1	2.4	2.6	2.6
3	-	3.4	3.7	2.3	2.5	2.4
4	-	3.3	3.4	2.2	2.1	2.4
5	-	3.2	3.3	2.2	2.0	2.2
6	-	3.1	3.2	2.1	2.0	2.1
7	-	3.0	3.0	2.0	1.9	2.0
8	-	2.7	2.8	1.9	1.9	1.9
9	-	2.6	2.7	1.8	1.8	1.8
10	-	2.6	2.7	1.8	1.8	1.6

Table I-59 **Maximum 1-hour mean benzene concentration (excluding background) at community receptors, ranked by increase and by decrease in concentration**

Rank	Ranking by increase in concentration relative to Do Minimum (µg/m³)			Ranking by decrease in concentration relative to Do Minimum (µg/m³)		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	0.98	0.44	0.80	-0.81	-0.45	-0.70
2	0.75	0.42	0.49	-0.53	-0.25	-0.64
3	0.72	0.34	0.33	-0.47	-0.24	-0.55
4	0.70	0.31	0.24	-0.47	-0.22	-0.44
5	0.67	0.27	0.24	-0.39	-0.20	-0.36
6	0.54	0.26	0.19	-0.35	-0.18	-0.36
7	0.50	0.18	0.18	-0.31	-0.18	-0.34
8	0.42	0.14	0.18	-0.22	-0.15	-0.31
9	0.35	0.13	0.12	-0.21	-0.14	-0.24
10	0.34	0.09	0.12	-0.18	-0.13	-0.21

Table I-60 **Maximum 1-hour mean benzene concentration (excluding background) at RWR receptors, ranked by concentration**

Rank	Ranking by concentration (µg/m³)					
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1	-	9.7	7.7	5.4	4.6	5.0
2	-	7.3	7.3	5.0	4.6	4.3
3	-	7.1	6.9	5.0	4.5	4.2
4	-	7.1	6.9	4.8	4.3	4.2
5	-	6.8	6.7	4.7	4.3	4.2
6	-	6.7	6.6	4.5	4.3	4.2
7	-	6.6	6.6	4.5	4.3	4.1
8	-	6.6	6.6	4.5	4.2	4.1
9	-	6.6	6.6	4.5	4.2	4.1
10	-	6.6	6.5	4.4	4.1	4.1

Table I-61 Maximum 1-hour mean benzene concentration (excluding background) at RWR receptors, ranked by increase and by decrease in concentration

Rank		Ranking by increase in concentration relative to Do Minimum (µg/m^3)				Ranking by decrease in concentration relative to Do Minimum (µg/m^3)		
		2026-DS	2036-DS	2036-DSC		2026-DS	2036-DS	2036-DSC
1		2.6	1.4	1.22		-2.4	-1.5	-1.6
2		1.8	1.4	1.1		-1.9	-1.5	-1.4
3		1.8	1.2	1.1		-1.8	-1.3	-1.4
4		1.7	1.1	1.1		-1.8	-1.3	-1.4
5		1.7	1.1	1.0		-1.8	-1.3	-1.3
6		1.7	1.1	1.0		-1.7	-1.2	-1.3
7		1.6	1.1	0.9		-1.7	-1.2	-1.2
8		1.6	1.1	0.9		-1.7	-1.2	-1.2
9		1.5	1.1	0.9		-1.6	-1.2	-1.2
10		1.5	1.1	0.9		-1.6	-1.2	-1.2

I.10 Air toxics: benzo(a)pyrene (maximum 1-hour mean)

Table I-62 Maximum 1-hour mean benzo(a)pyrene concentration (excluding background) at community receptors

Receptor	Maximum 1-hour b(a)p concentration ($\mu g/m^3$)						Change relative to Do Minimum ($\mu g/m^3$)		
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
CR01	-	0.011	0.011	0.011	0.010	0.009	0.000	-0.001	-0.003
CR02	-	0.019	0.018	0.017	0.017	0.013	-0.001	0.000	-0.004
CR03	-	0.014	0.015	0.014	0.015	0.013	0.001	0.002	-0.001
CR04	-	0.028	0.028	0.027	0.025	0.025	0.000	-0.003	-0.003
CR05	-	0.017	0.020	0.017	0.015	0.020	0.003	-0.002	0.002
CR06	-	0.024	0.030	0.020	0.023	0.030	0.006	0.003	0.010
CR07	-	0.016	0.019	0.016	0.018	0.014	0.003	0.002	-0.002
CR08	-	0.018	0.022	0.018	0.018	0.013	0.004	0.000	-0.005
CR09	-	0.029	0.024	0.023	0.023	0.026	-0.004	0.000	0.003
CR10	-	0.021	0.025	0.020	0.024	0.020	0.005	0.003	0.000
CR11	-	0.016	0.019	0.018	0.018	0.017	0.003	0.000	-0.001
CR12	-	0.020	0.015	0.018	0.015	0.014	-0.005	-0.003	-0.005
CR13	-	0.018	0.023	0.018	0.018	0.017	0.004	0.000	-0.001
CR14	-	0.010	0.012	0.010	0.008	0.011	0.002	-0.002	0.001
CR15	-	0.018	0.017	0.020	0.018	0.012	-0.001	-0.002	-0.008
CR16	-	0.009	0.008	0.008	0.007	0.014	-0.001	-0.001	0.006
CR17	-	0.027	0.024	0.024	0.018	0.019	-0.003	-0.006	-0.004
CR18	-	0.014	0.012	0.013	0.018	0.015	-0.002	0.005	0.002
CR19	-	0.030	0.037	0.025	0.031	0.029	0.006	0.006	0.004
CR20	-	0.024	0.021	0.020	0.018	0.016	-0.004	-0.002	-0.004
CR21	-	0.016	0.023	0.017	0.015	0.015	0.007	-0.001	-0.002
CR22	-	0.014	0.011	0.009	0.013	0.012	-0.003	0.004	0.003
CR23	-	0.024	0.030	0.016	0.020	0.018	0.006	0.004	0.002
CR24	-	0.023	0.019	0.023	0.021	0.016	-0.004	-0.002	-0.007
CR25	-	0.022	0.020	0.021	0.022	0.022	-0.002	0.001	0.001
CR26	-	0.034	0.027	0.028	0.025	0.027	-0.007	-0.003	-0.001
CR27	-	0.030	0.039	0.033	0.034	0.035	0.009	0.001	0.001
CR28	-	0.035	0.033	0.031	0.033	0.033	-0.002	0.002	0.002
CR29	-	0.022	0.022	0.027	0.026	0.024	-0.001	-0.001	-0.003
CR30	-	0.023	0.023	0.027	0.024	0.018	0.000	-0.003	-0.009

Table I-63 Maximum 1-hour mean benzo(a)pyrene concentration (excluding background) at community receptors, ranked by concentration

Rank	Ranking by concentration (µg/m³)					
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1	-	0.035	0.039	0.033	0.034	0.035
2	-	0.034	0.037	0.031	0.033	0.033
3	-	0.030	0.033	0.028	0.031	0.030
4	-	0.030	0.030	0.027	0.026	0.029
5	-	0.029	0.030	0.027	0.025	0.027
6	-	0.028	0.028	0.027	0.025	0.026
7	-	0.027	0.027	0.025	0.024	0.025
8	-	0.024	0.025	0.024	0.024	0.024
9	-	0.024	0.024	0.023	0.023	0.022
10	-	0.024	0.024	0.023	0.023	0.020

Table I-64 Maximum 1-hour mean benzo(a)pyrene concentration (excluding background) at community receptors, ranked by increase and by decrease in concentration

Rank	Ranking by increase in concentration relative to Do Minimum (µg/m³)			Ranking by decrease in concentration relative to Do Minimum (µg/m³)		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	0.009	0.006	0.010	-0.007	-0.006	-0.009
2	0.007	0.005	0.006	-0.005	-0.003	-0.008
3	0.006	0.004	0.004	-0.004	-0.003	-0.007
4	0.006	0.004	0.003	-0.004	-0.003	-0.005
5	0.006	0.003	0.003	-0.004	-0.003	-0.005
6	0.005	0.003	0.002	-0.003	-0.002	-0.004
7	0.004	0.002	0.002	-0.003	-0.002	-0.004
8	0.004	0.002	0.002	-0.002	-0.002	-0.004
9	0.003	0.002	0.002	-0.002	-0.002	-0.003
10	0.003	0.001	0.001	-0.002	-0.002	-0.003

Table I-65 Maximum 1-hour mean benzo(a)pyrene concentration (excluding background) at RWR receptors, ranked by concentration

Rank	Ranking by concentration (µg/m³)					
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1	-	0.087	0.068	0.067	0.058	0.062
2	-	0.066	0.065	0.062	0.057	0.053
3	-	0.064	0.062	0.062	0.056	0.053
4	-	0.064	0.061	0.060	0.054	0.053
5	-	0.061	0.060	0.059	0.054	0.052
6	-	0.060	0.059	0.057	0.054	0.052
7	-	0.059	0.059	0.056	0.054	0.051
8	-	0.059	0.059	0.056	0.053	0.051
9	-	0.059	0.059	0.056	0.053	0.051
10	-	0.059	0.058	0.054	0.052	0.051

Table I-66 Maximum 1-hour mean benzo(a)pyrene concentration (excluding background) at RWR receptors, ranked by increase and by decrease in concentration

Rank	Ranking by increase in concentration relative to Do Minimum (µg/m^3)			Ranking by decrease in concentration relative to Do Minimum (µg/m^3)		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	0.023	0.018	0.015	-0.022	-0.019	-0.020
2	0.016	0.018	0.014	-0.017	-0.018	-0.018
3	0.016	0.015	0.014	-0.016	-0.017	-0.018
4	0.016	0.014	0.013	-0.016	-0.016	-0.017
5	0.015	0.014	0.013	-0.016	-0.016	-0.017
6	0.015	0.014	0.012	-0.016	-0.016	-0.016
7	0.015	0.014	0.012	-0.015	-0.015	-0.015
8	0.014	0.014	0.011	-0.015	-0.015	-0.015
9	0.014	0.013	0.011	-0.015	-0.015	-0.015
10	0.013	0.013	0.011	-0.014	-0.014	-0.015

I.11 Air toxics: formaldehyde (maximum 1-hour mean)

Table I-67 Maximum 1-hour mean formaldehyde concentration (excluding background) at community receptors

Receptor	Maximum 1-hour formaldehyde concentration (µg/m³)						Change relative to Do Minimum (µg/m³)		
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
CR01	-	1.0	1.0	1.2	1.0	0.9	0.0	-0.1	-0.3
CR02	-	1.7	1.6	1.8	1.8	1.4	-0.1	0.0	-0.4
CR03	-	1.3	1.4	1.4	1.6	1.3	0.1	0.2	-0.1
CR04	-	2.6	2.6	2.9	2.6	2.6	0.0	-0.3	-0.3
CR05	-	1.6	1.9	1.8	1.6	2.0	0.3	-0.2	0.2
CR06	-	2.2	2.8	2.0	2.4	3.1	0.6	0.4	1.0
CR07	-	1.5	1.7	1.7	1.9	1.5	0.2	0.2	-0.2
CR08	-	1.7	2.0	1.9	1.9	1.3	0.3	0.0	-0.6
CR09	-	2.6	2.3	2.4	2.4	2.7	-0.4	0.0	0.3
CR10	-	1.9	2.3	2.1	2.5	2.1	0.4	0.3	0.0
CR11	-	1.5	1.8	1.9	1.9	1.8	0.3	0.0	-0.1
CR12	-	1.8	1.4	1.9	1.6	1.4	-0.4	-0.3	-0.5
CR13	-	1.7	2.1	1.9	1.9	1.8	0.4	0.0	-0.1
CR14	-	0.9	1.1	1.0	0.9	1.1	0.2	-0.2	0.1
CR15	-	1.7	1.6	2.1	1.9	1.3	-0.1	-0.2	-0.8
CR16	-	0.8	0.8	0.8	0.7	1.5	-0.1	-0.1	0.6
CR17	-	2.5	2.2	2.5	1.9	2.0	-0.3	-0.6	-0.5
CR18	-	1.3	1.1	1.4	1.9	1.5	-0.2	0.5	0.2
CR19	-	2.8	3.4	2.6	3.2	3.1	0.6	0.6	0.4
CR20	-	2.2	1.9	2.0	1.9	1.6	-0.3	-0.2	-0.4
CR21	-	1.5	2.1	1.7	1.6	1.6	0.6	-0.1	-0.2
CR22	-	1.3	1.0	1.0	1.4	1.3	-0.3	0.4	0.3
CR23	-	2.2	2.7	1.7	2.1	1.9	0.6	0.4	0.2
CR24	-	2.2	1.8	2.4	2.2	1.7	-0.4	-0.2	-0.7
CR25	-	2.1	1.9	2.2	2.3	2.3	-0.2	0.1	0.1
CR26	-	3.2	2.5	2.9	2.6	2.9	-0.7	-0.3	-0.1
CR27	-	2.8	3.6	3.5	3.5	3.6	0.8	0.1	0.2
CR28	-	3.2	3.1	3.2	3.4	3.4	-0.1	0.2	0.2
CR29	-	2.1	2.0	2.8	2.7	2.5	-0.1	-0.1	-0.3
CR30	-	2.2	2.1	2.8	2.5	1.9	0.0	-0.3	-0.9

Table I-68 Maximum 1-hour mean formaldehyde concentration (excluding background) at community receptors, ranked by concentration

Rank	Ranking by concentration (µg/m³)					
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1	-	3.2	3.6	3.5	3.5	3.6
2	-	3.2	3.4	3.2	3.4	3.4
3	-	2.8	3.1	2.9	3.2	3.1
4	-	2.8	2.8	2.9	2.7	3.1
5	-	2.6	2.7	2.8	2.6	2.9
6	-	2.6	2.6	2.8	2.6	2.7
7	-	2.5	2.5	2.6	2.5	2.6
8	-	2.2	2.3	2.5	2.5	2.5
9	-	2.2	2.3	2.4	2.4	2.3
10	-	2.2	2.2	2.4	2.4	2.1

Table I-69 Maximum 1-hour mean formaldehyde concentration (excluding background) at community receptors, ranked by increase and by decrease in concentration

Rank	Ranking by increase in concentration relative to Do Minimum (µg/m³)			Ranking by decrease in concentration relative to Do Minimum (µg/m³)		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	0.81	0.58	1.04	-0.66	-0.58	-0.91
2	0.62	0.54	0.64	-0.44	-0.33	-0.84
3	0.60	0.44	0.43	-0.39	-0.32	-0.71
4	0.58	0.40	0.31	-0.39	-0.28	-0.57
5	0.55	0.35	0.31	-0.32	-0.26	-0.47
6	0.44	0.34	0.25	-0.29	-0.23	-0.46
7	0.41	0.24	0.24	-0.25	-0.23	-0.44
8	0.34	0.18	0.23	-0.18	-0.20	-0.41
9	0.28	0.17	0.16	-0.18	-0.19	-0.31
10	0.28	0.12	0.15	-0.14	-0.17	-0.28

Table I-70 Maximum 1-hour mean formaldehyde concentration (excluding background) at RWR receptors, ranked by concentration

Rank	Ranking by concentration (µg/m³)					
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1	-	8.0	6.3	7.0	6.0	6.5
2	-	6.0	6.0	6.5	6.0	5.6
3	-	5.9	5.7	6.5	5.8	5.5
4	-	5.9	5.6	6.2	5.6	5.5
5	-	5.6	5.5	6.1	5.6	5.5
6	-	5.5	5.5	5.9	5.6	5.4
7	-	5.4	5.5	5.9	5.6	5.4
8	-	5.4	5.4	5.9	5.5	5.3
9	-	5.4	5.4	5.8	5.5	5.3
10	-	5.4	5.3	5.7	5.4	5.3

Table I-71 Maximum 1-hour mean formaldehyde concentration (excluding background) at RWR receptors, ranked by increase and by decrease in concentration

Rank	Ranking by increase in concentration relative to Do Minimum (µg/m^3)			Ranking by decrease in concentration relative to Do Minimum (µg/m^3)		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	2.1	1.8	1.6	-2.0	-2.0	-2.0
2	1.5	1.8	1.5	-1.6	-1.9	-1.9
3	1.5	1.5	1.5	-1.5	-1.7	-1.8
4	1.4	1.5	1.4	-1.5	-1.7	-1.8
5	1.4	1.5	1.4	-1.4	-1.6	-1.7
6	1.4	1.5	1.3	-1.4	-1.6	-1.6
7	1.4	1.5	1.2	-1.4	-1.6	-1.6
8	1.3	1.4	1.2	-1.4	-1.6	-1.6
9	1.2	1.4	1.2	-1.4	-1.5	-1.6
10	1.2	1.4	1.2	-1.3	-1.5	-1.5

I.12 Air toxics: 1,3-butadiene (maximum 1-hour mean)

Table I-72 Maximum 1-hour mean 1,3-butadiene concentration (excluding background) at community receptors

Receptor	Maximum 1-hour 1,3-butadiene concentration (µg/m^3)						Change relative to Do Minimum (µg/m^3)		
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
CR01	-	0.3	0.3	0.2	0.2	0.2	0.0	0.0	-0.1
CR02	-	0.6	0.5	0.4	0.4	0.3	0.0	0.0	-0.1
CR03	-	0.4	0.4	0.3	0.3	0.3	0.0	0.0	0.0
CR04	-	0.8	0.8	0.6	0.5	0.5	0.0	-0.1	-0.1
CR05	-	0.5	0.6	0.4	0.3	0.4	0.1	0.0	0.1
CR06	-	0.7	0.9	0.4	0.5	0.6	0.2	0.1	0.2
CR07	-	0.5	0.6	0.4	0.4	0.3	0.1	0.0	0.0
CR08	-	0.5	0.7	0.4	0.4	0.3	0.1	0.0	-0.1
CR09	-	0.9	0.7	0.5	0.5	0.6	-0.1	0.0	0.1
CR10	-	0.6	0.8	0.4	0.5	0.4	0.1	0.1	0.0
CR11	-	0.5	0.6	0.4	0.4	0.4	0.1	0.0	0.0
CR12	-	0.6	0.5	0.4	0.3	0.3	-0.1	-0.1	-0.1
CR13	-	0.5	0.7	0.4	0.4	0.4	0.1	0.0	0.0
CR14	-	0.3	0.4	0.2	0.2	0.2	0.0	0.0	0.0
CR15	-	0.6	0.5	0.4	0.4	0.3	0.0	0.0	-0.2
CR16	-	0.3	0.3	0.2	0.2	0.3	0.0	0.0	0.1
CR17	-	0.8	0.7	0.5	0.4	0.4	-0.1	-0.1	-0.1
CR18	-	0.4	0.4	0.3	0.4	0.3	-0.1	0.1	0.0
CR19	-	0.9	1.1	0.6	0.7	0.6	0.2	0.1	0.1
CR20	-	0.7	0.6	0.4	0.4	0.3	-0.1	0.0	-0.1
CR21	-	0.5	0.7	0.4	0.3	0.3	0.2	0.0	0.0
CR22	-	0.4	0.3	0.2	0.3	0.3	-0.1	0.1	0.1
CR23	-	0.7	0.9	0.3	0.4	0.4	0.2	0.1	0.0
CR24	-	0.7	0.6	0.5	0.5	0.4	-0.1	0.0	-0.2
CR25	-	0.7	0.6	0.5	0.5	0.5	-0.1	0.0	0.0
CR26	-	1.0	0.8	0.6	0.5	0.6	-0.2	-0.1	0.0
CR27	-	0.9	1.2	0.7	0.7	0.8	0.3	0.0	0.0
CR28	-	1.0	1.0	0.7	0.7	0.7	0.0	0.1	0.0
CR29	-	0.7	0.6	0.6	0.6	0.5	0.0	0.0	-0.1
CR30	-	0.7	0.7	0.6	0.5	0.4	0.0	-0.1	-0.2

Table I-73 Maximum 1-hour mean 1,3-butadiene concentration (excluding background) at community receptors, ranked by concentration

Rank	Ranking by concentration (µg/m³)					
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1	-	1.0	1.2	0.7	0.7	0.8
2	-	1.0	1.1	0.7	0.7	0.7
3	-	0.9	1.0	0.6	0.7	0.6
4	-	0.9	0.9	0.6	0.6	0.6
5	-	0.9	0.9	0.6	0.5	0.6
6	-	0.8	0.8	0.6	0.5	0.6
7	-	0.8	0.8	0.6	0.5	0.5
8	-	0.7	0.8	0.5	0.5	0.5
9	-	0.7	0.7	0.5	0.5	0.5
10	-	0.7	0.7	0.5	0.5	0.4

Table I-74 Maximum 1-hour mean 1,3-butadiene concentration (excluding background) at community receptors, ranked by increase and by decrease in concentration

Rank	Ranking by increase in concentration relative to Do Minimum (µg/m³)			Ranking by decrease in concentration relative to Do Minimum (µg/m³)		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	0.26	0.12	0.22	-0.22	-0.12	-0.19
2	0.20	0.11	0.13	-0.14	-0.07	-0.18
3	0.19	0.09	0.09	-0.13	-0.07	-0.15
4	0.19	0.08	0.06	-0.13	-0.06	-0.12
5	0.18	0.07	0.06	-0.11	-0.06	-0.10
6	0.14	0.07	0.05	-0.09	-0.05	-0.10
7	0.13	0.05	0.05	-0.08	-0.05	-0.09
8	0.11	0.04	0.05	-0.06	-0.04	-0.09
9	0.09	0.04	0.03	-0.06	-0.04	-0.07
10	0.09	0.02	0.03	-0.05	-0.04	-0.06

Table I-75 Maximum 1-hour mean 1,3-butadiene concentration (excluding background) at RWR receptors, ranked by concentration

Rank	Ranking by concentration (µg/m³)					
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1	-	2.6	2.0	1.5	1.3	1.4
2	-	2.0	2.0	1.4	1.3	1.2
3	-	1.9	1.8	1.4	1.2	1.2
4	-	1.9	1.8	1.3	1.2	1.2
5	-	1.8	1.8	1.3	1.2	1.1
6	-	1.8	1.8	1.2	1.2	1.1
7	-	1.8	1.8	1.2	1.2	1.1
8	-	1.8	1.8	1.2	1.2	1.1
9	-	1.8	1.8	1.2	1.2	1.1
10	-	1.8	1.7	1.2	1.1	1.1

Table I-76 Maximum 1-hour mean 1,3-butadiene concentration (excluding background) at RWR receptors, ranked by increase and by decrease in concentration

Rank		Ranking by increase in concentration relative to Do Minimum (µg/m³)				Ranking by decrease in concentration relative to Do Minimum (µg/m³)		
		2026-DS	2036-DS	2036-DSC		2026-DS	2036-DS	2036-DSC
1		0.7	0.4	0.33		-0.6	-0.4	-0.4
2		0.5	0.4	0.3		-0.5	-0.4	-0.4
3		0.5	0.3	0.3		-0.5	-0.4	-0.4
4		0.5	0.3	0.3		-0.5	-0.4	-0.4
5		0.4	0.3	0.3		-0.5	-0.3	-0.4
6		0.4	0.3	0.3		-0.5	-0.3	-0.3
7		0.4	0.3	0.3		-0.5	-0.3	-0.3
8		0.4	0.3	0.3		-0.5	-0.3	-0.3
9		0.4	0.3	0.3		-0.4	-0.3	-0.3
10		0.4	0.3	0.2		-0.4	-0.3	-0.3

I.13 Air toxics: ethylbenzene (maximum 1-hour mean)

Table I-77 Maximum 1-hour mean ethylbenzene concentration (excluding background) at community receptors

Receptor	Maximum 1-hour ethylbenzene concentration (µg/m³)						Change relative to Do Minimum (µg/m³)		
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
CR01	-	0.4	0.4	0.3	0.3	0.2	0.0	0.0	-0.1
CR02	-	0.7	0.7	0.5	0.5	0.3	0.0	0.0	-0.1
CR03	-	0.5	0.6	0.4	0.4	0.3	0.1	0.0	0.0
CR04	-	1.0	1.1	0.7	0.7	0.7	0.0	-0.1	-0.1
CR05	-	0.6	0.8	0.5	0.4	0.5	0.1	0.0	0.1
CR06	-	0.9	1.1	0.5	0.6	0.8	0.2	0.1	0.3
CR07	-	0.6	0.7	0.4	0.5	0.4	0.1	0.0	-0.1
CR08	-	0.7	0.8	0.5	0.5	0.3	0.1	0.0	-0.1
CR09	-	1.1	0.9	0.6	0.6	0.7	-0.2	0.0	0.1
CR10	-	0.8	1.0	0.5	0.6	0.5	0.2	0.1	0.0
CR11	-	0.6	0.7	0.5	0.5	0.5	0.1	0.0	0.0
CR12	-	0.8	0.6	0.5	0.4	0.4	-0.2	-0.1	-0.1
CR13	-	0.7	0.9	0.5	0.5	0.5	0.2	0.0	0.0
CR14	-	0.4	0.5	0.3	0.2	0.3	0.1	0.0	0.0
CR15	-	0.7	0.6	0.5	0.5	0.3	-0.1	-0.1	-0.2
CR16	-	0.3	0.3	0.2	0.2	0.4	0.0	0.0	0.2
CR17	-	1.0	0.9	0.6	0.5	0.5	-0.1	-0.1	-0.1
CR18	-	0.5	0.5	0.3	0.5	0.4	-0.1	0.1	0.0
CR19	-	1.1	1.4	0.7	0.8	0.8	0.2	0.1	0.1
CR20	-	0.9	0.8	0.5	0.5	0.4	-0.1	0.0	-0.1
CR21	-	0.6	0.9	0.4	0.4	0.4	0.3	0.0	0.0
CR22	-	0.5	0.4	0.2	0.4	0.3	-0.1	0.1	0.1
CR23	-	0.9	1.1	0.4	0.5	0.5	0.2	0.1	0.1
CR24	-	0.9	0.7	0.6	0.5	0.4	-0.2	-0.1	-0.2
CR25	-	0.8	0.8	0.6	0.6	0.6	-0.1	0.0	0.0
CR26	-	1.3	1.0	0.7	0.7	0.7	-0.3	-0.1	0.0
CR27	-	1.1	1.5	0.9	0.9	0.9	0.3	0.0	0.0
CR28	-	1.3	1.3	0.8	0.9	0.9	-0.1	0.1	0.1
CR29	-	0.8	0.8	0.7	0.7	0.6	0.0	0.0	-0.1
CR30	-	0.9	0.9	0.7	0.6	0.5	0.0	-0.1	-0.2

Table I-78 **Maximum 1-hour mean ethylbenzene concentration (excluding background) at community receptors, ranked by concentration**

Rank	Ranking by concentration (µg/m³)					
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1	-	1.3	1.5	0.9	0.9	0.9
2	-	1.3	1.4	0.8	0.9	0.9
3	-	1.1	1.3	0.7	0.8	0.8
4	-	1.1	1.1	0.7	0.7	0.8
5	-	1.1	1.1	0.7	0.7	0.7
6	-	1.0	1.1	0.7	0.7	0.7
7	-	1.0	1.0	0.7	0.6	0.7
8	-	0.9	1.0	0.6	0.6	0.6
9	-	0.9	0.9	0.6	0.6	0.6
10	-	0.9	0.9	0.6	0.6	0.5

Table I-79 **Maximum 1-hour mean ethylbenzene concentration (excluding background) at community receptors, ranked by increase and by decrease in concentration**

Rank	Ranking by increase in concentration relative to Do Minimum (µg/m³)			Ranking by decrease in concentration relative to Do Minimum (µg/m³)		
	2026-DS	2036-DS	2036-DSC	2026-DS	2036-DS	2036-DSC
1	0.33	0.15	0.26	-0.27	-0.15	-0.23
2	0.25	0.14	0.16	-0.18	-0.08	-0.21
3	0.24	0.11	0.11	-0.16	-0.08	-0.18
4	0.24	0.10	0.08	-0.16	-0.07	-0.14
5	0.23	0.09	0.08	-0.13	-0.07	-0.12
6	0.18	0.09	0.06	-0.12	-0.06	-0.12
7	0.17	0.06	0.06	-0.10	-0.06	-0.11
8	0.14	0.05	0.06	-0.07	-0.05	-0.10
9	0.12	0.04	0.04	-0.07	-0.05	-0.08
10	0.11	0.03	0.04	-0.06	-0.04	-0.07

Table I-80 **Maximum 1-hour mean ethylbenzene concentration (excluding background) at RWR receptors, ranked by concentration**

Rank	Ranking by concentration (µg/m³)					
	2016-BY	2026-DM	2026-DS	2036-DM	2036-DS	2036-DSC
1	-	3.3	2.6	1.8	1.5	1.6
2	-	2.5	2.5	1.6	1.5	1.4
3	-	2.4	2.3	1.6	1.5	1.4
4	-	2.4	2.3	1.6	1.4	1.4
5	-	2.3	2.3	1.6	1.4	1.4
6	-	2.3	2.2	1.5	1.4	1.4
7	-	2.2	2.2	1.5	1.4	1.4
8	-	2.2	2.2	1.5	1.4	1.3
9	-	2.2	2.2	1.5	1.4	1.3
10	-	2.2	2.2	1.4	1.4	1.3

Table I-81 Maximum 1-hour mean ethylbenzene concentration (excluding background) at RWR receptors, ranked by increase and by decrease in concentration

Rank		Ranking by increase in concentration relative to Do Minimum (µg/m^3)				Ranking by decrease in concentration relative to Do Minimum (µg/m^3)		
		2026-DS	2036-DS	2036-DSC		2026-DS	2036-DS	2036-DSC
1		0.9	0.5	0.40		-0.8	-0.5	-0.5
2		0.6	0.5	0.4		-0.6	-0.5	-0.5
3		0.6	0.4	0.4		-0.6	-0.4	-0.5
4		0.6	0.4	0.3		-0.6	-0.4	-0.4
5		0.6	0.4	0.3		-0.6	-0.4	-0.4
6		0.6	0.4	0.3		-0.6	-0.4	-0.4
7		0.6	0.4	0.3		-0.6	-0.4	-0.4
8		0.5	0.4	0.3		-0.6	-0.4	-0.4
9		0.5	0.3	0.3		-0.6	-0.4	-0.4
10		0.5	0.3	0.3		-0.5	-0.4	-0.4

Annexure J - Dispersion modelling results – ventilation outlets only

Annexure J - Dispersion modelling results - ventilation outlets only

J.1 Overview

Given the increase in emphasis on tunnel ventilation outlets, it was considered important to provide a separate summary of the dispersion modelling results for these. This Annexure therefore brings together the various different outcomes for tunnel ventilation outlets for ease of access.

J.2 Approach

The general assessment and modelling approaches were described in section 5 and section 8. The tunnel ventilation outlet parameters are given in Annexure G.

The results presented here are for the ventilation outlet contribution only. The contributions of other sources (background, tunnel portals and surface roads) were not considered and are not presented. The exception to this is NO_2, as the ventilation outlet contribution to NO_2 is dependent on the amount of NO_X present from other sources. The other sources were therefore considered in the NO_2 calculation for ventilation outlets.

It should also be noted that the results presented here relate to all tunnel ventilation outlets combined. That is to say, the tunnel outlet concentration at a given location included contributions from all tunnel outlets in the GRAL domain.

J.3 Results for community receptors

Tunnel ventilation outlet contributions were determined for both annual mean and short-term air quality metrics, and the results for criteria pollutants are given in Table J-1 and Table J-2 respectively. The corresponding air quality criteria are also shown. For the short term criteria two different results are presented:

- The ventilation outlet contribution when the maximum total concentration (including all sources) during the year occurred.
- The largest contribution from tunnel ventilation outlets at any time during the year.

The results are discussed by pollutant and metric below. The largest ventilation outlet contributions relate to any scenario.

For CO, there is no annual mean air quality metric. The contribution of tunnel ventilation outlets to the maximum 1-hour and 8-hour CO concentration was zero or negligible for all community receptors.

For NO_2 the contribution of tunnel ventilation outlets to the annual mean was less than 1.3 per cent of the criterion (62 µg/m^3) in all scenarios. The tunnel ventilation outlet contribution to the maximum total 1-hour NO_2 concentration was either zero or negligible at all community receptors. Larger 1-hour contributions from ventilation outlets (up to 39 µg/m^3) occurred during other hours of the year, but the total concentration was lower of course. In fact, the largest NO_2 contributions were equal to the largest NO_X contributions. This 1:1 relationship only occurred at relatively low total NO_X concentrations.

For annual mean PM_{10} there was generally a small contribution from tunnel ventilation outlets; the largest contribution was 0.29 µg/m^3, or 1.2 per cent of the criterion (25 µg/m^3). For the maximum total 24-hour PM_{10} concentration the largest contribution from ventilation outlets was 0.55 µg/m^3, or 1.1 per cent of the criterion. The largest ventilation outlet contribution to 24-hour PM_{10} at any time was 2.6 µg/m^3 (or 5.2 per cent of the criterion), but again this would have coincided with relatively low contributions from other sources.

Table J-1 Contribution of ventilation outlets to annual average concentrations of criteria pollutants[(a)]

Scenario	Statistic for outlet contribution (range across receptors)	NO_X (µg/m³)	NO_2 (µg/m³)	PM_{10} (µg/m³)	$PM_{2.5}$ (µg/m³)
2026-DM	Average contribution	0.054 to 1.467	0.014 to 0.327	0.007 to 0.246	0.004 to 0.173
2026-DS	Average contribution	0.107 to 1.298	0.027 to 0.292	0.02 to 0.214	0.011 to 0.145
2036-DM	Average contribution	0.059 to 1.523	0.015 to 0.347	0.007 to 0.289	0.005 to 0.189
2036-DS	Average contribution	0.108 to 1.304	0.027 to 0.294	0.023 to 0.242	0.015 to 0.163
2036-DSC	Average contribution	0.11 to 1.519	0.028 to 0.341	0.025 to 0.275	0.018 to 0.183
Air quality criterion		N/A	62	25	8

(a) Ranges reflect values across all community receptors.

Table J-2 Contribution of ventilation outlets to maximum short-term concentrations of criteria pollutants[(a)]

Scenario	Statistic for outlet contribution (range across receptors)	CO Max. 1-hour (mg/m³)	CO Max. 8-hour (mg/m³)	NO_X Max. 1-hour (µg/m³)	NO_2 Max. 1-hour (µg/m³)	PM_{10} Max. 24-hour (µg/m³)	$PM_{2.5}$ Max. 24-hour (µg/m³)
2026-DM	Contribution when max. total occurs	0 to 0.001	0 to 0.001	0 to 0.14	0 to 0.008	0 to 0.449	0.001 to 0.057
	Largest contribution at any time	0.007 to 0.055	0.001 to 0.045	4.37 to 38.88	2.03 to 38.88	0.06 to 2.38	0.01 to 1.69
2026-DS	Contribution when max. total occurs	0 to 0.004	0 to 0.002	0 to 5.855	0 to 0.349	0 to 0.350	0 to 0.065
	Largest contribution at any time	0.007 to 0.042	0.002 to 0.026	3.60 to 27.40	3.60 to 27.40	0.112 to 1.51	0.03 to 1.01
2036-DM	Contribution when max. total occurs	0 to 0.001	0 to 0.001	0 to 0.762	0 to 0.04	0 to 0.552	0 to 0.062
	Largest contribution at any time	0.006 to 0.056	0.001 to 0.042	4.59 to 37.56	1.99 to 37.56	0.052 to 2.63	0.05 to 1.78
2036-DS	Contribution when max. total occurs	0 to 0.001	0 to 0.001	0 to 3.942	0 to 0.235	0 to 0.379	0 to 0.101
	Largest contribution at any time	0.006 to 0.049	0.002 to 0.027	3.71 to 32.35	3.71 to 32.35	0.132 to 1.71	0.07 to 1.18
2036-DSC	Contribution when max. total occurs	0 to 0.005	0 to 0.003	0 to 0.835	0 to 0.047	0 to 0.506	0 to 0.094
	Largest contribution at any time	0.007 to 0.05	0.003 to 0.036	4.64 to 33.60	4.64 to 33.60	0.151 to 2.14	0.02 to 1.47
Air quality criterion		30	10	N/A	246	50	25

(a) Ranges reflect values across all community receptors.

(b) '-' = zero contribution from outlets at all community receptors

For annual mean $PM_{2.5}$ there was again a small contribution from tunnel ventilation outlets; the largest contribution was 0.19 µg/m^3, or 2.4 per cent of the criterion (8 µg/m^3). For the maximum total 24-hour $PM_{2.5}$ concentration the largest contribution from ventilation outlets was around 0.01 µg/m^3, or 0.4 per cent of the criterion. The largest ventilation outlet contribution to 24-hour PM_{10} at any time was 1.8 µg/m^3 (or around 7 per cent of the criterion), but again this would have coincided with relatively low contributions from other sources.

For total hydrocarbons and air toxics, only the largest outlet contributions are shown in Table J-3.

Table J-3 Largest contribution of ventilation outlets to concentrations of air toxics[(a)]

Statistic	Scenario	THC (µg/m^3)	Benzene (µg/m^3)	Toluene (µg/m^3)	Xylenes (µg/m3)	PAH (µg/m^3)	Formaldehyde (µg/m^3)	1,3-butadiene (µg/m^3)	Ethylbenzene (µg/m^3)
Annual average	2026-DM	0.097	0.0039	0.0071	0.0058	0.00003	-	-	-
	2026-DS	0.085	0.0034	0.0062	0.0051	0.00003	-	-	-
	2036-DM	0.096	0.0033	0.0058	0.0048	0.00004	-	-	-
	2036-DS	0.083	0.0029	0.0050	0.0041	0.00004	-	-	-
	2036-DSC	0.094	0.0032	0.0057	0.0047	0.00004	-	-	-
Maximum 24-hour	2026-DM	0.973	-	0.0708	0.0583	-	0.032	-	-
	2026-DS	0.602	-	0.0438	0.0361	-	0.020	-	-
	2036-DM	0.934	-	0.0564	0.0464	-	0.042	-	-
	2036-DS	0.581	-	0.0350	0.0288	-	0.026	-	-
	2036-DSC	0.705	-	0.0425	0.0350	-	0.032	-	-
Maximum 1-hour	2026-DM	2.632	0.1049	-	-	0.00000	0.087	0.028	0.0355
	2026-DS	1.853	0.0739	-	-	0.00066	0.061	0.020	0.0250
	2036-DM	2.430	0.0840	-	-	0.00105	0.109	0.023	0.0276
	2036-DS	1.920	0.0663	-	-	0.00083	0.086	0.018	0.0218
	2036-DSC	2.556	0.0883	-	-	0.00110	0.115	0.024	0.0290

(a) Ranges reflect values across all community receptors.

J.4 Results for RWR receptors

Figure J-1 presents the ranked results for the ventilation outlet contributions at all RWR receptors, and statistics for these receptors are given in Table J-4.

The largest contributions of tunnel ventilation outlets at any RWR receptor in any scenario were as follows:

- Max. 1-hour CO: 0.08 mg/m^3, or 0.3 per cent of the criterion (30 mg/m^3) [2036-DS]
- Annual NO_2: 0.63 µg/m^3, or 1.0 per cent of the criterion (62 µg/m^3) [2036-DM]
- Annual PM_{10}: 0.59 µg/m^3, or 2.4 per cent of the criterion (25 µg/m^3) [2036-DM]
- Max. 24-hour PM_{10}: 2.69 µg/m^3, or 5.4 per cent of the criterion (50 µg/m^3) [2036-DM]
- Annual $PM_{2.5}$: 0.40 µg/m^3, or 5.0 per cent of the criterion (8 µg/m^3) [2036-DM]
- Max. 24-hour $PM_{2.5}$: 1.79 µg/m^3, or 7.2 per cent of the criterion (25 µg/m^3) [2036-DM]

As noted above, the highest concentrations mainly occurred in the 2036-DM scenario.

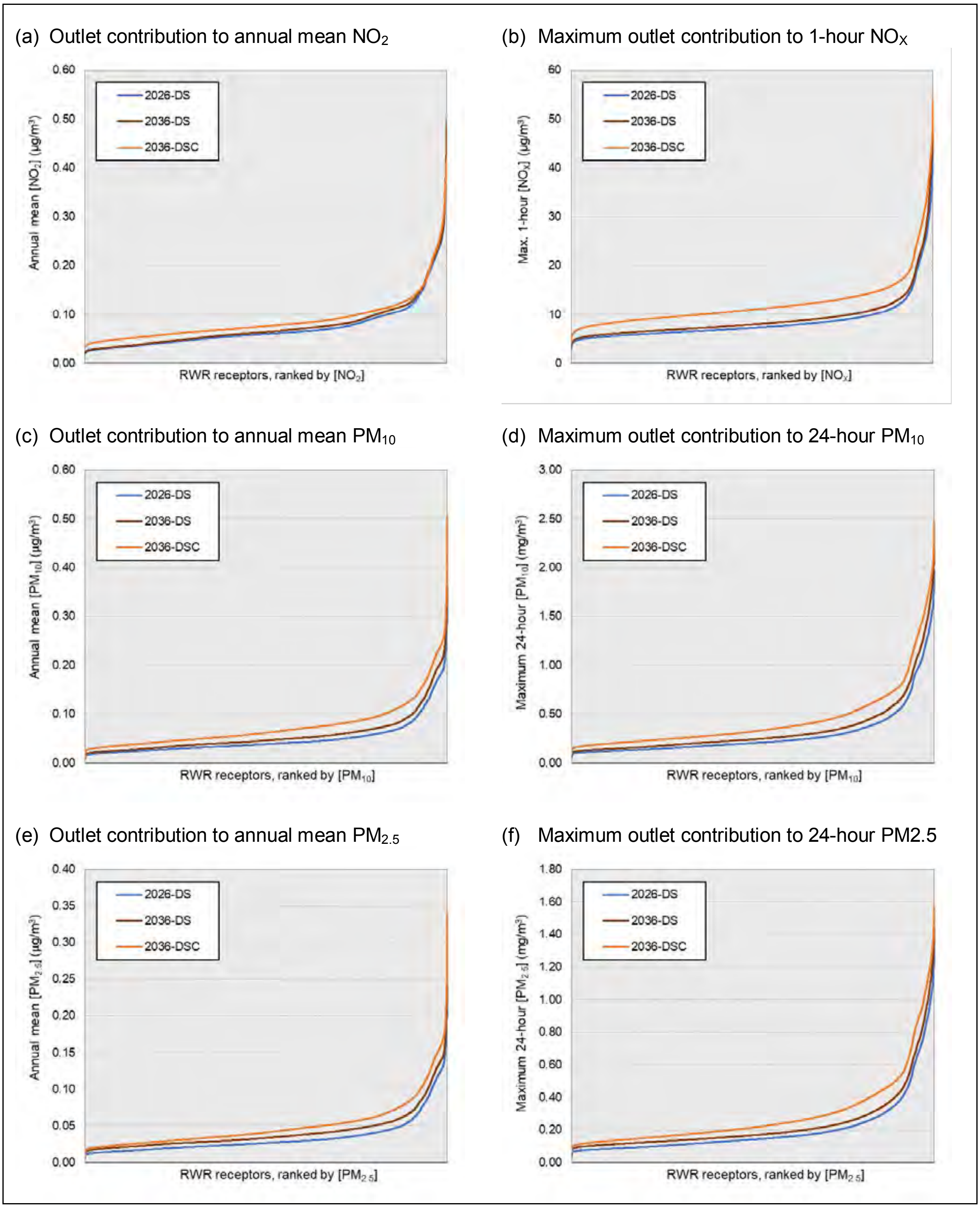


Figure J-1 Ventilation outlet contributions to NO_2/NO_X, PM_{10} and $PM_{2.5}$ at RWR receptors

Table J-4 Maximum contributions of ventilation outlets at RWR receptors

Scenario	Statistic	CO 1-hour (mg/m^3)	NO_X Annual (µg/m^3)	NO_X 1-hour (µg/m^3)	NO_2 Annual (µg/m^3)	NO_2 1-hour (µg/m^3)	PM_{10} Annual (µg/m^3)	PM_{10} 24-hour (µg/m^3)	$PM_{2.5}$ Annual (µg/m^3)	$PM_{2.5}$ 24-hour (µg/m^3)
2026-DM	Average	0.014	0.313	8.967	0.072	N/A	0.032	0.220	0.022	0.151
	Maximum	0.077	2.411	48.778	0.501	N/A	0.496	2.404	0.343	1.640
	98th percentile	0.048	1.077	31.302	0.237	N/A	0.213	1.480	0.146	1.016
2026-DS	Average	0.014	0.313	8.414	0.072	N/A	0.048	0.286	0.033	0.197
	Maximum	0.073	2.411	49.248	0.498	N/A	0.402	1.986	0.280	1.366
	98th percentile	0.039	1.077	25.386	0.237	N/A	0.178	1.271	0.121	0.873
2036-DM	Average	0.014	0.238	9.545	0.055	N/A	0.037	0.259	0.025	0.172
	Maximum	0.079	3.038	53.146	0.629	N/A	0.590	2.686	0.400	1.790
	98th percentile	0.049	1.323	33.306	0.295	N/A	0.249	1.768	0.165	1.163
2036-DS	Average	0.015	0.329	9.181	0.076	N/A	0.057	0.337	0.041	0.231
	Maximum	0.080	2.389	53.896	0.490	N/A	0.461	2.292	0.305	1.552
	98th percentile	0.041	1.091	26.989	0.243	N/A	0.201	1.454	0.135	0.967
2036-DSC	Average	0.019	0.373	12.194	0.088	N/A	0.075	0.433	0.049	0.287
	Maximum	0.078	2.065	53.741	0.418	N/A	0.505	2.466	0.339	1.575
	98th percentile	0.050	1.137	32.401	0.251	N/A	0.235	1.664	0.155	1.094

J.5 Contour plots – ventilation outlets only

J.5.1 Annual mean NO_X

J.5.1.1 2026-DS scenario

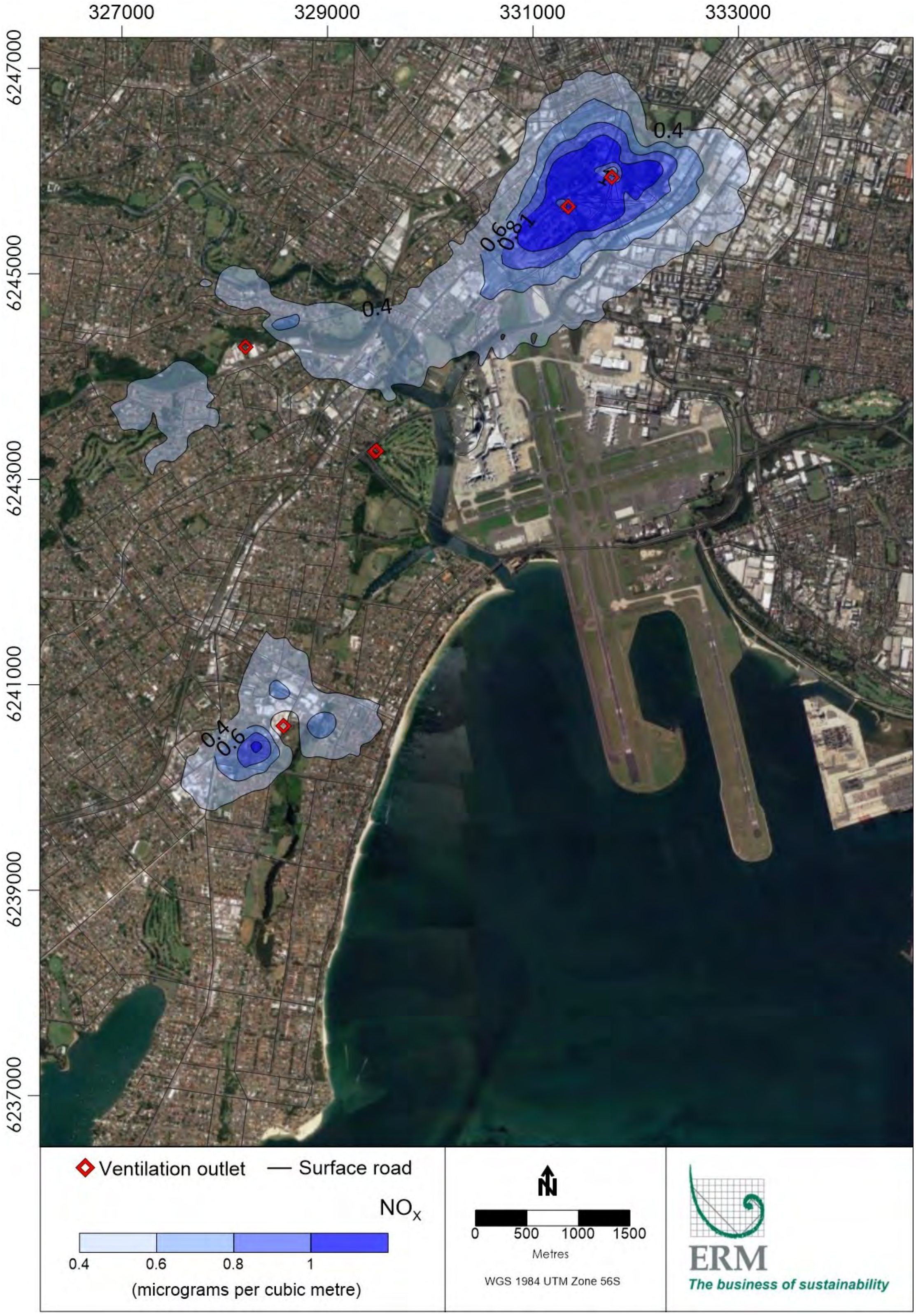


Figure J-2 Contour plot of annual mean NO_X for all ventilation outlets in 2026-DS scenario

J.5.1.2 2036-DS scenario

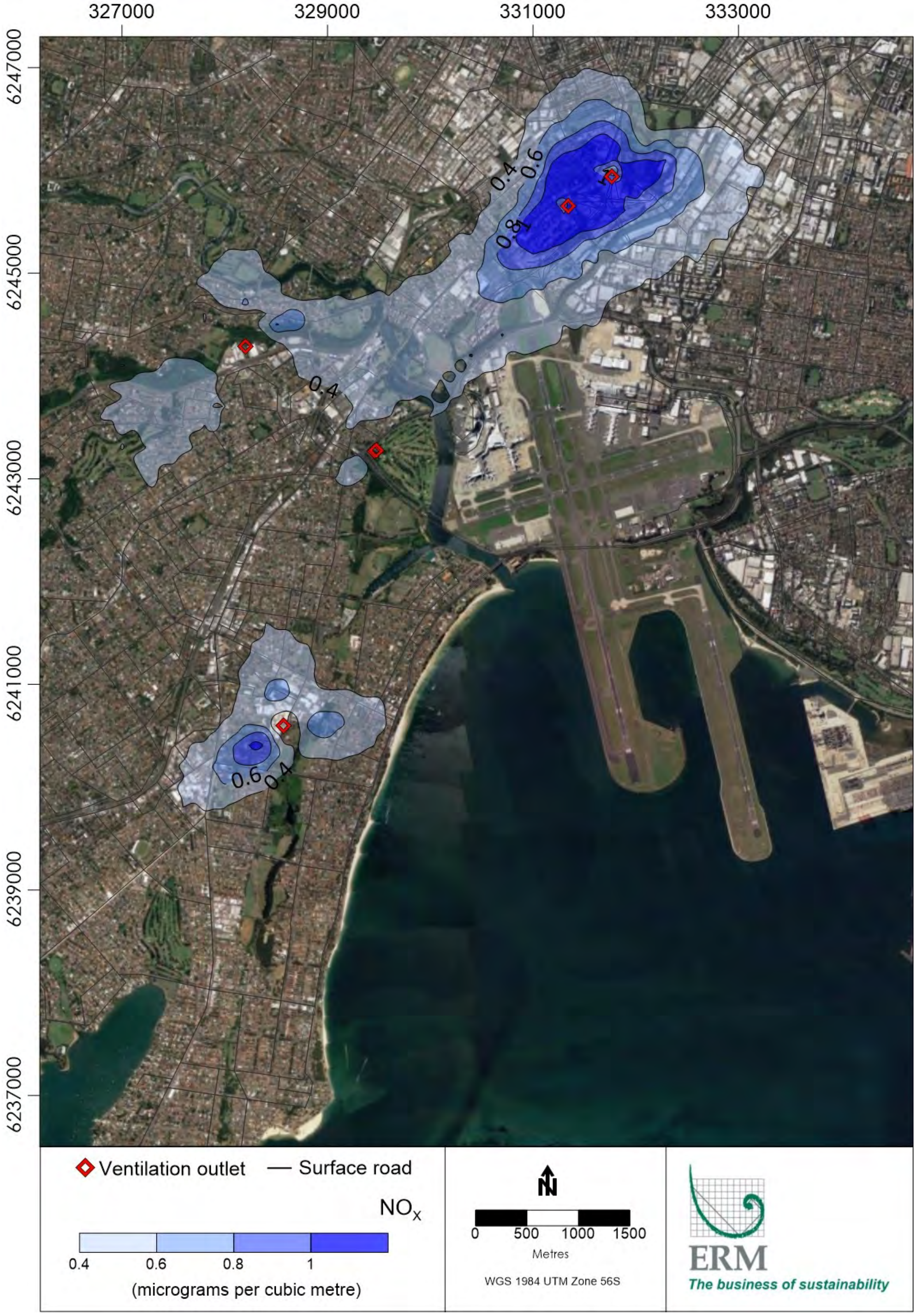


Figure J-3 Contour plot of annual mean NO_X for all ventilation outlets in 2036-DSscenario

J.5.1.3 2036-DSC scenario

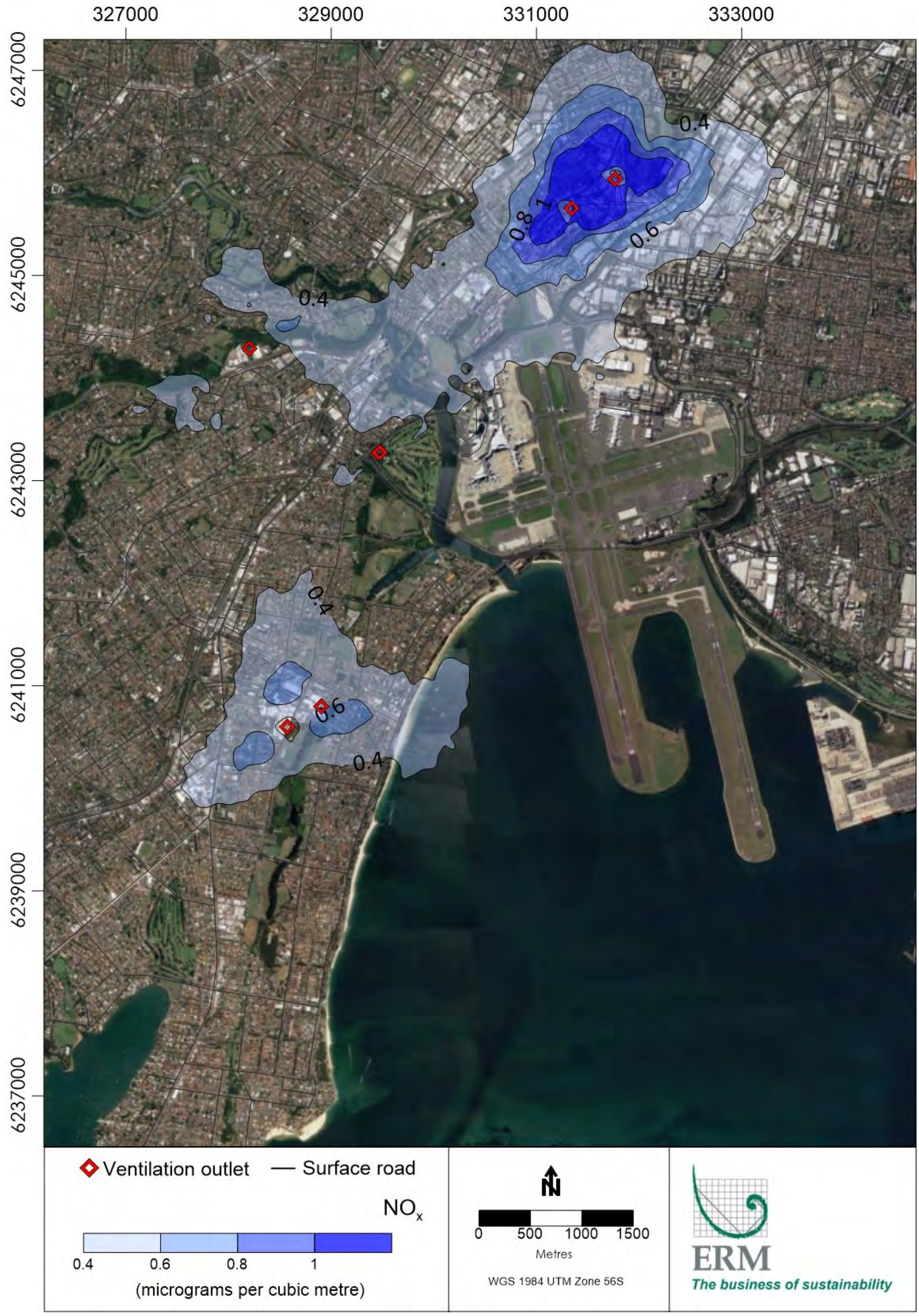


Figure J-4 Contour plot of annual mean NO_X for all ventilation outlets in 2036-DSC scenario

J.5.2 Maximum 1-hour NO_X

J.5.2.1 2026-DS scenario

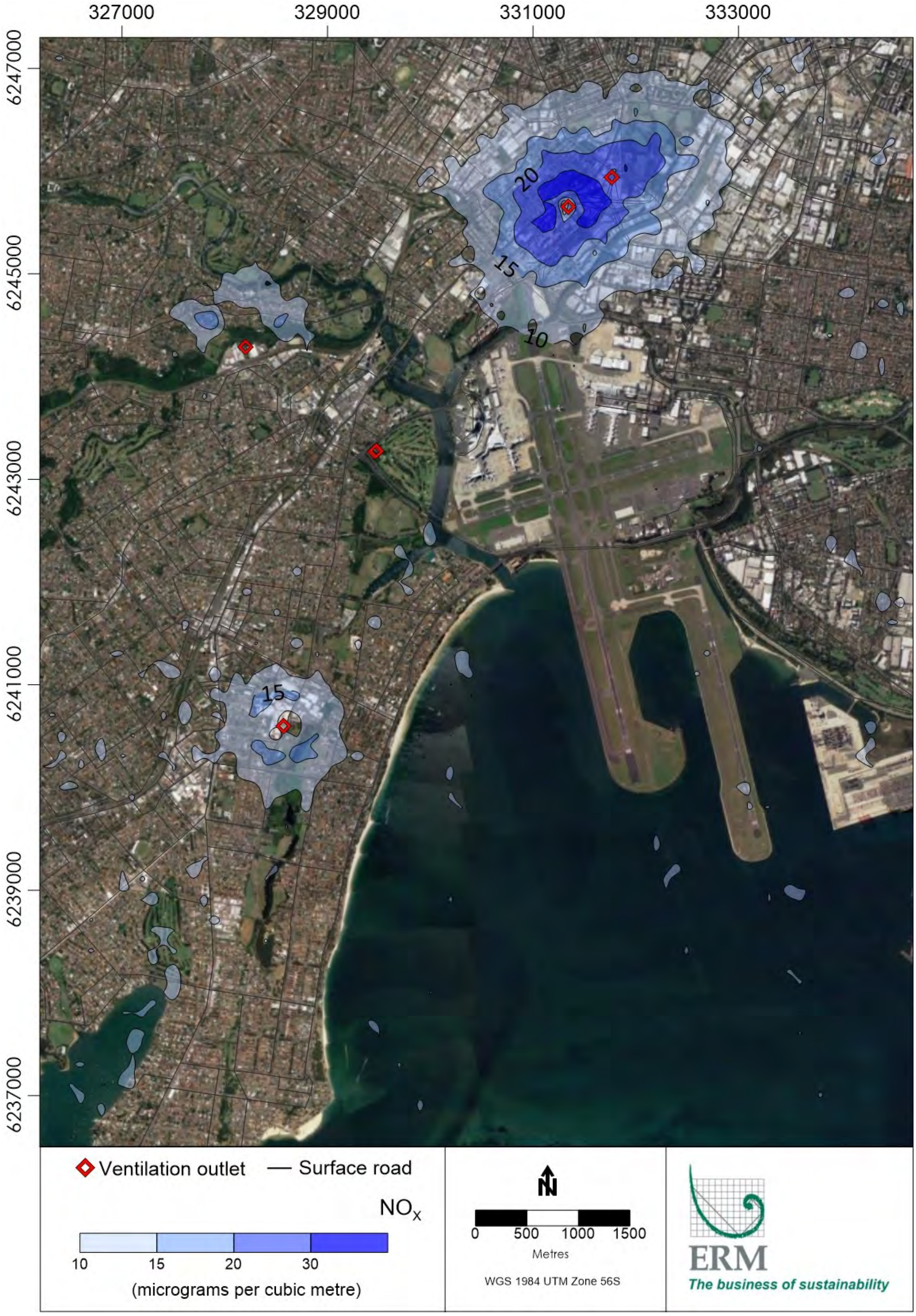


Figure J-5 Contour plot of maximum 1-hour NO_X for all ventilation outlets in 2026-DSscenario

J.5.2.2 2036-DS scenario

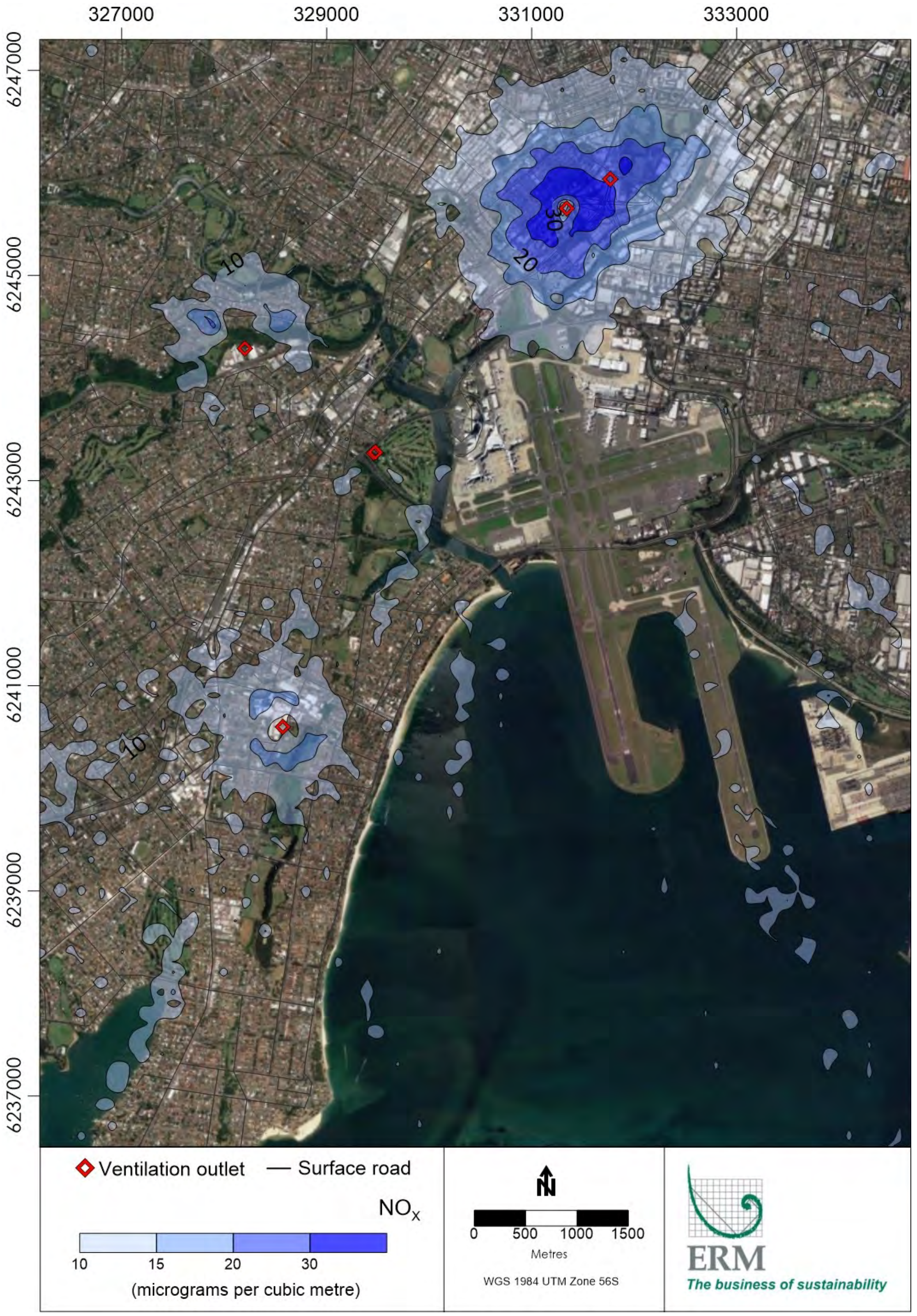


Figure J-6 Contour plot of maximum 1-hour NO_X for all ventilation outlets in 2036-DS scenario

J.5.2.3 2036-DSC scenario

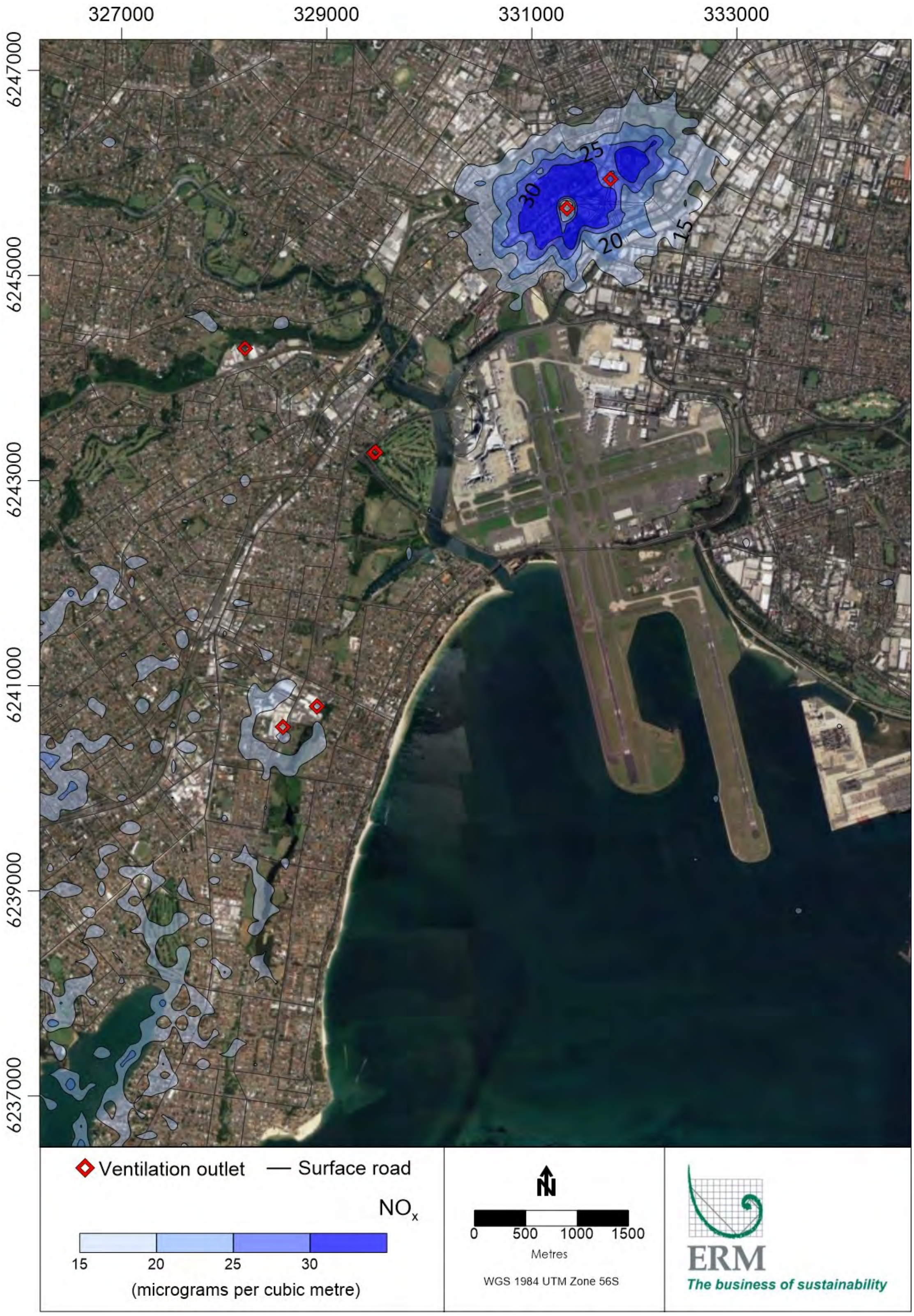


Figure J-7 Contour plot of maximum 1-hour NO_X for all ventilation outlets in 2036-DSC scenario

J.5.3 Annual PM_{10}

J.5.3.1 2026-DS scenario

Figure J-8 Contour plot of annual mean PM_{10} for all ventilation outlets in 2026-DS scenario

J.5.3.2 2036-DS scenario

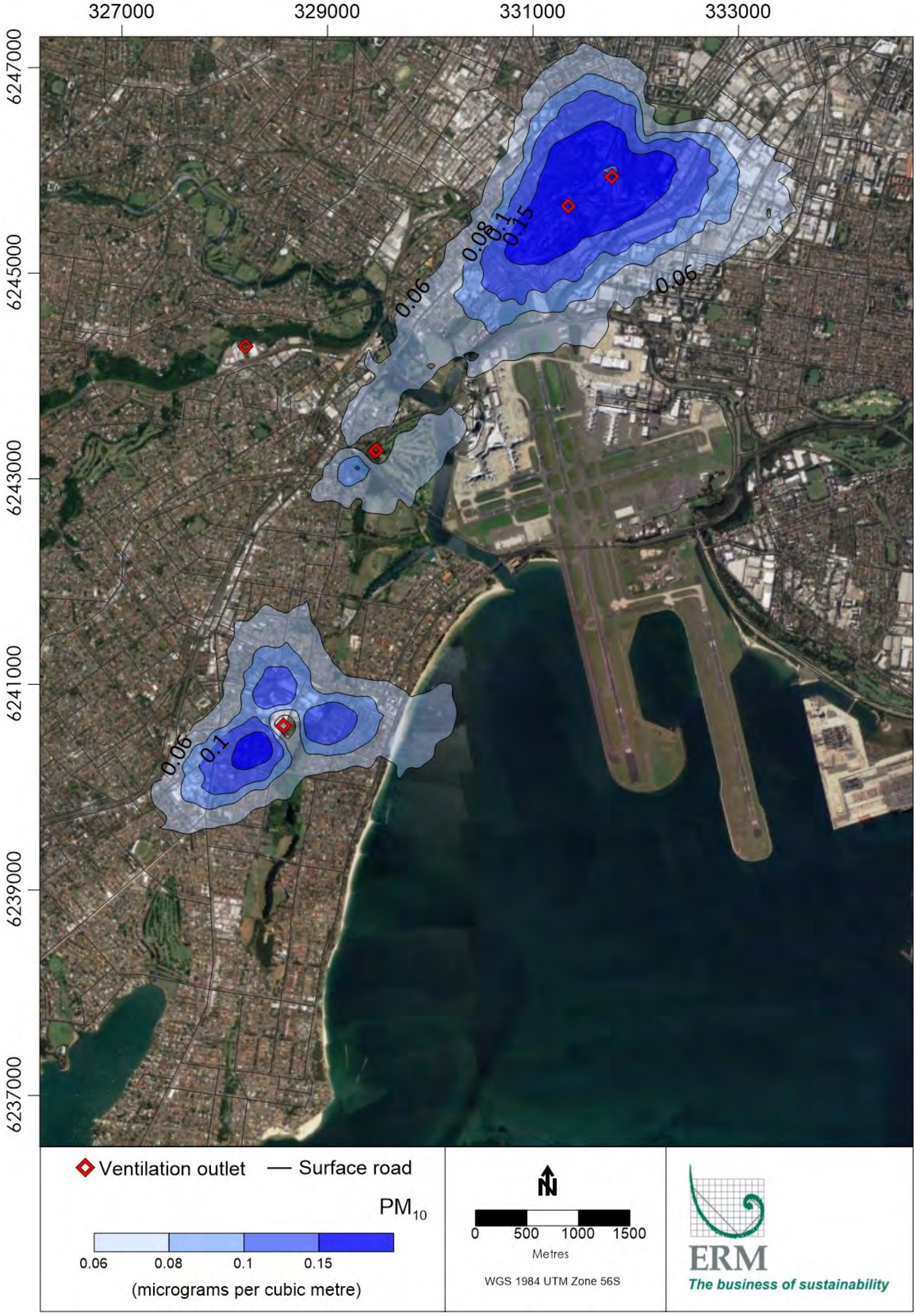


Figure J-9 Contour plot of annual mean PM_{10} for all ventilation outlets in 2036-DS scenario

J.5.3.3 2036-DSC scenario

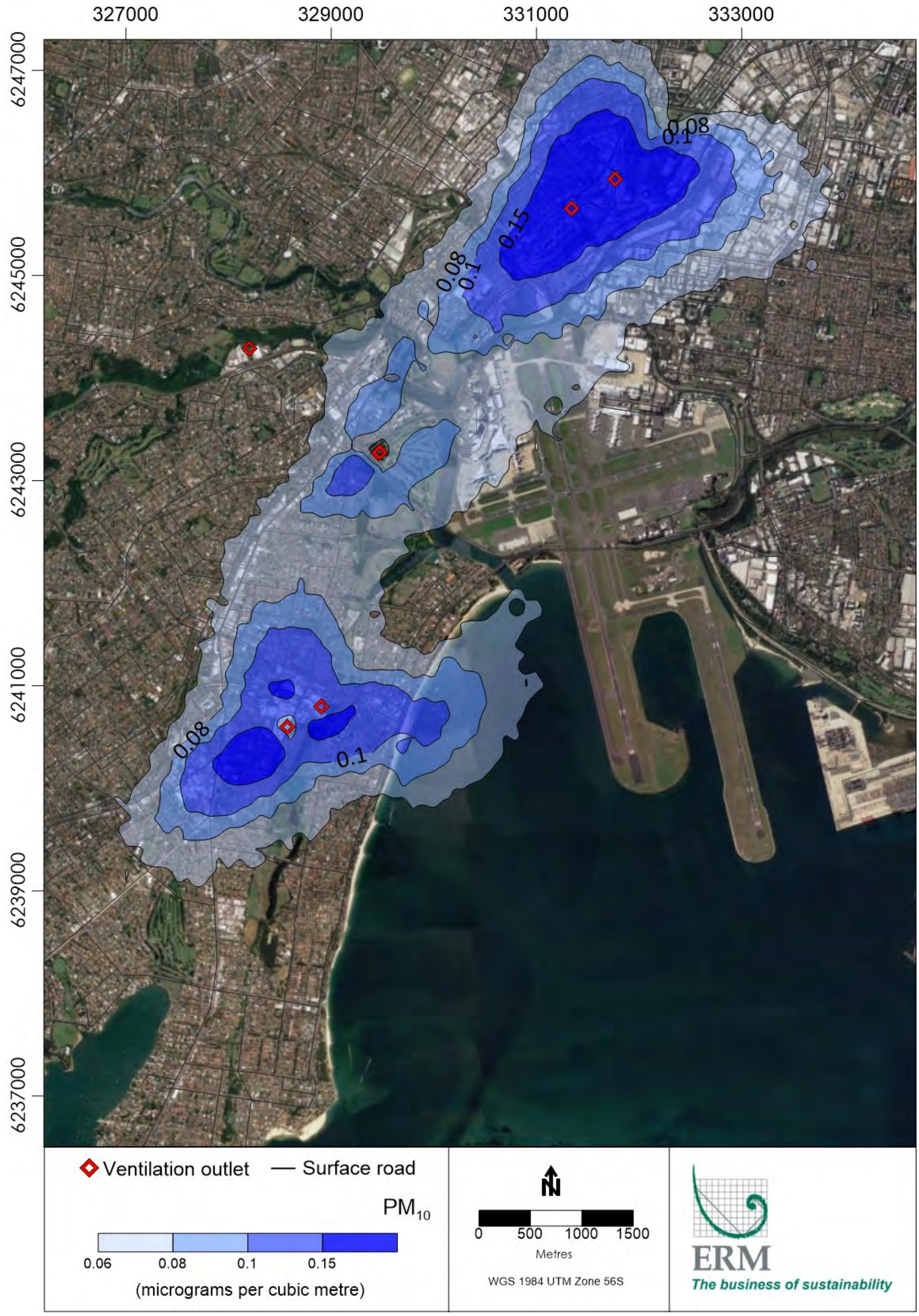


Figure J-10 Contour plot of annual mean PM_{10} for all ventilation outlets in 2036-DSC scenario

J.5.4 Maximum 24-hour PM_{10}

J.5.4.1 2026-DS scenario

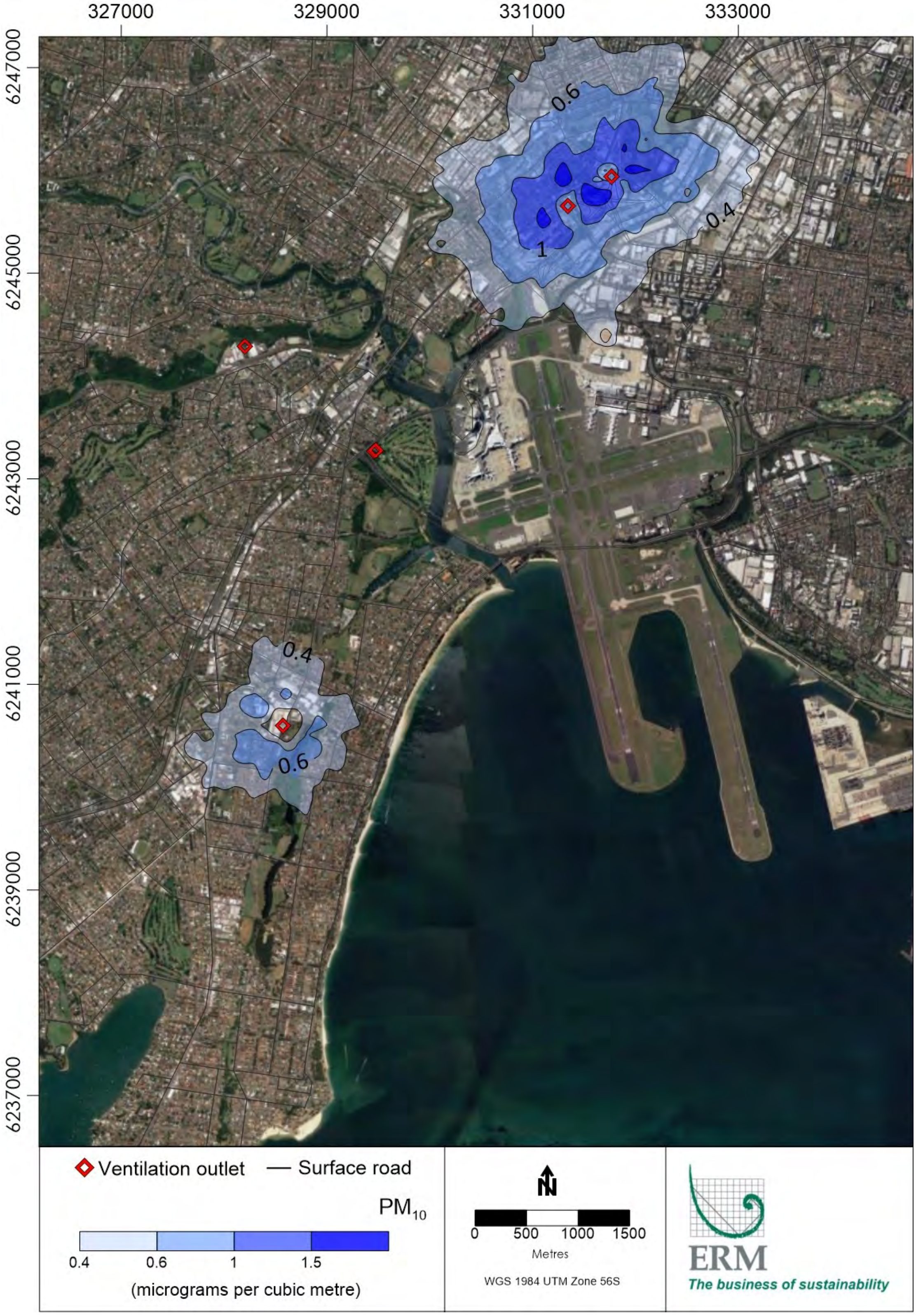


Figure J-11 Contour plot of maximum 24-hour PM_{10} for all ventilation outlets in 2026-DS scenario

J.5.4.2 2036-DS scenario

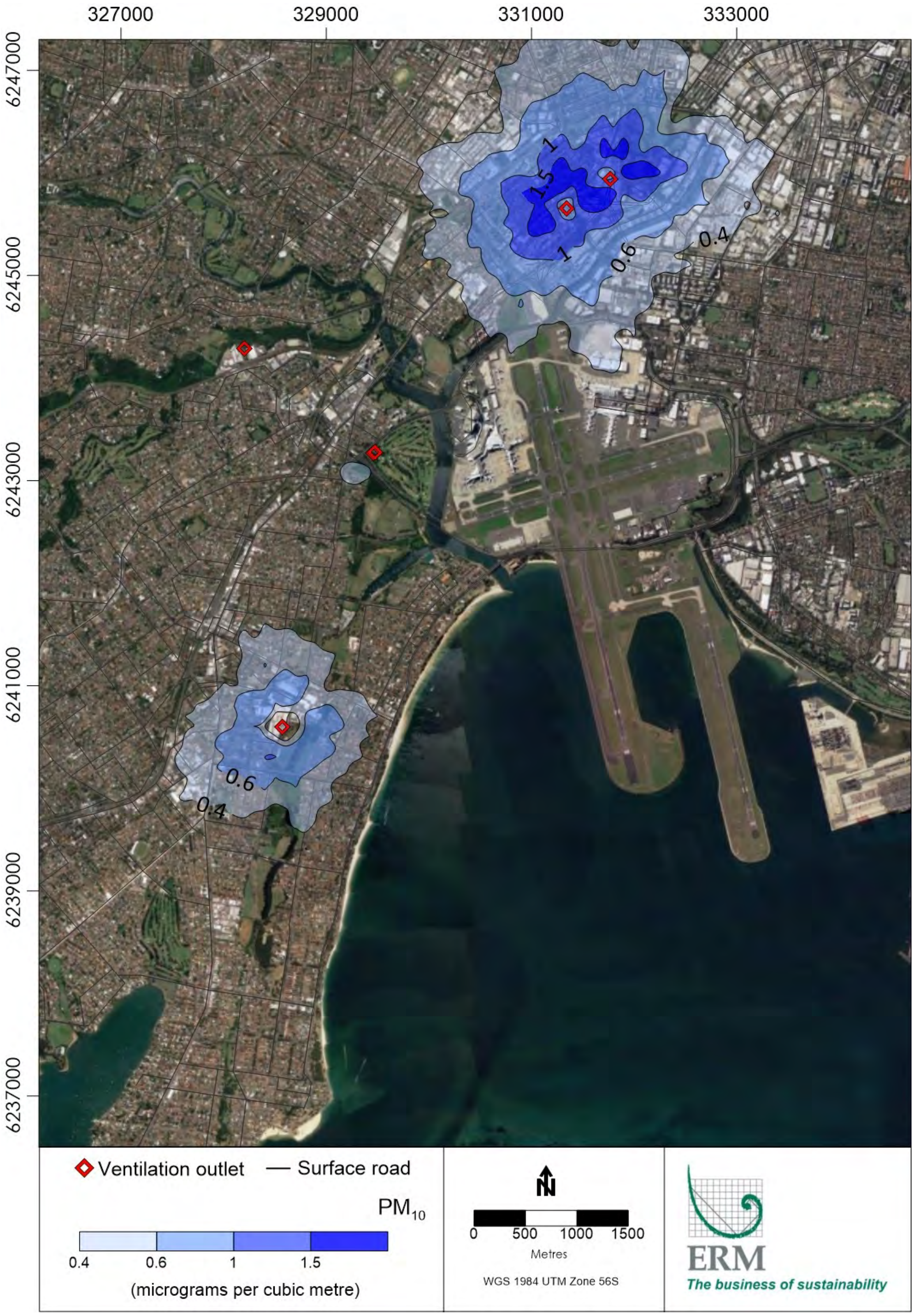


Figure J-12 Contour plot of maximum 24-hour PM_{10} for all ventilation outlets in 2036-DS scenario

J.5.4.3 2036-DSC scenario

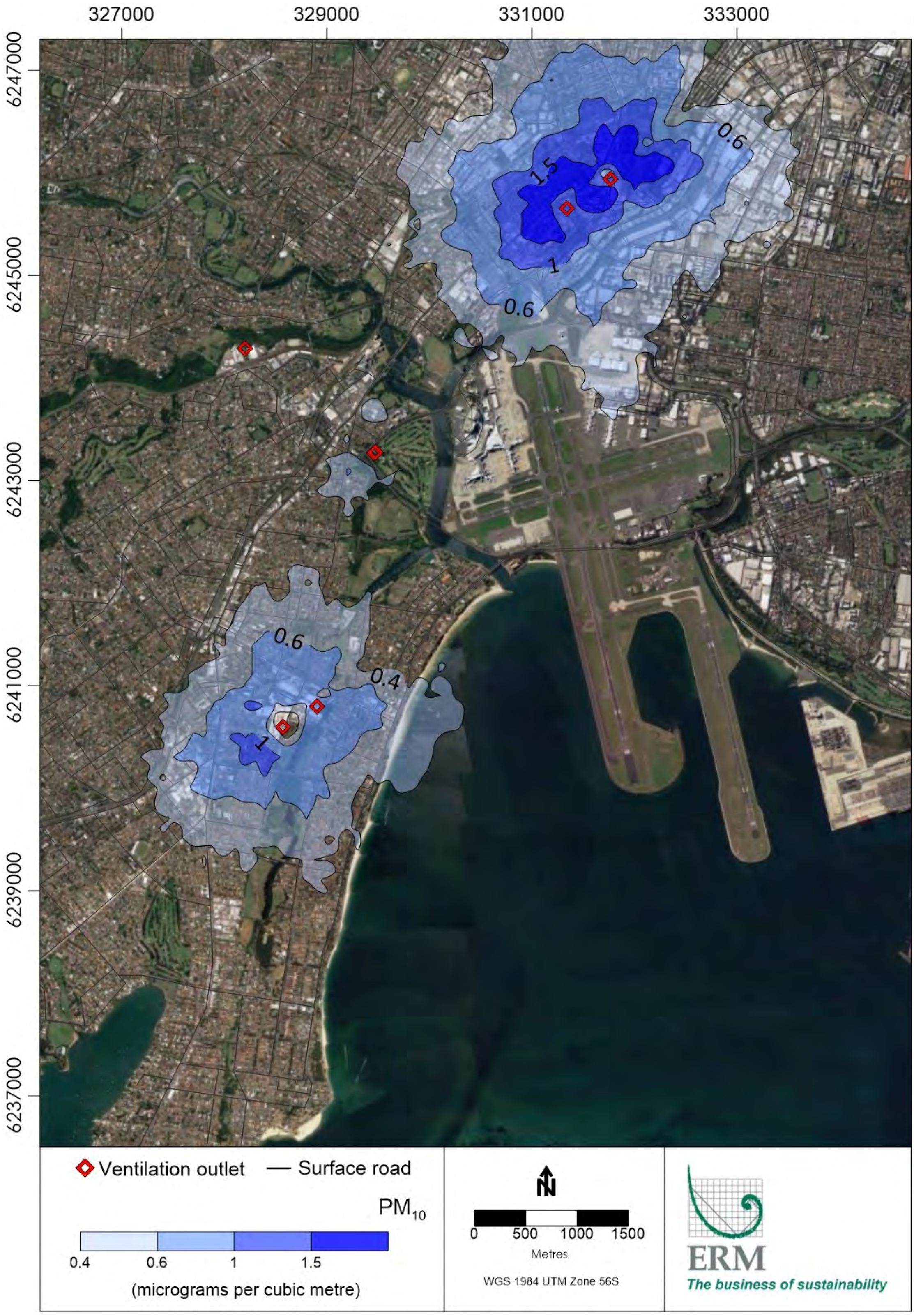


Figure J-13 Contour plot of maximum 24-hour PM_{10} for all ventilation outlets in 2036-DSC scenario

J.5.5 Annual $PM_{2.5}$

J.5.5.1 2026-DSscenario

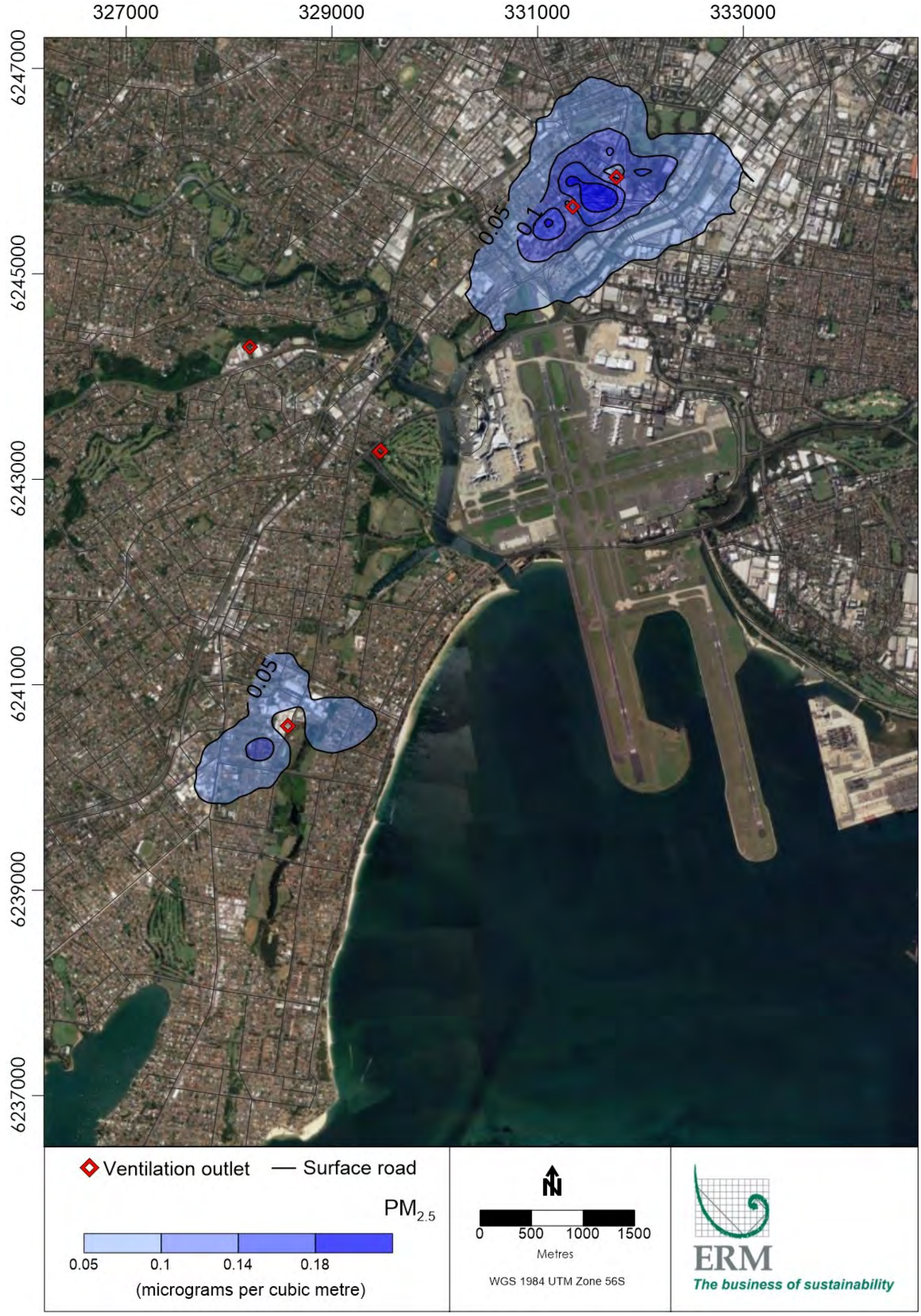


Figure J-14 Contour plot of annual mean $PM_{2.5}$ for all ventilation outlets in 2026-DS scenario

J.5.5.2 2036-DS scenario

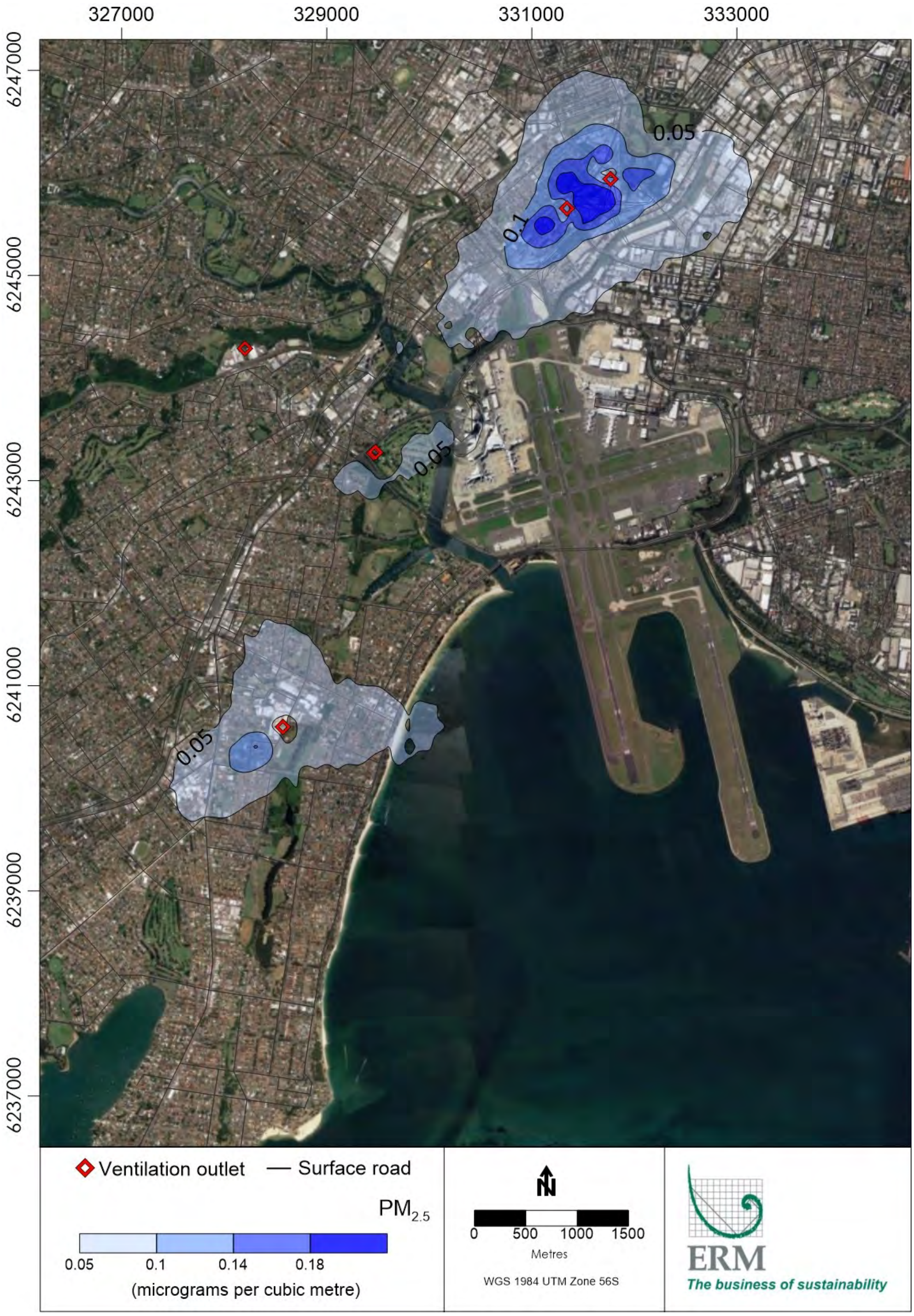


Figure J-15 Contour plot of annual mean $PM_{2.5}$ for all ventilation outlets in 2036-DS scenario

J.5.5.3 2036-DSC scenario

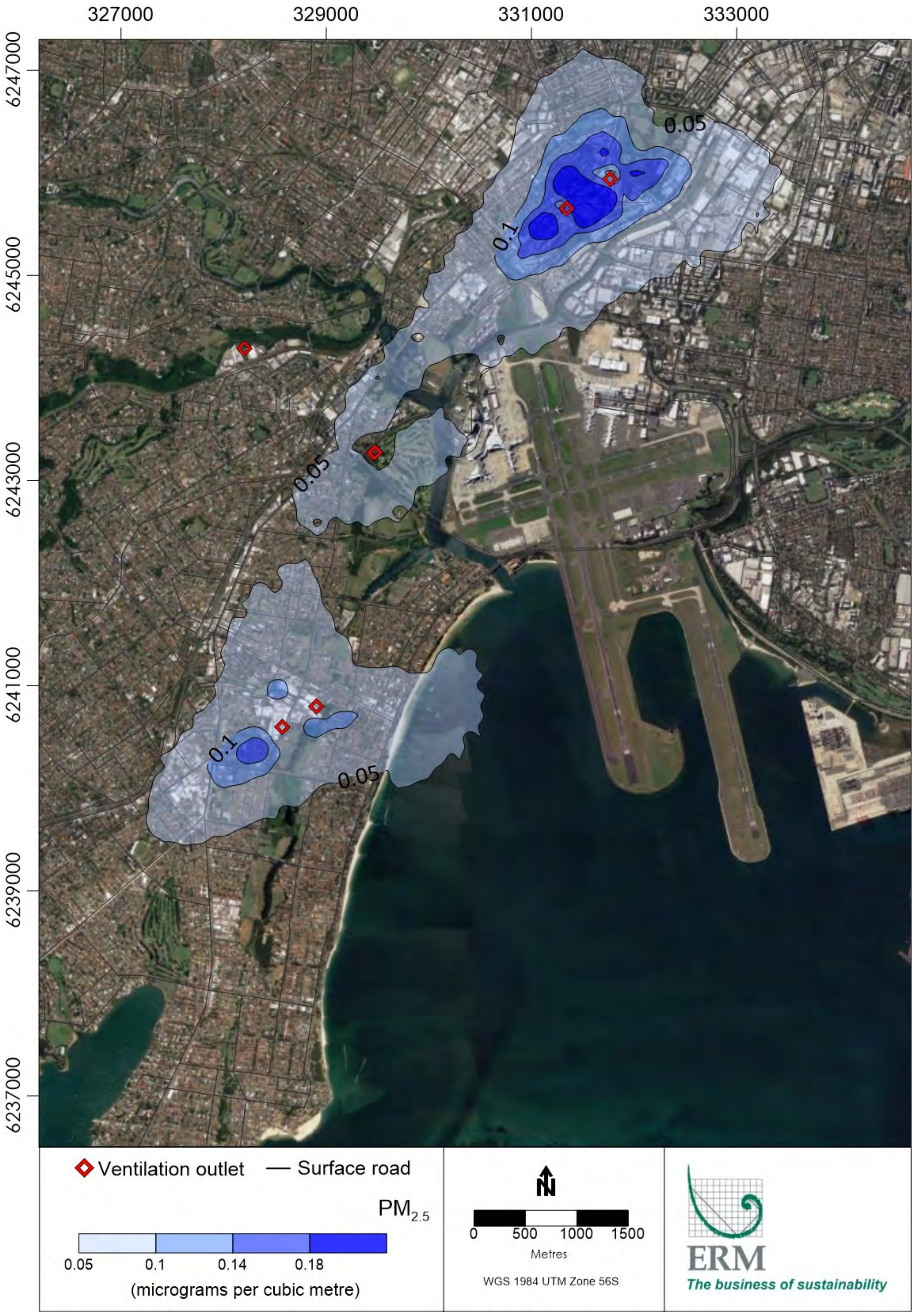


Figure J-16 Contour plot of annual mean $PM_{2.5}$ for all ventilation outlets in 2036-DSC scenario

J.5.6 Maximum 24-hour $PM_{2.5}$

J.5.6.1 2026-DS scenario

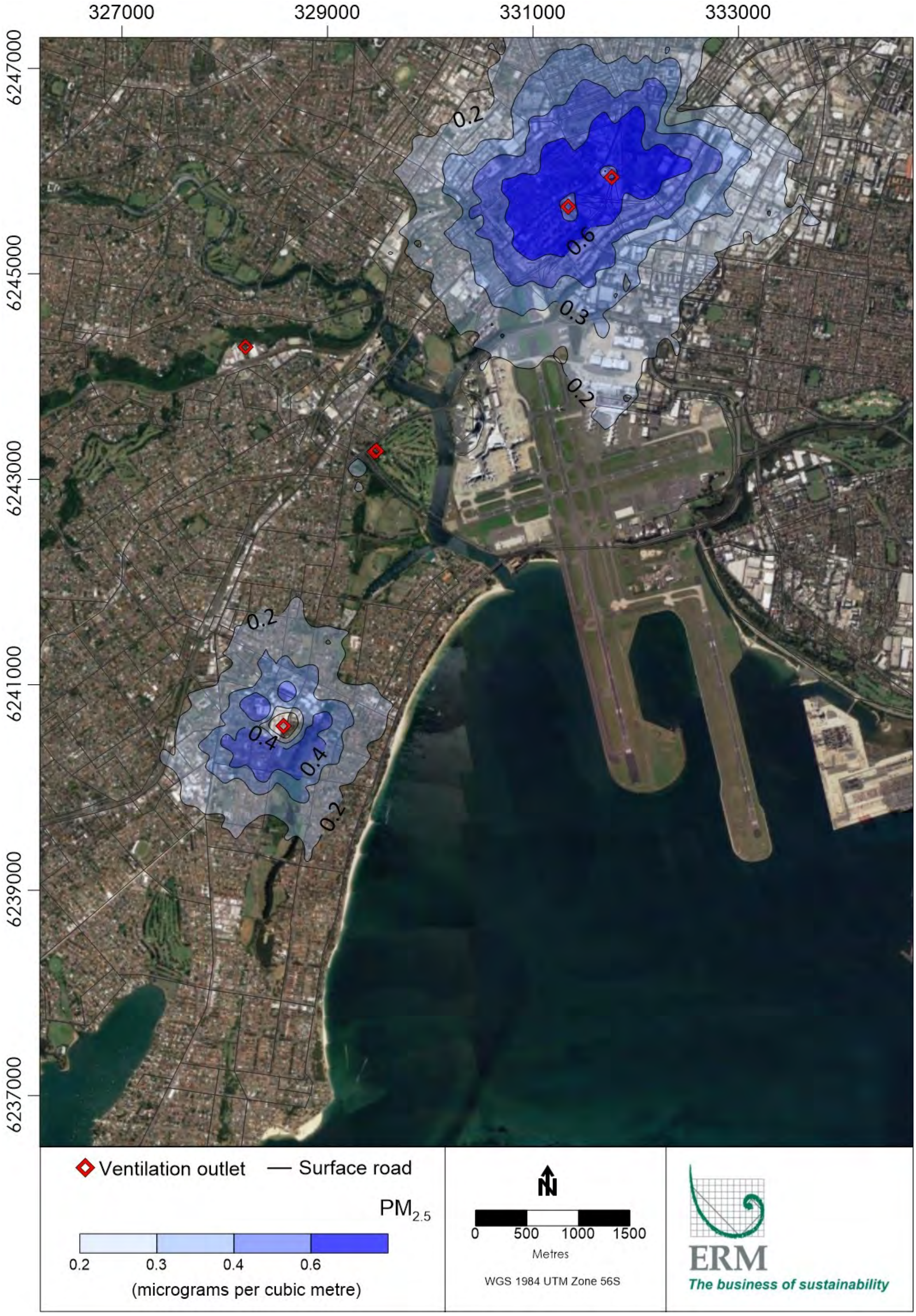


Figure J-17 Contour plot of maximum 24-hour $PM_{2.5}$ for all ventilation outlets in 2026-DS scenario

J.5.6.2 2036-DS scenario

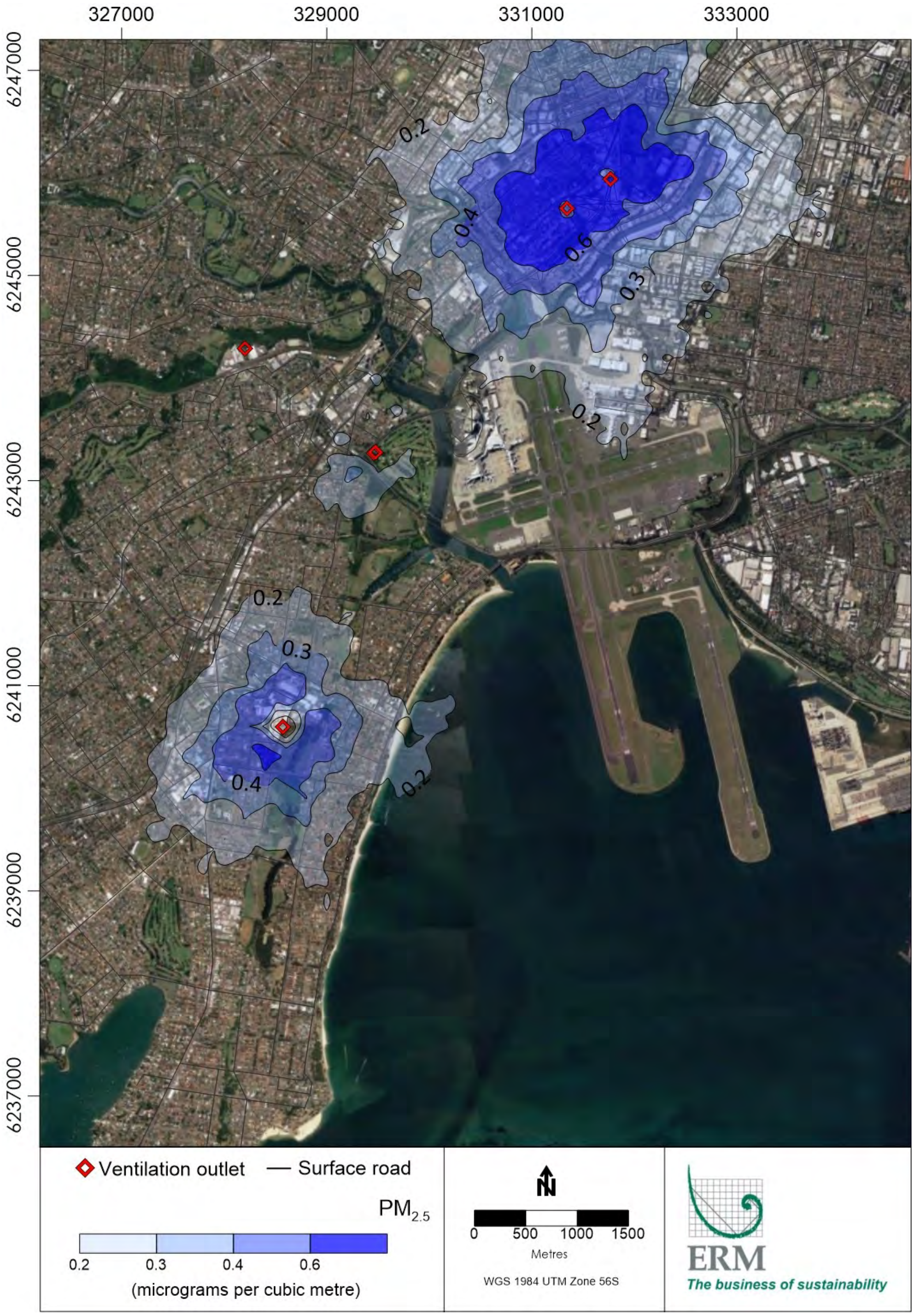


Figure J-18 Contour plot of maximum 24-hour $PM_{2.5}$ for all ventilation outlets in 2036-DS scenario

J.5.6.3 2036-DSC scenario

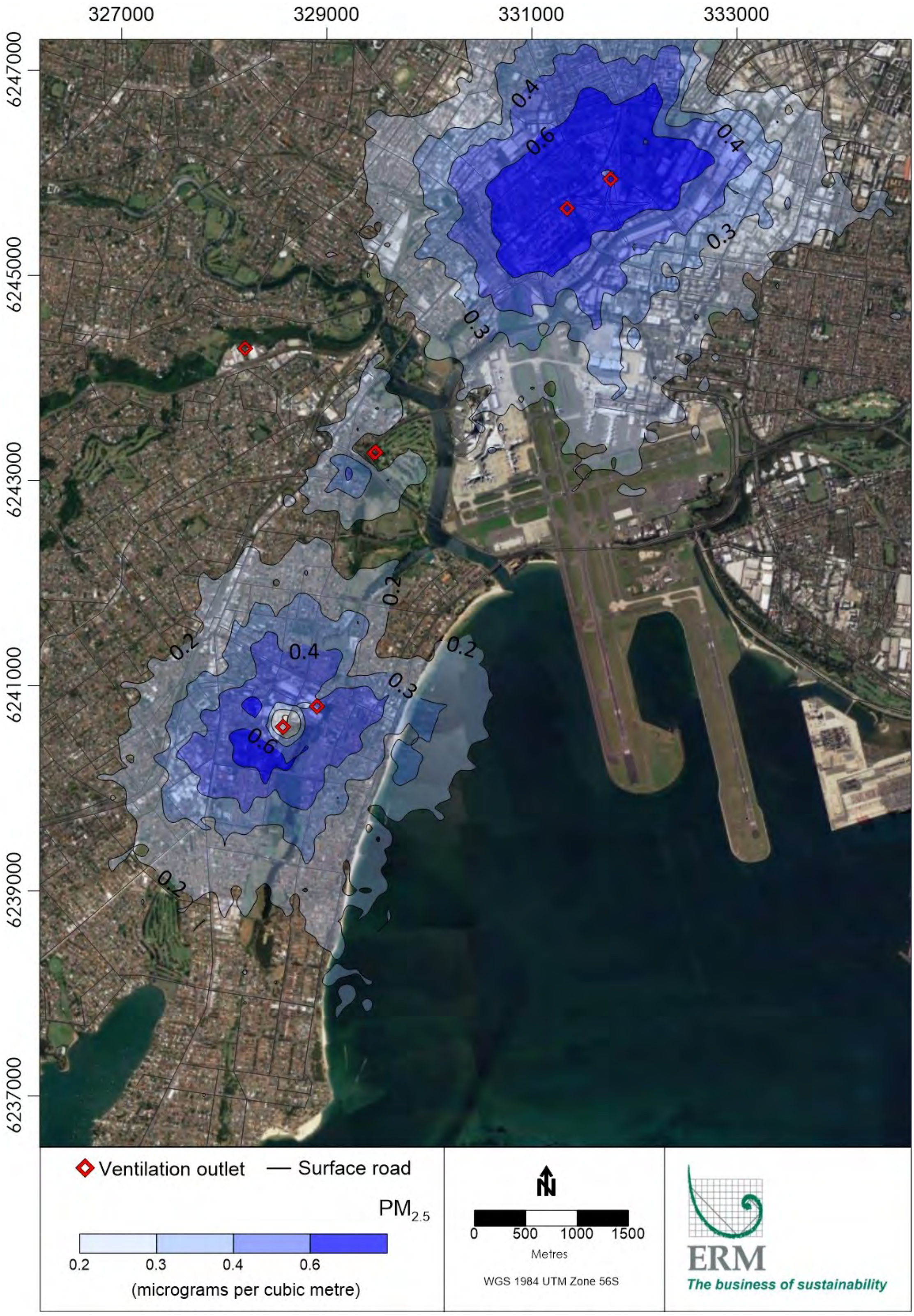


Figure J-19 Contour plot of maximum 24-hour $PM_{2.5}$ for all ventilation outlets in 2036-DSC scenario

Annexure K - Ventilation report

F6 EXTENSION - STAGE 1 (NEW M5 MOTORWAY, ARNCLIFFE TO PRESIDENT AVENUE, KOGORAH)

VENTILATION REPORT FOR ENVIRONMENTAL IMPACT STATEMENT

for AECOM via Bamser

23RD MAY 2018

REVISION HISTORY			
No.	**Date**	**Comment**	**Signed**
2	23rd May 2018	Final for EIS exhibition	C Stacey

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EXECUTIVE SUMMARY

This report describes the tunnel ventilation system concept design and performance for the F6 Extension - Stage 1 (New M5 motorway to President Avenue, Kogarah) (the project) in the context of the Environmental Impact Statement (EIS) for the project. As well as explaining the design, later sections give the analysis results necessary for inclusion in the EIS. In support of the outcomes presented, this report includes the assumptions made, the treatment of analysis inputs, and the analysis methodology.

The Project incorporates an underground connection part way along the WestConnex New M5 project at Arncliffe, which is currently under construction. Once completed, traffic will be able to travel completely underground between President Avenue (Kogarah) and the WestConnex tunnel network including any possible future connections at Rozelle Interchange.

All tunnels must be controlled together for a successful ventilation outcome. This report documents the ventilation design of the project as an integral part of the New M5 (and wider WestConnex) ventilation system.

The project is based on a longitudinal ventilation arrangement. Ventilation plants will be required at all traffic exit portals to ensure net inflow of air, to prevent portal emissions. Traffic entry portals will naturally have net portal inflow due to vehicle driven airflows.

The ventilation facility at Arncliffe which is the interface point with New M5 will include provision for extracting tunnel air or supplying fresh air in both directions of travel (see Figure E.1).

- In the northbound direction of travel, some of the air arriving at Arncliffe from both New M5 and F6 Extension may be exhausted during normal operations to maintain in-tunnel air quality. The exhaust will also be used during emergencies for smoke extraction.
- In the southbound direction of travel, no air is exhausted during normal operations with all air passing through the interface to both New M5 and F6 Extension. The southbound exhaust is provided to exhaust smoke during emergencies.

The ventilation system of New M5 and F6 Extension, as outlined in this report, meets or exceeds the functional performance requirements of the M4-M5 Link EIS. As such, the integrated analysis of the overarching tunnel network completed as part of the M4-M5 Link EIS remains valid.

This report includes the detailed analysis outputs necessary for environmental assessment, including the outlet emission parameters that are inputs to pollutant dispersion analysis. In line with other EIS components, in-tunnel air quality and external emissions have been assessed at 2026 and 2036, corresponding to opening year and 10 years after opening.

The design meets the in-tunnel pollution criteria for all design traffic conditions. The limiting design traffic scenarios (severe congestion) are more onerous than the expected traffic flows, and so the criteria are met comfortably for the expected 2026 and 2036 traffic.

Figure E.4 below shows the overall ventilation scheme for the project and the direct interfaces with WestConnex New M5 project. Possible future stages of F6 Extension are also indicated.

In-tunnel airflow, pollution levels, and temperature, are simulated and analysed using software called IDA Tunnel, developed by EQUA AB in Sweden. The PIARC detailed Euro-based methodology has been used for estimating in-tunnel vehicle emissions.

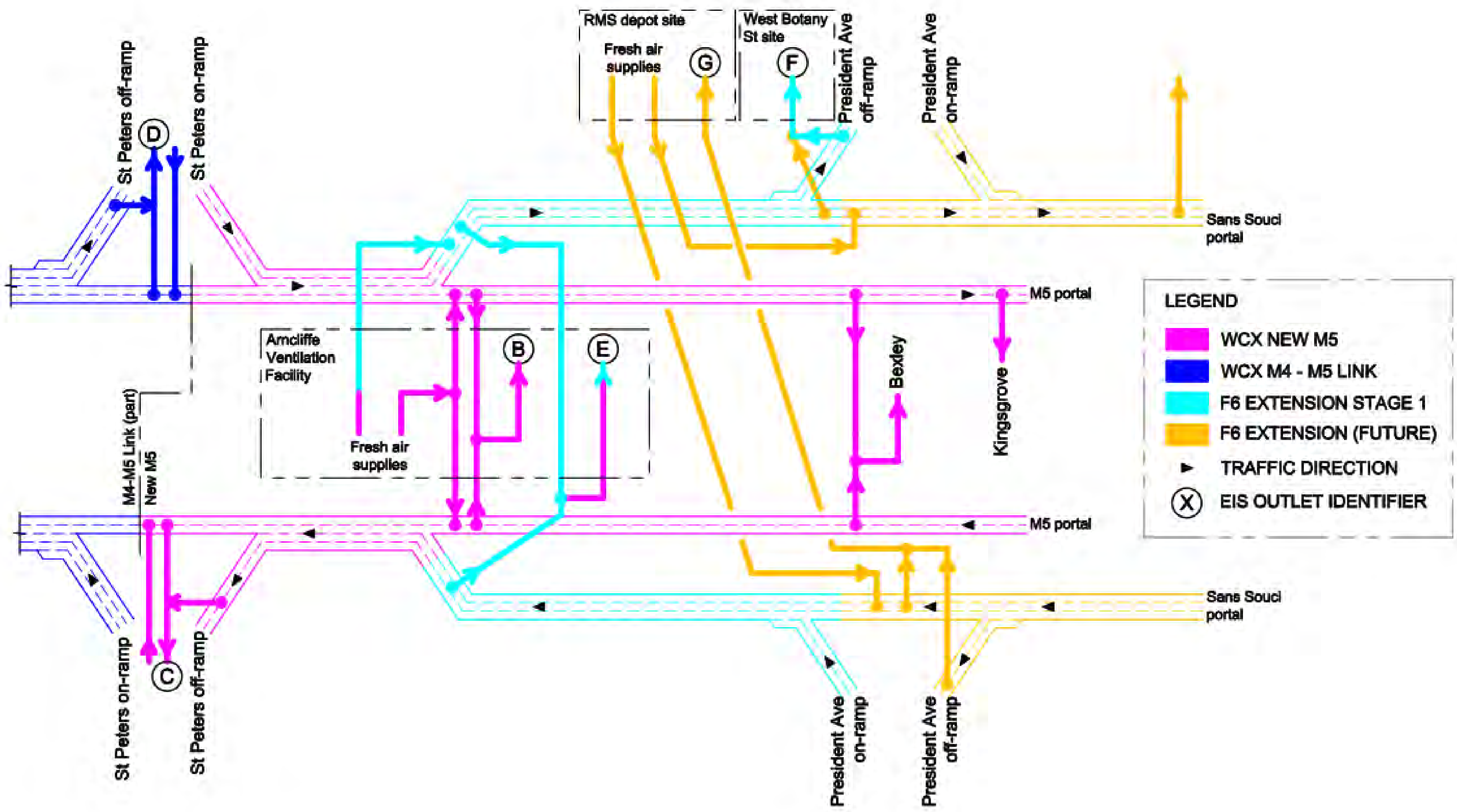

Figure E.1. Ventilation schematic for the project (including proposed future stages) and New M5.

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1 DEFINITIONS, ABBREVIATIONS AND NOMENCLATURE

Term	Explanation
ACTAQ	Advisory Committee on Tunnel Air Quality. A committee chaired by the Chief Scientist and Engineer of NSW.
BOM	(Australian) Bureau of Meteorology. The source of climate and weather data.
Do minimum	A model or analysis scenario for the tunnel system with M4 East, New M5 and M4-M5 Link, but without F6 Extension.
Do something	A model or analysis scenario for the tunnel system with M4 East, New M5, M4-M5 Link and F6 Extension Stage 1.
CASA	Civil Aviation Safety Authority.
CCW	The counter-clockwise traffic direction, see “M5 to M4”.
CO	Carbon monoxide.
CW	The clockwise traffic direction, see “M4 to M5”.
Cumulative	A model or analysis scenario for the tunnel system with M4 East, New M5, M4-M5 Link and F6 Extension Stage 1. Includes proposed future Western Harbour Tunnel, Beaches Link and future stages of the F6 Extension in some scenarios.
Expected (traffic)	The traffic profiles based on demand predicted by SMPM.
FBC	Final Business Case, refers to Stage 1 of the F6 Extension Project Final Business Case.
F6 Extension	The development of a proposed motorway that links the existing A1 Princes Highway at Loftus, with the Sydney motorway network at Arncliffe.
Future stages of the F6 Extension	Refers to the proposed extension of the project to future stages of the F6 Extension, extending from the stub tunnels at Kogarah (to be constructed as part of the project)
F6 Extension - Stage 1 (New M5, Arncliffe to President Avenue, Kogarah)	F6 Extension - Stage 1 (New M5, Arncliffe to President Avenue, Kogarah).
HGV	Heavy Goods Vehicle, generally aligned with PIARC HGV vehicle category.
Hour	Hour of the day, with the value representing the start time for the hour. That is, Hour 0 is the period midnight to 1 am, Hour 1 is the period 1 am to 2 am, etc.
Jet fan	A fan hung under the tunnel ceiling to add momentum to the tunnel air via a high-speed outlet air stream, and hence promote longitudinal airflow.
LDV	Light Duty Vehicle, generally aligned with PIARC LDV vehicle category.
PC	Passenger Car, generally aligned with PIARC PC vehicle category.

Term	Explanation
PCU	Passenger Car Unit. A unit used to represent lane occupancy by an equivalent number of passenger cars for each real vehicle.
PIARC	Permanent International Association of Road Congresses, the global body which develops, collects and disseminates information about all aspects of road design and operation. Also known as the World Road Association. http://www.piarc.org/en/.
PIARC Australian tables	Tables in Section 3.1 of document 2012R05EN "Road tunnels: vehicle emissions and air demand for ventilation" by PIARC Technical Committee C4, December 2012. Used in a simplified estimation of vehicle emissions in Australian tunnels.
PIARC detailed method	The method for estimating vehicle emissions using the base emission tables in PIARC document 2012R05EN noted above.
Piston effect	Common term used to describe the effect of the vehicle aerodynamic drag force acting on the tunnel air to promote longitudinal air flow.
M4 East (New M4)	A component of the WestConnex program of works. Extension of the M4 Motorway in tunnels between Homebush and Haberfield via Concord.
M4 to M5	The general direction of traffic heading clockwise in the WestConnex project. This includes routes generally in the direction: • From the M4 East portal at Underwood Rd to the New M5 portal at Kingsgrove or F6 Extension at President Ave. • From the M4 East portal at Underwood Rd to Rozelle (including WHT, Anzac Bridge and Iron Cove link) • From Rozelle (including WHT, Anzac bridge and Iron Cove link) to the New M5 portal at Kingsgrove or F6 Extension at President Ave. Corresponds with the southbound direction of travel within the project.
M5 to M4	The general direction of traffic heading counter clockwise (CCW) in the WestConnex project. This includes routes generally in the direction: • From the New M5 portal at Kingsgrove or F6 Extension at President Ave to the M4 East portal at Underwood Rd. • From the New M5 portal at Kingsgrove or F6 Extension at President Ave to Rozelle (including WHT and Iron Cove link). • From Rozelle (including WHT and Iron Cove link) to the M4 East portal at Underwood Rd. Corresponds with the northbound direction of travel within the project.

Term	Explanation
New M5	A component of the WestConnex program of works. A motorway project located from Kingsgrove to St Peters.
NO_2	Nitrogen dioxide.
NO_X (NO_2 equivalent)	Oxides of Nitrogen. Within this report, is assumed as NO + NO_2 only and expressed as NO_2 equivalent.
Northbound	The direction of travel within the project from President Ave at Kogarah to New M5 at Arncliffe . Corresponds to the M5 to M4 direction of travel.
PM	Particulate matter. Within this report means either vehicle exhaust or roadway sourced (non-exhaust).
Project	A new, multi-lane road link between the New M5 at Arncliffe and President Avenue at Kogarah, built in tunnels.
Roads and Maritime	NSW Roads and Maritime Services.
SEARs	Secretary's Environmental Assessment Requirements.
SMPM	Sydney Strategic Motorway Planning Model (version 1). The strategic traffic model that was developed by NSW Roads and Maritime Services and is the source of the traffic forecasts used in this work.
Southbound	The direction of travel within the project from New M5 at Arncliffe to President Ave at Kogarah. Corresponds to the M4 to M5 direction of travel.
WestConnex (WCX) program of works	A 33 kilometre motorway linking Sydney's west and south-west with Sydney Airport and the Port Botany precinct. It includes the M4 Widening, King Georges Road Interchange Upgrade, M4 East, New M5, M4-M5 Link and Sydney Gateway projects.
Worst case (traffic)	The traffic case(s) which result in the most onerous requirements for the tunnel ventilation system.
WHT	Western Harbour Tunnel.
WHT&BL	Western Harbour Tunnel and Beaches Link.

1.1 Schematic nomenclature

To assist the reader, schematic diagrams throughout this report have been prepared in a uniform manner wherever practicable. Figure 1.1 outlines the nomenclature used.

The schematics are intended only to show the overall connectivity between the tunnel and ventilation outlet and supply plant. They do not represent the physical layout and/or connections.

Colour coding is used to represent, at a broad level, the scope elements of the various projects. The colour coding may generally follow the contractual scope responsibility but is not guaranteed to be an exact representation.

Table 6.2 lists the ventilation outlets shown in the schematics with their EIS outlet identifier.

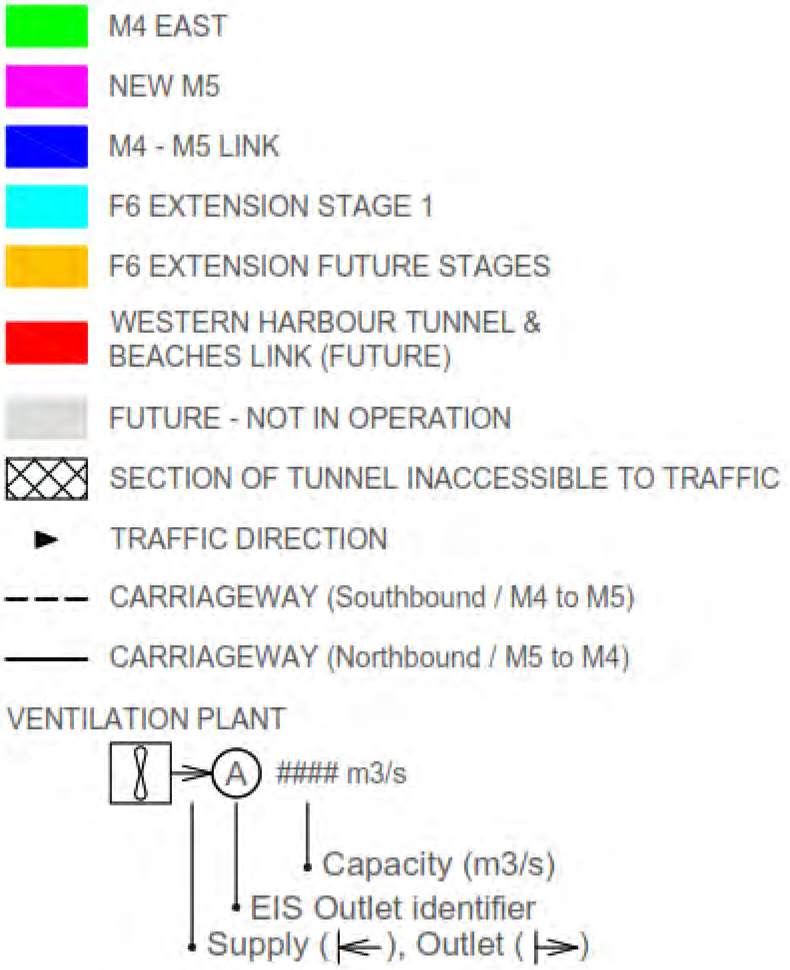


Figure 1.1 Schematic nomenclature

2 INTRODUCTION

The tunnel ventilation system must continuously, reliably and efficiently provide a safe environment for tunnel users and external communities. Figure 2.1 shows the layout of the whole tunnel system, including the proposed future Western Harbour Tunnel and Beaches Links projects.

With the number of underground intersections, there are a significant number of different potential incidents requiring effective ventilation. Even without an incident, the random variation in traffic requires a robust and responsive ventilation system. The ventilation will be controlled as one system across the project and WestConnex, both for safe emergency responses and for minimizing power costs for day to day coordinated operations.

This report discusses a range of analyses and presents the associated results for a number of different tunnel configurations. As a guide to the content, Table 2.1 outlines the matrix of analysis completed and identifies the location of the associated results within this report.

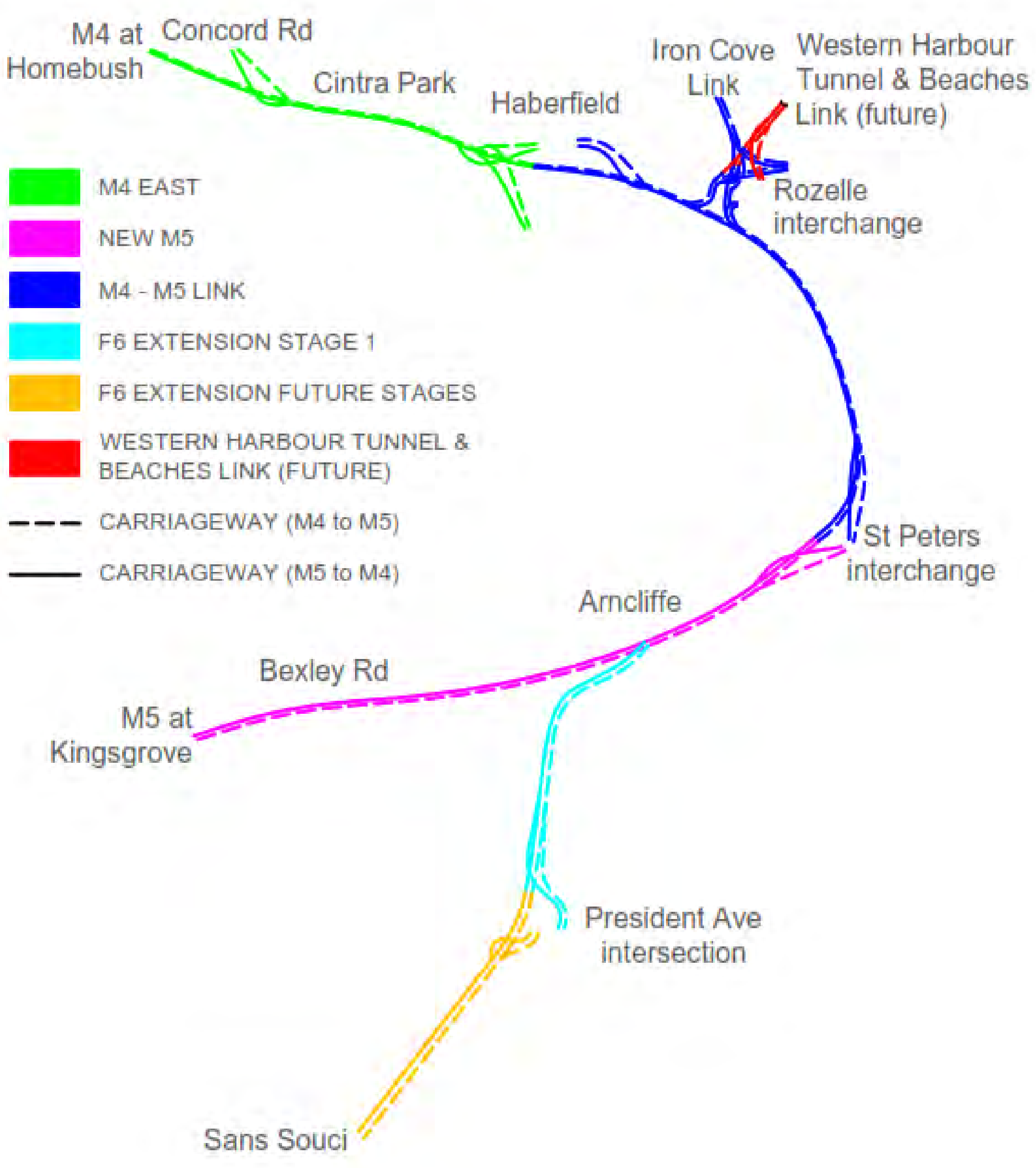


Figure 2.1. Layout of F6 Extension and interconnected tunnel network.

Table 2.1. Summary of analysis scenarios.

Scenario	**Do Minimum**		**Do something**		**Cumulative**	
Year (traffic and vehicle emissions)	**2026**	**2036**	**2026**	**2036**	**2026**	**2036**
Tunnel arrangement						
M4 East	X	X	X	X	X	X
New M5	X	X	X	X	X	X
M4-M5 Link	X	X	X	X	X	X
Sydney Gateway*	X	X			X	X
King Georges Road Interchange Upgrade*	X	X	X	X	X	X
Western Harbour Tunnel						X
Beaches Link						X
F6 Extension - Stage 1			X	X	X	X
F6 Extension - future stages						X
Expected traffic operations	Section 8.1.1	Section 8.1.2	Section 8.2.1	Section 8.2.2	Section 8.3.1	Section 8.3.2
Worst case traffic operations	n/a	n/a	Section 9.1			Section 9.2

*surface road that does not form part of the tunnel network but forms part of the traffic predictions.

Expected traffic (24 hr) operations: Represents the expected operation of the tunnel ventilation system under day-to-day conditions of expected traffic demand. Vehicle emissions are based on the design fleet in the corresponding year, with results presented both for in-tunnel air quality and for outlet emissions for use by others in assessing ambient air quality.

Worst case traffic operations: The range of traffic cases which result in the most onerous requirements for the tunnel ventilation system. This encompasses traffic conditions such as congestion (with average speed ≥20 km/h) and vehicle breakdowns as well as free-flowing traffic at maximum tunnel capacity with traffic continuity.

3 PROJECT OVERVIEW

3.1 F6 Extension Stage 1

The Project links the southern Sydney road network at President Avenue, Kogarah to the WestConnex tunnels part way along New M5 at Arncliffe. The F6 Extension tunnel ventilation systems will be fully integrated with the New M5, which is in turn integrated within the wider WestConnex tunnel ventilation systems.

The ventilation provisions at the interface of F6 Extension and New M5 are shown in Figure 3.1. This work assumes the following at the F6 Extension Stage 1 / New M5 interface:

- In the northbound direction of travel during normal operations, some of the air arriving at Arncliffe from both New M5 and F6 Extension may be exhausted and the tunnel re-supplied with fresh air only as necessary to maintain in-tunnel air quality.
- In the southbound direction during normal operations, no air is exhausted, with all arriving air passing through the interface to both New M5 and F6 Extension.

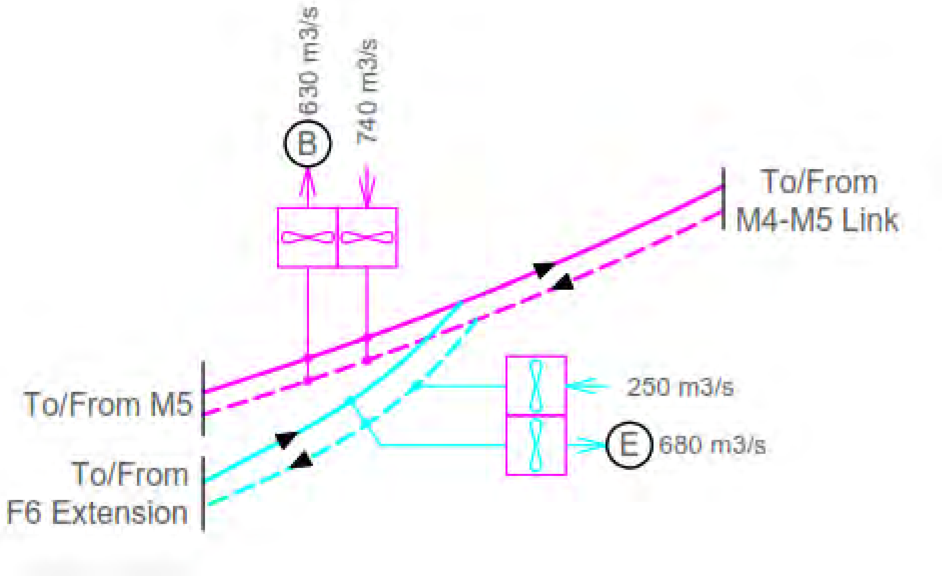


Figure 3.1. Schematic of F6 Extension Stage 1 interface with New M5.

The ventilation provisions at President Avenue as shown in Figure 3.2 including the future stages of F6 Extension. Assumptions for the future stage of F6 Extensions are described in Section 3.4.1.

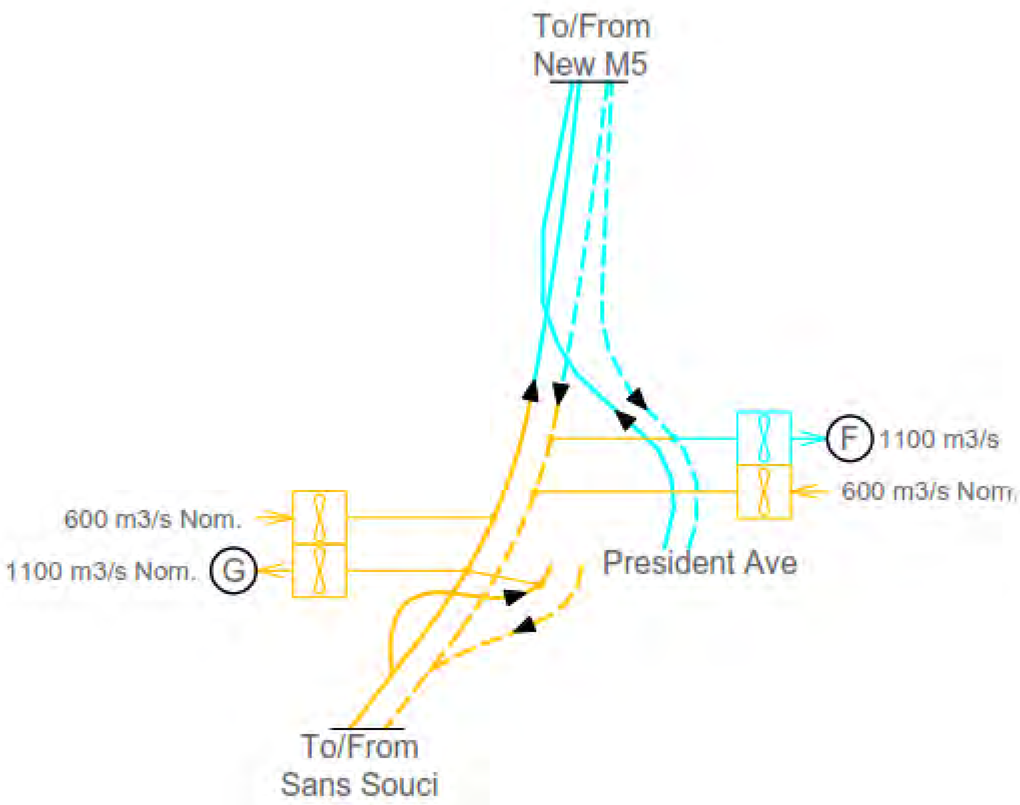


Figure 3.2. Schematic of President Avenue intersection (with future stages of F6 Extension)

3.2 M4-M5 Link

As shown in Figure 2.1, the M4-M5 Link connects three other motorway tunnel projects; two of which are already under construction (New M5 and M4 East), and the proposed future Western Harbour Tunnel and Beaches Link (WHT&BL).

The project may be constructed and opened to traffic in two stages:

1) Mainline tunnels between the M4 East at Haberfield and the New M5 at St Peters including entry and exit ramps to the Wattle Street interchange at Haberfield and the St Peters interchange at St Peters.
2) Rozelle interchange to connect the mainline tunnels with a) the surface road network and Anzac Bridge, b) the Iron Cove Link and c) the future WHT&BL.

Throughout this report, the M4-M5 Link is analysed with both stages noted above completed and is assumed to have the ventilation capacity defined within the M4-M5 Link EIS.

3.3 New M5

The New M5 tunnels connect to the M4-M5 Link between the two sets of ramps at St Peters Interchange (SPI) as shown in Figure 3.3. Provision for mainline air exchange at St Peters is being made by the New M5 contractor for the northbound tube, and by M4-M5 Link for the southbound tube. The reasoning behind splitting the ventilation plant between the projects was to allow the interface exhaust plant to be co-located with the exhaust plant capturing the exit ramp flows.

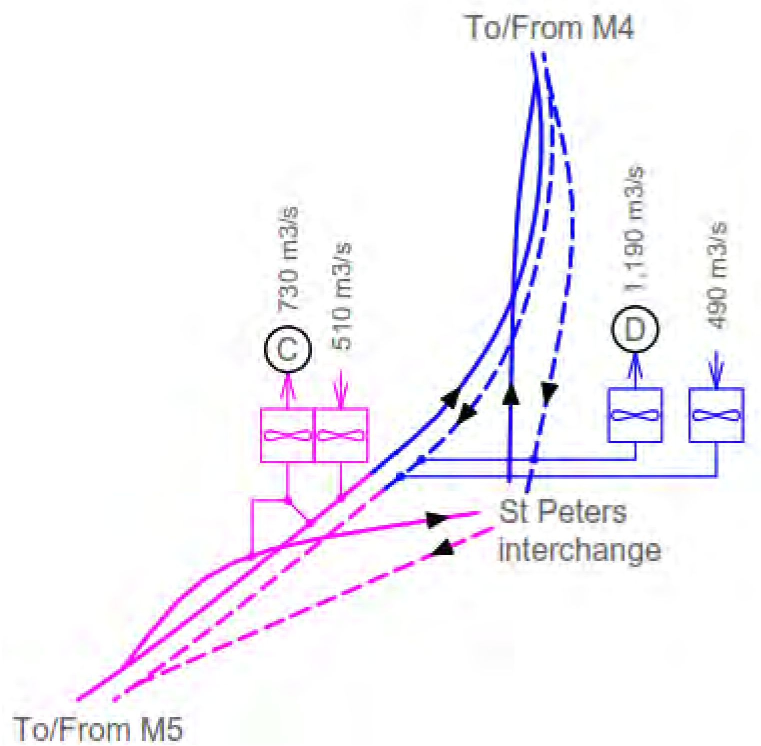


Figure 3.3. Schematic of the St Peters interchange (M4-M5 Link / New M5 interface).

3.4 Potential Future Tunnel connections

3.4.1 Future stages of F6 Extension

The proposed future stages of F6 Extension extend southward from the stub tunnels at Kogarah. From a ventilation perspective, it is assumed that complete exchange of air will be effected at or around the interface of the project with future stages of F6 Extension, located nominally at the President Avenue intersection. That is; in this assessment, there will be no-carry over of pollution in either direction. Figure 3.2 above outlines the nominal ventilation arrangement at President Ave intersection.

Emissions arriving at President Avenue from the northbound tunnels south of President Avenue have only been assessed for the expected traffic scenario to support ambient air-quality modelling. Emissions in the southbound tunnels south of President Avenue have not been assessed within this report.

Any changes to the assumptions herein would need to be considered separately as part of the development and assessment of futures stages of F6 Extension.

4 SCOPE AND STRUCTURE

4.1 Purpose of Report

This report documents the concept ventilation design and analysis for the purposes of the Environmental Impact Statement (EIS). It records the input data used in the tunnel ventilation analysis, and the predicted air flow and pollution levels, both in-tunnel and at the ventilation outlets. The important outputs are the predicted emissions for the expected traffic cases, pollution levels along the tunnel, and the ventilation plant capacity. The ventilation design for capacity traffic cases and emergency response is also described.

4.1.1 M4-M5 Link EIS Ventilation Report

The M4-M5 Link EIS Ventilation Report (Appendix L to the Air Quality Impact Assessment in Appendix H of the M4-M5 Link EIS) remains valid for the integrated operation of the WestConnex and F6 Extension Stage 1 tunnel ventilation systems. The current geometry and alignment of F6 Extension Stage 1 is quite similar to that adopted for integrated analysis undertaken in the M4-M5 Link EIS.

This F6 Extension EIS report:

- Demonstrates that changes in geometry and alignment of the project from that foreseen in the M4-M5 Link EIS do not impact the integrated operation of the WestConnex and F6 Extension tunnel system as it was outlined in the M4-M5 Link EIS.
- Supplements the M4-M5 Link EIS, reviewing alternative plant operating philosophy for the coordinated operation of the integrated tunnel network including WestConnex and F6 Extension, incorporating revised tunnel geometry for the project and traffic demand for differing years of operation.

4.1.2 New M5 EIS Ventilation Report

The New M5 EIS Ventilation Report (Appendix L to the Air Quality Impact Assessment in Appendix H of the New M5 EIS) is largely superseded by this report, the M4-M5 Link EIS and the New M5 project. The current geometry and alignment of the M4-M5 Link and F6 Extension differs from that foreseen in the New M5 project and the New M5 EIS. The significant changes include:

- M4-M5 Link now incorporates a continuous underground connection between M4 East and New M5. Previously the project surfaced at Rozelle, which from a ventilation perspective meant the M4 East and New M5 were isolated from each other.
- Increase in the mainline project carriageways, linking Rozelle to St Peters, from 3 to 4 lanes.
- Potential future increase in the F6 Extension mainline from 2 lanes to 3 lanes.

Responsibility for design and construction of the New M5 ventilation plant now lies with the New M5 project, superseding all plant capacity and other requirements outlined in the New M5 EIS report.

This F6 Extension EIS report:

- Supplements the New M5 project reports, reviewing interface plant capacity for the coordinated operation of the WestConnex tunnel system, incorporating revised tunnel geometry for the project and traffic demand for different years of operation.
- Supersedes the New M5 EIS Ventilation report for analysis and results associated with operation after connection of the project.

5 TUNNEL VENTILATION OVERVIEW

5.1 Objectives

The primary objectives of the ventilation system are:

1) Maintain in-tunnel air quality within the adopted criteria under the range of plausible traffic conditions. Within the context of the concept design, this means all traffic conditions where the average vehicle speed is above 20 km/h.
2) Maintain a net inflow of air into all traffic portals to prevent emissions from these locations during normal operations.
3) During a fire, control the spread of smoke to support both the safe evacuation of occupants from the tunnel and access for emergency response personnel. The primary goal is to achieve critical velocity at the fire site to prevent back layering of smoke.

5.2 Concept design scheme

The tunnel ventilation scheme for the project and the wider WestConnex tunnel system is based on longitudinal ventilation. The scheme is shown in Figure 5.1 for the project and New M5 sections of the network. Longitudinal ventilation is driven by the vehicle piston effect, supplemented with jet fans if the traffic were to become too slow such that the piston effect was insufficient. The ventilation plant for the concept design scheme consists of three major elements, each with a different general purpose:

1) Portal emissions capture plant: Ventilation plant (exhaust) will be provided at approaches to all vehicle exit portals, to ensure a net inflow of air to the tunnel, preventing portal emissions. As the vehicle piston effect results in a natural inflow of air for vehicle on-ramps, there is no requirement to provide ventilation plant at vehicle entry portals.
2) Project interface plant: Ventilation plant (exhaust and supply) will also be provided at the interface points between the various WestConnex projects and also at the interface of the project with New M5. The purpose of these facilities is twofold:
    a. Provide smoke separation between the projects during emergency scenarios, minimising the smoke-affected portions of the network as far as practicable.
    b. Assist in maintaining air quality criteria across the tunnel network if the traffic was to become slow across significant portions of the network.
3) Jet fans: Jet fans are used to supplement the vehicle piston effect if the traffic is slow.

The interface plant at the boundary between F6 Extension and New M5 (Arncliffe ventilation facility) is not intended to exhaust in the southbound direction of travel during normal operations. During normal operation, the vehicle emissions generated upstream of the New M5 / F6 Extension diverge (in the southbound direction) will continue downstream into F6 Extension and New M5, to be exhausted at Kingsgrove and West Botany St facilities. The exhaust connections in the southbound tunnels are intended only for smoke extraction during an emergency.

In the northbound direction of travel, the interface plant at Arncliffe is not provisioned to provide complete air exchange and so some or all vehicle emissions generated within F6 Extension will be carried over into the New M5 tunnels. The amount of exhaust from the northbound tube will be determined by the downstream in-tunnel air quality criteria and operational requirements of the New M5 St Peters exhaust plant.

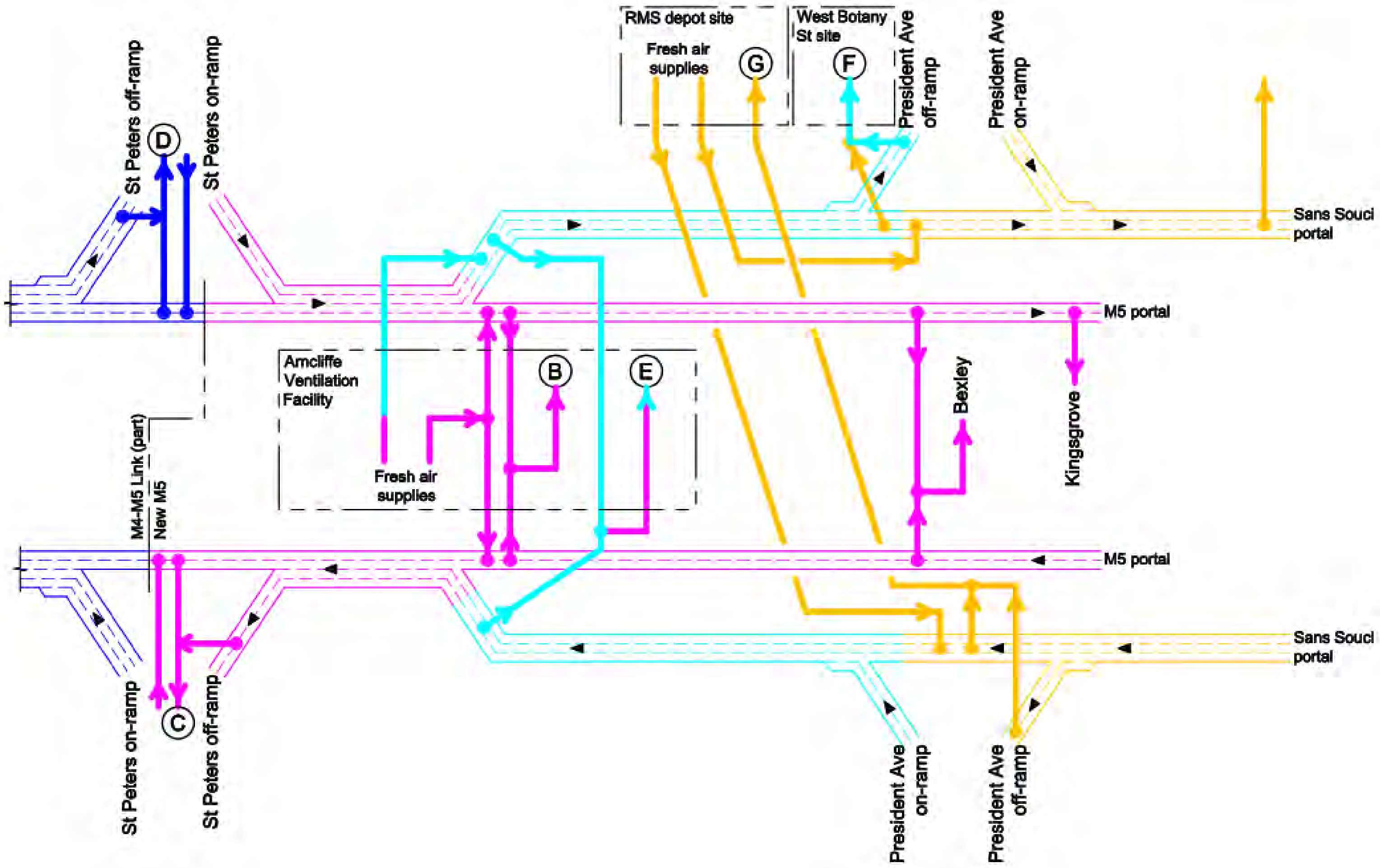


Figure 5.1. F6 Extension and New M5 tunnel and ventilation network in schematic form.

The operation, and consequently the required plant capacity, of the ventilation equipment is dependent on the traffic conditions within the tunnel. In practice, operating requirements will depend on traffic speed, traffic flows and their variation across the network. At a conceptual level, the ventilation equipment needed during normal operations is correlated with the traffic speed as shown in Table 5.1.

Table 5.1. Indicative ventilation plant requirements for normal operations.

Traffic speed (km/hr)	Portal capture ventilation plant	Interface ventilation plant	Jet fans
80	Maximum demand	Not required	Not required
70			
60		Minimal demand	Minimal demand
40	Minimum demand	Maximum demand	
30			Moderate demand
20	Moderate demand		Maximum demand

5.3 Ventilation control and operating philosophy

5.3.1 Normal operations

Figure 5.2 outlines the typical control block diagram and operating philosophy used in the concept design for the project. The control philosophy consists of two primary actions during normal operations indicated by different highlighted colours in Figure 5.2.

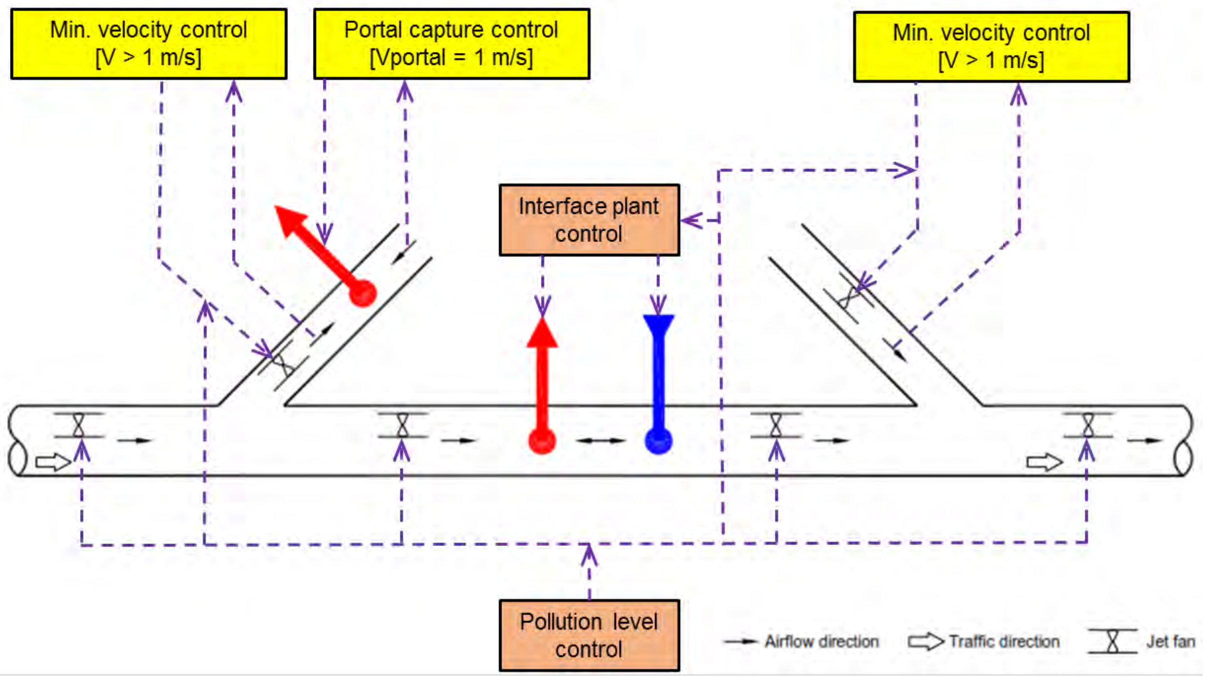


Figure 5.2. Overview of ventilation control.

The ventilation design has adopted the following targets across all normal operations simulations for the project, consistent with that of WestConnex.

Minimum requirements (yellow):

- Minimum velocity: A minimum velocity of 1 m/s, intended to avoid possible situations of stagnation and flow reversal. Jet fans are used in control loops in the simulations to ensure that these minimum airflow requirements are respected in on and off-ramps.
- Portal emissions capture: A target portal inflow of 1 m/s, measured at the nominal cross-section of the off-ramp is ensured by setting the extraction rate prior to the portal.

Under most traffic conditions, the ventilation system can be operated in a number of ways to achieve the required outcomes. Ventilation plant (exhaust and supply) plants generally offer better efficiency and controllability compared to using jet fans to achieve the required air quality. For these reasons, the following philosophy has been adopted throughout the ventilation design, with the control actions listed in order of first preference in operation to achieve maximum overall efficiency:

1) Portal emissions capture plant is operated to ensure net portal inflow with the natural vehicle-driven airflows.
2) Where in-tunnel pollution needs to be further controlled, such as during increasing levels of congestion, interface plant is operated to exchange air at the naturally occurring airflows, in preference to using jet fans to increase tunnel airflows.
3) Jet fans are operated to increase tunnel airflows as required to limit pollution, after other available actions are fully taken.

5.3.2 Emergency operations

Except for short sections between portal flow capture plants and the exit portals themselves, prior to an incident the air will be flowing with the traffic. At the onset of a fire, any exit portal flow against traffic will be reversed, with the pre-incident flow direction maintained for the rest of the tunnel. Exit portal inflows can be reversed quickly by turning off the ventilation station fans which extract the tunnel air prior to the portal.

Jet fans will maintain an air flow in the traffic direction in order to prevent people held behind the fire from being affected by smoke. Sufficient jet fans will be provided to control back-layering of the smoke at the fire-site.

Under normal operation, traffic control measures will be applied to ensure that the traffic speed in the tunnel does not drop below 20 km/h for any significant period. This will ensure that, if a vehicle ignites, the smoke movement does not overtake downstream traffic.

Depending on the fire location, the smoke may be discharged through the ventilation outlet, using the ventilation station fans. The alternative is to drive the smoke out of the exit portal. The adjacent non-incident tube will be closed to traffic and the airflow in that tube may be reversed using jet fans. This is to ensure that smoke issuing from a portal is not drawn into the adjacent entry portal of the non-incident tube. The jet fans will also be used to maintain the adjacent non-incident tube at a higher pressure than the incident tube, to prevent smoke flow through cross passages.

6 INPUT DATA AND DESIGN ASSUMPTIONS

6.1 Summary

References to design inputs and assumptions in this report are listed in Table 6.1 below.

Table 6.1. Summary of key design inputs and assumptions used.

Input	Value	Reference
NO_2 limits	0.5 ppm averaged over any route, 15 min rolling average.	Section 6.9, Table 6.24
CO limits	87 ppm averaged over any route, 15 min rolling average. 50 ppm averaged over any route, 30 min rolling average.	Section 6.9, Table 6.24
Extinction coefficient limits	0.005 /m at any location, 15 min rolling average	Section 6.9, Table 6.24
Vertical alignment	FBC drawings	Section 6.3
Cross section	FBC drawings	
Vehicle sizes	Roads and Maritime Services design criteria	Section 6.8
Fleet fuel mix	Roads and Maritime Services design criteria	Section 6.5.1, Table 6.7 (2024) Table 6.8 (2026) Table 6.9 (2036)
Fleet age profile	Roads and Maritime Services design criteria	Section 6.5.1, Table 6.7 (2024) Table 6.8 (2026) Table 6.9 (2036)
HGV mass	21 tonne	Section 6.5.4
Traffic demand	SMPM (version 1)	Section 6.4.1
Vehicle aerodynamic drag coefficients	Roads and Maritime Services design criteria	Section 6.8, Table 6.23
Vehicle emission factors, for NO_X, CO and PM.	PIARC (2012) detailed Euro method	Section 6.5.7, Table 6.12. (PC 2024) Table 6.13. (LDV 2024) Table 6.14. (HGV 2024 Table 6.15. (PC 2026) Table 6.16 (LDV 2026) Table 6.17. (HGV 2026)
Vehicle emission factors, for NO_2	PIARC NO_X above with NO_2:NO_X ratio based on “EMEP/EEA air pollutant emission inventory guidebook 2016 – Last Update June 2017”	
Background air quality	Roads and Maritime Services design criteria	Section 6.7, Table 6.22.

6.2 Tunnel schematic

Figure 6.1 shows the tunnel schematic for F6 Extension and New M5 incorporating the future stages of F6 Extension. Ventilation outlets within the ambient air-quality modelling domain are listed in Table 6.2 Tunnel schematics specific to each scenario analysed are included in Section 8 and Section 8.4 of this report.

Table 6.2. List of ventilation outlets.

EIS Outlet Identifier	Project	Description
B	New M5	Arncliffe
C	New M5	St Peters
D	M4-M5 Link	St Peters
E	F6 Extension Stage 1	Arncliffe
F	F6 Extension Stage 1	Rockdale (West Botany St)
G	F6 Extension – future stages	Rockdale (RMS depot)

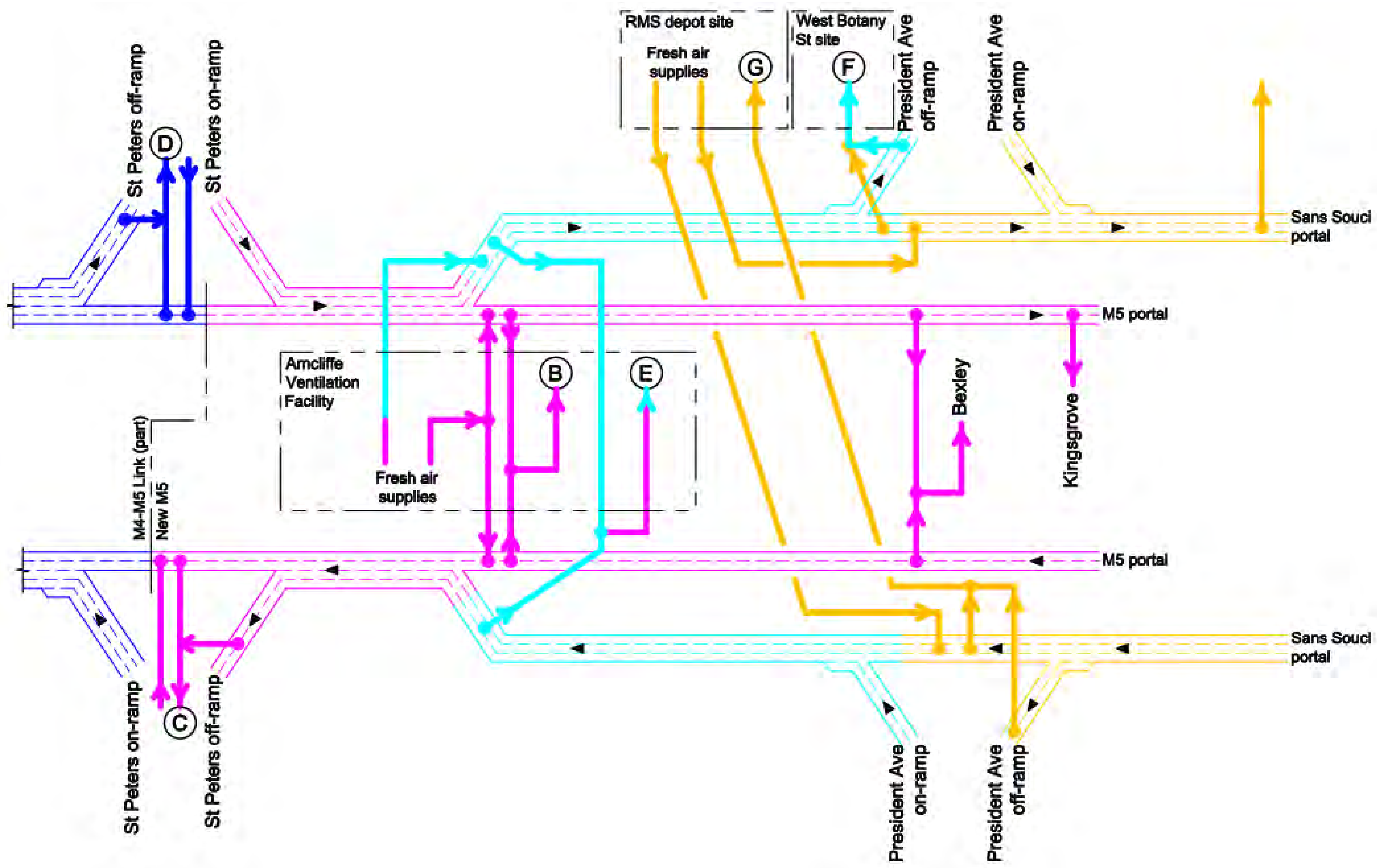


Figure 6.1. F6 Extension and New M5 tunnel ventilation schematic.

6.3 Tunnel vertical alignment

The following figures show the vertical alignment adopted. It should be noted that different vertical and horizontal scales are used within the graphs and as such tunnel gradients are exaggerated in the graphs.

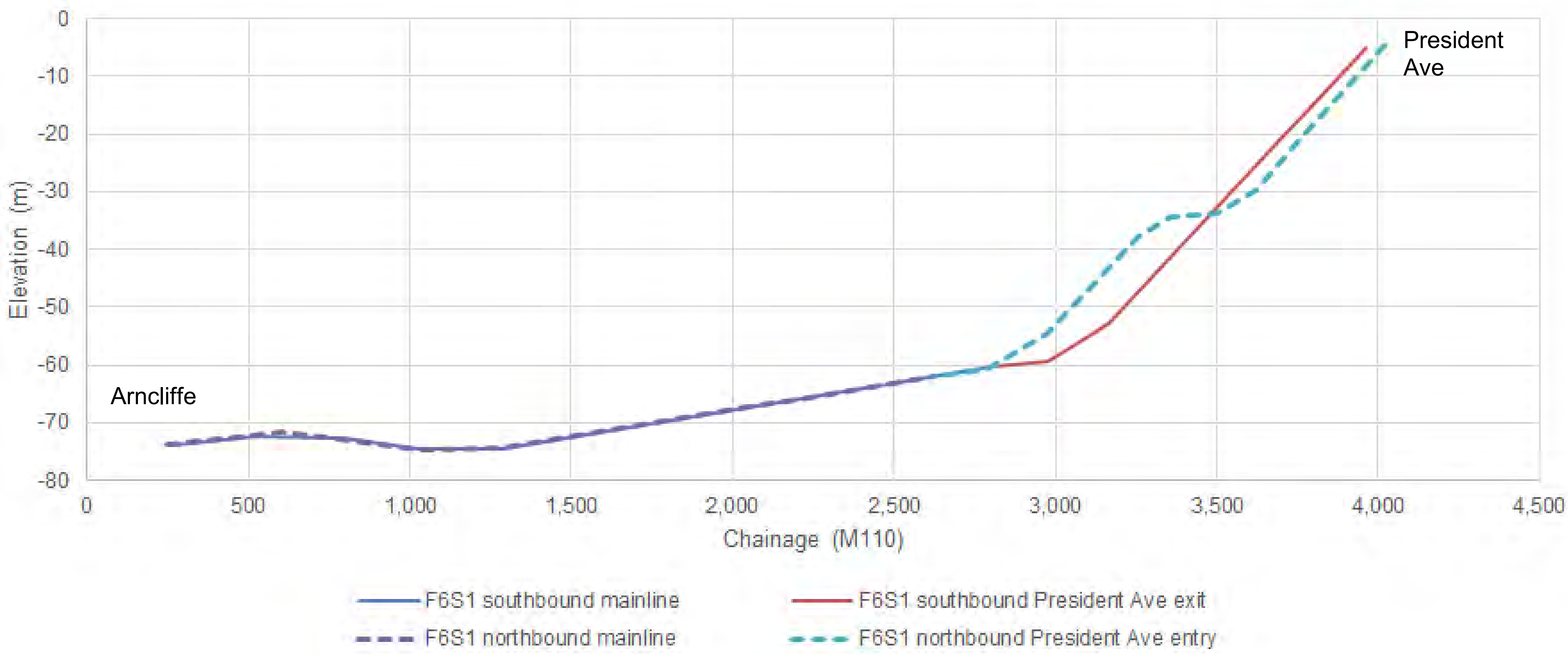


Figure 6.2. F6 Extension vertical alignment for Stage 1.

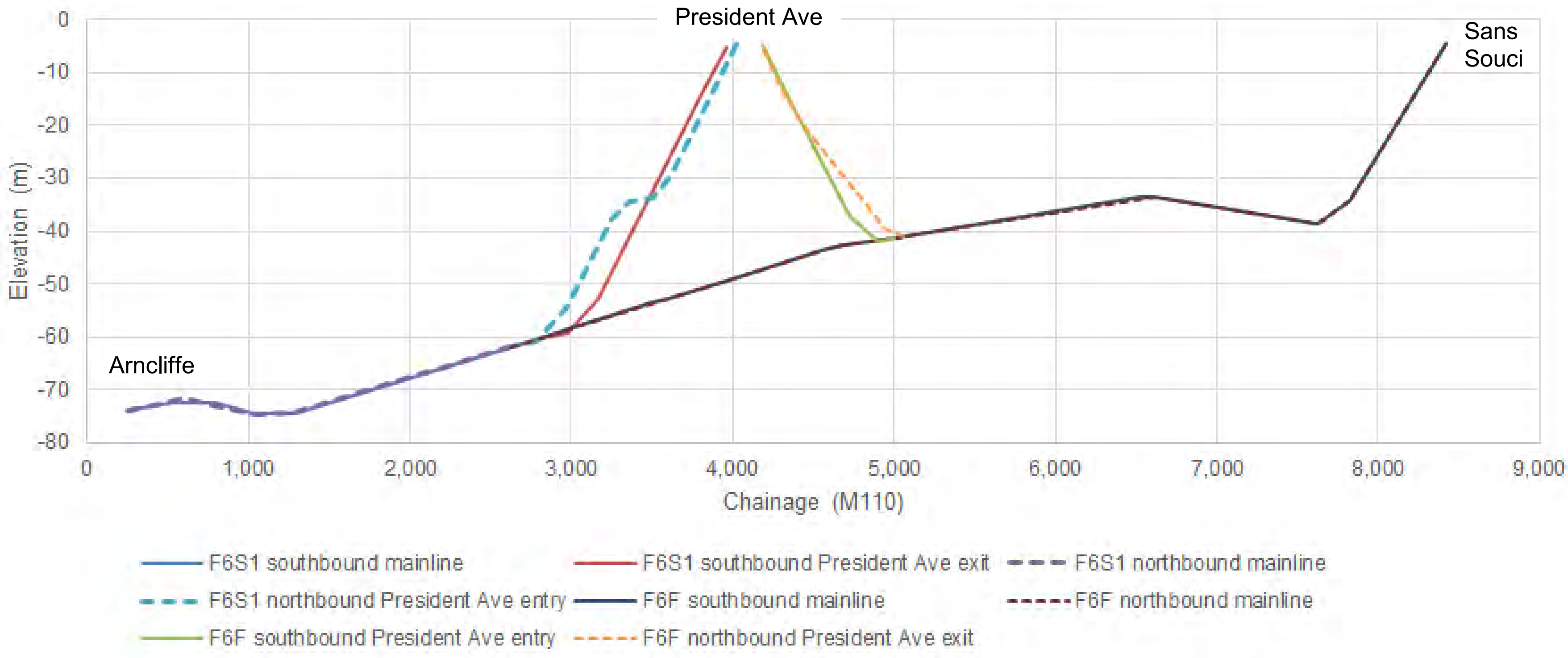


Figure 6.3. F6 Extension vertical alignment for Stage 1 and future stages.

6.4 Traffic and tunnel occupancy

It is generally acknowledged that traffic flow is a complex topic. While some of the complexity can be addressed in ventilation design by modelling traffic behaviours with ventilation operation, there is a need to simplify the traffic behaviour down to some reasonable worst case scenarios which then give a design suitable for all reasonable operation. This subsection records those bounding scenarios and any assumptions made to arrive at them.

The expected (demand) daily traffic profile not only forms the basis for prediction of environmental impacts, it may also inform, along with the lane geometry and the adopted operational rules, the congested and free-flowing scenarios that are likely to occur and those which cannot occur or which can realistically be prevented.

All these traffic regimes were addressed in the modelling.

Table 6.3. Description of traffic cases.

Term	Explanation
Expected traffic	Tunnel ventilation operations with expected traffic forecast by SMPM. This is intended to represent the (average) day-to-day operations of the ventilation system subjected to forecast traffic demand. Simulations were completed for all six traffic scenarios shown in Table 6.5.
Worst case traffic	Tunnel ventilation operations with the most onerous traffic conditions for the ventilation system. These simulations are based on simplified bounding case traffic conditions at 20 km/h, 60 km/h and 80 km/h that encompass: • Congestion (down to 20 km/h on average) • Ramp metering • Breakdown or minor incident • Accident closing a tube • Free-flowing traffic at maximum capacity
Normal (operations)	Means any of “Expected traffic”, “Regulatory demand traffic” or “Worst case traffic”. That is, all non-emergency operations.
Emergency (operations)	Fire.

6.4.1 Traffic demand

Demand traffic profiles for each section of the tunnel network were sourced from the SMPM Traffic Model. SMPM provides a platform to understand changes in future year travel patterns under different land use, transport infrastructure and pricing scenarios. Although the SMPM is a network-wide model that encompasses existing and future road network coverage in the Sydney Greater Metropolitan Area (GMA), it provides the ability to assess infrastructure improvements associated with various projects; both in isolation and combination.

The data supplied are total flows for cars, LCVs and HCVs for each period of the day (Table 6.4) in each of the tunnel network links, for a total of six scenarios as shown in Table 6.5.

Table 6.4. Daily traffic periods.

ID	Description	Period of the day
AM	Morning Peak	7am to 9am
IP	Inter peak	9am to 3pm
PM	Afternoon peak	3pm to 6pm
EV	Evening	6pm to 7am

Table 6.5. Expected traffic scenarios.

Description	Year	Arrangement
Do minimum	2026	M4 East + New M5 + M4-M5 Link + King Georges Road interchange upgrade + Sydney Gateway
Do minimum	2036	M4 East + New M5 + M4-M5 Link + King Georges Road interchange upgrade + Sydney Gateway
Do something	2026	M4 East + New M5 + M4-M5 Link + King Georges Road interchange upgrade + F6 Extension Stage 1
Do something	2036	M4 East + New M5 + M4-M5 Link + King Georges Road interchange upgrade + F6 Extension Stage 1
Cumulative	2026	M4 East + New M5 + M4-M5 Link + King Georges Road interchange upgrade + Sydney Gateway + F6 Extension Stage 1 + Western Harbour Tunnel + Beaches Link
Cumulative	2036	M4 East + New M5 + M4-M5 Link + King Georges Road interchange upgrade + Sydney Gateway + F6 Extension Stage 1 + F6 Extension future stages + Western Harbour Tunnel + Beaches Link

Fleet characterization used in the SMPM is set to reflect tolling classes, for traffic study and economic purposes, not vehicle classes for pollution and ventilation design. SMPM uses the following classification of vehicles:

- Cars are light vehicles (AustRoads Classes 1 and 2) that are privately registered;
- LCV are “light commercial vehicles” (AustRoads Classes 1 and 2) that are not privately registered (i.e. the class that cannot claim toll cashback on M5), and;
- HCV are “heavy commercial vehicles” AustRoads Classes 3 and above.

For ventilation design, Roads and Maritime concluded that:

1) the PIARC description of HGV is consistent with AustRoads Classes 3 and above, generally having a vehicle mass greater than 3.5 t, and;
2) the remaining AustRoads Classes 1 and 2 could be classified 84% PCs and 16% LDVs in the PIARC definitions. The proportion of PCs and LDVs was based on review of the Automatic Number Plate Recognition (ANPR) data that informed the development of SMPM.

For the purposes of ventilation analysis, SMPM traffic flows are converted to PIARC pollution categories using the following formulae:

$$HGV = HCV_{SMPM}$$

$$LDV = 0.16 \times (LCV_{SMPM} + PC_{SMPM})$$

$$PC = 0.84 \times (LCV_{SMPM} + PC_{SMPM})$$

All vehicle flows within this report refer to PIARC pollution categories unless expressly stated otherwise.

6.4.2 Speed limits

The posted speed limit in mainline tunnels and in motorway to motorway connections will be 80 km/h. It is assumed that traffic will not travel faster than that. This assumption may not be valid when traffic is very light, but that is not a controlling case for ventilation. When traffic is very heavy, the speed may drop below 80 km/h as suggested by traffic flow models.

On and off-ramps that connect to local roads rather than other motorways will have a posted speed of 60 km/h, with that also taken as a maximum speed on such ramps.

6.4.3 Lane capacity

The average density of vehicles within the tunnel under the various traffic conditions is a key parameter in the ventilation design. Vehicle dimensions, dynamics and driver behaviour vary greatly. In looking at lane capacity, the Passenger Car Unit (PCU) is a unit used to represent an equivalent number of passenger cars for each real vehicle. For the current analysis, both PC and LDV correspond to one PCU. HGVs are generally much longer vehicles and travel more slowly uphill, and therefore occupy more lane space than a PC or LDV. In slow speed traffic, the 'pitch' (front bumper to front bumper spacing) between vehicles is closely related to vehicle length. As traffic moves faster, the vehicle to vehicle pitch is set more by the need to provide adequate reaction and stopping distance and so vehicle length is relatively less important. The lane occupancy of HGVs can be described by a ratio to the lane occupancy of PCs. This ratio is a function of traffic speed as tabulated below.

Work by Roads and Maritime has shown that lane capacity upper limit at 80 km/h is 1900 PCU/lane/h, with flowrate peaking at 2060 PCU/lane/h at 70 km/h. The values in Table 6.6, measured by Roads and Maritime for Sydney traffic, are adopted in lieu of the more generic PIARC recommendations.

Table 6.6. Adopted maximum lane capacity as a function of speed. The ratios in the third column are the equivalence between HGVs and PCUs in terms of lane space used at each speed.

Traffic speed (km/h)	PCU/lane/h	HGV:PCU ratio
0	165 PCU/km	3:1
20	1350	3:1
30	1650	2.5:1
40	1860	2:1
50	1990	2:1
60	2050	2:1
70	2060	2:1
80	1900	2:1

6.4.4 Normal operations

From a tunnel ventilation perspective, normal (traffic) operations means the range of possible traffic conditions, including such conditions as the expected traffic, congestion, vehicles breakdowns and the like.

The problem with analysing the pollution for real traffic cases is that real traffic flow prediction is time consuming and is a significant modelling exercise in itself. This is particularly so for random events such as a breakdown, whether they be within the tunnel or external to it. For the expected demand traffic cases, the SMPM outputs and the traffic model within IDA Tunnel were used to estimate the in-tunnel traffic conditions.

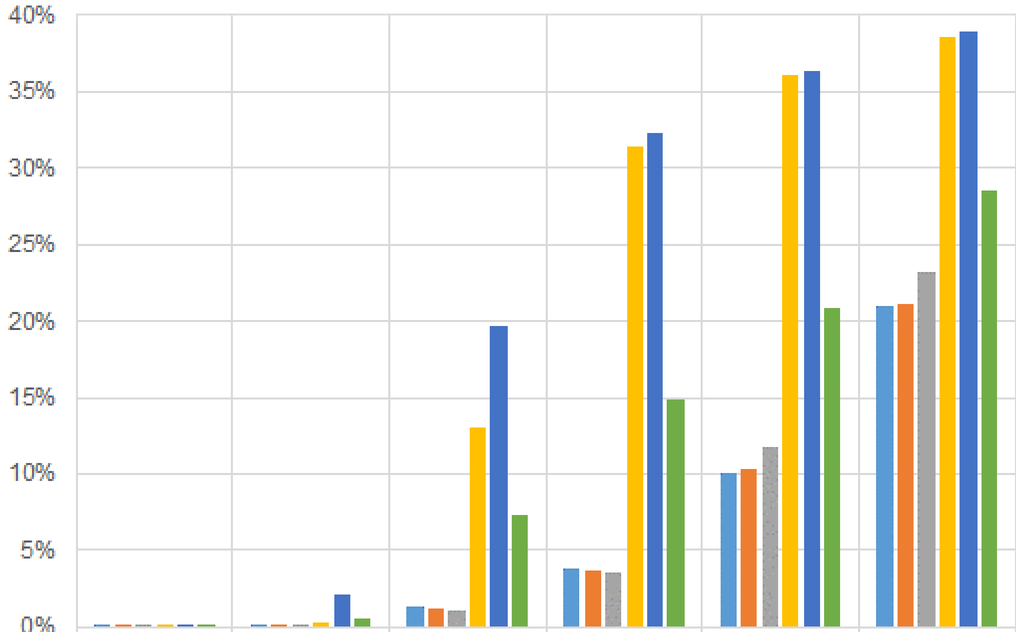
For other traffic conditions, the analysis for conservative (worst case operations, Section 7.1.3) but simple cases is done, even if they are physically impossible to achieve and/or highly unlikely to occur in practice. In the concept design, a number of traffic patterns were analysed that seek to push the limits of each element of the ventilation system at speeds of 20 and 80 km/h throughout the network.

If those conservative cases meet the criteria, then no further assessment is required. Only if the criteria are not met in the conservative view, or require disproportionate ventilation equipment capacities is there a need to look in more detail at the real traffic for the situation of concern. The use of unrealistically onerous traffic cases for the analysis in this report should not be interpreted as adding those cases to the design criteria for the project, they serve only as a simplified method to demonstrate the capability of the concept design ventilation system.

Live travel time data gathered from the M5 East tunnel for the period January 2016 through September 2016 has been used to review the average speeds for an inner Sydney road tunnel without active traffic control measures. The data were generated by Google using an application written by NGIS Australia Pty Ltd, and consisted of average transit times through M5 East at five minute intervals between 12th January 2016 and 1st September 2016 for the following routes:

1) EBMainline: eastbound mainline entrance to mainline exit.
2) EBMarshSt: easbound mainline entrance to Marsh St exit.
3) EBPrincesHwy: eastbound mainline entrance to Princes Hwy exit.
4) WBMainline: westbound mainline entrance to mainline exit.
5) WBMarshSt: westbound Marsh St entrance to mainline exit.

Figure 6.4 below shows the cumulative proportion of time that average vehicle speed falls below certain speeds for each route. It is important to highlight that for the westbound routes, WBMarshSt and WBMainline are identical except for the short distance before they merge. The higher proportions for WBMarshSt route at slow speeds compared to WBMainline indicates that the average speed in the Marsh St on-ramp is below that in the mainline entry and from the merge to the exit portal. As the Marsh St on-ramp forms only a small proportion of the total westbound tunnel length (300 m in 4 km), from an overall emissions perspective, the average traffic condition within the westbound sections of the M5 East are actually closer to the WBMainline data.



	< 10kph	< 20kph	< 30kph	< 40kph	< 50kph	< 60kph
EBMainline	0.01%	0.21%	1.35%	3.80%	10.04%	20.93%
EBMarshSt	0.01%	0.19%	1.29%	3.63%	10.29%	21.15%
EBPrincesHwy	0.00%	0.12%	1.09%	3.58%	11.71%	23.25%
WBMainline	0.01%	0.35%	13.03%	31.32%	36.03%	38.59%
WBMarshSt	0.00%	2.19%	19.73%	32.35%	36.35%	38.91%
All routes	0.01%	0.61%	7.30%	14.94%	20.89%	28.57%

Figure 6.4. Cumulative proportion of time average travel speed is below nominated values for M5 East tunnel (January 2016 to September 2016).

Based on the M5 East data, the likelihood of average traffic speed throughout the tunnel being less than 20 km/h would be of the order of 0.5%. M5 East includes merges and steep exit grades which increase the chance of slow traffic. Traffic management plans will be developed during the detailed design phase, to provide the capability to further reduce the likelihood of slow moving traffic with the project. Traffic management plans may include active and/or passive control measures to influence driving behaviours to maintain the speed of traffic through the tunnel.

Controlling the traffic speed to not fall below 20 km/h in any section of the tunnel is also a safety measure to minimise the chance of a fire at the back of a line of stopped traffic and allow vehicles in front of any fire to drive out of the tunnel without being overrun by smoke. That is; such control is required for fire safety.

All of this supports the adoption of 20 km/h as a design basis for minimum average traffic speed when assessing pollution in the tunnel.

6.4.5 Breakdown or minor accident

Analysis has assumed only that traffic control is exercised so as to maintain a minimum traffic speed of 20 km/h in all tunnel sections. The pollution criteria can still be met under that conservative simplifying assumption, with required jet fan numbers being similar to those required for the fire cases.

6.4.6 Accident closing a tube

The simplifying assumption for an accident closing a tube is that on-ramps just upstream of the incident will be closed, all drivers upstream of an exit ramp will use that ramp as instructed, and a reasonable fraction of drivers will comply with an instruction to turn engines off. That will take the pressure off ventilating for pollution, such that tube closure is no longer a defining design case for pollution control.

6.4.7 Emergency operations (fire)

When in operation, the project will be part of a tunnel network with a total mainline length of some 27 km and 11 or more on or off-ramps in each direction. The traffic occupancy of the various sections during a fire scenario will affect the ventilation plant required to handle such design scenarios.

The “defacto” standard previously adopted for projects is to assume that the tunnel behind the fire is completely full of stopped vehicles during a fire scenario. Adopting the same design scenario for the project would result in design scenarios with potentially up to 41 km (the approximate length of the mainline and on/off ramps in either direction) of queued traffic at standstill, a very onerous requirement for any ventilation system. It would also take several hours to fill the tunnel to that level, even with high traffic flows.

For a tunnel system with multiple exit paths and traffic control systems that actively prevent additional vehicles from entering the tunnel, allowing the entire tunnel to become completely choked with vehicles (with an active emergency) does not appear a plausible scenario. It is also the case that sections of the tunnel system away from the incident may continue to be safely operated.

For concept design capacity purposes it is assumed that the upstream tunnel sections are full of stopped vehicles, with all downstream sections cleared of vehicles. This may be slightly conservative, but not grossly so. The reason it is only slightly conservative is that it is only the flow in the incident section that is critical, and the vehicle drag in the tunnel sections upstream of the incident section (the other side of intersections), has a reducing influence on flow in the incident section.

6.5 Emissions factors

Average exhaust emission factors for the Australian vehicle fleet are generally decreasing as new emissions control technologies are supplied on new vehicles, and old vehicles pass out of service. PIARC[1] provides Australian fleet emissions tables valid up to and including year 2020 which has been the approach generally adopted within Australia. However, a number of factors give rise to uncertainty in adopting this approach for estimating in-tunnel vehicle emissions for the project:

- No methodology for estimating beyond 2020 is provided,
- The LDV fleet is fixed at 50% petrol and 50% diesel whereas it is forecast to be dominated by diesel vehicles by the time the project opens in 2024.

The primary, more general PIARC methodology, and the supporting data to estimate fleet average emissions, are based on more detailed breakdown of the expected fleet, referred to herein as the "PIARC detailed method". Relevant input parameters used for estimating emissions using the detailed method are outlined in the following sections.

Together with the other inputs recorded here, this analysis adopts the following basis for estimating vehicle emissions using the PIARC information:

1) PIARC 2012 detailed Euro method for CO, NOx and Exhaust PM;
2) PIARC 2012 for Non-exhaust PM;
3) Fleet Euro classification provided by NSW Roads and Maritime;
4) NO_2:NO_X ratios based on European Environment Agency "EMEP/EEA air pollutant emission inventory guidebook 2016 – Last Update June 2017"[2]

The appropriateness of this approach has been verified using data recorded from M5 East Tunnel in 2015, refer to Section 6.5.8.

6.5.1 Fleet characteristics

Roads and Maritime have determined the age and fuel type distribution within each class of vehicle (PC, LDV and HGV) for 2024, 2026 and 2036 as tabulated below. These fleet characteristics have been used in estimating average vehicle emissions (CO, NO_X, exhaust PM) in each vehicle category using the PIARC detailed methodology.

The fleet characterisation has been updated by Roads and Maritime from the basis adopted in the M4-M5 Link EIS to incorporate the most current understanding of vehicle standards implementation within Australia. Changes include:

- Revised implementation of Euro standards for PC and LDV categories:
  - Euro 5a (ADR79/03) assumed to be equivalent to Euro 4, and;
  - Euro 5b (ADR79/04) assumed to be equivalent to Euro 5 and mandated from 2017, and
  - Euro 6 assumed to be implemented for all vehicles from 2021.

[1] PIARC Technical Committee C4 Road Tunnels Operation. Road Tunnels: Vehicle Emissions and Air Demand for Ventilation, World Road Association, document 2012R05EN, revised December 2012.

[2] In-Tunnel Air Quality (Nitrogen Dioxide) Policy, Advisory Committee on Tunnel Air Quality (NSW), February 2016.

Table 6.7. Fleet emission standards characteristics, year 2024.

Emission standard	PC		LDV		HGV
	Petrol (%)	Diesel (%)	Petrol (%)	Diesel (%)	Diesel (%)
Pre-Euro	0.06	0.00	0.73	0.12	3.26
Euro 1	0.39	0.01	1.05	0.15	2.59
Euro 2	0.92	0.15	0.97	0.75	0.00
Euro 3	3.78	0.00	2.28	0.00	5.74
Euro 4	24.54	5.28	7.41	22.22	11.75
Euro 5	23.39	7.42	4.05	24.35	76.65
Euro 6	24.34	9.72	3.16	32.76	0.00
Total	**74.73**	**25.19**	**21.91**	**78.07**	**100.00**

Table 6.8. Fleet emission standards characteristics, year 2026.

Emission standard	PC		LDV		HGV
	Petrol (%)	Diesel (%)	Petrol (%)	Diesel (%)	Diesel (%)
Pre Euro	0.01	0.00	0.17	0.03	1.36
Euro 1	0.17	0.00	0.66	0.08	2.11
Euro 2	0.23	0.08	0.50	0.51	0.00
Euro 3	2.03	0.00	1.38	0.00	5.04
Euro 4	17.82	3.85	5.29	15.82	6.77
Euro 5	17.90	5.72	3.38	19.19	84.72
Euro 6	36.57	15.62	4.25	48.74	0.00
Total	**74.73**	**25.27**	**15.63**	**84.37**	**100.00**

Table 6.9. Fleet emission standards characteristics, year 2036.

Emission standard	PC		LDV		HGV
	Petrol (%)	Diesel (%)	Petrol (%)	Diesel (%)	Diesel (%)
Pre Euro	0.00	0.00	0.02	0.00	0.68
Euro 1	0.00	0.00	0.03	0.000	0.85
Euro 2	0.00	0.00	0.03	0.02	0.00
Euro 3	0.01	0.00	0.03	0.00	1.69
Euro 4	0.65	0.15	0.40	1.18	2.27
Euro 5	2.28	0.76	0.37	2.10	94.51
Euro 6	58.06	38.08	3.54	92.25	0.00
Total	**65.07**	**34.93**	**6.59**	**93.43**	**100.00**

6.5.2 NO_2 emissions

PIARC tables give NO_X generation rates as a function of vehicle speed and road gradient. Since NO_2 is the dominant design pollutant for in-tunnel air quality, it is highly desirable to have tables of NO_2 evolution rather than its proxy NO_X which bundles together the NO and NO_2. The provision of tables giving NO_2 directly is under consideration by the relevant PIARC Working Group. In the absence of tables giving NO_2 emissions directly, the NO_2:NO_X ratio is a key parameter to supplement the PIARC method.

Table 6.10 provides NO_2:NO_X ratios used for estimating NO_2 emissions based on the "EMEP/EEA air pollutant emission inventory guidebook 2016 – Last Update June 2017".

Table 6.10. Fleet NO_2:NO_X ratio[3].

Emission standard	PC		LDV		HGV
	Gasoline	Diesel	Gasoline	Diesel	Diesel
Pre Euro	0.04	0.15	0.04	0.15	0.11
Euro 1	0.04	0.13	0.04	0.13	0.11
Euro 2	0.04	0.13	0.04	0.13	0.11
Euro 3	0.03	0.51	0.03	0.27	0.14
Euro 4	0.03	0.46	0.03	0.46	0.10
Euro 5	0.03	0.33	0.03	0.33	0.12
Euro 6	0.03	0.30	0.03	0.30	0.08

Tables of NO_2 emissions are calculated as the NO_X weighted average for each vehicle category as follows, using the PC category for explanation purposes:

$q_{NO2=}$ NO_2 emission rate

$q_{NOx=}$ NO_X emission rate

$f_{NO2=}$ NO_2 NO_X ratio from Table 6.10

$f_{fleet=}$ Fraction of vehicles within the vehicle category, from Table 6.7 or Table 6.8.

$$
\begin{aligned}
q_{NO2(PC)}=q_{NOx(PC\ Diesel,pre\ Euro)} &\times f_{NO2(PC\ Diesel,pre-Euro)} \times f_{fleet(PC\ Diesel,pre-Euro)} \\
&+ q_{NOx(PC\ Diesel,Euro\ 1)} \times f_{NO2(PC\ Diesel,Euro\ 1)} \times f_{fleet(PC\ Diesel,Euro\ 1)} \\
&+ q_{NOx(PC\ Diesel,Euro\ 2)} \times f_{NO2(PC\ Diesel,Euro\ 2)} \times f_{fleet(PC\ Diesel,Euro\ 2)} \\
&+ \cdots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \\
&+ q_{NOx(PC\ Gas,Euro\ 5)} \times f_{NO2(PC\ Gas,Euro\ 5)} \times f_{fleet(PC\ Gas,Euro\ 5)} \\
&+ q_{NOx(PC\ Gas,Euro\ 6)} \times f_{NO2(PC\ Gas,Euro\ 6)} \times f_{fleet(PC\ Gas,Euro\ 6)}
\end{aligned}
$$

[3] https://www.eea.europa.eu/publications/emep-eea-guidebook-2016/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-b-i, accessed 20th December 2017.

6.5.3 Particulates and in-tunnel visibility

In-tunnel visibility is assessed including the contributions of both exhaust and non-exhaust emissions using a conversion factor of 0.0047 m^2/mg. Outlet emissions report each component (exhaust and non-exhaust) separately.

6.5.4 Heavy vehicle mass

Weigh-in-motion (WIM) stations are installed at strategic locations across the Roads and Maritime classified road network. For all vehicles, WIM stations measure and record the; date, time, lane (direction), vehicle speed, axle count, inter-axle spacing, individual and group axle weights and gross vehicle weights. The raw data are then automatically processed and cross-referenced to provide useful information relating the vehicle usage and traffic flow patterns at each monitored location. The information is analysed to generate seasonal and daily distribution of vehicle class (Austroads Classes 3-12), vehicle speed, flow and mass distributions.

HGV mass and vehicle counts throughout 2015 were reviewed for Botany WIM station located on Foreshore Road, in order to estimate an appropriate HGV mass for ventilation design.

The annual average hourly distribution of HGV mass and vehicle flows, in each direction (inbound and outbound) for the Botany WIM station are shown in Figure 6.5 and Figure 6.6 below. It can be seen that the mass of HGVs in the outbound direction are generally greater than for the inbound direction throughout the day. It can also be seen that during off-peak periods, the average HGV mass in both directions increases, and the number of HGVs decreases. The mass of HGVs is lowest through the middle of each day when the flows of HGVs are the highest. This is an important point in that it indicates that high HGV masses do not coincide with periods of peak tunnel occupancy when the tunnel ventilation system would be operating a peak capacity. During off-peak hours when tunnel occupancy is low, and the risk of significant congestion is also low, the tunnel ventilation system will not be operating at peak flows, with capacity available to cater for increased emissions from the HGV portion of the fleet.

For the vehicle emissions estimate and ventilation design, a mass of 21 tonnes has been assumed for all HGVs consistent with the M4-M5 Link EIS. This is based on the average HGV mass in the outbound direction during the 8am-9am morning peak hour period. The conservatism of this assumption for other links is accepted, in preference to the complexity of modelling different HGV masses in different links. The average HGV mass on which the PIARC tables are based is 23 tonnes. The pollution estimates include a mass correction factor of 0.925 in accordance with the PIARC approach.

The New M5 project adopted a HGV mass of nominally 18 tonnes for design purposes. That makes the analysis of the project, which includes analysis of New M5 tunnel sections slightly more onerous.

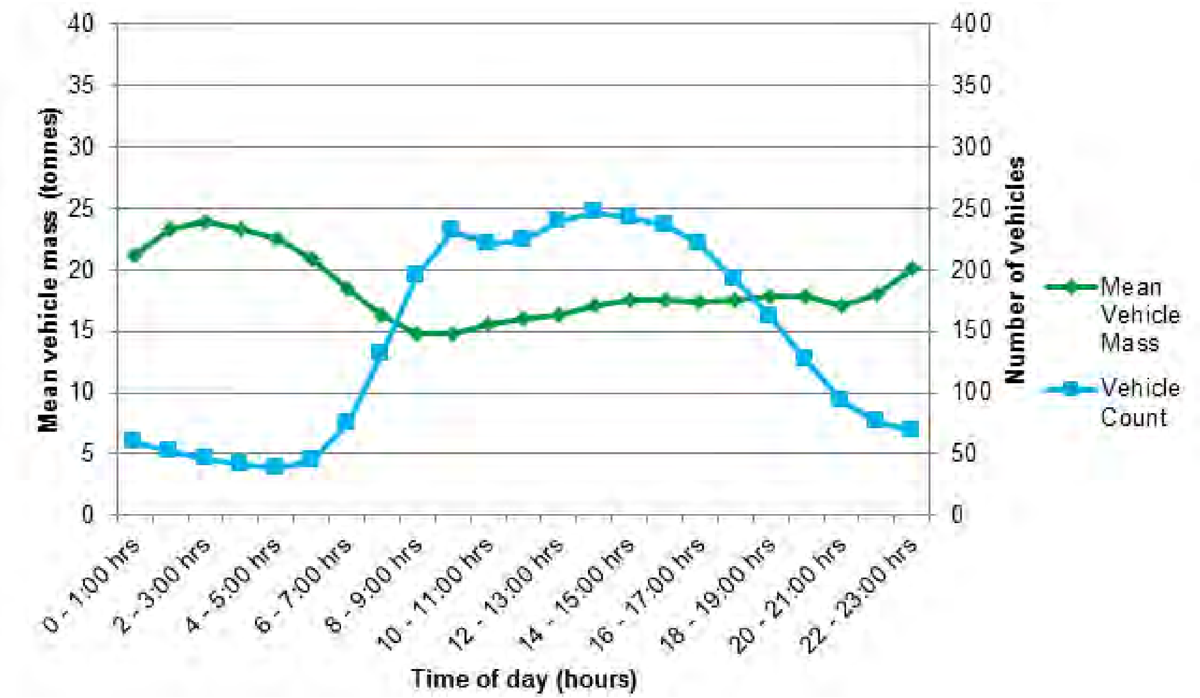


Figure 6.5. Inbound direction 2015 Annual Average Daily distribution of HGV mass and HGV vehicle count at Botany WIM station, across all traffic lanes (towards Port Botany).

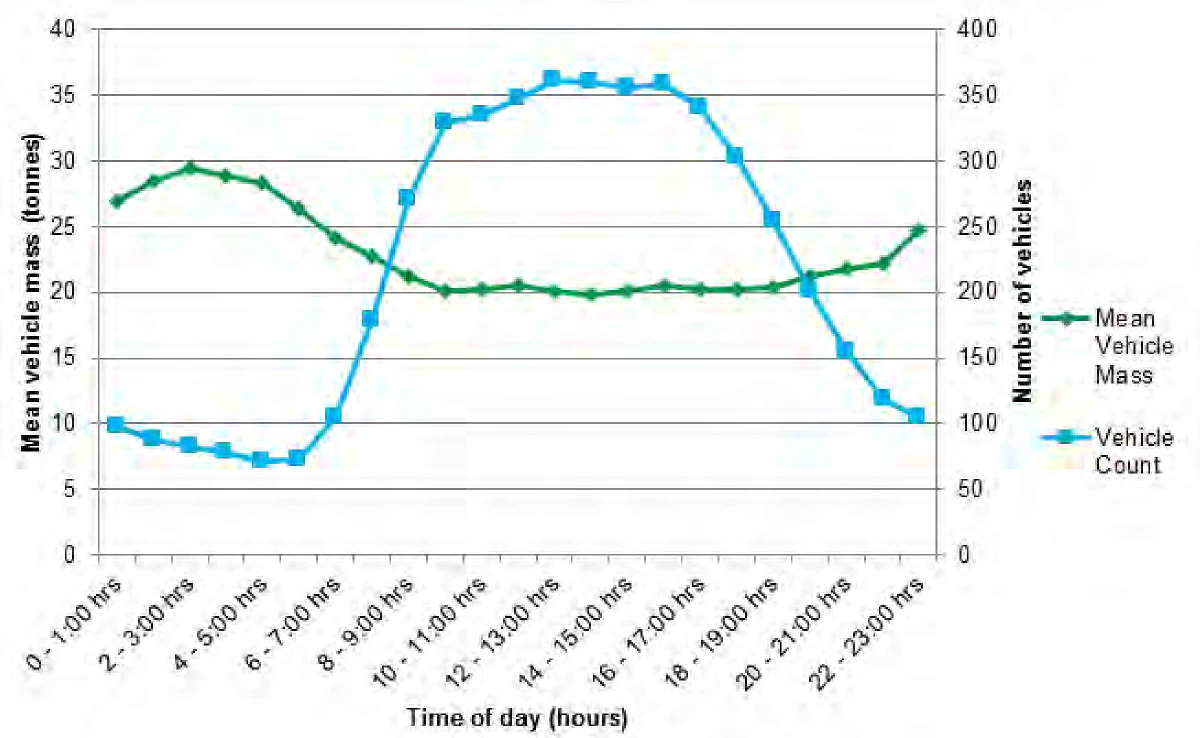


Figure 6.6 Outbound direction 2015 Annual Average Daily distribution of HGV mass and HGV vehicle count at Botany WIM station, for all traffic lanes (travelling away from Port Botany).

6.5.5 Other factors

No altitude factors are required as the tunnels are near sea level.

Cold start factors are excluded. The vast majority of vehicles will have travelled some distance to access the tunnel and so engines will be at their normal operating temperatures within the tunnel.

Age degradation factors are included for all petrol-fueled vehicles in accordance with Table 78 of PIARC 2012. Table 6.11 outlines the assumed year of implementation of each vehicle standard as adopted by Roads and Maritime for fleet estimation purposes. These values have also been adopted in estimating age degradation. PIARC does not provide any data for age degradation of Euro 5 and Euro 6 vehicles. For the purposes of this work, both are assumed to degrade in the same way as Euro 4.

Table 6.11. Assumed year of implementation for emission standards[4].

Emission standard	PC		LDV		HGV
	Petrol	Diesel	Petrol	Diesel	Diesel
Pre Euro					
Euro 1	1996	1996	1996	1996	1996
Euro 2	2004	2003	2004	2003	n/a
Euro 3	2006	n/a	2006	n/a	2003
Euro 4	2010	2008	2010	2008	2008
Euro 5	2017	2017	2017	2017	2011
Euro 6	2021	2021	2021	2021	n/a

6.5.6 Vehicle emissions during fire

It is assumed that, during a fire scenario, vehicles stopped within the tunnel will be directed to shut off their engines and that, even with only partial compliance, pollution levels within the tunnel will not be a significant factor for the duration of the emergency.

6.5.7 Emission factors

Table 6.12. through Table 6.20 show the calculated vehicle category average pollutant emissions rate as a function of speed and gradient. These tables are used as input tables in simulations, with the resultant total vehicle emissions calculated based on the (variable) traffic flows in each vehicle category.

[4] Roads and Maritime Services, NSW Fleet forecast for future road tunnel projects (TT-TN-16-12) Rev 3 dated 12th September 2016

Table 6.12. PC emission rates for 2024.

PC - CO emission rate (g/hr) - 2024

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	1.8	1.8	1.8	1.8	1.8	1.8	1.8
10	13.9	11.6	12.2	14.2	15.6	16.8	17.9
20	7.3	12.9	12.3	15.8	17.8	20.8	24.6
30	6.0	8.7	12.8	17.0	20.8	26.3	32.8
40	5.9	8.2	14.4	18.2	24.6	32.8	46.4
50	5.8	6.2	13.4	19.7	28.7	41.6	64.2
60	5.8	6.2	14.4	22.3	34.2	57.3	95.6
70	5.8	6.2	15.8	26.1	44.4	76.8	169.6
80	5.8	6.5	17.4	31.4	60.1	128.6	292.1
90	5.8	10.0	21.4	39.3	81.8	222.3	485.7
100	5.9	10.8	26.0	55.4	143.4	374.9	786.4
110	6.0	15.2	33.0	77.0	252.1	618.0	1,246.7
120	6.2	18.6	47.3	142.8	434.2	998.3	1,937.4
130	14.1	27.1	70.9	267.7	732.6	1,585.2	2,958.6

PC - NOx emission rate (g/hr) - 2024

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	1.2	1.2	1.2	1.2	1.2	1.2	1.2
10	1.5	1.5	1.5	2.2	2.8	3.3	3.8
20	1.5	1.5	1.6	2.9	3.7	4.8	6.6
30	1.5	1.5	1.9	3.5	4.9	7.0	9.3
40	1.5	1.5	2.0	3.9	6.2	9.0	12.3
50	1.5	1.5	2.0	4.3	7.4	11.1	15.3
60	1.5	1.5	2.2	5.1	9.1	13.9	19.0
70	1.5	1.5	2.7	6.5	11.4	17.1	22.9
80	1.5	1.5	3.4	7.9	14.0	20.6	27.1
90	1.5	1.5	4.5	9.9	17.1	24.3	31.6
100	1.5	1.6	6.1	12.6	20.7	28.7	36.7
110	1.5	2.0	7.9	16.0	24.8	33.5	42.4
120	1.5	4.2	10.7	20.1	29.4	38.9	48.5
130	1.5	6.1	14.4	24.6	34.7	44.9	55.3

PC - NO2 emission rate (g/hr) - 2024

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	0.32	0.32	0.32	0.32	0.32	0.32	0.32
10	0.32	0.32	0.32	0.54	0.72	0.88	1.04
20	0.32	0.32	0.36	0.75	1.02	1.27	1.72
30	0.32	0.32	0.45	0.93	1.29	1.83	2.54
40	0.32	0.32	0.48	1.06	1.62	2.44	3.53
50	0.32	0.32	0.44	1.14	1.94	3.13	4.49
60	0.32	0.32	0.51	1.29	2.46	4.03	5.66
70	0.32	0.32	0.66	1.63	3.19	5.07	6.86
80	0.32	0.32	0.88	2.07	4.03	6.13	8.15
90	0.32	0.32	1.11	2.68	5.01	7.26	9.54
100	0.32	0.32	1.46	3.55	6.10	8.58	11.11
110	0.32	0.40	2.00	4.61	7.33	10.05	12.83
120	0.32	0.92	2.86	5.84	8.74	11.71	14.73
130	0.32	1.40	4.04	7.20	10.35	13.56	16.83

PC - Exhaust PM emission rate (m2/hr) - 2024

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	0.09	0.09	0.09	0.09	0.09	0.09	0.09
10	0.10	0.10	0.10	0.19	0.26	0.32	0.39
20	0.10	0.10	0.12	0.27	0.38	0.48	0.62
30	0.10	0.10	0.15	0.34	0.48	0.65	0.86
40	0.10	0.10	0.16	0.39	0.59	0.83	1.14
50	0.10	0.10	0.15	0.43	0.68	1.03	1.40
60	0.10	0.10	0.18	0.48	0.84	1.28	1.68
70	0.10	0.10	0.23	0.59	1.05	1.55	1.89
80	0.10	0.10	0.32	0.72	1.28	1.76	2.11
90	0.10	0.10	0.41	0.90	1.54	1.96	2.33
100	0.10	0.10	0.53	1.15	1.76	2.18	2.56
110	0.10	0.13	0.70	1.43	1.97	2.41	2.81
120	0.10	0.33	0.95	1.71	2.20	2.65	3.06
130	0.10	0.51	1.28	1.95	2.45	2.91	3.33

PC - Non-exhaust PM emission rate (g/hr) - 2024

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.28	0.28	0.28	0.28	0.28	0.28	0.28
20	0.56	0.56	0.56	0.56	0.56	0.56	0.56
30	0.84	0.84	0.84	0.84	0.84	0.84	0.84
40	1.12	1.12	1.12	1.12	1.12	1.12	1.12
50	1.40	1.40	1.40	1.40	1.40	1.40	1.40
60	1.68	1.68	1.68	1.68	1.68	1.68	1.68
70	1.96	1.96	1.96	1.96	1.96	1.96	1.96
80	2.24	2.24	2.24	2.24	2.24	2.24	2.24
90	2.52	2.52	2.52	2.52	2.52	2.52	2.52
100	2.80	2.80	2.80	2.80	2.80	2.80	2.80
110	3.08	3.08	3.08	3.08	3.08	3.08	3.08
120	3.36	3.36	3.36	3.36	3.36	3.36	3.36
130	3.64	3.64	3.64	3.64	3.64	3.64	3.64

Table 6.13. LDV emission rates for 2024.

LDV - CO emission rate (g/hr) - 2024

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	1.3	1.3	1.3	1.3	1.3	1.3	1.3
10	10.7	10.7	11.9	23.1	31.6	39.3	30.5
20	10.7	10.7	16.6	34.2	30.5	16.8	19.8
30	10.7	10.7	22.1	36.6	15.9	24.7	46.3
40	10.7	10.7	27.0	22.8	20.8	47.4	88.1
50	10.7	10.7	29.1	17.1	33.5	76.6	141.5
60	10.7	10.7	36.3	17.7	57.3	126.5	198.9
70	10.7	10.7	31.2	32.6	96.3	183.0	268.3
80	10.7	10.7	16.3	57.9	152.8	244.8	352.0
90	10.7	24.1	22.9	97.8	205.6	319.2	450.3
100	10.7	33.1	48.9	160.6	277.2	415.8	574.1
110	10.7	37.2	96.6	225.3	367.6	534.1	722.4
120	18.7	41.3	167.7	309.1	480.1	677.3	774.4
130	26.5	94.2	243.7	415.1	617.8	709.9	838.5

LDV - NOx emission rate (g/hr) - 2024

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	4.8	4.8	4.8	4.8	4.8	4.8	4.8
10	4.9	4.9	5.2	8.6	11.3	14.0	13.6
20	4.9	4.9	6.6	12.2	13.6	12.3	15.0
30	4.9	4.9	8.3	14.3	12.2	17.2	24.7
40	4.9	4.9	9.8	12.9	15.5	25.0	35.5
50	4.9	4.9	10.5	12.3	20.5	32.8	46.3
60	4.9	4.9	12.9	14.1	27.9	43.5	61.7
70	4.9	4.9	13.7	20.2	37.3	57.3	80.6
80	4.9	4.9	12.3	28.1	48.9	74.3	102.7
90	4.9	7.6	16.4	37.7	63.6	94.1	128.2
100	4.9	10.6	25.5	51.1	83.0	119.3	159.6
110	4.9	13.0	37.4	69.0	106.8	149.5	196.5
120	9.8	23.0	53.1	91.4	135.8	185.3	210.0
130	12.5	36.9	74.0	119.1	170.5	193.5	226.9

LDV - NO2 emission rate (g/hr) - 2024

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	1.66	1.66	1.66	1.66	1.66	1.66	1.66
10	1.64	1.64	1.74	2.51	3.00	3.40	3.58
20	1.64	1.64	2.09	3.13	3.58	3.74	4.66
30	1.64	1.64	2.45	3.55	3.75	5.28	7.40
40	1.64	1.64	2.74	3.65	4.80	7.49	10.35
50	1.64	1.64	2.86	3.73	6.23	9.63	13.20
60	1.64	1.64	3.24	4.38	8.28	12.46	18.01
70	1.64	1.64	3.58	6.14	10.83	16.61	24.08
80	1.64	1.64	3.75	8.33	13.94	22.04	31.31
90	1.64	2.52	5.07	10.93	18.60	28.48	39.71
100	1.64	3.44	7.62	14.63	24.85	36.77	50.19
110	1.64	4.07	10.85	20.33	32.65	46.82	62.64
120	2.75	6.92	15.26	27.61	42.25	58.87	67.06
130	3.72	10.72	21.94	36.71	53.88	61.61	72.56

LDV - Exhaust PM emission rate (m2/hr) - 2024

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	1.51	1.51	1.51	1.51	1.51	1.51	1.51
10	0.29	0.29	0.33	0.65	0.88	1.09	1.31
20	0.29	0.29	0.46	0.95	1.31	1.74	2.21
30	0.30	0.30	0.62	1.22	1.78	2.46	3.30
40	0.29	0.29	0.75	1.49	2.26	3.40	4.42
50	0.29	0.29	0.81	1.72	2.84	4.15	5.19
60	0.29	0.29	1.01	2.12	3.64	5.02	6.01
70	0.29	0.29	1.30	2.81	4.60	5.79	6.87
80	0.29	0.29	1.77	3.66	5.34	6.59	7.75
90	0.30	0.67	2.37	4.63	6.10	7.42	8.65
100	0.29	1.27	3.39	5.46	6.97	8.35	9.64
110	0.29	2.01	4.61	6.35	7.91	9.34	10.68
120	0.76	3.11	5.57	7.32	8.90	10.38	11.23
130	1.67	4.56	6.58	8.34	9.96	10.62	12.02

LDV - Non-exhaust PM emission rate (g/hr) - 2024

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.28	0.28	0.28	0.28	0.28	0.28	0.28
20	0.56	0.56	0.56	0.56	0.56	0.56	0.56
30	0.84	0.84	0.84	0.84	0.84	0.84	0.84
40	1.12	1.12	1.12	1.12	1.12	1.12	1.12
50	1.40	1.40	1.40	1.40	1.40	1.40	1.40
60	1.68	1.68	1.68	1.68	1.68	1.68	1.68
70	1.96	1.96	1.96	1.96	1.96	1.96	1.96
80	2.24	2.24	2.24	2.24	2.24	2.24	2.24
90	2.52	2.52	2.52	2.52	2.52	2.52	2.52
100	2.80	2.80	2.80	2.80	2.80	2.80	2.80
110	3.08	3.08	3.08	3.08	3.08	3.08	3.08
120	3.36	3.36	3.36	3.36	3.36	3.36	3.36
130	3.64	3.64	3.64	3.64	3.64	3.64	3.64

Table 6.14. HGV emissions rates for 2024.

HGV - CO emission rate (g/hr) - 2024

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	9.6	9.6	9.6	9.6	9.6	9.6	9.6
10	7.7	10.4	20.1	27.6	37.8	51.6	64.7
20	5.0	8.6	20.2	34.9	54.2	79.0	98.1
30	4.2	8.5	25.5	42.8	71.2	103.0	125.5
40	3.6	7.2	26.1	49.7	88.8	123.4	139.2
50	3.6	5.8	24.8	55.8	106.4	135.8	145.1
60	3.6	4.8	22.2	63.9	121.2	140.7	152.4
70	3.6	3.9	19.5	76.9	134.9	143.3	161.4
80	3.6	4.0	21.4	92.8	137.2	149.8	175.9
90	3.6	4.3	21.4	101.7	145.8	159.4	195.8
100	3.6	4.9	24.9	108.7	155.9	174.4	215.7
110	3.6	5.5	29.0	115.4	167.1	189.5	235.3
120	3.7	7.2	33.2	120.7	178.5	204.4	254.7
130	4.0	8.5	38.5	125.1	190.3	219.0	274.7

HGV - NOx emission rate (g/hr) - 2024

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	77.9	77.9	77.9	77.9	77.9	77.9	77.9
10	19.2	33.6	84.7	134.6	164.2	177.5	170.1
20	9.5	27.0	79.0	142.3	175.4	196.1	238.9
30	6.9	27.2	108.6	160.9	174.3	240.9	276.1
40	5.9	17.7	103.5	171.1	201.4	269.7	318.4
50	5.9	11.5	94.1	172.9	221.5	295.3	352.2
60	5.9	8.0	81.8	177.8	240.1	320.6	415.6
70	5.9	6.4	79.2	171.2	256.1	364.7	480.2
80	5.9	6.6	75.2	170.2	288.5	416.3	546.7
90	5.9	7.4	84.1	186.1	327.7	466.8	612.8
100	5.9	9.3	108.9	222.6	366.3	516.1	678.3
110	5.9	12.9	139.3	261.8	403.1	564.7	743.4
120	6.0	21.3	175.4	293.2	435.4	612.8	808.1
130	7.2	32.5	220.9	314.5	468.6	660.4	872.9

HGV - NO2 emission rate (g/hr) - 2024

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	9.39	9.39	9.39	9.39	9.39	9.39	9.39
10	2.32	4.06	10.21	16.21	19.78	21.39	20.52
20	1.16	3.26	9.52	17.15	21.14	23.65	28.79
30	0.84	3.28	13.08	19.39	21.02	29.02	33.27
40	0.72	2.15	12.48	20.61	24.28	32.48	38.34
50	0.72	1.40	11.35	20.84	26.70	35.57	42.41
60	0.72	0.98	9.86	21.43	28.93	38.61	50.02
70	0.72	0.77	9.56	20.65	30.85	43.90	57.78
80	0.72	0.81	9.08	20.52	34.75	50.11	65.78
90	0.72	0.90	10.14	22.43	39.46	56.19	73.73
100	0.72	1.13	13.12	26.81	44.10	62.11	81.61
110	0.72	1.56	16.78	31.53	48.54	67.96	89.45
120	0.73	2.58	21.11	35.33	52.42	73.75	97.23
130	0.87	3.92	26.60	37.90	56.41	79.47	105.02

HGV - Exhaust PM emission rate (m2/hr) - 2024

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	7.04	7.04	7.04	7.04	7.04	7.04	7.04
10	8.42	7.82	6.82	8.51	11.10	13.50	14.95
20	7.43	8.51	6.66	9.98	13.80	16.33	18.81
30	7.17	8.52	7.62	12.00	15.57	19.53	23.14
40	6.86	8.23	8.06	13.41	17.51	22.77	27.19
50	6.86	8.02	7.98	14.13	19.88	25.75	31.57
60	6.86	7.66	8.52	14.84	22.29	28.90	36.19
70	6.85	7.04	8.66	15.76	24.52	32.32	41.02
80	6.86	7.15	8.73	17.44	27.04	36.16	46.45
90	6.86	7.41	10.07	19.69	29.75	40.09	51.86
100	6.86	7.88	11.04	22.28	32.55	44.11	57.26
110	6.86	7.74	12.84	24.82	35.32	48.09	62.62
120	6.87	8.56	15.09	26.78	37.97	52.03	67.95
130	7.14	10.09	17.52	28.50	40.69	55.97	73.31

HGV - Non-exhaust PM emission rate (g/hr) - 2024

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	1.04	1.04	1.04	1.04	1.04	1.04	1.04
20	2.08	2.08	2.08	2.08	2.08	2.08	2.08
30	3.12	3.12	3.12	3.12	3.12	3.12	3.12
40	4.16	4.16	4.16	4.16	4.16	4.16	4.16
50	5.20	5.20	5.20	5.20	5.20	5.20	5.20
60	6.24	6.24	6.24	6.24	6.24	6.24	6.24
70	7.28	7.28	7.28	7.28	7.28	7.28	7.28
80	8.32	8.32	8.32	8.32	8.32	8.32	8.32
90	9.36	9.36	9.36	9.36	9.36	9.36	9.36
100	10.40	10.40	10.40	10.40	10.40	10.40	10.40
110	11.44	11.44	11.44	11.44	11.44	11.44	11.44
120	12.48	12.48	12.48	12.48	12.48	12.48	12.48
130	13.52	13.52	13.52	13.52	13.52	13.52	13.52

Table 6.15. PC emission rates for 2026.

PC - CO emission rate (g/hr) - 2026

Speed (km/hr)	Gradient -6%	-4%	-2%	0%	2%	4%	6%
0	1.7	1.7	1.7	1.7	1.7	1.7	1.7
10	13.4	11.1	11.7	13.7	15.1	16.2	17.2
20	6.9	12.5	11.9	15.2	17.1	19.7	23.2
30	5.7	8.3	12.3	16.4	19.6	24.7	30.2
40	5.6	7.8	13.9	17.4	23.0	30.1	42.2
50	5.6	5.8	12.7	18.7	26.5	37.8	58.4
60	5.5	5.8	13.7	20.9	31.1	52.1	88.1
70	5.5	5.8	15.0	24.3	40.3	70.1	158.8
80	5.5	6.0	16.5	28.9	54.8	120.2	275.1
90	5.5	9.5	20.3	35.9	75.1	208.9	459.6
100	5.6	10.3	24.3	50.8	134.3	353.7	746.5
110	5.6	14.4	30.3	70.7	237.4	584.8	1,185.2
120	5.8	17.4	43.3	133.6	410.2	947.1	1,844.4
130	13.6	25.3	65.1	251.3	693.3	1,506.1	2,819.6

PC - NOx emission rate (g/hr) - 2026

Speed (km/hr)	Gradient -6%	-4%	-2%	0%	2%	4%	6%
0	1.1	1.1	1.1	1.1	1.1	1.1	1.1
10	1.3	1.3	1.3	2.0	2.5	3.0	3.4
20	1.3	1.3	1.4	2.6	3.4	4.3	5.9
30	1.3	1.3	1.7	3.1	4.4	6.3	8.4
40	1.3	1.3	1.8	3.5	5.6	8.1	11.2
50	1.3	1.3	1.7	3.9	6.6	10.1	13.9
60	1.3	1.3	2.0	4.5	8.2	12.6	17.3
70	1.3	1.3	2.4	5.8	10.3	15.6	20.8
80	1.3	1.3	3.0	7.1	12.7	18.8	24.7
90	1.3	1.3	4.0	9.0	15.6	22.1	28.7
100	1.3	1.4	5.4	11.4	18.8	26.0	33.3
110	1.3	1.8	7.1	14.6	22.5	30.3	38.3
120	1.3	3.7	9.6	18.2	26.6	35.2	43.9
130	1.4	5.4	13.1	22.3	31.3	40.6	49.9

PC - NO2 emission rate (g/hr) - 2026

Speed (km/hr)	Gradient -6%	-4%	-2%	0%	2%	4%	6%
0	0.28	0.28	0.28	0.28	0.28	0.28	0.28
10	0.28	0.28	0.28	0.49	0.65	0.79	0.93
20	0.28	0.28	0.32	0.68	0.91	1.14	1.55
30	0.28	0.28	0.41	0.84	1.16	1.65	2.29
40	0.28	0.28	0.43	0.95	1.46	2.19	3.17
50	0.28	0.28	0.40	1.02	1.74	2.81	4.04
60	0.28	0.28	0.46	1.16	2.22	3.63	5.10
70	0.28	0.28	0.59	1.46	2.87	4.57	6.18
80	0.28	0.28	0.79	1.86	3.63	5.52	7.34
90	0.28	0.28	0.99	2.41	4.51	6.54	8.59
100	0.28	0.29	1.31	3.19	5.50	7.72	10.00
110	0.28	0.35	1.80	4.16	6.60	9.05	11.55
120	0.28	0.83	2.57	5.26	7.87	10.54	13.26
130	0.29	1.26	3.64	6.48	9.31	12.20	15.14

PC - Exhaust PM emission rate (m2/hr) - 2026

Speed (km/hr)	Gradient -6%	-4%	-2%	0%	2%	4%	6%
0	0.07	0.07	0.07	0.07	0.07	0.07	0.07
10	0.09	0.09	0.09	0.16	0.21	0.26	0.32
20	0.09	0.09	0.10	0.22	0.31	0.39	0.51
30	0.09	0.09	0.13	0.28	0.39	0.53	0.71
40	0.09	0.09	0.14	0.32	0.48	0.69	0.94
50	0.09	0.09	0.12	0.35	0.56	0.85	1.15
60	0.09	0.09	0.15	0.39	0.69	1.05	1.38
70	0.09	0.09	0.19	0.48	0.86	1.28	1.56
80	0.09	0.09	0.26	0.59	1.05	1.45	1.73
90	0.09	0.09	0.33	0.74	1.26	1.61	1.91
100	0.09	0.09	0.43	0.94	1.44	1.79	2.10
110	0.09	0.11	0.57	1.18	1.62	1.97	2.30
120	0.09	0.27	0.78	1.40	1.81	2.17	2.51
130	0.09	0.42	1.05	1.60	2.01	2.38	2.72

PC - Non-exhaust PM emission rate (g/hr) - 2026

Speed (km/hr)	Gradient -6%	-4%	-2%	0%	2%	4%	6%
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.28	0.28	0.28	0.28	0.28	0.28	0.28
20	0.56	0.56	0.56	0.56	0.56	0.56	0.56
30	0.84	0.84	0.84	0.84	0.84	0.84	0.84
40	1.12	1.12	1.12	1.12	1.12	1.12	1.12
50	1.40	1.40	1.40	1.40	1.40	1.40	1.40
60	1.68	1.68	1.68	1.68	1.68	1.68	1.68
70	1.96	1.96	1.96	1.96	1.96	1.96	1.96
80	2.24	2.24	2.24	2.24	2.24	2.24	2.24
90	2.52	2.52	2.52	2.52	2.52	2.52	2.52
100	2.80	2.80	2.80	2.80	2.80	2.80	2.80
110	3.08	3.08	3.08	3.08	3.08	3.08	3.08
120	3.36	3.36	3.36	3.36	3.36	3.36	3.36
130	3.64	3.64	3.64	3.64	3.64	3.64	3.64

Table 6.16 LDV emission rates for 2026.

LDV - CO emission rate (g/hr) - 2026

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
10	8.4	8.4	9.2	17.6	23.9	29.6	23.0
20	8.4	8.4	12.7	25.8	23.1	12.9	15.0
30	8.4	8.4	16.8	27.6	12.2	18.7	34.4
40	8.4	8.4	20.5	17.4	15.8	35.2	64.9
50	8.4	8.4	22.0	13.1	25.1	56.6	103.9
60	8.4	8.4	27.3	13.5	42.5	92.9	145.7
70	8.4	8.4	23.6	24.4	70.9	134.1	196.2
80	8.4	8.4	12.5	43.0	112.1	179.1	257.1
90	8.4	18.3	17.4	72.1	150.5	233.2	328.6
100	8.4	25.0	36.4	117.8	202.6	303.5	418.7
110	8.4	28.0	71.1	164.9	268.5	389.6	526.6
120	14.5	30.9	122.9	225.9	350.3	493.9	564.6
130	20.0	69.4	178.3	303.0	450.6	517.6	611.2

LDV - NOx emission rate (g/hr) - 2026

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	4.2	4.2	4.2	4.2	4.2	4.2	4.2
10	4.2	4.2	4.5	7.1	9.1	11.0	11.0
20	4.2	4.2	5.6	9.8	11.0	10.3	12.6
30	4.2	4.2	6.9	11.3	10.2	14.4	20.5
40	4.2	4.2	8.0	10.5	13.0	20.8	29.3
50	4.2	4.2	8.5	10.3	17.1	27.1	38.0
60	4.2	4.2	10.3	11.8	23.1	35.7	51.0
70	4.2	4.2	11.0	16.8	30.8	47.2	66.9
80	4.2	4.2	10.2	23.3	40.1	61.6	85.7
90	4.2	6.5	13.8	31.0	52.5	78.4	107.5
100	4.2	9.0	21.2	41.9	68.9	99.9	134.3
110	4.2	10.9	30.8	57.1	89.2	125.7	166.0
120	8.0	19.1	43.6	76.1	114.0	156.5	177.5
130	10.4	30.4	61.3	99.7	143.7	163.4	191.9

LDV - NO2 emission rate (g/hr) - 2026

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	1.43	1.43	1.43	1.43	1.43	1.43	1.43
10	1.40	1.40	1.48	2.13	2.53	2.86	3.02
20	1.40	1.40	1.78	2.64	3.02	3.17	3.96
30	1.40	1.40	2.08	2.99	3.19	4.48	6.27
40	1.40	1.40	2.32	3.09	4.08	6.36	8.77
50	1.40	1.40	2.42	3.17	5.29	8.16	11.18
60	1.40	1.40	2.73	3.72	7.02	10.56	15.26
70	1.40	1.40	3.02	5.21	9.18	14.07	20.43
80	1.40	1.40	3.18	7.06	11.81	18.69	26.57
90	1.40	2.15	4.30	9.26	15.76	24.17	33.73
100	1.40	2.93	6.46	12.39	21.08	31.23	42.66
110	1.40	3.46	9.20	17.24	27.72	39.78	53.26
120	2.32	5.87	12.92	23.43	35.89	50.05	57.02
130	3.15	9.08	18.61	31.18	45.80	52.38	61.70

LDV - Exhaust PM emission rate (m2/hr) - 2026

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	1.18	1.18	1.18	1.18	1.18	1.18	1.18
10	0.25	0.25	0.28	0.54	0.74	0.91	1.09
20	0.25	0.25	0.39	0.80	1.09	1.45	1.84
30	0.25	0.25	0.52	1.02	1.49	2.05	2.76
40	0.25	0.25	0.63	1.24	1.89	2.83	3.70
50	0.25	0.25	0.68	1.44	2.37	3.47	4.34
60	0.25	0.25	0.84	1.76	3.04	4.20	5.02
70	0.25	0.25	1.08	2.34	3.85	4.84	5.73
80	0.25	0.25	1.47	3.06	4.47	5.50	6.46
90	0.25	0.56	1.98	3.88	5.09	6.18	7.20
100	0.25	1.06	2.83	4.56	5.81	6.95	8.01
110	0.25	1.68	3.86	5.30	6.58	7.76	8.86
120	0.63	2.60	4.65	6.10	7.40	8.61	9.31
130	1.39	3.82	5.49	6.94	8.27	8.80	9.96

LDV - Non-exhaust PM emission rate (g/hr) - 2026

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.28	0.28	0.28	0.28	0.28	0.28	0.28
20	0.56	0.56	0.56	0.56	0.56	0.56	0.56
30	0.84	0.84	0.84	0.84	0.84	0.84	0.84
40	1.12	1.12	1.12	1.12	1.12	1.12	1.12
50	1.40	1.40	1.40	1.40	1.40	1.40	1.40
60	1.68	1.68	1.68	1.68	1.68	1.68	1.68
70	1.96	1.96	1.96	1.96	1.96	1.96	1.96
80	2.24	2.24	2.24	2.24	2.24	2.24	2.24
90	2.52	2.52	2.52	2.52	2.52	2.52	2.52
100	2.80	2.80	2.80	2.80	2.80	2.80	2.80
110	3.08	3.08	3.08	3.08	3.08	3.08	3.08
120	3.36	3.36	3.36	3.36	3.36	3.36	3.36
130	3.64	3.64	3.64	3.64	3.64	3.64	3.64

Table 6.17. HGV emissions rates for 2026.

HGV - CO emission rate (g/hr) - 2026

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	8.2	8.2	8.2	8.2	8.2	8.2	8.2
10	6.6	9.3	18.7	26.1	36.3	50.2	63.4
20	4.3	7.5	18.9	33.5	52.8	77.9	96.9
30	3.5	7.4	24.0	41.3	69.9	101.8	124.1
40	3.0	6.1	24.6	48.2	87.6	122.0	137.2
50	3.0	4.9	23.3	54.4	105.2	134.1	142.2
60	3.0	4.0	20.7	62.6	119.9	138.3	148.4
70	3.0	3.3	18.1	75.7	133.6	140.1	156.4
80	3.0	3.3	19.9	91.7	135.3	145.8	169.9
90	3.0	3.5	19.6	100.3	143.4	154.4	189.0
100	3.0	4.0	22.8	106.8	153.1	169.0	208.2
110	3.0	4.4	26.6	113.1	164.0	183.5	227.1
120	3.0	5.5	30.5	118.1	175.0	197.9	245.8
130	3.2	6.7	35.2	122.2	186.6	212.0	265.0

HGV - NOx emission rate (g/hr) - 2026

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	76.0	76.0	76.0	76.0	76.0	76.0	76.0
10	17.7	32.2	82.4	130.6	158.4	170.0	158.6
20	8.6	25.7	76.6	136.3	167.0	183.2	223.9
30	6.0	25.8	103.9	152.9	160.8	223.9	250.4
40	5.1	16.3	97.4	161.9	185.7	244.5	282.0
50	5.1	10.2	87.9	162.9	201.3	262.0	303.9
60	5.1	6.9	76.7	166.5	213.5	278.6	358.0
70	5.1	5.5	73.9	156.7	223.0	314.4	413.3
80	5.1	5.7	69.2	151.2	249.4	358.7	470.4
90	5.1	6.4	76.0	162.3	283.0	402.1	527.2
100	5.1	7.9	98.1	193.6	316.2	444.4	583.5
110	5.1	10.9	125.1	227.7	348.2	486.2	639.4
120	5.2	17.7	157.1	255.4	375.8	527.5	695.0
130	6.0	27.0	198.0	273.9	404.4	568.4	750.7

HGV - NO2 emission rate (g/hr) - 2026

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	9.18	9.18	9.18	9.18	9.18	9.18	9.18
10	2.16	3.90	9.95	15.76	19.13	20.55	19.21
20	1.05	3.11	9.25	16.47	20.19	22.17	27.10
30	0.74	3.13	12.55	18.47	19.47	27.11	30.34
40	0.63	1.98	11.78	19.56	22.48	29.63	34.19
50	0.63	1.25	10.63	19.70	24.40	31.76	36.87
60	0.63	0.85	9.28	20.15	25.89	33.79	43.43
70	0.63	0.67	8.94	18.99	27.07	38.14	50.12
80	0.63	0.70	8.38	18.34	30.27	43.51	57.05
90	0.63	0.78	9.20	19.71	34.34	48.77	63.93
100	0.63	0.97	11.88	23.49	38.37	53.90	70.76
110	0.63	1.33	15.14	27.63	42.25	58.97	77.55
120	0.64	2.17	19.01	31.00	45.60	63.98	84.28
130	0.74	3.29	23.96	33.24	49.07	68.94	91.03

HGV - Exhaust PM emission rate (m2/hr) - 2026

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	5.65	5.65	5.65	5.65	5.65	5.65	5.65
10	7.70	6.95	5.45	6.83	9.24	11.42	12.64
20	6.97	7.76	5.35	8.20	11.68	13.74	15.75
30	6.78	7.76	5.98	10.08	13.12	16.30	19.15
40	6.52	7.53	6.38	11.33	14.68	18.85	22.30
50	6.52	7.37	6.33	11.93	16.57	21.16	25.69
60	6.52	7.09	6.98	12.51	18.46	23.60	29.30
70	6.51	6.65	7.34	13.22	20.19	26.25	33.09
80	6.52	6.73	7.20	14.57	22.13	29.26	37.44
90	6.52	6.90	8.34	16.33	24.22	32.39	41.77
100	6.52	7.21	9.04	18.35	26.42	35.61	46.11
110	6.52	7.00	10.52	20.37	28.65	38.80	50.40
120	6.53	7.33	12.41	21.94	30.76	41.96	54.68
130	6.71	8.63	14.41	23.35	32.94	45.12	58.97

HGV - Non-exhaust PM emission rate (g/hr) - 2026

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	1.04	1.04	1.04	1.04	1.04	1.04	1.04
20	2.08	2.08	2.08	2.08	2.08	2.08	2.08
30	3.12	3.12	3.12	3.12	3.12	3.12	3.12
40	4.16	4.16	4.16	4.16	4.16	4.16	4.16
50	5.20	5.20	5.20	5.20	5.20	5.20	5.20
60	6.24	6.24	6.24	6.24	6.24	6.24	6.24
70	7.28	7.28	7.28	7.28	7.28	7.28	7.28
80	8.32	8.32	8.32	8.32	8.32	8.32	8.32
90	9.36	9.36	9.36	9.36	9.36	9.36	9.36
100	10.40	10.40	10.40	10.40	10.40	10.40	10.40
110	11.44	11.44	11.44	11.44	11.44	11.44	11.44
120	12.48	12.48	12.48	12.48	12.48	12.48	12.48
130	13.52	13.52	13.52	13.52	13.52	13.52	13.52

Table 6.18. PC emission rates for 2036.

PC - CO emission rate (g/hr) - 2036

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	1.8	1.8	1.8	1.8	1.8	1.8	1.8
10	13.9	11.3	12.0	14.3	15.8	17.1	18.3
20	7.1	13.0	12.3	15.9	18.1	20.1	23.5
30	5.9	8.6	12.7	17.3	20.0	24.7	29.7
40	5.8	8.1	14.4	18.4	23.1	29.6	40.9
50	5.8	6.0	13.1	19.3	26.3	36.6	56.7
60	5.7	6.0	14.1	21.1	30.4	50.5	86.4
70	5.7	6.0	15.5	24.3	39.1	68.2	158.1
80	5.7	6.2	17.3	28.5	53.3	119.5	275.1
90	5.7	9.8	21.1	34.9	73.4	208.6	461.1
100	5.7	10.5	24.4	49.6	133.8	354.1	750.6
110	5.8	14.6	29.8	69.2	237.4	586.7	1,192.9
120	5.9	17.5	42.2	133.0	411.0	951.7	1,857.9
130	14.2	25.2	63.6	250.5	695.3	1,514.9	2,842.6

PC - NOx emission rate (g/hr) - 2036

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
10	1.2	1.2	1.2	1.8	2.3	2.7	3.2
20	1.2	1.2	1.3	2.4	3.1	4.0	5.4
30	1.2	1.2	1.6	2.9	4.0	5.8	7.8
40	1.2	1.2	1.7	3.2	5.1	7.5	10.5
50	1.2	1.2	1.6	3.6	6.1	9.4	13.1
60	1.2	1.2	1.8	4.1	7.6	11.9	16.4
70	1.2	1.2	2.2	5.3	9.6	14.8	19.7
80	1.2	1.2	2.8	6.6	12.0	17.7	23.3
90	1.2	1.2	3.6	8.3	14.7	20.9	27.2
100	1.2	1.3	4.9	10.7	17.8	24.6	31.5
110	1.2	1.5	6.5	13.7	21.2	28.7	36.3
120	1.2	3.3	8.9	17.1	25.1	33.3	41.5
130	1.2	4.9	12.2	21.0	29.6	38.4	47.3

PC - NO2 emission rate (g/hr) - 2036

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	0.24	0.24	0.24	0.24	0.24	0.24	0.24
10	0.24	0.24	0.24	0.41	0.55	0.67	0.79
20	0.24	0.24	0.27	0.57	0.77	0.96	1.31
30	0.24	0.24	0.34	0.71	0.98	1.39	1.93
40	0.24	0.24	0.36	0.80	1.23	1.86	2.69
50	0.24	0.24	0.33	0.87	1.47	2.38	3.43
60	0.24	0.24	0.39	0.98	1.88	3.07	4.32
70	0.24	0.24	0.50	1.24	2.43	3.87	5.24
80	0.24	0.24	0.67	1.57	3.08	4.68	6.22
90	0.24	0.24	0.84	2.04	3.82	5.54	7.28
100	0.24	0.24	1.11	2.70	4.66	6.55	8.47
110	0.24	0.30	1.52	3.52	5.59	7.67	9.79
120	0.24	0.70	2.18	4.46	6.67	8.93	11.23
130	0.24	1.06	3.08	5.49	7.89	10.34	12.83

PC - Exhaust PM emission rate (m2/hr) - 2036

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	0.04	0.04	0.04	0.04	0.04	0.04	0.04
10	0.05	0.05	0.05	0.09	0.13	0.16	0.19
20	0.05	0.05	0.06	0.13	0.18	0.23	0.30
30	0.05	0.05	0.08	0.17	0.23	0.31	0.41
40	0.05	0.06	0.08	0.19	0.28	0.40	0.55
50	0.05	0.05	0.07	0.20	0.33	0.49	0.67
60	0.05	0.05	0.09	0.23	0.40	0.61	0.81
70	0.05	0.05	0.11	0.28	0.50	0.75	0.91
80	0.05	0.05	0.15	0.34	0.62	0.85	1.01
90	0.05	0.05	0.19	0.43	0.74	0.94	1.11
100	0.05	0.05	0.25	0.55	0.85	1.04	1.23
110	0.05	0.06	0.33	0.69	0.95	1.15	1.34
120	0.05	0.16	0.46	0.82	1.05	1.27	1.46
130	0.05	0.24	0.61	0.94	1.17	1.39	1.58

PC - Non-exhaust PM emission rate (g/hr) - 2036

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.28	0.28	0.28	0.28	0.28	0.28	0.28
20	0.56	0.56	0.56	0.56	0.56	0.56	0.56
30	0.84	0.84	0.84	0.84	0.84	0.84	0.84
40	1.12	1.12	1.12	1.12	1.12	1.12	1.12
50	1.40	1.40	1.40	1.40	1.40	1.40	1.40
60	1.68	1.68	1.68	1.68	1.68	1.68	1.68
70	1.96	1.96	1.96	1.96	1.96	1.96	1.96
80	2.24	2.24	2.24	2.24	2.24	2.24	2.24
90	2.52	2.52	2.52	2.52	2.52	2.52	2.52
100	2.80	2.80	2.80	2.80	2.80	2.80	2.80
110	3.08	3.08	3.08	3.08	3.08	3.08	3.08
120	3.36	3.36	3.36	3.36	3.36	3.36	3.36
130	3.64	3.64	3.64	3.64	3.64	3.64	3.64

Table 6.19 LDV emission rates for 2036.

LDV - CO emission rate (g/hr) - 2036

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	0.9	0.9	0.9	0.9	0.9	0.9	0.9
10	3.8	3.8	4.1	6.9	8.9	10.7	8.6
20	3.8	3.8	5.3	9.5	8.6	5.3	5.9
30	3.8	3.8	6.7	10.0	5.1	6.9	11.3
40	3.8	3.8	7.8	6.8	6.1	11.5	19.6
50	3.8	3.8	8.3	5.4	8.7	17.3	30.0
60	3.8	3.8	10.0	5.4	13.5	27.1	41.1
70	3.8	3.8	8.8	8.5	21.2	38.0	54.5
80	3.8	3.8	5.2	13.6	32.2	50.0	70.6
90	3.8	7.2	6.5	21.5	42.4	64.3	89.5
100	3.8	9.2	11.8	33.7	56.2	82.8	113.2
110	3.8	10.0	21.2	46.2	73.6	105.6	141.7
120	6.3	10.7	35.1	62.3	95.2	133.0	151.8
130	7.3	20.8	49.8	82.7	121.6	139.3	164.2

LDV - NOx emission rate (g/hr) - 2036

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	2.8	2.8	2.8	2.8	2.8	2.8	2.8
10	2.6	2.6	2.8	4.1	5.0	5.7	5.9
20	2.6	2.6	3.4	5.2	5.9	6.1	7.6
30	2.6	2.6	4.0	5.9	6.1	8.6	12.1
40	2.6	2.6	4.5	6.0	7.8	12.2	17.0
50	2.6	2.6	4.7	6.1	10.2	15.8	21.7
60	2.6	2.6	5.4	7.1	13.5	20.5	29.5
70	2.6	2.6	5.9	10.0	17.8	27.3	39.4
80	2.6	2.6	6.1	13.6	22.9	36.0	51.1
90	2.6	4.1	8.3	17.9	30.5	46.5	64.6
100	2.6	5.6	12.5	24.0	40.6	59.9	81.6
110	2.6	6.6	17.8	33.3	53.2	76.1	101.7
120	4.5	11.3	25.0	45.1	68.7	95.6	108.8
130	6.1	17.6	35.9	59.8	87.5	100.0	117.7

LDV - NO2 emission rate (g/hr) - 2036

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	0.86	0.86	0.86	0.86	0.86	0.86	0.86
10	0.80	0.80	0.84	1.21	1.42	1.59	1.70
20	0.80	0.80	1.01	1.48	1.70	1.80	2.25
30	0.80	0.80	1.18	1.67	1.81	2.55	3.56
40	0.80	0.80	1.31	1.74	2.32	3.60	4.96
50	0.80	0.80	1.36	1.80	3.00	4.62	6.31
60	0.80	0.80	1.53	2.11	3.98	5.96	8.63
70	0.80	0.80	1.69	2.96	5.19	7.96	11.58
80	0.80	0.80	1.81	4.00	6.67	10.58	15.08
90	0.80	1.23	2.44	5.23	8.92	13.71	19.16
100	0.80	1.67	3.66	7.00	11.95	17.74	24.26
110	0.80	1.97	5.20	9.76	15.73	22.62	30.32
120	1.31	3.33	7.30	13.29	20.40	28.48	32.47
130	1.79	5.13	10.54	17.71	26.06	29.81	35.13

LDV - Exhaust PM emission rate (m2/hr) - 2036

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	0.47	0.47	0.47	0.47	0.47	0.47	0.47
10	0.16	0.16	0.17	0.34	0.45	0.56	0.66
20	0.16	0.16	0.24	0.49	0.66	0.88	1.12
30	0.16	0.16	0.32	0.62	0.91	1.25	1.69
40	0.16	0.16	0.39	0.76	1.15	1.71	2.28
50	0.16	0.16	0.42	0.88	1.45	2.14	2.67
60	0.16	0.16	0.52	1.07	1.87	2.59	3.08
70	0.16	0.16	0.66	1.43	2.38	2.97	3.50
80	0.16	0.16	0.90	1.88	2.75	3.36	3.93
90	0.16	0.35	1.21	2.39	3.12	3.77	4.37
100	0.16	0.65	1.74	2.80	3.55	4.22	4.84
110	0.16	1.02	2.38	3.25	4.00	4.69	5.34
120	0.39	1.59	2.86	3.72	4.48	5.19	5.61
130	0.85	2.36	3.36	4.21	4.99	5.31	6.00

LDV - Non-exhaust PM emission rate (g/hr) - 2036

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.28	0.28	0.28	0.28	0.28	0.28	0.28
20	0.56	0.56	0.56	0.56	0.56	0.56	0.56
30	0.84	0.84	0.84	0.84	0.84	0.84	0.84
40	1.12	1.12	1.12	1.12	1.12	1.12	1.12
50	1.40	1.40	1.40	1.40	1.40	1.40	1.40
60	1.68	1.68	1.68	1.68	1.68	1.68	1.68
70	1.96	1.96	1.96	1.96	1.96	1.96	1.96
80	2.24	2.24	2.24	2.24	2.24	2.24	2.24
90	2.52	2.52	2.52	2.52	2.52	2.52	2.52
100	2.80	2.80	2.80	2.80	2.80	2.80	2.80
110	3.08	3.08	3.08	3.08	3.08	3.08	3.08
120	3.36	3.36	3.36	3.36	3.36	3.36	3.36
130	3.64	3.64	3.64	3.64	3.64	3.64	3.64

Table 6.20. HGV emissions rates for 2036.

HGV - CO emission rate (g/hr) - 2036

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	7.2	7.2	7.2	7.2	7.2	7.2	7.2
10	5.3	7.9	17.1	24.5	34.9	49.1	62.5
20	3.2	6.1	17.4	32.1	51.8	77.2	96.6
30	2.5	5.9	22.4	40.1	69.1	101.6	124.3
40	2.0	4.8	22.9	47.0	87.1	122.2	137.2
50	2.0	3.6	21.6	53.3	105.1	134.3	141.4
60	2.0	2.8	19.0	61.7	120.0	138.0	146.7
70	2.0	2.2	16.5	75.1	134.0	139.0	153.8
80	2.0	2.2	18.2	91.4	135.2	144.0	166.6
90	2.0	2.4	17.6	99.9	143.2	151.9	185.2
100	2.0	2.7	20.5	106.1	152.7	166.2	204.0
110	2.0	3.0	24.0	112.3	163.6	180.5	222.5
120	2.1	3.7	27.4	117.1	174.5	194.5	240.8
130	2.1	4.4	31.7	121.1	185.9	208.4	259.6

HGV - NOx emission rate (g/hr) - 2036

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	74.1	74.1	74.1	74.1	74.1	74.1	74.1
10	15.9	30.5	80.1	126.9	153.0	162.3	146.0
20	7.2	24.1	74.3	130.5	158.2	168.8	207.3
30	4.7	24.1	99.5	145.0	145.9	205.1	222.0
40	4.0	14.4	91.3	152.5	168.2	216.8	242.2
50	4.0	8.3	81.4	152.5	178.7	225.3	251.0
60	4.0	5.4	71.2	154.6	184.0	232.5	295.5
70	4.0	4.3	68.2	140.7	186.5	259.6	340.9
80	4.0	4.5	62.7	130.0	206.5	296.0	387.9
90	4.0	4.9	67.2	135.9	234.1	331.8	434.7
100	4.0	6.1	86.7	161.8	261.5	366.7	481.1
110	4.0	8.4	110.4	190.3	288.1	401.1	527.2
120	4.0	13.5	138.4	213.7	310.8	435.2	572.9
130	4.6	20.4	174.6	229.1	334.4	468.9	618.8

HGV - NO2 emission rate (g/hr) - 2036

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	8.90	8.90	8.90	8.90	8.90	8.90	8.90
10	1.91	3.67	9.62	15.26	18.39	19.52	17.56
20	0.87	2.90	8.93	15.69	19.03	20.30	24.93
30	0.57	2.90	11.95	17.44	17.55	24.67	26.70
40	0.48	1.74	10.97	18.34	20.23	26.08	29.14
50	0.48	1.01	9.79	18.34	21.50	27.11	30.20
60	0.48	0.66	8.56	18.58	22.14	27.97	35.55
70	0.48	0.52	8.20	16.93	22.44	31.24	41.01
80	0.48	0.54	7.55	15.64	24.85	35.61	46.67
90	0.48	0.60	8.09	16.36	28.17	39.92	52.29
100	0.48	0.73	10.43	19.46	31.47	44.11	57.87
110	0.48	1.01	13.28	22.90	34.66	48.25	63.41
120	0.49	1.63	16.64	25.72	37.40	52.35	68.91
130	0.56	2.46	20.99	27.57	40.23	56.40	74.43

HGV - Exhaust PM emission rate (m2/hr) - 2036

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	4.57	4.57	4.57	4.57	4.57	4.57	4.57
10	6.73	5.85	3.88	5.12	7.42	9.44	10.46
20	6.24	6.77	3.83	6.45	9.67	11.33	12.94
30	6.09	6.76	4.24	8.24	10.83	13.37	15.58
40	5.90	6.60	4.62	9.36	12.08	15.35	18.00
50	5.90	6.48	4.59	9.87	13.57	17.12	20.58
60	5.90	6.28	5.33	10.32	15.03	18.97	23.36
70	5.89	5.99	5.92	10.86	16.36	20.99	26.29
80	5.90	6.04	5.61	11.95	17.83	23.32	29.72
90	5.90	6.15	6.61	13.33	19.42	25.77	33.13
100	5.90	6.33	7.12	14.87	21.12	28.31	36.55
110	5.90	6.03	8.33	16.45	22.88	30.82	39.94
120	5.90	6.09	9.97	17.70	24.53	33.32	43.32
130	6.01	7.15	11.62	18.87	26.25	35.82	46.70

HGV - Non-exhaust PM emission rate (g/hr) - 2036

Speed	Gradient						
(km/hr)	-6%	-4%	-2%	0%	2%	4%	6%
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	1.04	1.04	1.04	1.04	1.04	1.04	1.04
20	2.08	2.08	2.08	2.08	2.08	2.08	2.08
30	3.12	3.12	3.12	3.12	3.12	3.12	3.12
40	4.16	4.16	4.16	4.16	4.16	4.16	4.16
50	5.20	5.20	5.20	5.20	5.20	5.20	5.20
60	6.24	6.24	6.24	6.24	6.24	6.24	6.24
70	7.28	7.28	7.28	7.28	7.28	7.28	7.28
80	8.32	8.32	8.32	8.32	8.32	8.32	8.32
90	9.36	9.36	9.36	9.36	9.36	9.36	9.36
100	10.40	10.40	10.40	10.40	10.40	10.40	10.40
110	11.44	11.44	11.44	11.44	11.44	11.44	11.44
120	12.48	12.48	12.48	12.48	12.48	12.48	12.48
130	13.52	13.52	13.52	13.52	13.52	13.52	13.52

6.5.8 Validity of emissions estimates

A project to compare the emissions calculated using the methodology outlined in this report (i.e. the detailed PIARC approach) against measurements made in the M5 East Tunnel has been completed. The work[5] provides a first order comparison of the emissions estimate methodology adopted in this report, using the NSW Roads and Maritime fleet estimate methods, evaluated for the M5 East in March 2015, and for the range of tunnel grades in the relevant part of M5 East.

For the controlling pollutant, NO_2, the conclusions were that the emissions estimated using the detailed PIARC method and Roads and Maritime fleet forecast are consistent with in-tunnel measurements. In terms of the experiment conducted, this is saying that the methodology is as accurate as we can know it to be.

The underlying fleet forecast methodology and emission parameters have been revised for this work to incorporate the most current understanding. The revisions are around vehicles complying with the later Euro standards, which were present in very small numbers in the 2015 verification exercise. Changes from the basis of the M5 East Tunnel comparison are:

- Revised implementation of Euro standards for PC and LDV categories:
  - Euro 5a (ADR79/03) assumed to be equivalent to Euro 4, and;
  - Euro 5b (ADR79/04) assumed to be equivalent to Euro 5 and mandated from 2017, and
  - Euro 6 assumed to be implemented for all vehicles from 2021.
- Revised NO_2:NO_X ratios used for estimating NO_2 emissions based on the "EMEP/EEA air pollutant emission inventory guidebook 2016 – Last Update June 2017".

The cumulative impact of those changes, calculated for a fleet average vehicle traversing the tunnel profile of interest in the M5 East, in 2015, is shown in Table 6.21. A positive value indicates that vehicle emissions calculated in the M5 East comparison would increase if that assessment were completed with the methodology and parameters used for this work. It is seen that any impact is quite small and generally results in an increase to vehicle emissions.

Table 6.21. Cumulative impact to vehicle emissions of current methology compared to that used for the M5 East comparison.

Pollutant	Delta for fleet average vehicle
NO_2	-2% to +1%
NO_X	< +1%
CO	< +1%
Visibility (extinction co-efficient)	+3% to +4%

6.6 Climate assumptions

In calculating the vehicle-induced airflow and associated pollution levels throughout a tunnel network, the influence of air temperature is largely insignificant for normal operations. This is because buoyancy forces are quite small compared to tunnel wall friction and the piston effect of vehicles, for most real operating conditions. There are also the large forces from jet fans and tunnel extraction points which make buoyancy less significant. All simulations and results assume constant ambient air conditions of 20°C and 50% relative humidity.

[5] Comparison of PIARC-based Pollution Estimates with Measurements in the M5 East Tunnel", Stacey Agnew, January 2017.

The variability of normal operation system airflows across the year (due to differing ambient conditions) is expected to be within the accuracy band of the results for ventilation outlet airflows and pollutant emissions so the complexity of estimating in-tunnel temperatures at different times of the years is unnecessary.

6.7 Background air quality

Table 6.22. below shows the assumed background air quality at all ventilation supply points and portals. It is assumed to apply at all times.

Table 6.22. Assumed background air quality.

Pollutant	Unit	Value
NO_2	ppm	0.03
CO	ppm	1.3
Visibility (extinction co-efficient)	m^{-1}	0.0001

The F6 Extension and WestConnex ventilation system is designed to ensure net inflow of air at all traffic entry and exit portals and so no allowance for recirculation of pollutants between adjacent portals is necessary.

Further, at this stage of design, no allowance has been made for the following effects as they are insignificant within the context of the design definition:

- Recirculation of pollutants from ventilation outlets to ventilation supply points and/or portals.
- Localised increases in background levels due to portal geometry and surface road traffic emissions.

For the purposes of ventilation design and results within this report, all simulations and results are completed with zero background pollutant levels. Consequently:

1) In-tunnel pollution criteria are assessed against revised criteria, being the limit value (Table 6.24) minus background (Table 6.22.).
2) In-tunnel pollution levels shown throughout the report (Section 8 and Section 8.4) exclude background pollutant levels.
3) All ventilation outlet emissions include only vehicle-sourced emissions, without a background component.

6.8 Vehicle drag and tunnel aerodynamics

The adopted tunnel aerodynamic parameters and criteria are:

Parameter	Value	Comments
Wall friction factors λ	0.035 0.030	Conservative for in-tunnel pollution levels and fire scenario. Conservative for tunnel flows and hence portal capture.
Adverse portal wind pressure	20 Pa	Applied only at portals where that would resist the ventilation effort.
Maximum in-tunnel air velocity	10 m/s	Applied only to cases where jet fans are used to assist tunnel airflows to meet in-tunnel air quality criteria.

Vehicle aerodynamic drag force on an isolated vehicle in open air is expressed by the equation: $F_d = \frac{1}{2}\rho C_d A_v (v - U)^2$, where;

- ρ is the density of air which is dependent on temperature [kg/m^3];
- C_d is the drag coefficient measured in open air. Typical drag coefficients for isolated vehicles in open air facing an oncoming air stream are given in Figure 6.7. The height of the bars in this graph indicate that drag coefficients are highly variable.

  When the airstream comes from the rear of the vehicle, as would occur with stopped traffic, the drag coefficient may be larger than when the airstream is coming from the front;
- A_v is the frontal area [m^2] of the vehicle;
- v is the vehicle speed [m/s], and;
- U is the tunnel air speed [m/s].

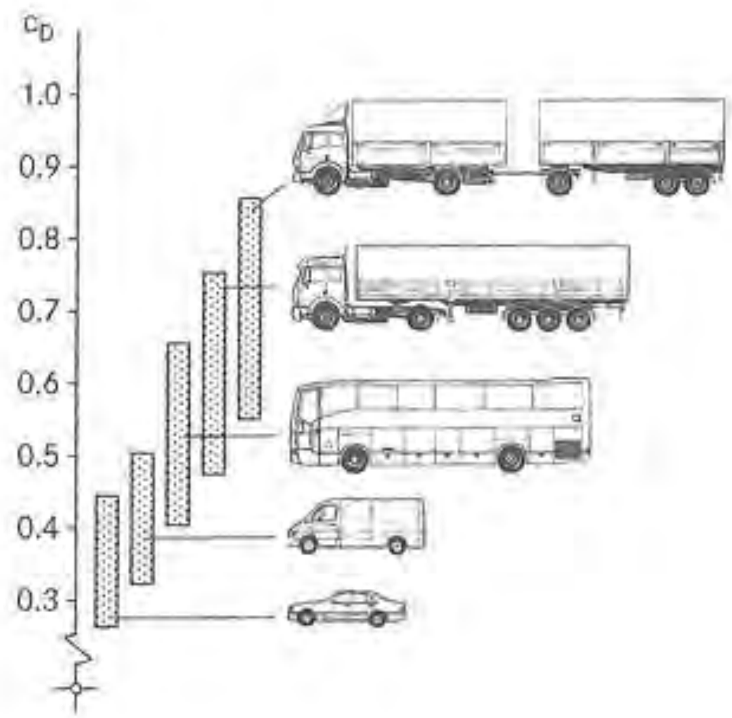


Figure 6.7. Typical drag coefficients for isolated vehicles in open air. (http://www.part20.eu/en/background/aerodynamics/)

The aerodynamic drag on vehicles varies considerably with vehicle spacing. The reduction of drag force by slipstreaming is demonstrated each year through the bunches and breakaways of the Tour de France. Of course, the same slipstreaming effect is seen with cars and trucks. One example dataset showing the effect is shown in Figure 6.8.

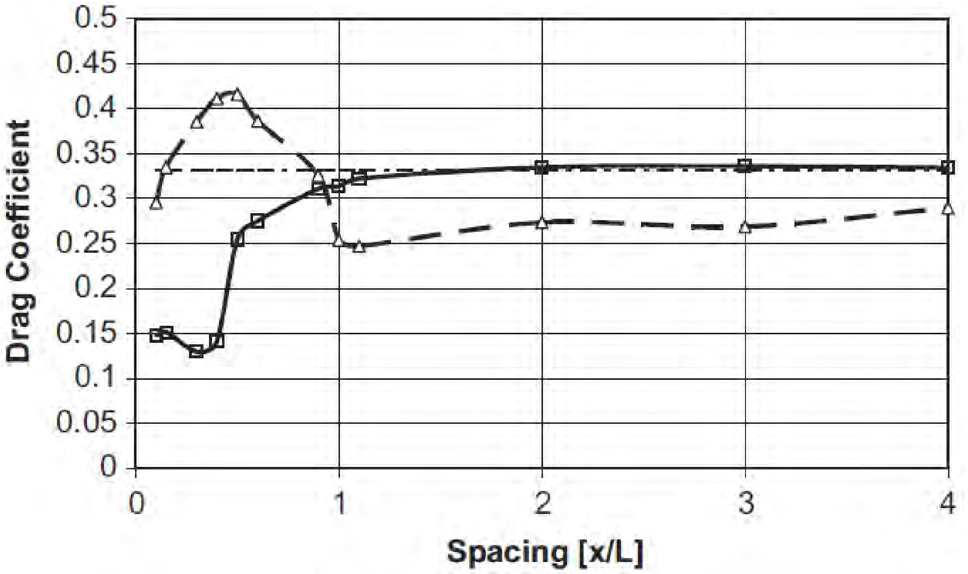


Figure 6.8. Effect of vehicle spacing (separation) on vehicle drag coefficients of the lead (square) and trailing (triangle) vehicle (Watkins & Gino 2007).

With the tunnel walls affecting both the airspeed around the vehicle and the nature of the vehicle wake, and with vehicles sometimes packed quite closely with no cross wind, the drag is different to (lower than) that in open air. Proximity of the tunnel walls and traffic in adjacent lanes has the effect of suppressing the wake being shed from a vehicle, thus reducing its effective drag coefficient.

For the purposes of concept design, typical single-vehicle drag coefficients, as shown in Table 6.23 have been used. Using the single vehicle drag coefficients is generally conservative from a design perspective because:

- at high traffic speeds, the higher drag coefficients will result in an over-estimate of the flow driven towards exit portals, and hence a conservative design for the portal emissions capture ventilation plant
- for 20 km/h traffic, the jet fans may be promoting flow faster than 20 km/h, meaning that the flow is coming from behind the vehicles. In that case, ignoring slipstreaming increases the calculated jet fan requirement.
- The effect at low speeds is in any case small, as the relative velocity between vehicles and the air is low, and drag is proportional to the square of relative velocity.

The drag coefficient values nominated by Roads and Maritime are:

Table 6.23. Vehicle aerodyamic factors.

Vehicle Type	Area (m^2)	Coefficient of Drag
PC	2.5	0.4
LDV	5.0	0.6
HGV	7.0	0.8

The local blockage effect of the vehicles has been included in all simulations.

6.9 In-tunnel air quality limits

The Secretary's Environmental Assessment Requirements (SEARS) require: *"a demonstration of how the project and ventilation design ensures that concentrations of air emissions meet NSW, national and international best practice for in-tunnel and ambient air quality, and taking into consideration the approved criteria for the M4 East project, New M5 project and the In-Tunnel Air Quality (Nitrogen Dioxide) Policy"*.

The pollution limit criteria as established for the recent WestConnex tunnel project including M4 East, New M5 and M4-M5 Link projects are given in Table 6.24. The three pollutants assessed in-tunnel are nitrogen dioxide (NO_2), carbon monoxide (CO) and particulate matter (PM) which is measured as an optical extinction coefficient. With the current pollution limits, for the assessment years of the project, NO_2 will be the pollutant that determines the required airflow and drives the design of ventilation for in-tunnel pollution.

In February 2016, the NSW Government's Advisory Committee on Tunnel Air Quality (ACTAQ) issued a document titled "In-tunnel air quality (nitrogen dioxide) policy". That document further consolidated the approach taken earlier for NorthConnex, M4 East and New M5. The policy wording requires tunnels to be *"designed and operated so that the tunnel average nitrogen dioxide (NO_2) concentration is less than 0.5 ppm as a rolling 15 minute average"*.

The words "*tunnel average*" had been interpreted by Roads and Maritime as an average over all tunnel sections forming a project stage. As the policy document notes, the average over the tunnel is a proxy for motorist exposure, which is impractical to measure directly. Of course, in any trip, motorists don't traverse all underground sections in a project, but take just one route through particular sections. For simpler tunnel geometries like NorthConnex with limited ramps, that distinction is perhaps too fine to be of concern, however as the tunnel network becomes more complex as the projects combine, the difference could become significant.

In the integrated tunnel network, "tunnel average" is interpreted as a "route average", being the "length-weighted average pollutant concentration over a portal to portal route through the system". Tunnel average NO_2 was assessed for every possible route through the system between St Peters (both daylight portals and the New M5/M4-M5 Link mainline interface) and F6E President Avenue and New M5 Kingsgrove portals under all circumstances. The calculation of this and interaction with the wider tunnel network is outlined in Section 7.3.

With the predicted maximum CO levels falling well below the "tunnel average" requirement, the complexity of evaluating "tunnel average" CO criteria has been simplified and assessed as an in-tunnel maximum criteria throughout this work.

The "averaging period" included in Table 6.24 is interpreted as a measure to allow short term perturbations above the nominated criteria in the operational tunnel. This would include such things as:

- a single vehicle with abnormally high dirty exhaust locally affecting visibility,
- a convoy of trucks passing through the tunnel, momentarily increasing the HGV fraction beyond the design values.

For this work, the simulations governing the system design (worst case operations) have been completed on the basis of steady-state operations, meaning that the averaging period for the purpose of this analysis is conservatively zero. That is, the ventilation system would maintain in-tunnel air quality indefinitely when continuously subjected to the most onerous design traffic conditions. During later stages of design, the dynamics of traffic may need to be reviewed to ensure that the control system (and associated ventilation plant) provides a timely response to evolving traffic conditions with the tunnel.

Table 6.24. In-tunnel air quality criteria.

Pollutant	Concentration Limit	Unit	Averaging period
In-tunnel average along length of tunnel			
CO	87	ppm	Rolling 15-minute
CO	50	ppm	Rolling 30-minute
NO_2	0.5	ppm	Rolling 15-minute
In-tunnel single point maxima			
CO	200	ppm	Rolling 3-minute
Visibility	0.005	m^{-1}	Rolling 15-minute

6.10 Sensitivity of input data and assumptions

Within the analysis, there are numerous inputs which are estimated. While many inputs to the ventilation analysis cannot be known with absolute certainty, from experience and measurements within existing tunnels, they are typically known with sufficient accuracy to give a basis of design.

The concept design adopts a “reasonable worst case” of inputs throughout, with the most onerous combination of inputs used for the limiting design scenarios, in lieu of performing a range of sensitivity analyses for each input separately. That is; the more onerous inputs that might ordinarily appear in sensitivity analyses have all been used in this analysis, negating the need for any further sensitivity work. An alternative basis of analysis may be adopted during detailed design phase of the project. Discussion on the possible range of inputs and the application within the concept design is made in the sections above where applicable.

Further, we understand that the Roads and Maritime fleet forecast model, the source of fleet characteristics for the vehicle emissions estimates in this work, adopts a similar methodology with the intent to predict a conservative fleet mix for use with the PIARC methodology. Examples of this include[6]:

- New model and existing model vehicles typically have differing years of Euro implementation as part of the Australian Design Rules. The fleet forecast model assumes the latest year of implementation (mandated year), so all vehicles during the phase in period are categorised into the earlier (older) Euro category.
- Alternative low emission vehicles (e.g. electric, hybrid) are excluded from the fleet forecast model.

[6] Roads and Maritime Services, NSW Fleet forecast for future road tunnel projects (TT-TN-16-12) Rev 3 dated 12th September 2016.

7 METHODOLOGY

7.1 Simulation approach

7.1.1 Models

The modelling undertaken for this analysis incorporates all WestConnex projects, to provide representative aerodynamic and pollution boundary conditions at the interface between M4-M5 Link and New M5. WestConnex is modelled as defined in the M4-M5 Link EIS and incorporates connections to Western Harbour Tunnel as defined in each scenario. To reduce overall complexity of models, the overall system has been sub-divided into two distinct models which are aerodynamically separated from each other and do not involve underground traffic connections.

1) Southbound direction (WestConnex M4 to M5 direction)
2) Northbound direction (WestConnex M5 to M4 direction)

Future stages of F6 Extension are included for the purposes of estimating emissions capture at the northbound interface between Stage 1 and futures stages (Outlet G) for the expected traffic operations. The future stages of F6 Extension have not been analysed for design purposes.

7.1.2 Expected traffic operations

A comprehensive set of dynamic simulations using the expected traffic demand predicted by the SMPM have been completed. These simulations represent the expected behavior of the tunnel ventilation system under day-to-day conditions of expected traffic demand. These models adopt the expected traffic demand at all inlet portals and the expected exit fractions at all diverges. The traffic input parameters increase or decrease as a step change for each traffic period, with traffic demand equally distributed across each period. The resulting traffic conditions are calculated by the IDA Tunnel traffic “congestion” model.

A continuous 24 hr simulation is done with a snapshot of conditions taken 54 minutes after the hour as representing the conditions for each hour of the day. The snapshot for the last hour within each period (Table 6.4) is taken as representing the condition for each period of the day. An outline of the traffic input demand and timing of results snapshots is shown in Table 7.1.

Table 7.1. Outline of expected traffic simulation inputs and results.

Hour Start	Hour End	Traffic Period	Traffic demand	Hourly results snapshot	Period results snapshot
0	1	EV	'EV period flow' / 13	0:54	
1	2	EV	'EV period flow' / 13	1:54	
2	3	EV	'EV period flow' / 13	2:54	
3	4	EV	'EV period flow' / 13	3:54	
4	5	EV	'EV period flow' / 13	4:54	
5	6	EV	'EV period flow' / 13	5:54	
6	7	EV	'EV period flow' / 13	6:54	6:54
7	8	AM	'AM period flow' / 2	7:54	
8	9	AM	'AM period flow' / 2	8:54	8:54
9	10	IP	'IP period flow' / 6	9:54	
10	11	IP	'IP period flow' / 6	10:54	
11	12	IP	'IP period flow' / 6	11:54	
12	13	IP	'IP period flow' / 6	12:54	
13	14	IP	'IP period flow' / 6	13:54	
14	15	IP	'IP period flow' / 6	14:54	14:54
15	16	PM	'PM period flow' / 3	15:54	
16	17	PM	'PM period flow' / 3	16:54	
17	18	PM	'PM period flow' / 3	17:54	17:54
18	19	EV	'EV period flow' / 13	18:54	
19	20	EV	'EV period flow' / 13	19:54	
20	21	EV	'EV period flow' / 13	20:54	
21	22	EV	'EV period flow' / 13	21:54	
22	23	EV	'EV period flow' / 13	22:54	
23	24	EV	'EV period flow' / 13	23:54	

Generally, when the expected traffic is below capacity, the traffic, airflow and pollution levels throughout the tunnel will have reached a steady state condition at some time prior to the hourly and/or period results snapshot. The results are effectively a steady-state solution obtained using a dynamic simulation, with the simulated traffic flows corresponding to the demand parameters.

If the traffic demand approaches or exceeds the lane capacity, the IDA Tunnel traffic model simulates the amount of congestion and queuing. As a result, the traffic conditions may be constantly evolving, not reaching the demand traffic flows and resulting in carryover of the demand flow to subsequent hours or possibly traffic periods. Consequently, the airflow and pollution levels throughout the tunnel at a result snapshot will not have reached a steady state condition that correlates directly with the demand traffic parameters. This same behaviour would be expected in the real tunnel.

All normal operations simulations are performed on the following basis:

- Constant ambient conditions, see Section 6.6
- Heat-neutral conditions (no vehicle heat, no heat flow through tunnel wall) effectively eliminating any buoyancy effects and air-temperature changes along the tunnel
- No external portal wind pressures

For the expected traffic cases, the ventilation operation is based on producing the reasonable worst-case outlet emissions for the project outlets and for the WestConnex outlets directly affected by the project. The purpose of this is to provide the highest outlet emissions reasonably expected within the ambient air quality modelling domain, rather than providing the most efficient ventilation operation across the interconnected network.

The ventilation operation adopted at the key interface plant between projects is, for the southbound (M4 to M5) direction of travel;

1) M4-M5 Link at St Peters (D): Mainline exchange is used only when required to maintain in-tunnel air quality. This results in the maximum carry-over of pollution from M4-M5 Link into the project, resulting in the highest emissions at President Avenue (Outlet F).
2) F6 Extension at President Ave (F): Complete mainline exchange for scenarios incorporating futures stages of F6 Extension.

For the northbound (M5 to M4) direction of travel:

1) New M5 at St Peters (C): Complete mainline exchange is used at all times regardless of downstream air quality. This results in the maximum emissions from the outlet.
2) New M5 at Arncliffe (B) and F6 Extension at Arncliffe (E): Exhaust operation is used as required to support complete mainline exchange at St Peters with the available plant capacity at St Peters. This represents a reasonable operating regime with the constraint of 1).
3) F6 Extension at President Ave (G): Complete mainline exchange for scenarios incorporating future stages of F6 Extension. This results in the maximum emissions from the outlet.

7.1.3 Worst case operations

The tunnel ventilation system must be designed to cater for a wide range of varied traffic conditions, ranging from high traffic volumes at high speed (free flow) to low speed at high traffic density (congested). The demand traffic data, taken from the SMPM is aimed at predicting the typical traffic volumes and journeys through the road network. However, it does not inform the potential variation from these flows and patterns, due to, for example, closures in the external road network or incidents within the tunnel itself.

For the NSW fleet (as adopted for the project), the fleet average vehicle exhaust emissions are declining year on year. As a result, the worst-case operations can be simplified by looking only at the most onerous case of fleet emissions (year 2024) for each potential tunnel configuration. Worst case operations have been assessed on the basis of 2024 emissions for two tunnel arrangements:

Tunnel arrangement	Do something	Cumulative
M4 East	X	X
New M5	X	X
M4-M5 Link	X	X
F6 Extension – Stage 1	X	X
F6 Extension – future stages		X

The worst-case operations also required consideration of the HGV fraction in the traffic. While HGVs generally make up a small proportion of the fleet, they are responsible for a large percentage of the dominant pollutant (NO_2) emissions within the tunnel. As such the selection of an appropriate HGV fraction becomes an important consideration for the tunnel ventilation design.

The most onerous requirements upon the ventilation system occur when the tunnel is operating at peak traffic occupancy. For this reason, we take the HGV fraction in the peak period from the expected traffic forecasts as a reasonable worst-case HGV fraction for design purposes. As the ventilation systems of New M5 and F6 Extension are tightly integrated, we conservatively adopt the highest fraction in the peak period within any tunnel section within New M5 or F6 Extension.

Table 7.2 summarises the HGV fraction predicted during the peak periods for each direction of travel. For current purposes we conservatively adopt 17% (red bold value) as the highest HGV fraction within any section and either direction of travel as a design basis for in-tunnel air quality.

Table 7.2. Summary of HGV fractions in peak periods.

	2026 Do Something	2026 Cumulative	2036 Do Something
Southbound during evening peak period (PM)			
F6 Extension			
New M5 diverge to President Ave	7%	7%	7%
New M5			
St Peters on-ramp	9%	9%	9%
St Peters bypass from M4-M5 Link	14%	16%	16%
St Peters on-ramp to F6E diverge	10%	10%	12%
F6E diverge to M5 portal	15%	14%	**17%**
Northbound during morning peak period (AM)			
F6 Extension			
President Ave to New M5 merge	9%	8%	9%
New M5			
St Peters off-ramp	10%	10%	10%
St Peters bypass to M4-M5 Link	15%	13%	15%
F6E merge to St Peters off-rmap	12%	11%	12%
M5 portal to F6E merge	15%	14%	15%

For the project (and wider integrated tunnel network), there are numerous traffic flow patterns that could occur due to a wide variety of factors. However, from a ventilation perspective, a limited number of scenarios will capture the most onerous requirements, though they may not occur in practice.

The maximum demand on the ventilation system will generally occur:

- at maximum vehicle occupancy, i.e. all lanes full as possible
- where there is a maximum imbalance of traffic flows between two paths, i.e. all traffic leaving through one tunnel at a diverge.

Key traffic patterns which seek to push the various elements of the ventilation system were analysed. A selection of those key cases are presented in Section 8.4.

7.1.4 Smart motorways – Ramp metering

Ramp metering may be implemented during times of high traffic flows. Ramp metering is intended to prioritise traffic flowing along the mainline to avoid traffic flow breakdowns across the network, minimising the likelihood of widespread slow moving traffic. For this work, ramp metering is assumed to provide the following traffic conditions:

- A minimum traffic speed of 60 km/h on the mainline; and
- A minimum traffic speed of 5 km/h in the entry ramps behind the stop lines.

From a ventilation perspective, this results in additional emissions in the on-ramps but ensures free-flow conditions elsewhere. In general, this makes the ventilation task less onerous compared to the scenario where all traffic is travelling at 20 km/h.

To review the ventilation requirements for this operating regime, a number of simulations were completed generally following the worst-case operations methodology outlined above with the following changes:

- On-ramp traffic speed is fixed at 5 km/h up until the first merge. That provides the longest practical queue length and will conservatively overestimate the density of the queue where the number of stop lanes exceeds the number of queuing lanes.
- On-ramp traffic flows are set at 600 PCU/hr/lane (6-second interval) with the on-ramp flows conservatively based on the largest number of lanes in the ramp plus one (i.e. n+1 stop lanes). This ensures that the effective queue fills all lanes in ramp within IDA tunnel.
- The traffic speed in all other sections, motorway connections and all off-ramps is fixed at 60 km/h.
- Vehicle emissions based on 2024, year of opening. To our knowledge, Smart Motorways is not intended to be implemented at the time of opening, making the analysis somewhat conservative.

With ramp metering introduced, some tunnel sections cannot reach their theoretical capacity.

7.2 Simulation software

In-tunnel airflow, pollution levels and temperature, are simulated and analysed using software called IDA Tunnel, developed by EQUA AB in Sweden. IDA Tunnel was used for the previous M4 East EIS, New M5 EIS, M4-M5 Link EIS and remains a design tool in use for the execution of those projects.

IDA Tunnel is a comprehensive road and rail tunnel ventilation and smoke control simulation software package. Specific to road tunnels, IDA Tunnel includes traffic flow simulation, so that there is realism in the traffic behaviour as roads reach capacity or as lane numbers change. A traffic model within the simulation applies traffic continuity, and realistic rules on traffic flow versus speed, to predict the traffic density and speed throughout the tunnel. This avoids the assumptions involved in 'hard-coding' the traffic movement in input files before the simulation starts. The airflows resulting from traffic movement, in combination with the vehicle emissions, determine the pollutant levels in the tunnel.

IDA Tunnel is a one-dimensional network analysis program, meaning that entire underground systems can be analysed as one, with all the traffic and air flows being resolved. Being one-dimensional, all quantities are cross section averages. Sub-models within the IDA Tunnel package deal with the traffic speed and flow, aerodynamics of vehicles, the effect of jet fans on air flow, the tunnel flow resistance and the network flow balance, the generation of pollutants and heat by vehicles, the stack effect within tunnels with non-zero gradient, the heat flow from the air to the walls and on to the ground, and the thermal inertia of the walls.

Development of IDA Tunnel began around 2000, with the ambition to encompass the best and most trusted mathematical models for environmental conditions in road and rail tunnels that are available in the literature and that can be simulated with acceptable efficiency and with a manageable amount of input data. Early versions became available around 2003. The software has been mature for some time. The package is actively supported by EQUA AB.

There are other software packages for simulation of road tunnel aero-thermodynamics. The Subway Environmental Simulation (SES) software was first written in the 1970s and was the leading tunnel ventilation program for several decades, being supported by the US Department of Transportation. With advances in computing and simulation generally, it became harder to maintain and for some years now DoT support has been unavailable, with the program still used privately by some firms who maintain their own versions of the code. Other firms have independently developed in-house software, generally to address specific behaviours such as air compressibility for high speed trains. To our knowledge, IDA Tunnel is the only openly available tunnel ventilation simulation package.

IDA Tunnel was developed from scratch using the Modelica simulation environment, an advantage over the Fortran 77 base of SES. Development was informed by SES and comparative assessments of the two programs have been done, including by London Underground.

Compared to the SES program, IDA Tunnel includes more sophisticated modelling of the wall and ground temperatures and heat flows. On the thermal response of tunnels, Stacey Agnew has used IDA Tunnel to calibrate models against measured wall and air temperatures of several cable and rail tunnels, three of which were in Sydney sandstone[7]. IDA Tunnel also includes thermal buoyancy (stack effect) in non-fire simulations, which SES did not do.

[7] Reference tunnels in Sydney; Epping Chatswood Rail Link, City West Cable Tunnel, City South Cable Tunnel, and in Auckland; Vector Cable Tunnel.

7.3 Route average NO_2 calculation

The in-tunnel criterion for NO_2 has been assessed as an average along any route through the tunnel network. Mathematically this means:

$$Route\ average\ NO_2 = \frac{\int_0^L NO_2\,dx}{L}$$

For the current analysis, the IDA Tunnel discretized finite grid has been used to approximate the true integral average as the "centre-weighted cell integral average":

$$Route\ average\ NO_2 = \frac{\sum(Cell\ NO_2 \times Cell\ length)}{\sum(Cell\ length)}$$

Typically the models adopt a grid size of 100 m. The actual grid size is calculated by IDA Tunnel depending on the overall length of sections and positions of different features within each section. The calculation is expanded below using a simple example concentration profile shown in Figure 7.1, depicting a straight tunnel 1500 m long with an on-ramp merge at 1000 m using a fixed grid size of 100 m.

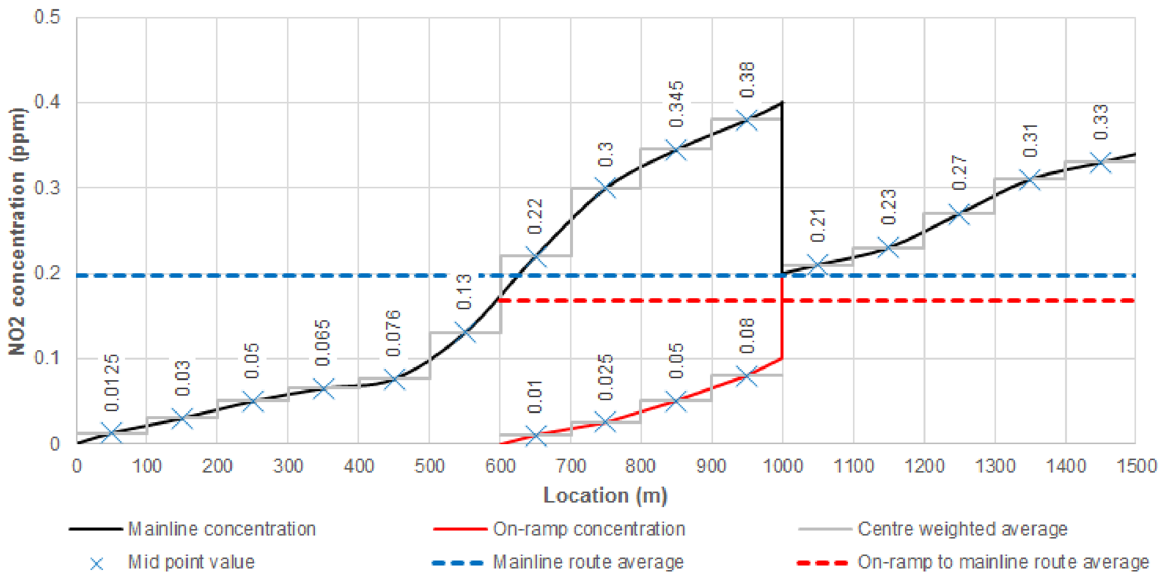


Figure 7.1. Example NO_2 concentration profile for route average calculation

For the mainline route (0 m to 1500 m):

$$Route\ average\ NO_2 = \frac{\begin{array}{c}0.0125 \times 100 + 0.03 \times 100 + 0.05 \times 100 + 0.065 \times 100 + \\ 0.076 \times 100 + 0.13 \times 100 + 0.22 \times 100 + 0.3 \times 100 + \\ 0.345 \times 100 + 0.38 \times 100 + 0.21 \times 100 + 0.23 \times 100 + \\ 0.27 \times 100 + 0.31 \times 100 + 0.33 \times 100\end{array}}{1500}$$

$$Route\ average\ NO_2 = \frac{295.85}{1500} = 0.197\ ppm$$

For the on-ramp route (600 m to 1500 m):

$$Route\ average\ NO_2 = \frac{\begin{array}{c} 0.01 \times 100 + 0.025 \times 100 + 0.05 \times 100 + 0.08 \times 100 \\ +0.21 \times 100 + 0.23 \times 100 + 0.27 \times 100 + 0.31 \times 100 \\ +0.33 \times 100 \end{array}}{900}$$

$$Route\ average\ NO_2 = \frac{151.5}{900} = 0.168\ ppm$$

For the concept design analysis, routes through New M5 and F6 Extension (as listed in Table 7.3) have been assessed using the calculation procedure outlined above. No allowance has been included for potential difficulties in performing in-tunnel measurements, including instrument accuracy and use of point measurements to approximate the overall profile.

For routes that will ultimately incorporate other parts of WestConnex, the route average NO_2 has been calculated as beginning or ending at the respective interface plant at the boundary between M4-M5 Link and New M5. This requires WestConnex ventilation system to achieve the same route average NO_2 criteria for all paths starting or ending at the M4-M5 Link interface plant. As each portion of the entire trip meets the air quality criteria on its own, the average of the entire route from origin portal to destination portal will meet or exceed the air quality criteria.

For this analysis, we conservatively take the most onerous boundary conditions at the M4-M5 Link / New M5 interface:

- Southbound – carry-over from M4-M5 Link is permitted meaning it is more onerous for the downstream New M5 and F6 Extension tunnel sections while being less onerous on upstream sections compared to the M4-M5 Link EIS.
- Northbound – carry-over into M4-M5 Link is not permitted ensuring M4-M5 Link can receive fresh air under all design traffic conditions. This is both more onerous upon the New M5/F6E ventilation system and less onerous boundary condition for the downstream sections compared to the M4-M5 Link EIS.

Table 7.3. List of routes assessed.

Route ID	Start at		Finish at		Approx. length
Southbound (M4 to M5) direction					
1A	New M5	St Peters	F6E	President Ave	6.7 km
1B	New M5	St Peters	New M5	M5 portal (Kingsgrove)	9.1 km
1C	New M5	M4-M5 Link interface	F6E	President Ave	6.7 km
1D	New M5	M4-M5 Link interface	New M5	M5 portal (Kingsgrove)	9.0 km
Northbound (M5 to M4) direction					
2A	F6E	President Ave	New M5	St Peters	6.8 km
2B	F6E	President Ave	New M5	M4-M5 Link interface	6.7 km
2C	New M5	M5 portal (Kingsgrove)	New M5	M4-M5 Link interface	9.0 km
2D	New M5	M5 portal (Kingsgrove)	New M5	St Peters	9.2 km

8 ANALYSIS OUTPUTS – EXPECTED TRAFFIC OPERATIONS

Following sections detail the results for expected traffic operations across all scenarios. All results exclude the background air quality as described in Section 6.7. The in-tunnel air quality criteria shown are adjusted accordingly, calculated as the limit value (Table 6.24) minus background (Table 6.22.).

In each set of results, the following data and graphs are provided:

1) Figure **"Ventilation Schematic"**: The ventilation schematic applicable to the scenario.
2) Table **"In-tunnel estimated air quality maximum"**: A summary of the maximum in-tunnel pollutant concentration levels within each project, including all on and off-ramps and mainline sections, for each period of the day. Route average NO_2 pollutant concentrations are given for all relevant routes. The relevant in-tunnel air quality criteria for each pollutant is also included for quick reference.
3) Graphs **"In-tunnel NO_2"**: Displays the NO_2 concentration (ppm) along the described route for each period of the day.
4) Graphs **"In-tunnel visibility":** Displays the in-tunnel visibility (as extinction coefficient) along the described route for each period of the day.
5) Table **"Outlet emissions summary"**: Shows the airflow and emissions of the key pollutants (NO_X, CO, Non-exhaust $PM_{2.5}$, Exhaust PM and Total PM) from each outlet for each period of the day. The outlet emissions do not include allowance for background ambient air quality; this will need to be considered as required for any analysis by others. For uniformity, these tables include all outlets for all scenarios; where a particular outlet is not relevant for the scenario, the value is shown as "-".

For all **"In-Tunnel XXX"** graphs, individual series (lines) are shown for each period of the day with major tunnel features (intersections, interface locations) added for reference. For the Cumulative and Do something scenarios, graphs are provided for the route from President Avenue to the mainline interface point between M4-M5 Link and New M5 in both directions of travel as directly applicable to the project. For the Do minimum scenario, routes are provided for the route M5 portal to St Peters as directly applicable to the New M5 project.

For each outlet, the results assume that the flows from each tunnel exhaust point are fully mixed through the ventilation plant before the outlet.

8.1 Do minimum

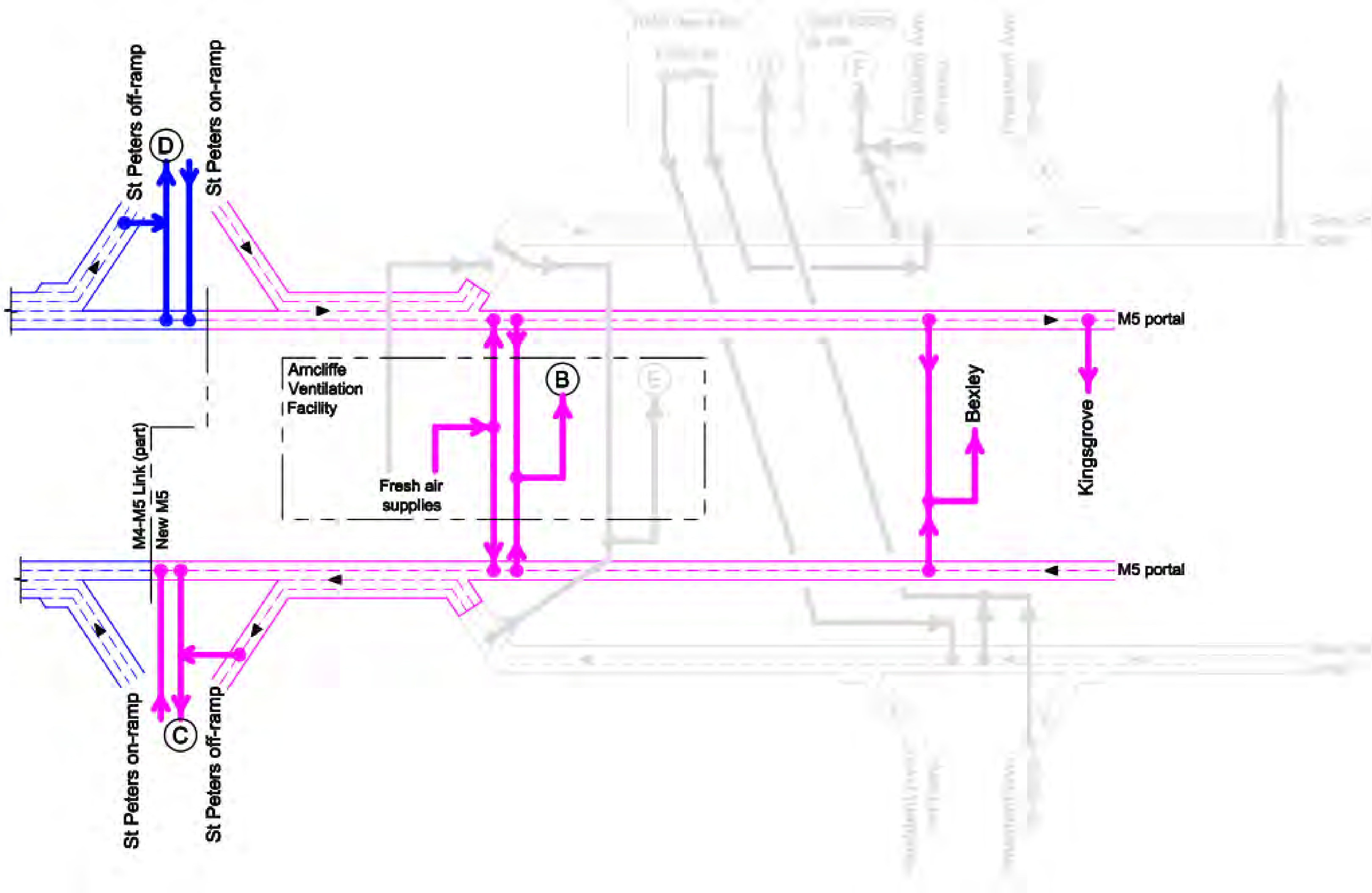


Figure 8.1. Ventilation schematic, 2026 and 2036 Do minimum.

8.1.1 2026 expected traffic operations

Table 8.1. In-tunnel estimated air quality maxima [2026 Do minimum, expected traffic].

	Southbound (M4 to M5) direction										Northbound (M5 to M4) direction									
	F6 Extension Stage 1			New M5			NO2 route average				F6 Extension Stage 1			New M5			NO2 route average			
	NO2 (ppm)	CO (ppm)	Vis (1/m)	NO2 (ppm)	CO (ppm)	Vis (1/m)	1A (ppm)	1B (ppm)	1C (ppm)	1D (ppm)	NO2 (ppm)	CO (ppm)	Vis (1/m)	NO2 (ppm)	CO (ppm)	Vis (1/m)	2A (ppm)	2B (ppm)	2C (ppm)	2D (ppm)
Criteria	n/a	48.7	0.0049	n/a	48.7	0.0049	0.47	0.47	0.47	0.47	n/a	48.7	0.0049	n/a	48.7	0.0049	0.47	0.47	0.47	0.47
Period																				
AM	-	-	-	0.34	5.0	0.0020	-	0.19	-	0.22	-	-	-	0.36	5.0	0.0024	-	-	0.13	0.13
IP	-	-	-	0.43	5.6	0.0025	-	0.23	-	0.26	-	-	-	0.24	2.9	0.0015	-	-	0.09	0.09
PM	-	-	-	0.52	7.6	0.0031	-	0.26	-	0.29	-	-	-	0.16	2.5	0.0011	-	-	0.06	0.06
EV	-	-	-	0.19	3.4	0.0011	-	0.10	-	0.11	-	-	-	0.11	1.8	0.0007	-	-	0.04	0.04

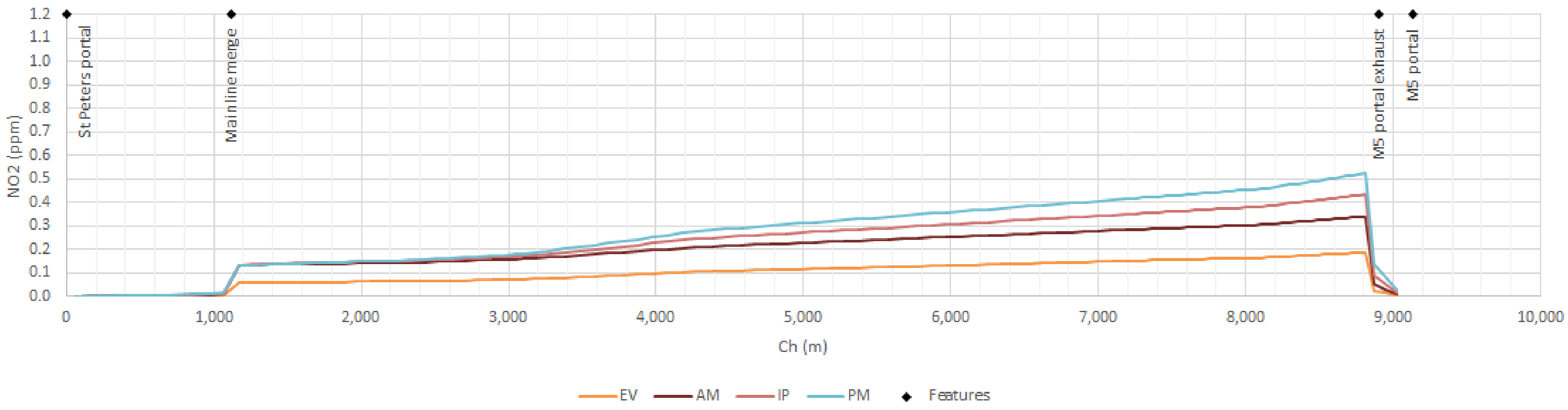


Figure 8.2. In-tunnel NO_2 levels along route 1B from St Peters to M5 portal [2026 Do minimum, expected traffic].

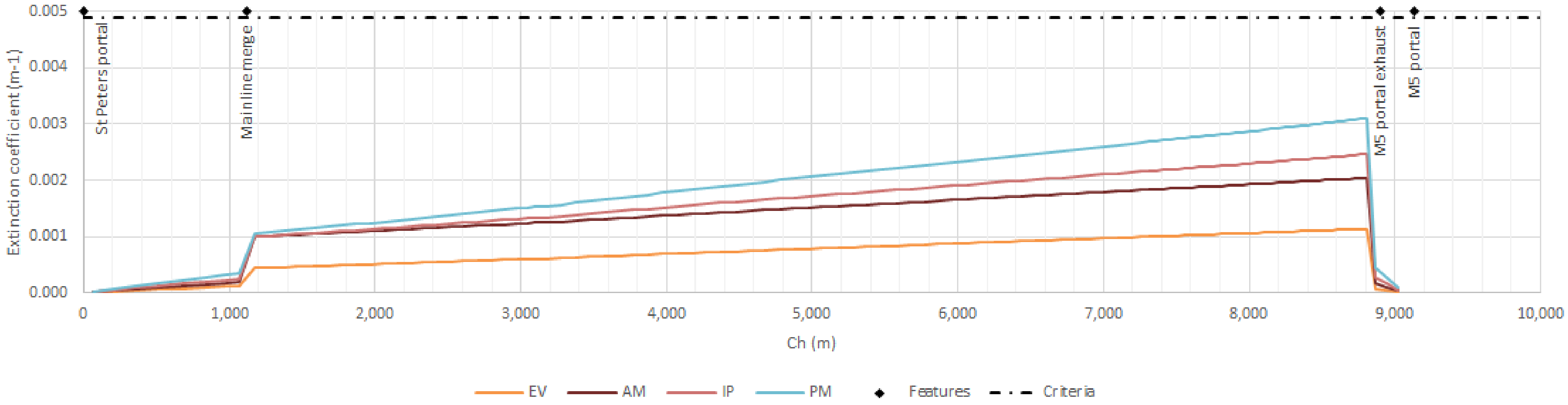


Figure 8.3. In-tunnel visibility along route 1B from St Peters to M5 portal [2026 Do minimum, expected traffic].

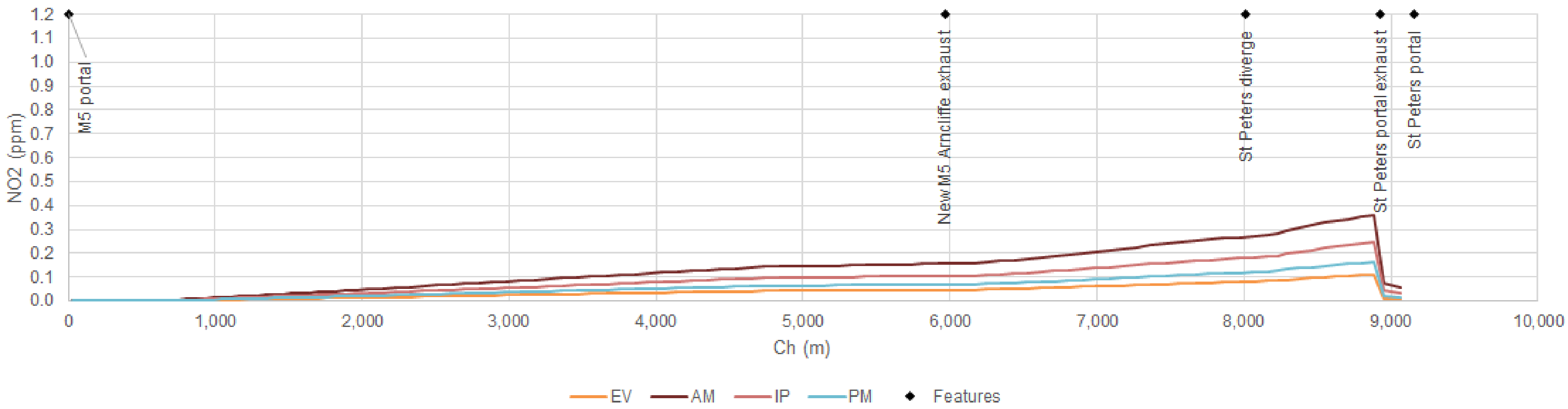


Figure 8.4. In-Tunnel NO_2 levels along route 2D from M5 portal to St Peters [2026 Do minimum, expected traffic].

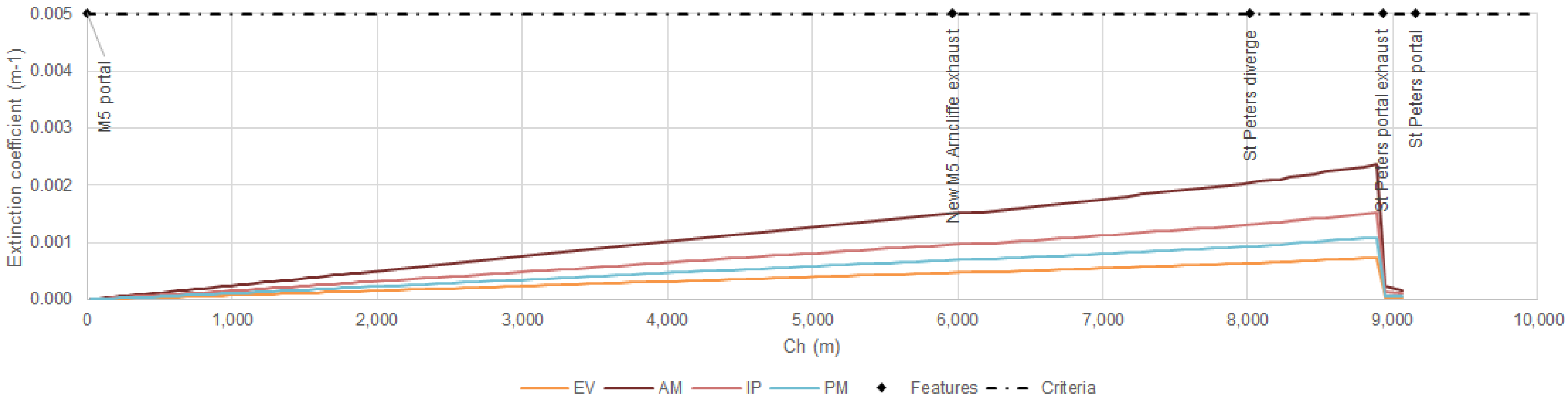


Figure 8.5. In-Tunnel visibility along route 2D from M5 portal to St Peters [2026 Do minimum, expected traffic].

Table 8.2. Outlet emissions summary [2026 Do minimum, expected traffic].

Outlet identifier:	B						C						D					
EIS name:	Arncliffe (New M5)						SPI (New M5)						SPI (M4-M5 Link)					
Period	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)
AM	0	0.00	0.00	0.00	0.00	0.00	619	2.08	3.12	0.23	0.04	0.27	708	2.21	3.95	0.23	0.04	0.27
IP	0	0.00	0.00	0.00	0.00	0.00	508	1.26	1.44	0.11	0.03	0.14	694	2.37	3.56	0.21	0.05	0.26
PM	0	0.00	0.00	0.00	0.00	0.00	430	0.55	1.00	0.07	0.01	0.08	663	1.81	3.44	0.19	0.04	0.23
EV	0	0.00	0.00	0.00	0.00	0.00	345	0.27	0.52	0.04	0.01	0.04	543	0.91	1.72	0.09	0.02	0.11

Outlet identifier:	E						F						G					
EIS name:	Arncliffe (F6 Extension)						Rockdale (F6 Extension - Stage 1)						Rockdale (F6 Extension future stages)					
Period	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)
AM	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PM	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

8.1.2 2036 expected traffic operations

Table 8.3. In-tunnel estimated air quality maximum [2036 Do minimum, expected traffic].

	Southbound (M4 to M5) direction									
	F6 Extension Stage 1			New M5			NO2 route average			
	NO2 (ppm)	CO (ppm)	Vis (1/m)	NO2 (ppm)	CO (ppm)	Vis (1/m)	1A (ppm)	1B (ppm)	1C (ppm)	1D (ppm)
Criteria	n/a	48.7	0.0049	n/a	48.7	0.0049	0.47	0.47	0.47	0.47
Period										
AM	-	-	-	0.30	4.7	0.0021	-	0.17	-	0.20
IP	-	-	-	0.39	5.5	0.0026	-	0.21	-	0.24
PM	-	-	-	0.56	7.5	0.0039	-	0.29	-	0.32
EV	-	-	-	0.16	3.1	0.0012	-	0.08	-	0.10

	Northbound (M5 to M4) direction									
	F6 Extension Stage 1			New M5			NO2 route average			
	NO2 (ppm)	CO (ppm)	Vis (1/m)	NO2 (ppm)	CO (ppm)	Vis (1/m)	2A (ppm)	2B (ppm)	2C (ppm)	2D (ppm)
Criteria	n/a	48.7	0.0049	n/a	48.7	0.0049	0.47	0.47	0.47	0.47
Period										
AM	-	-	-	0.37	5.3	0.0028	-	-	0.14	0.14
IP	-	-	-	0.23	2.9	0.0017	-	-	0.08	0.08
PM	-	-	-	0.14	2.3	0.0011	-	-	0.05	0.05
EV	-	-	-	0.10	1.6	0.0008	-	-	0.03	0.03

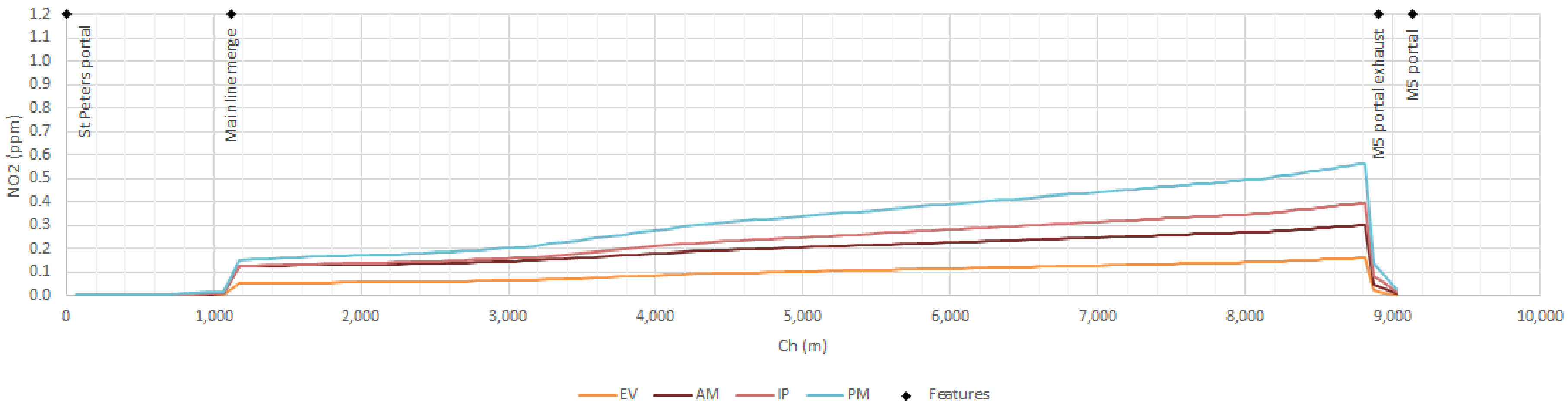


Figure 8.6. In-tunnel NO_2 levels along route 1B from St Peters to M5 portal [2036 Do minimum, expected traffic].

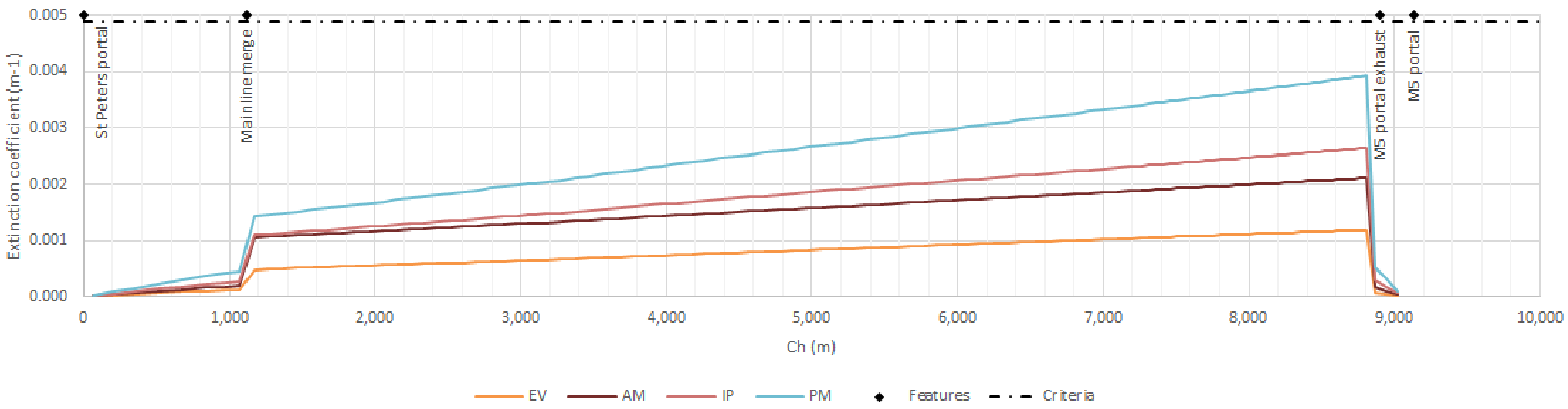


Figure 8.7. In-tunnel visibility along route 1B from St Peters to M5 portal [2036 Do minimum, expected traffic].

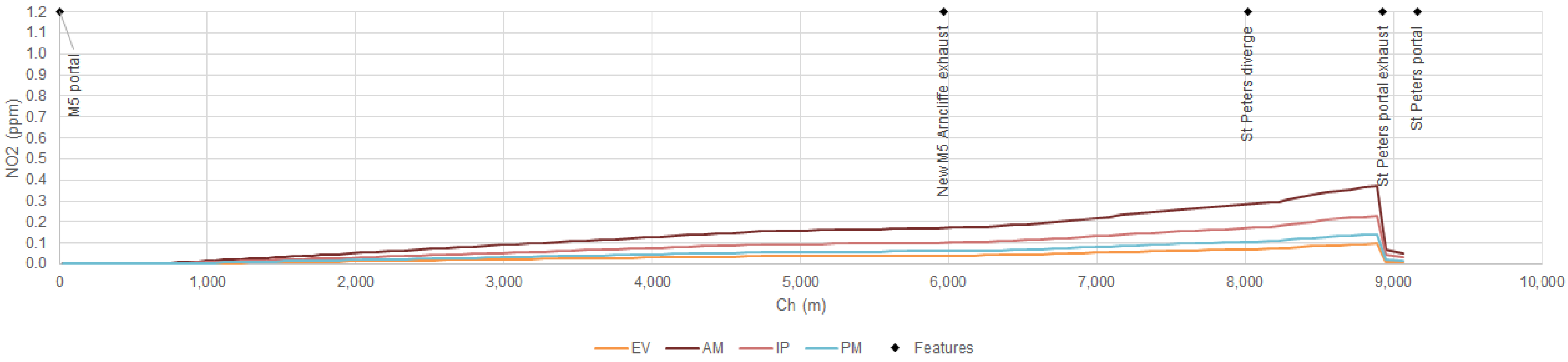


Figure 8.8. In-tunnel NO_2 levels along route 2D from M5 portal to St Peters [2036 Do minimum, expected traffic].

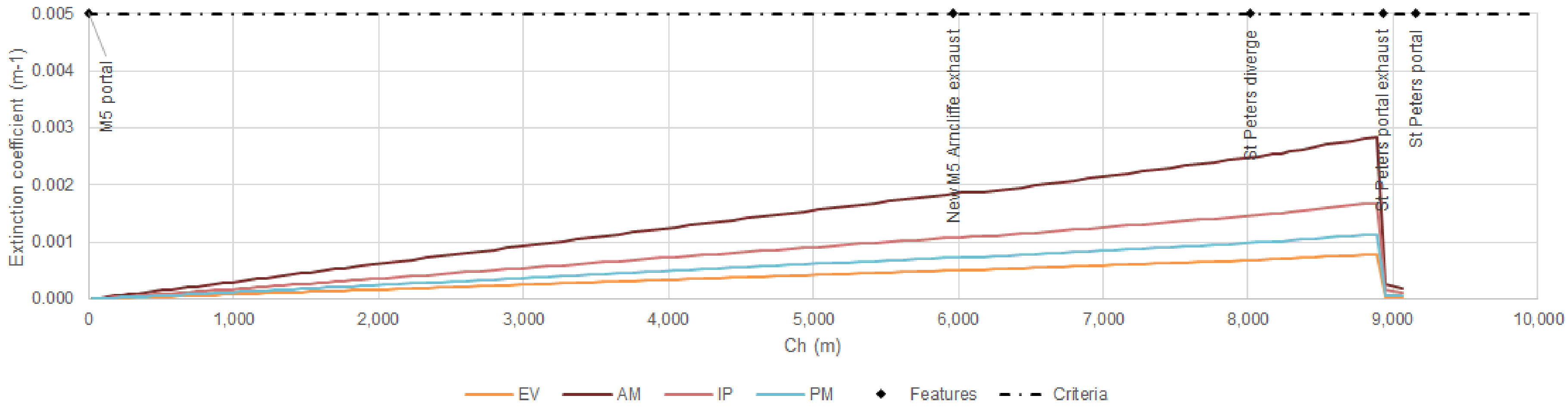


Figure 8.9. In-tunnel visility along route 2D from M5 portal Rd to St Peters [2036 Do minimum, expected traffic].

Table 8.4. Outlet emissions summary [2036 Do minimum, expected traffic].

Outlet identifier: EIS name:	B Arncliffe (New M5)						C SPI (New M5)						D SPI (M4-M5 Link)					
Period	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)
AM	0	0.00	0.00	0.00	0.00	0.00	631	2.44	3.37	0.29	0.04	0.33	728	2.32	3.86	0.26	0.04	0.30
IP	0	0.00	0.00	0.00	0.00	0.00	549	1.38	1.60	0.14	0.03	0.17	715	2.36	3.42	0.24	0.04	0.28
PM	0	0.00	0.00	0.00	0.00	0.00	451	0.57	0.97	0.08	0.01	0.09	694	2.04	3.51	0.24	0.04	0.28
EV	0	0.00	0.00	0.00	0.00	0.00	366	0.28	0.53	0.04	0.00	0.05	571	0.96	1.64	0.11	0.02	0.12

Outlet identifier: EIS name:	E Arncliffe (F6 Extension)						F Rockdale (F6 Extension - Stage 1)						G Rockdale (F6 Extension future stages)					
Period	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)
AM	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PM	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

8.2 Do something

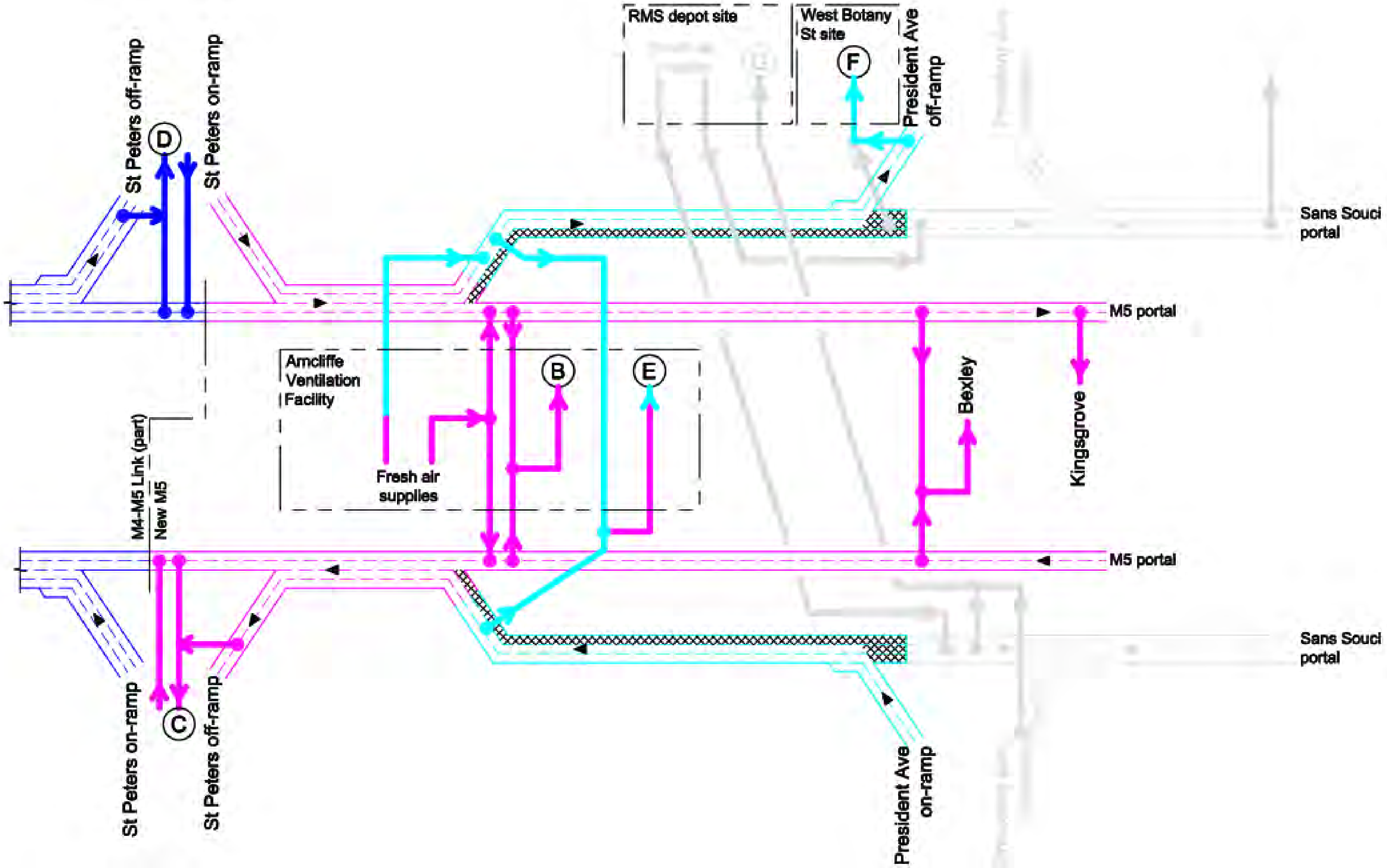


Figure 8.10. Ventilation schematic, 2026 and 2036 Do something.

8.2.1 2026 expected traffic operations

Table 8.5. In-tunnel estimated air quality maximum [2026 Do something, expected traffic].

	Southbound (M4 to M5) direction										Northbound (M5 to M4) direction									
	F6 Extension Stage 1			New M5			NO2 route average				F6 Extension Stage 1			New M5			NO2 route average			
	NO2 (ppm)	CO (ppm)	Vis (1/m)	NO2 (ppm)	CO (ppm)	Vis (1/m)	1A (ppm)	1B (ppm)	1C (ppm)	1D (ppm)	NO2 (ppm)	CO (ppm)	Vis (1/m)	NO2 (ppm)	CO (ppm)	Vis (1/m)	2A (ppm)	2B (ppm)	2C (ppm)	2D (ppm)
Criteria	n/a	48.7	0.0049	n/a	48.7	0.0049	0.47	0.47	0.47	0.47	n/a	48.7	0.0049	n/a	48.7	0.0049	0.47	0.47	0.47	0.47
Period																				
AM	0.26	3.7	0.0016	0.34	5.1	0.0020	0.14	0.19	0.18	0.22	0.07	1.0	0.0007	0.36	5.2	0.0020	0.10	0.10	0.11	0.11
IP	0.32	4.5	0.0019	0.42	5.5	0.0024	0.16	0.22	0.20	0.25	0.06	0.8	0.0006	0.25	3.2	0.0014	0.08	0.07	0.08	0.08
PM	0.37	5.7	0.0024	0.49	7.3	0.0029	0.18	0.25	0.22	0.28	0.04	0.7	0.0004	0.15	2.3	0.0009	0.05	0.05	0.05	0.05
EV	0.15	2.7	0.0010	0.19	3.5	0.0012	0.08	0.10	0.10	0.12	0.03	0.5	0.0003	0.10	1.7	0.0007	0.03	0.03	0.04	0.04

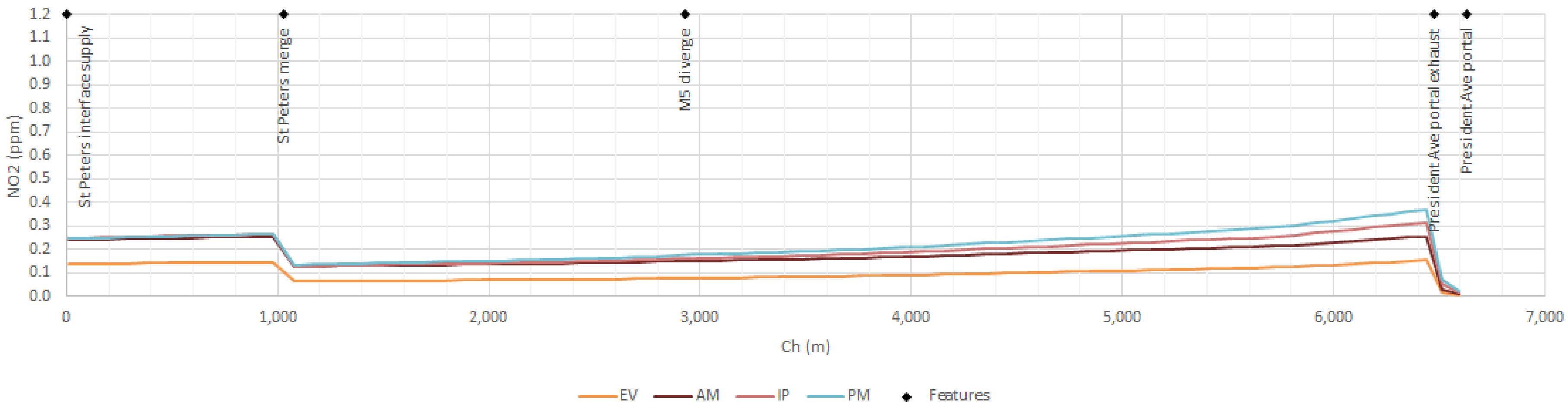


Figure 8.11. In-tunnel NO_2 levels along route 1C from M4-M5 Link to President Ave [2026 Do something, expected traffic].

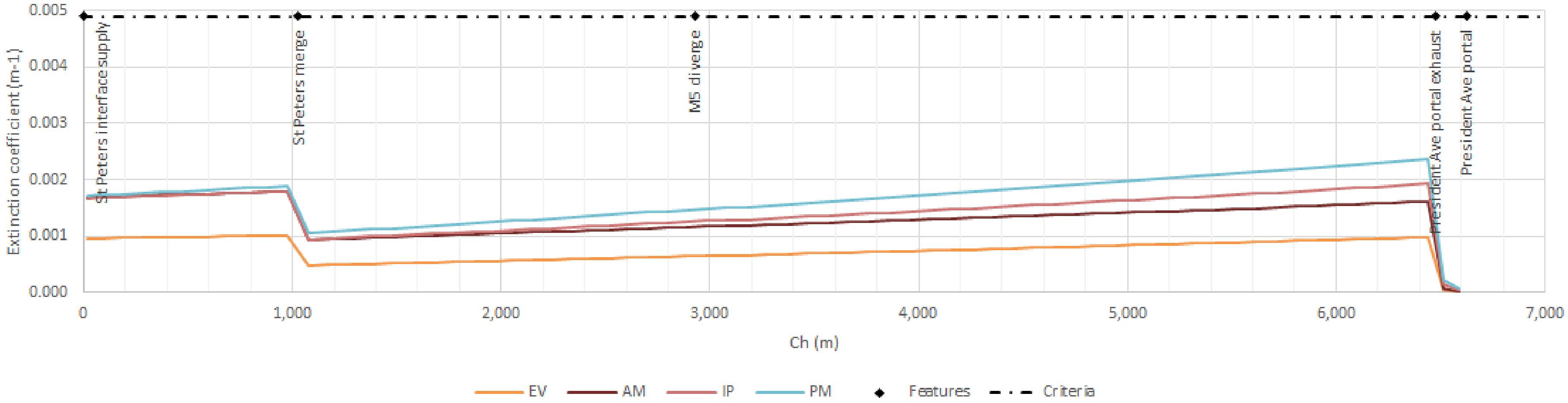


Figure 8.12. In-tunnel visibility along route 1C from M4-M5 Link to President Ave [2026 Do something, expected traffic].

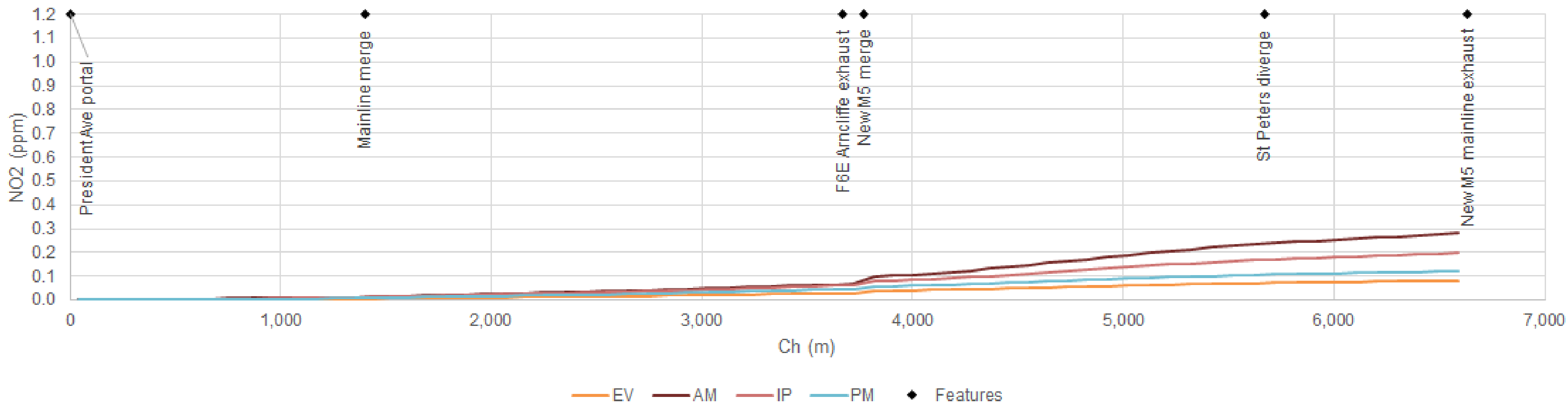


Figure 8.13. In-tunnel NO_2 levels along route 2A from President Ave to M4-M5 Link [2026 Do something, expected traffic].

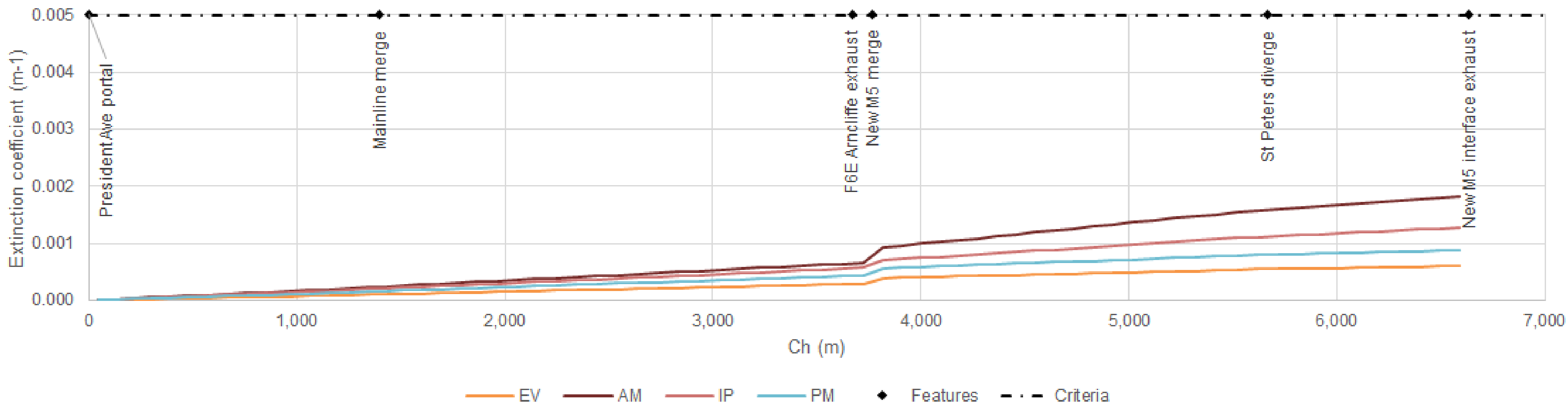


Figure 8.14. In-tunnel visibility along route 2A from President Ave to M4-M5 Link [2026 Do something, expected traffic].

Table 8.6. Outlet emissions summary [2026 Do something, expected traffic].

Outlet identifier: EIS name:	B Arncliffe (New M5)						C SPI (New M5)						D SPI (M4-M5 Link)					
Period	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)
AM	236	0.34	0.44	0.05	0.01	0.06	729	2.32	3.71	0.23	0.05	0.27	509	1.31	2.33	0.13	0.03	0.16
IP	121	0.14	0.15	0.02	0.00	0.02	725	1.78	2.26	0.15	0.04	0.19	509	1.50	2.20	0.13	0.03	0.16
PM	0	0.00	0.00	0.00	0.00	0.00	705	0.87	1.62	0.11	0.02	0.12	483	1.18	2.25	0.12	0.02	0.15
EV	0	0.00	0.00	0.00	0.00	0.00	554	0.42	0.88	0.06	0.01	0.06	426	0.63	1.18	0.06	0.01	0.08

Outlet identifier: EIS name:	E Arncliffe (F6 Extension)						F Rockdale (F6 Extension - Stage 1)						G Rockdale (F6 Extension future stages)					
Period	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)
AM	236	0.16	0.27	0.03	0.00	0.03	382	0.92	1.43	0.09	0.02	0.11	-	-	-	-	-	-
IP	121	0.08	0.11	0.01	0.00	0.01	481	1.52	2.33	0.14	0.03	0.17	-	-	-	-	-	-
PM	0	0.00	0.00	0.00	0.00	0.00	541	1.82	3.43	0.20	0.04	0.24	-	-	-	-	-	-
EV	0	0.00	0.00	0.00	0.00	0.00	336	0.40	0.91	0.05	0.01	0.06	-	-	-	-	-	-

8.2.2 2036 expected traffic operations

Table 8.7. In-tunnel estimated air quality maximum [2036 Do something, expected traffic].

	Southbound (M4 to M5) direction										Northbound (M5 to M4) direction									
	F6 Extension Stage 1			New M5			NO2 route average				F6 Extension Stage 1			New M5			NO2 route average			
	NO2 (ppm)	CO (ppm)	Vis (1/m)	NO2 (ppm)	CO (ppm)	Vis (1/m)	1A (ppm)	1B (ppm)	1C (ppm)	1D (ppm)	NO2 (ppm)	CO (ppm)	Vis (1/m)	NO2 (ppm)	CO (ppm)	Vis (1/m)	2A (ppm)	2B (ppm)	2C (ppm)	2D (ppm)
Criteria	n/a	48.7	0.0049	n/a	48.7	0.0049	0.47	0.47	0.47	0.47	n/a	48.7	0.0049	n/a	48.7	0.0049	0.47	0.47	0.47	0.47
Period																				
AM	0.24	3.8	0.0018	0.31	4.9	0.0022	0.13	0.17	0.17	0.20	0.07	1.0	0.0008	0.39	5.8	0.0026	0.11	0.10	0.11	0.11
IP	0.29	4.4	0.0021	0.39	5.4	0.0026	0.15	0.20	0.18	0.23	0.06	0.8	0.0006	0.25	3.3	0.0016	0.07	0.07	0.07	0.08
PM	0.34	5.5	0.0027	0.50	7.5	0.0035	0.17	0.25	0.21	0.28	0.04	0.6	0.0005	0.13	2.1	0.0010	0.04	0.04	0.05	0.05
EV	0.13	2.5	0.0010	0.16	3.2	0.0012	0.07	0.09	0.09	0.10	0.02	0.4	0.0003	0.08	1.5	0.0007	0.03	0.03	0.03	0.03

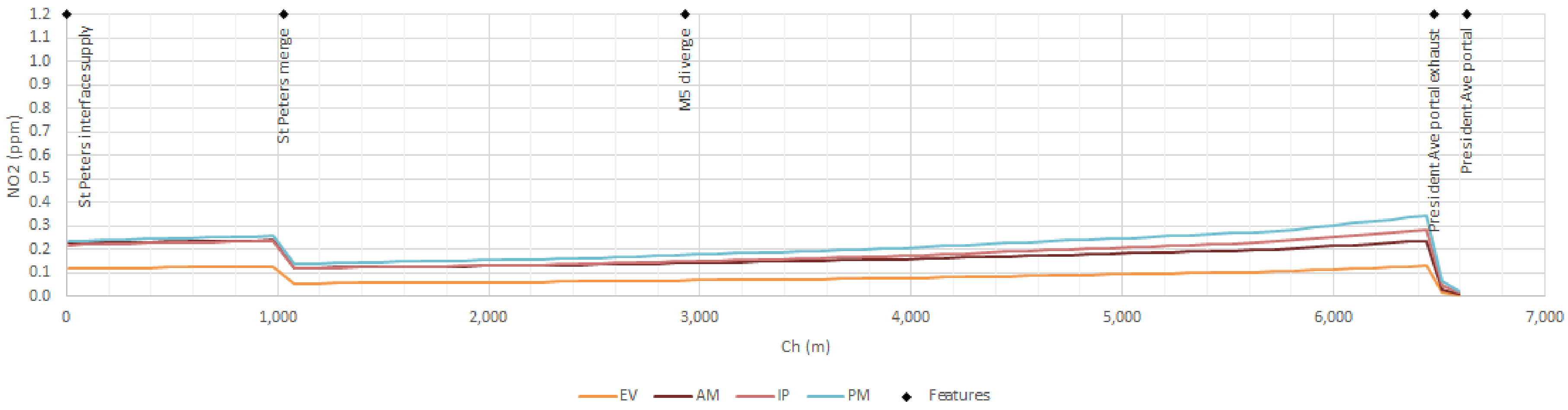


Figure 8.15. In-tunnel NO_2 levels along route 1C from M4-M5 Link to President Ave [2036 Do something, expected traffic].

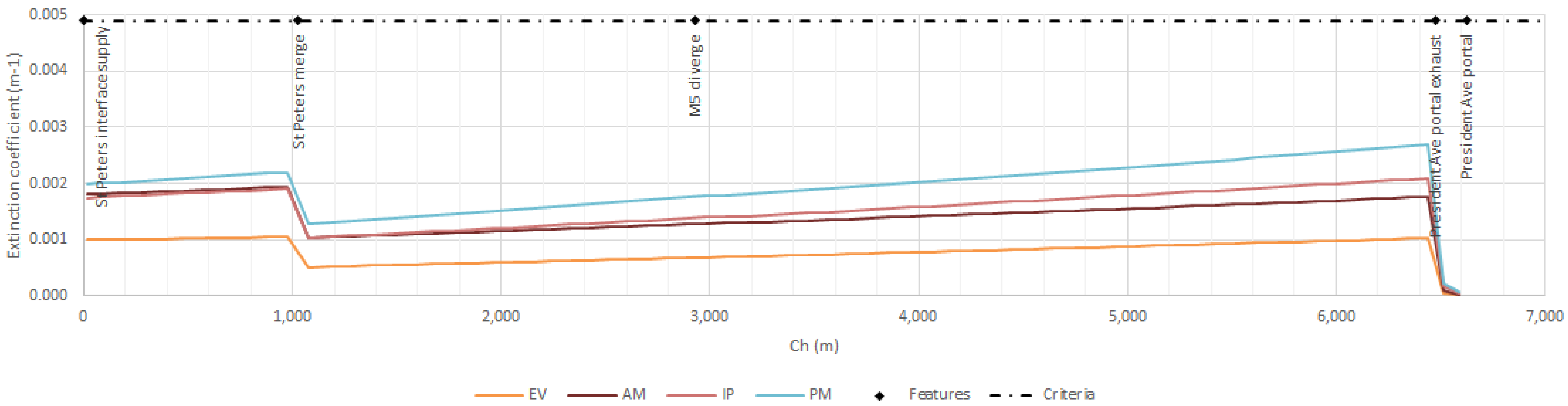


Figure 8.16. In-tunnel visibility along route 1C from M4-M5 Link to President Ave [2036 Do something, expected traffic].

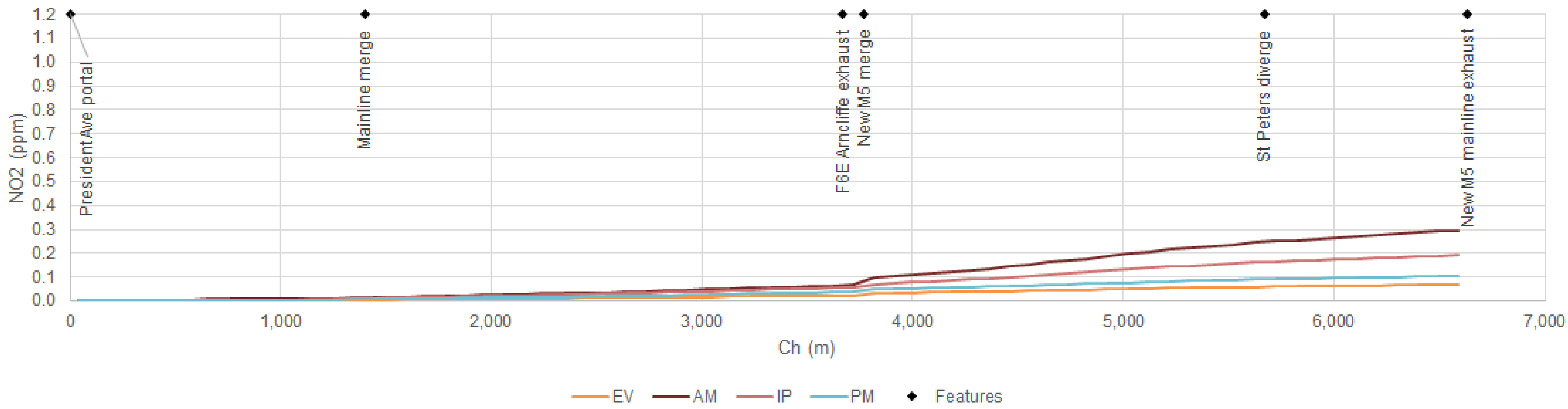


Figure 8.17. In-tunnel NO_2 levels along route 2B from President Ave to M4-M5 Link [2036 Do something, expected traffic].

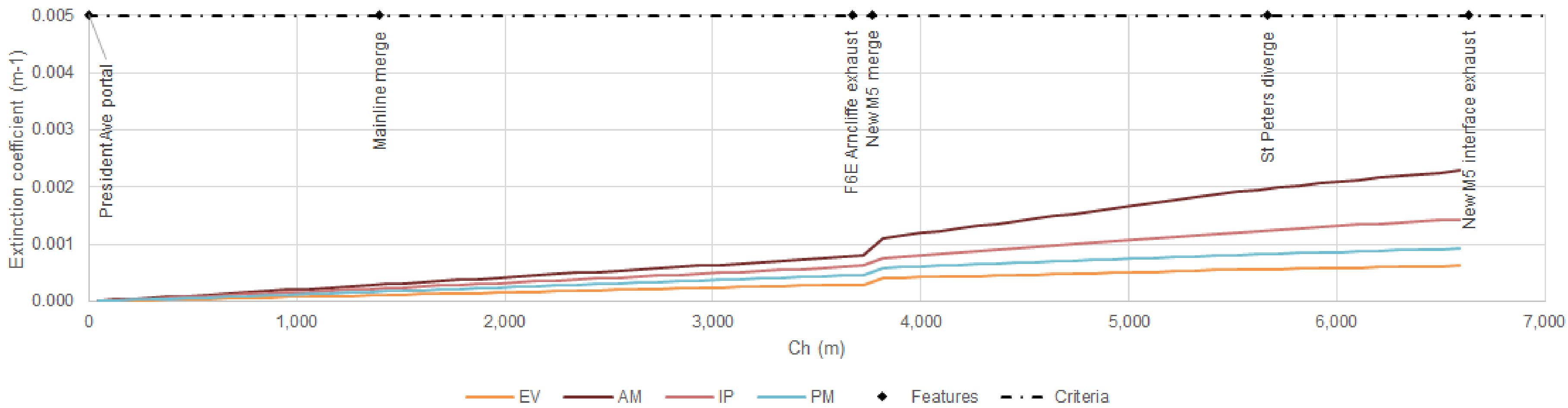


Figure 8.18. In-tunnel visibility along route 2B from President Ave to M4-M5 Link [2036 Do something, expected traffic].

Table 8.8. Outlet emissions summary [2036 Do something, expected traffic].

Outlet identifier:	B						C						D					
EIS name:	Arncliffe (New M5)						SPI (New M5)						SPI (M4-M5 Link)					
Period	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)
AM	306	0.48	0.62	0.08	0.01	0.09	728	2.63	4.05	0.29	0.05	0.34	520	1.36	2.33	0.15	0.02	0.17
IP	176	0.20	0.21	0.03	0.00	0.03	727	1.86	2.34	0.18	0.03	0.21	507	1.40	1.99	0.14	0.03	0.16
PM	0	0.00	0.00	0.00	0.00	0.00	738	0.86	1.54	0.12	0.02	0.13	496	1.25	2.21	0.15	0.02	0.17
EV	0	0.00	0.00	0.00	0.00	0.00	577	0.40	0.82	0.06	0.01	0.07	440	0.65	1.08	0.07	0.01	0.08

Outlet identifier:	E						F						G					
EIS name:	Arncliffe (F6 Extension)						Rockdale (F6 Extension - Stage 1)						Rockdale (F6 Extension future stages)					
Period	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)
AM	306	0.23	0.37	0.05	0.00	0.05	418	1.01	1.64	0.11	0.02	0.13	-	-	-	-	-	-
IP	176	0.12	0.16	0.02	0.00	0.02	513	1.59	2.47	0.17	0.03	0.20	-	-	-	-	-	-
PM	0	0.00	0.00	0.00	0.00	0.00	555	1.92	3.41	0.25	0.03	0.28	-	-	-	-	-	-
EV	0	0.00	0.00	0.00	0.00	0.00	354	0.40	0.90	0.06	0.01	0.06	-	-	-	-	-	-

8.3 Cumulative

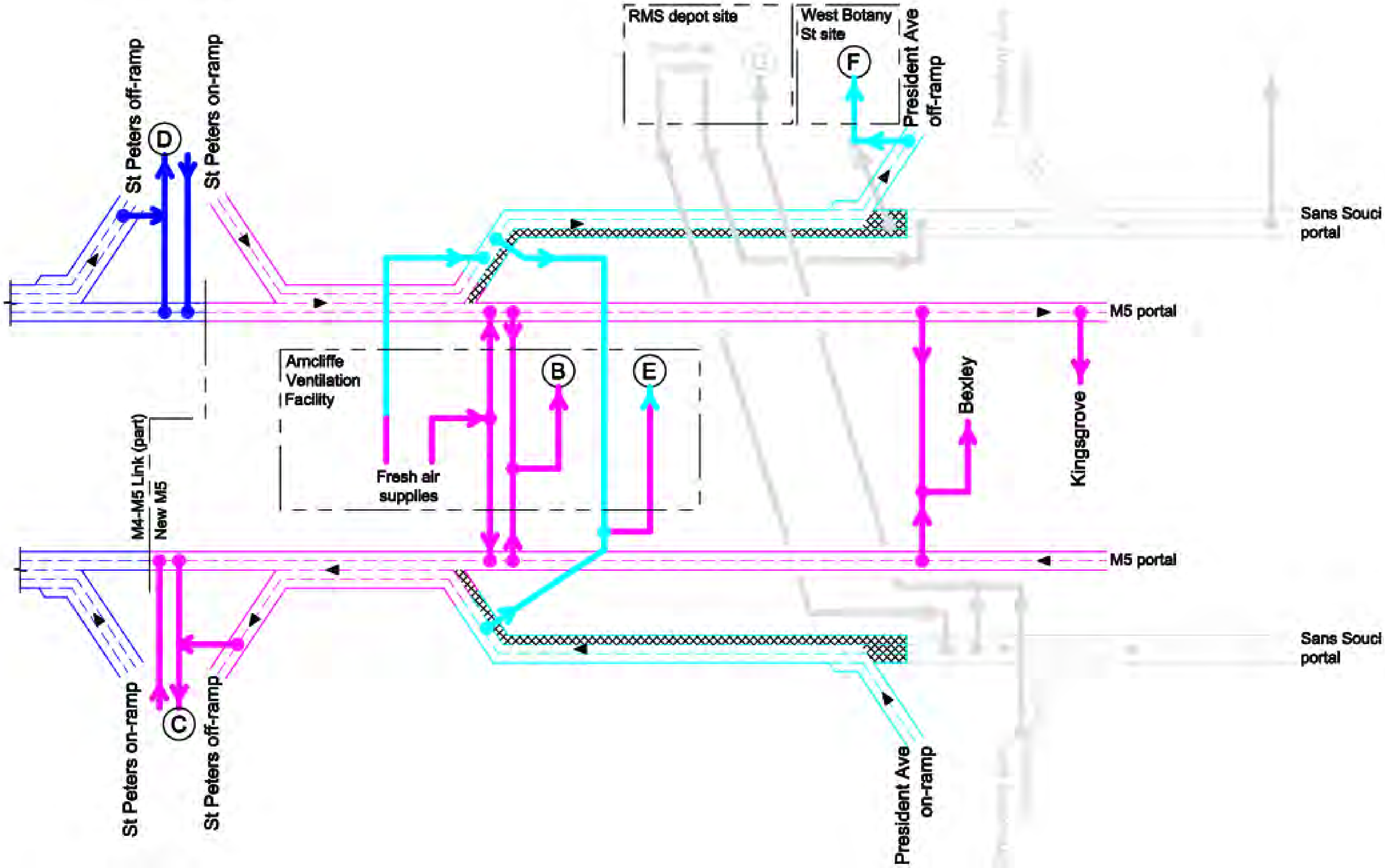


Figure 8.19. Ventilation schematic, 2026 Cumulative.

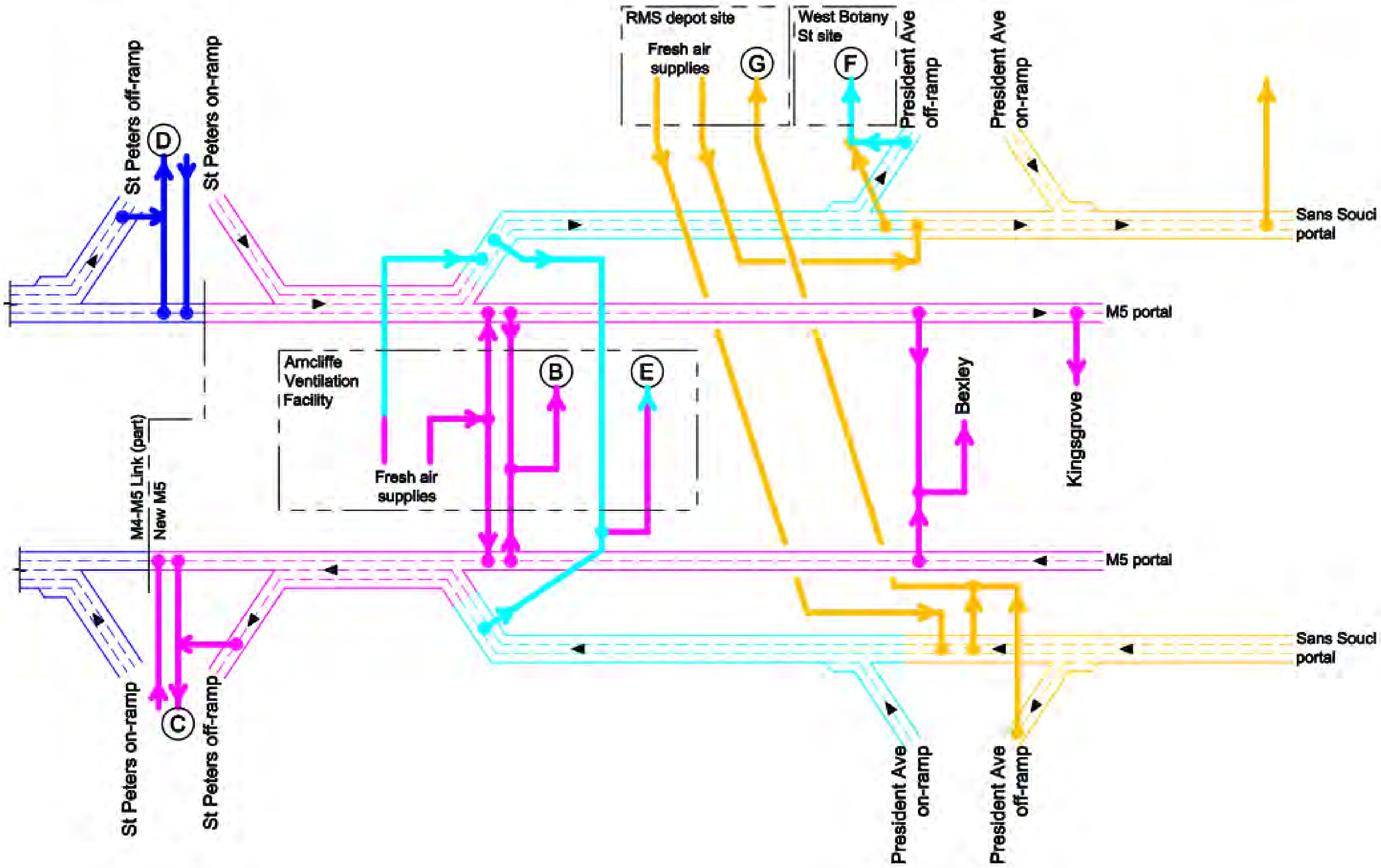


Figure 8.20. Ventilation schematic, 2036 Cumulative.

8.3.1 2026 expected traffic operations

Table 8.9. In-tunnel estimated air quality maximum [2026 Cumulative, expected traffic].

	Southbound (M4 to M5) direction										Northbound (M5 to M4) direction									
	F6 Extension Stage 1			New M5			NO2 route average				F6 Extension Stage 1			New M5			NO2 route average			
	NO2 (ppm)	CO (ppm)	Vis (1/m)	NO2 (ppm)	CO (ppm)	Vis (1/m)	1A (ppm)	1B (ppm)	1C (ppm)	1D (ppm)	NO2 (ppm)	CO (ppm)	Vis (1/m)	NO2 (ppm)	CO (ppm)	Vis (1/m)	2A (ppm)	2B (ppm)	2C (ppm)	2D (ppm)
Criteria	n/a	48.7	0.0049	n/a	48.7	0.0049	0.47	0.47	0.47	0.47	n/a	48.7	0.0049	n/a	48.7	0.0049	0.47	0.47	0.47	0.47
Period																				
AM	0.25	3.6	0.0016	0.35	5.1	0.0021	0.14	0.19	0.18	0.22	0.06	0.9	0.0006	0.35	5.1	0.0020	0.10	0.10	0.11	0.11
IP	0.31	4.4	0.0019	0.43	5.6	0.0024	0.16	0.22	0.20	0.25	0.05	0.7	0.0005	0.23	2.9	0.0013	0.07	0.07	0.07	0.08
PM	0.37	5.7	0.0024	0.51	7.6	0.0030	0.18	0.25	0.22	0.29	0.04	0.6	0.0004	0.15	2.3	0.0010	0.05	0.05	0.05	0.05
EV	0.15	2.7	0.0010	0.20	3.6	0.0012	0.08	0.10	0.10	0.12	0.03	0.4	0.0003	0.10	1.6	0.0006	0.03	0.03	0.04	0.04

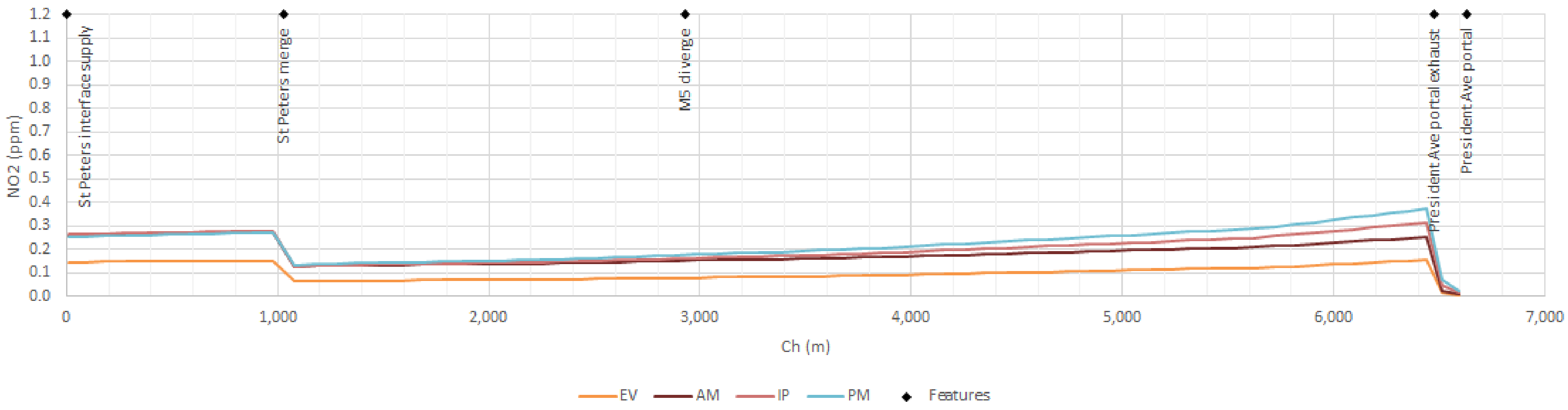


Figure 8.21. In-tunnel NO_2 levels along route 1C from M4-M5 Link to President Ave [2026 Cumulative, expected traffic].

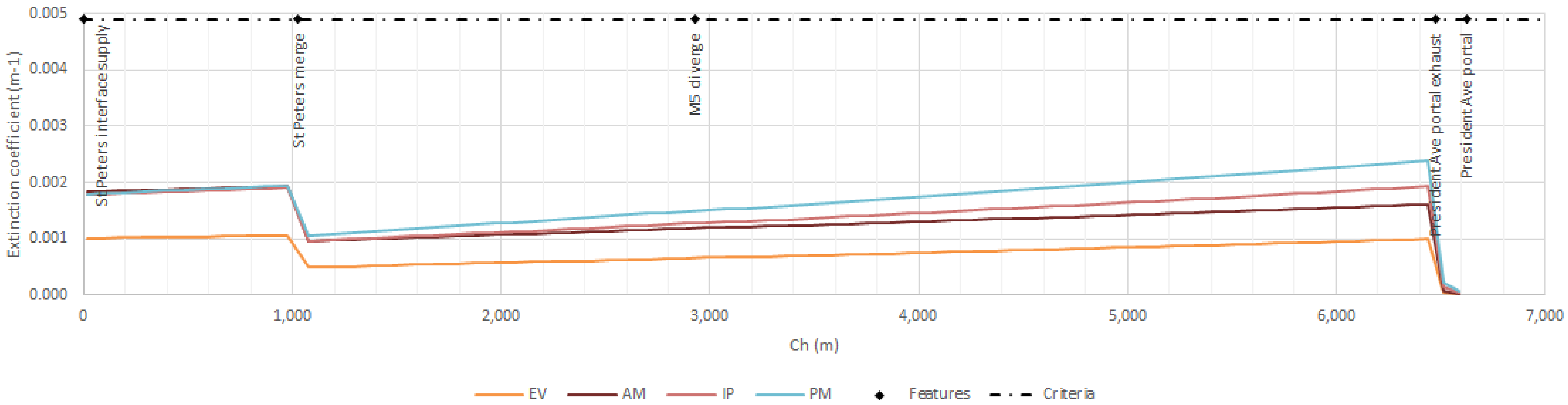


Figure 8.22. In-tunnel visibility along route 1C from M4-M5 Link to President Ave [2026 Cumulative, expected traffic].

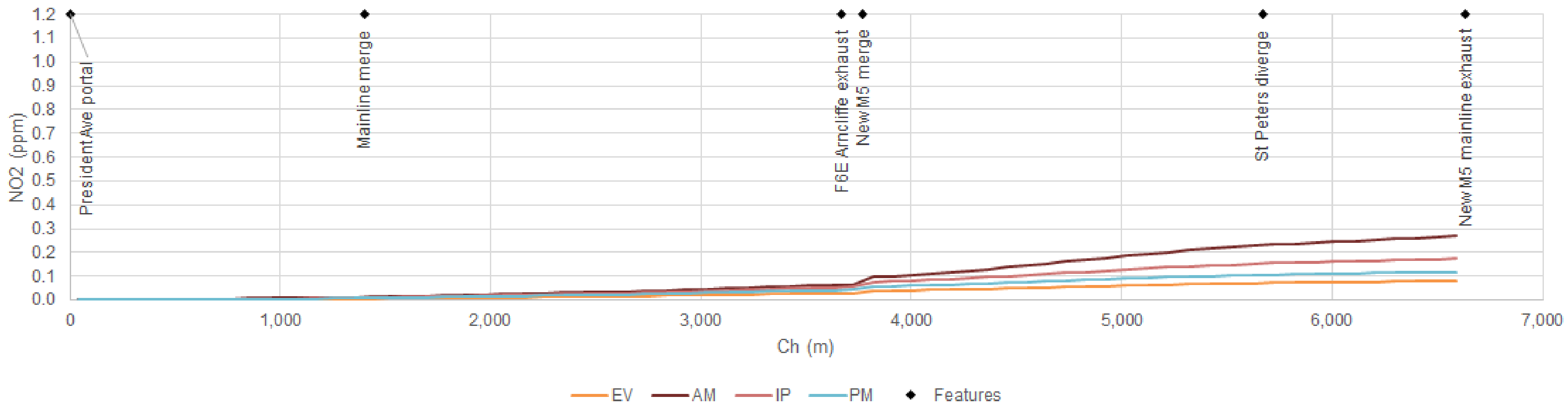


Figure 8.23. In-tunnel NO_2 levels along route 2A from President Ave to St Peters [2026 Cumulative, expected traffic].

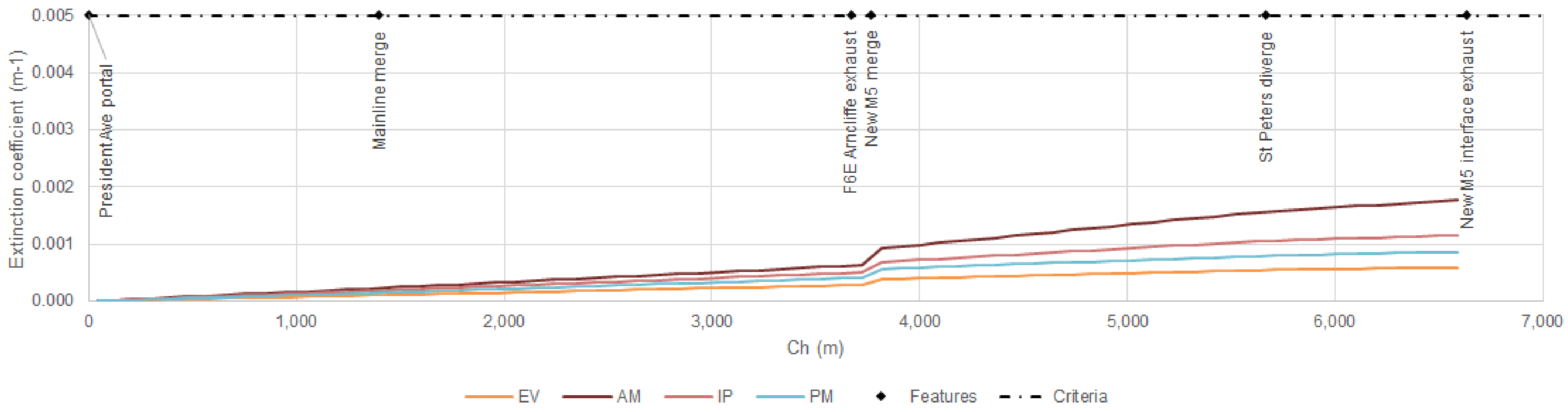


Figure 8.24. In-tunnel visibility along route 2A from President Ave to St Peters [2026 Cumulative, expected traffic].

Table 8.10. Outlet emissions summary [2026 Cumulative, expected traffic].

Outlet identifier: EIS name:	B Arncliffe (New M5)						C SPI (New M5)						D SPI (M4-M5 Link)					
Period	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)
AM	226	0.33	0.43	0.05	0.01	0.06	728	2.25	3.67	0.22	0.05	0.27	628	1.93	3.46	0.20	0.04	0.24
IP	86	0.10	0.11	0.01	0.00	0.02	726	1.61	2.12	0.14	0.03	0.17	595	2.00	3.01	0.18	0.04	0.21
PM	0	0.00	0.00	0.00	0.00	0.00	696	0.87	1.60	0.10	0.02	0.12	537	1.46	2.78	0.15	0.03	0.18
EV	0	0.00	0.00	0.00	0.00	0.00	549	0.42	0.86	0.05	0.01	0.06	474	0.77	1.46	0.08	0.02	0.09

Outlet identifier: EIS name:	E Arncliffe (F6 Extension)						F Rockdale (F6 Extension - Stage 1)						G Rockdale (F6 Extension future stages)					
Period	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)
AM	226	0.14	0.25	0.03	0.00	0.03	365	0.87	1.30	0.08	0.02	0.10	-	-	-	-	-	-
IP	86	0.05	0.07	0.01	0.00	0.01	470	1.50	2.22	0.14	0.03	0.17	-	-	-	-	-	-
PM	0	0.00	0.00	0.00	0.00	0.00	536	1.84	3.40	0.20	0.04	0.24	-	-	-	-	-	-
EV	0	0.00	0.00	0.00	0.00	0.00	331	0.40	0.89	0.05	0.01	0.06	-	-	-	-	-	-

8.3.2 2036 expected traffic operations

Table 8.11. In-tunnel estimated air quality maximum [2036 Cumulative, expected traffic].

	Southbound (M4 to M5) direction										Northbound (M5 to M4) direction									
	F6 Extension Stage 1			New M5			NO2 route average				F6 Extension Stage 1			New M5			NO2 route average			
	NO2 (ppm)	CO (ppm)	Vis (1/m)	NO2 (ppm)	CO (ppm)	Vis (1/m)	1A (ppm)	1B (ppm)	1C (ppm)	1D (ppm)	NO2 (ppm)	CO (ppm)	Vis (1/m)	NO2 (ppm)	CO (ppm)	Vis (1/m)	2A (ppm)	2B (ppm)	2C (ppm)	2D (ppm)
Criteria	n/a	48.7	0.0049	n/a	48.7	0.0049	0.47	0.47	0.47	0.47	n/a	48.7	0.0049	n/a	48.7	0.0049	0.47	0.47	0.47	0.47
Period																				
AM	0.26	4.3	0.0019	0.34	5.3	0.0023	0.14	0.19	0.18	0.22	0.07	1.2	0.0008	0.44	6.3	0.0028	0.12	0.11	0.11	0.12
IP	0.32	5.1	0.0022	0.41	5.8	0.0028	0.15	0.22	0.20	0.25	0.05	0.8	0.0005	0.25	3.4	0.0015	0.07	0.07	0.07	0.08
PM	0.42	7.8	0.0031	0.49	7.5	0.0035	0.19	0.25	0.23	0.29	0.04	0.7	0.0005	0.16	2.7	0.0011	0.05	0.05	0.05	0.05
EV	0.15	2.9	0.0011	0.18	3.4	0.0013	0.07	0.10	0.10	0.11	0.03	0.5	0.0004	0.10	1.6	0.0007	0.03	0.03	0.03	0.03

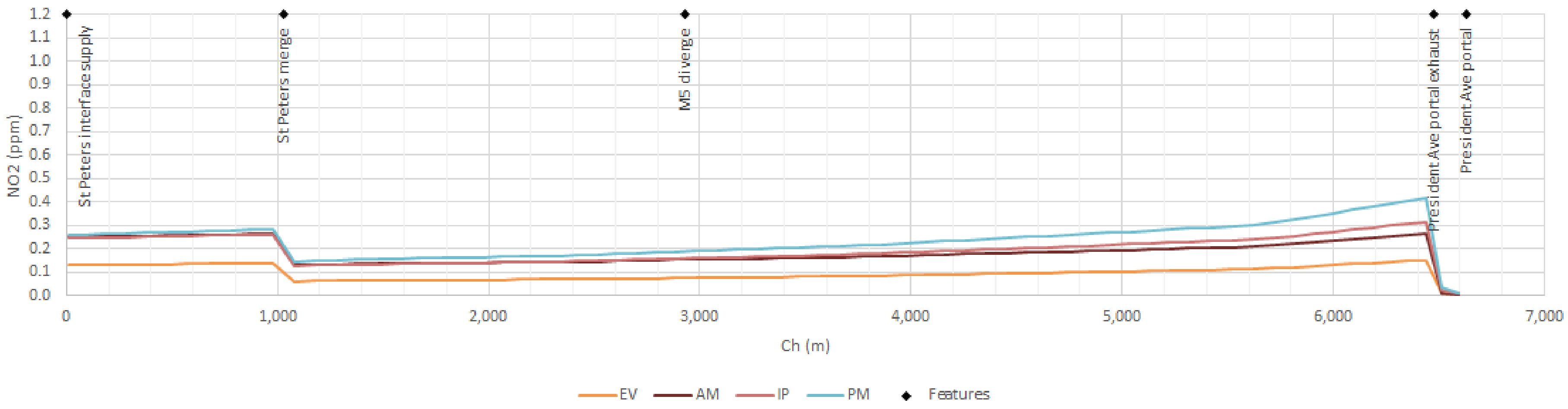


Figure 8.25. In-tunnel NO_2 levels along route 1C from M4-M5 Link to President Ave [2036 Cumulative, expected traffic].

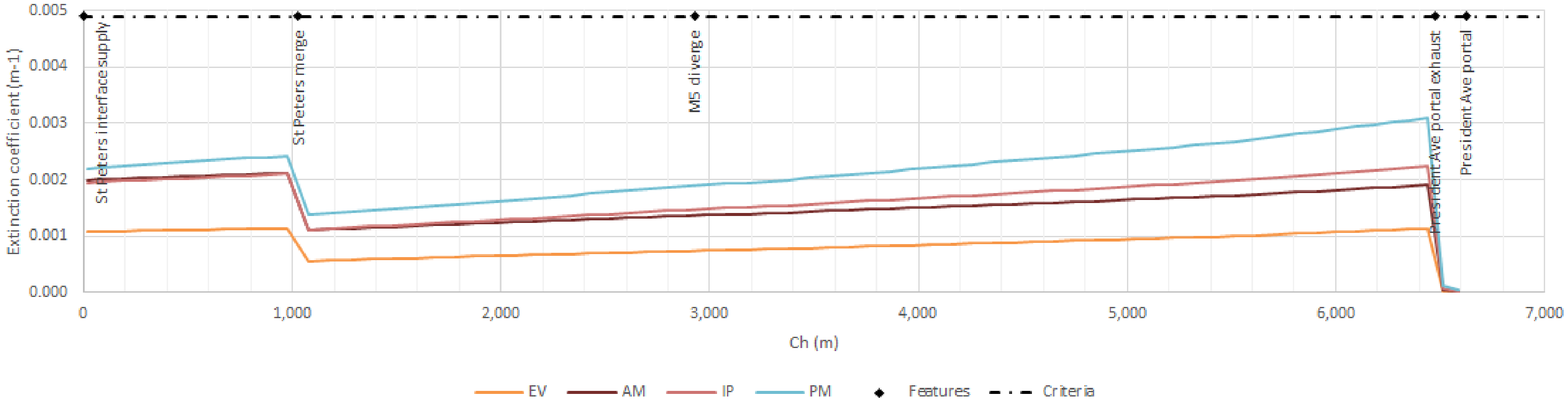


Figure 8.26. In-tunnel visibility levels along route 1C from M4-M5 Link to President Ave [2036 Cumulative, expected traffic].

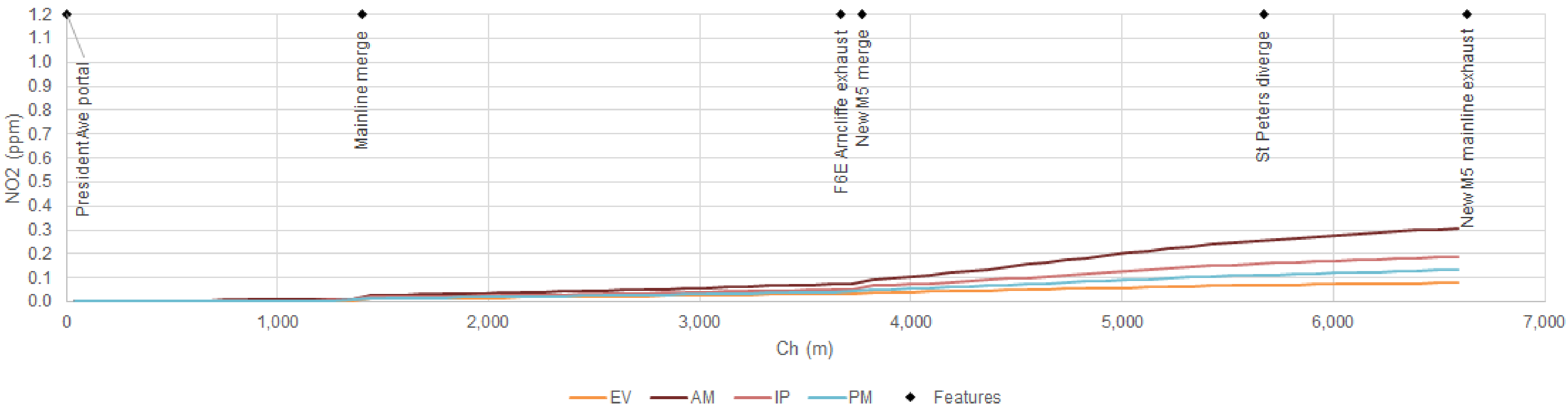


Figure 8.27. In-tunnel NO_2 levels along route 2B from President Ave to M4-M5 Link [2036 Cumulative, expected traffic].

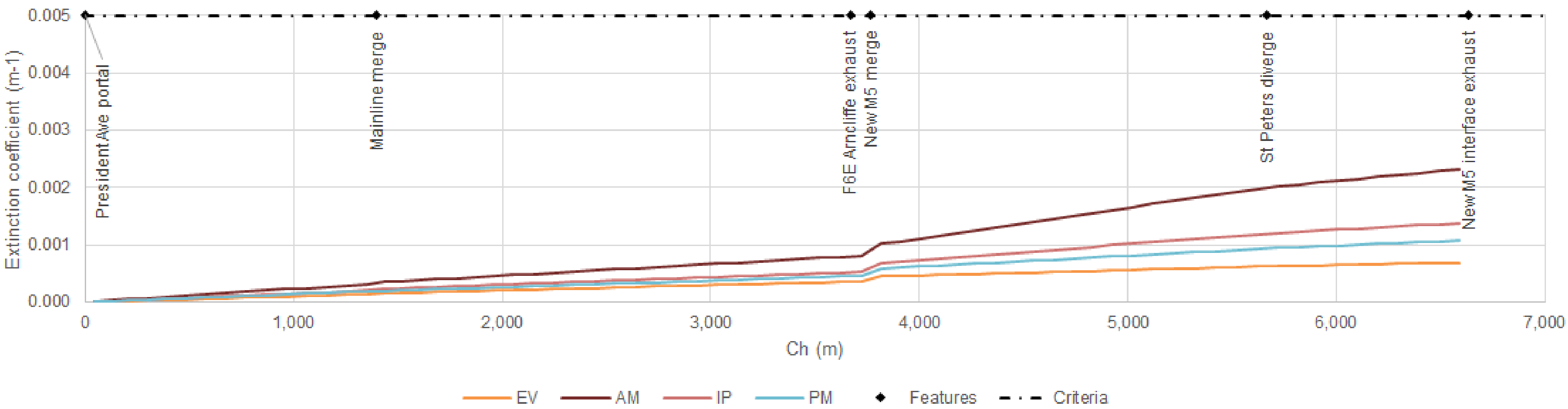


Figure 8.28. In-tunnel visibility along route 2B from President Ave to M4-M5 Link [2036 Cumulative, expected traffic].

Table 8.12. Outlet emissions summary [2036 Cumulative, expected traffic].

Outlet identifier:	B						C						D					
EIS name:	Arncliffe (New M5)						SPI (New M5)						SPI (M4-M5 Link)					
Period	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)
AM	422	0.69	0.86	0.11	0.01	0.13	730	2.86	4.25	0.30	0.05	0.35	639	2.07	3.44	0.23	0.03	0.26
IP	267	0.32	0.34	0.05	0.01	0.05	725	1.81	2.46	0.17	0.03	0.20	600	2.02	2.92	0.20	0.04	0.23
PM	151	0.11	0.18	0.02	0.00	0.02	730	1.06	1.92	0.14	0.02	0.16	556	1.69	2.99	0.20	0.03	0.23
EV	0	0.00	0.00	0.00	0.00	0.00	661	0.56	1.05	0.08	0.01	0.09	500	0.85	1.42	0.09	0.01	0.11

Outlet identifier:	E						F						G					
EIS name:	Arncliffe (F6 Extension)						Rockdale (F6 Extension - Stage 1)						Rockdale (F6 Extension future stages)					
Period	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)	Exhaust flow (m^3/s)	NO_x (g/s)	CO (g/s)	Non-exhaust PM2.5 (g/s)	Exhaust PM (g/s)	Total PM (g/s)
AM	422	0.34	0.59	0.07	0.01	0.07	508	1.10	1.71	0.13	0.02	0.15	750	0.67	1.16	0.10	0.01	0.11
IP	267	0.16	0.24	0.03	0.00	0.03	619	1.72	2.54	0.20	0.03	0.23	625	0.42	0.63	0.05	0.01	0.06
PM	151	0.07	0.12	0.01	0.00	0.01	732	2.39	4.52	0.34	0.04	0.38	552	0.25	0.48	0.04	0.00	0.04
EV	0	0.00	0.00	0.00	0.00	0.00	451	0.48	0.95	0.07	0.01	0.08	453	0.14	0.24	0.02	0.00	0.02

8.4 Conclusion

For the expected traffic cases the system is self-ventilating under all scenarios analysed, with the vehicle piston effect providing sufficient airflows to maintain in-tunnel conditions within the air quality criteria. Except for the New M5 outlet at St Peters (C), the outlets are operating well below capacity across all scenarios and periods of the day.

In the southbound direction of travel, mainline exchange at St Peters was not required in any scenario, with the natural exchange occurring through the exit and entry ramps at St Peters being sufficient to maintain air quality within the project. For the northbound direction of travel, the New M5 and F6 Extension ventilation system is seen to be capable of operating without any carry-over into M4-M5 Link. Together that means, for the expected traffic cases, that the ventilation system for New M5 and F6 Extension meets or exceeds the functional performance requirements of the overarching WestConnex integrated ventilation system as outlined in the M4-M5 Link EIS.

Pollution levels in the northbound tube are significantly below criteria. It is expected that complete exchange at St Peters, a simplifying assumption in this work, will not be necessary to maintain downstream in-tunnel air quality under most traffic conditions. Operating the overarching WestConnex scheme with mainline carry-over into M4-M5 Link would significantly reduce the energy consumption at Arncliffe (Outlets B and E) and St Peters (Outlet C) ventilation stations.

9 ANALYSIS OUTPUTS – WORST CASE OPERATIONS

Results within this section summarise the analysis outlined in Section 7.1.3. The analysis is based on the vehicle emissions at the year of opening, 2024. All results exclude the background air quality as described in Section 6.7. The in-tunnel air quality criteria shown is adjusted accordingly, calculated as the limit value (Table 6.24) minus background (Table 6.22.).

For the worst-case operations, the ventilation plant in each simulation was adjusted such that the system meets, or marginally improves on, the in-tunnel air quality criteria. Within each simulation, this represents the minimum required capacity of the ventilation plant.

The ventilation operating regime and air quality within the tunnel is depicted on ventilation schematics and graphs showing the pollution concentration profile along a key route for various operating scenarios. Select scenarios representing the most onerous requirements on the ventilation system for normal operations are shown:

- 20 km/h traffic with upper bound tunnel friction factor, maximum in-tunnel flow resistance being the most onerous for jet fans and in-tunnel pollution levels.
- 80 km/hr traffic with lower bound tunnel friction factor, maximum in-tunnel airflows being the most onerous for portal capture demand.
- Smart motorways operation (5 km/h in on-ramp with 60 km/h in mainlines).

As each tube is aerodynamically separate, scenarios are presented separately for the southbound and northbound tubes.

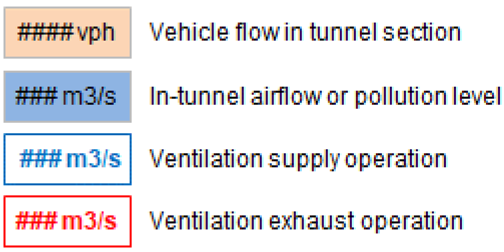


Figure 9.1. Legend for schematic diagrams depicting ventilation operation.

9.1 Do something arrangement (with F6 Extension Stage 1 only)

The results and analysis in this section describe the ventilation system operation with Stage 1 of F6 Extension integrated with the WestConnex tunnel systems as shown in Figure 9.2.

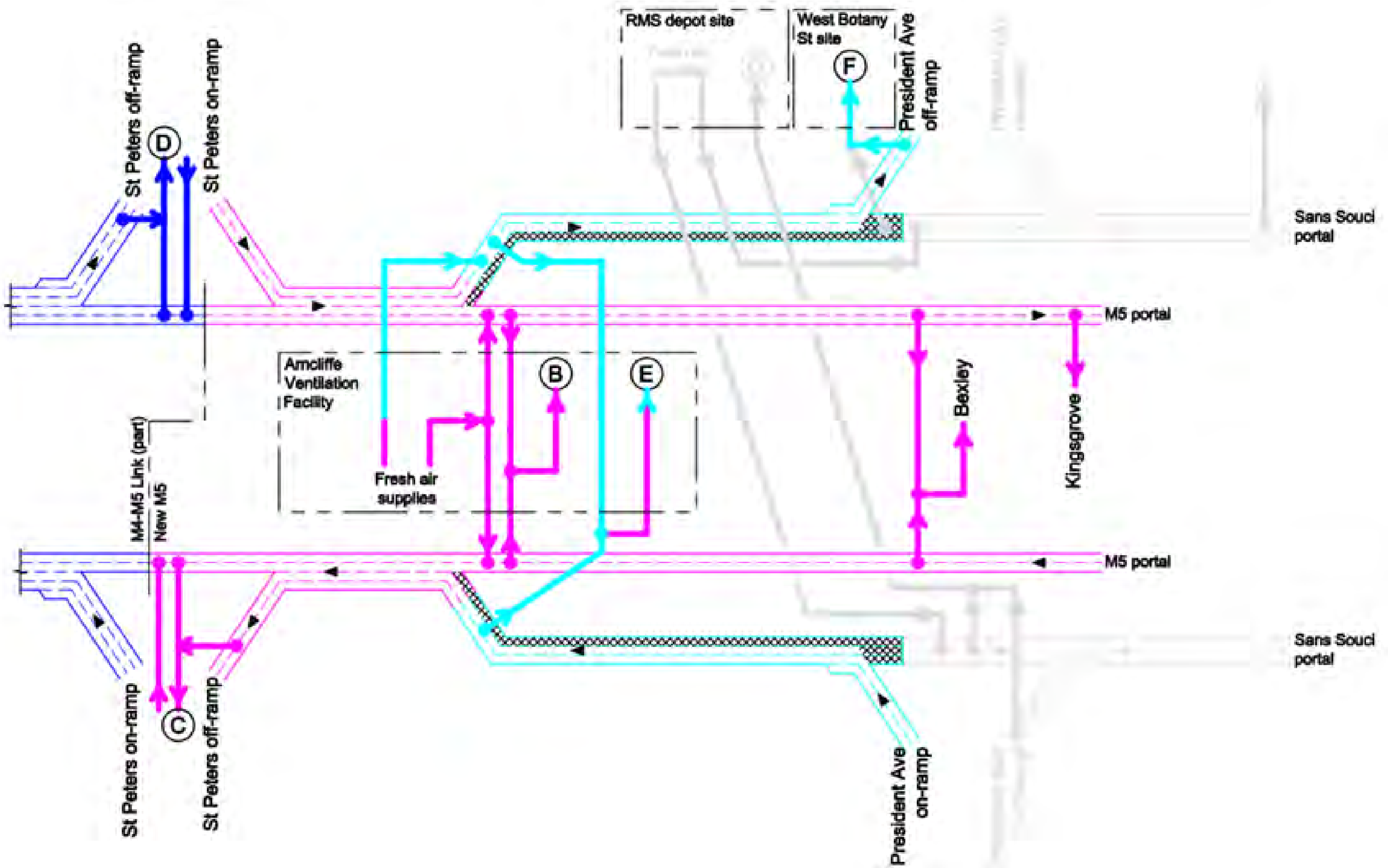


Figure 9.2. Ventilation schematic, worst case operations with F6 Extension Stage 1.

9.1.1 Southbound normal operation at 20 km/h

This scenario depicts a traffic pattern with maximum possible traffic volumes in both F6E and New M5 and represents the traffic which will generate the highest in-tunnel pollution levels. For this scenario, complete mainline exchange at St Peters will be necessary to maintain pollution levels within criteria. While there is equal traffic heading towards the M5 portal and F6E, the longer uphill climb to the M5 portal means higher airflows are necessary in New M5 compared to F6E. Operation of New M5 supply at Arncliffe is required.

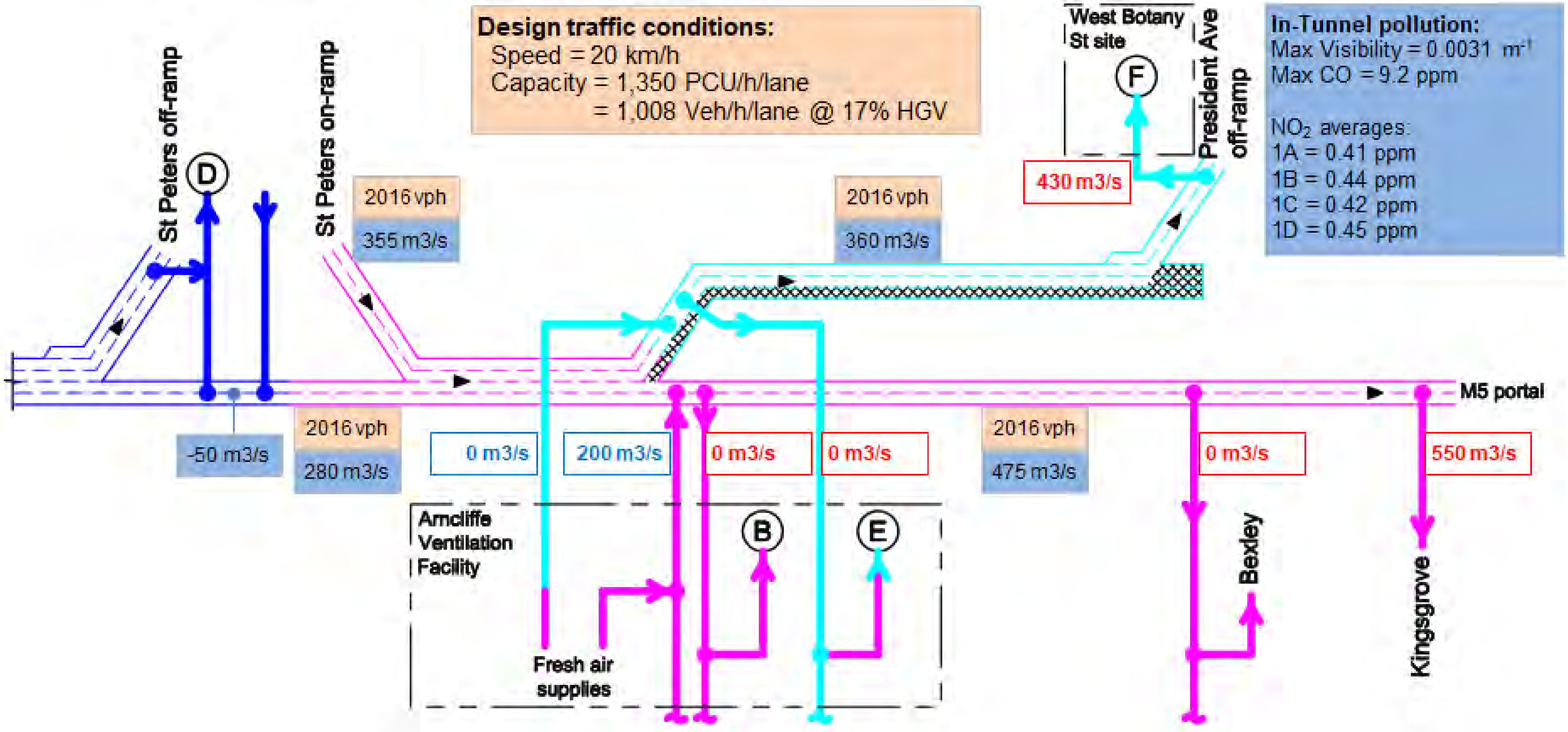


Figure 9.3. Ventilation operation for southbound tube with traffic moving at 20 km/h [Do something, worst case operations, 20 km/h].

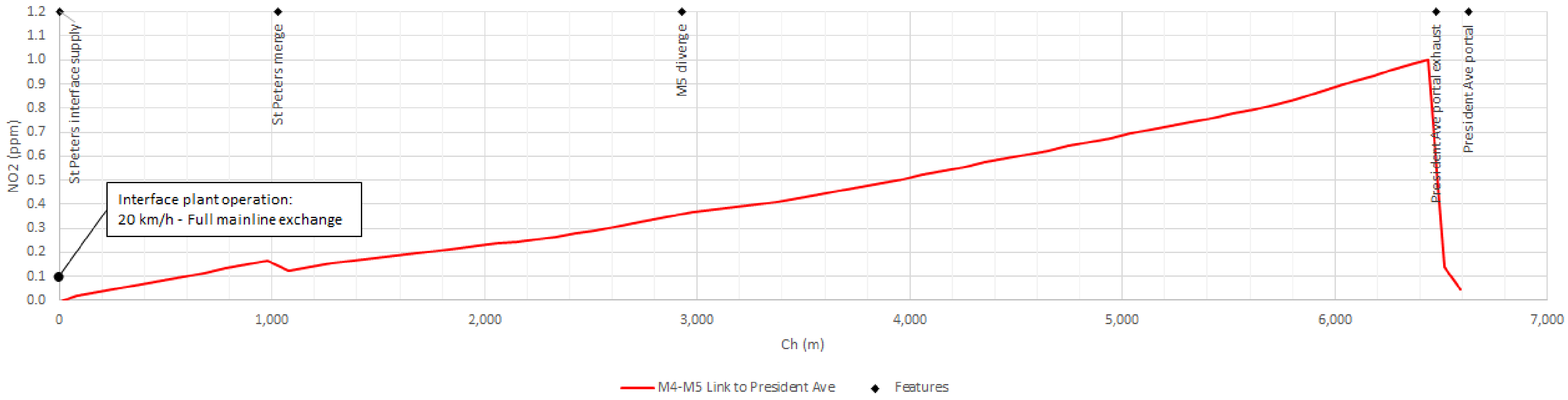


Figure 9.4. In-tunnel NO_2 levels along route 1C from M4-M5 Link to President Ave [Do something, worst case operations, 20 km/h].

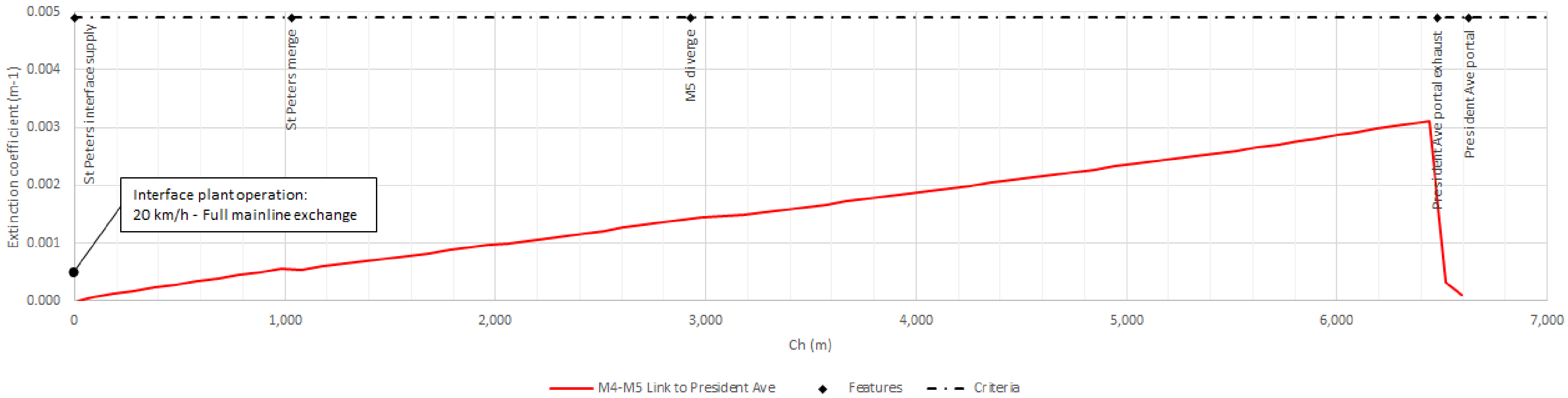


Figure 9.5. In-tunnel visibility along route 1C from M4-M5 Link to President Ave [Do something, worst case operations, 20 km/h].

9.1.2 Northbound normal operation at 20 km/h

This scenario depicts a traffic pattern with maximum possible traffic volumes in both F6E and New M5 and represents the traffic which will generate the highest in-tunnel pollution levels. For this scenario, complete mainline exchange at St Peters can be achieved using only exhaust operation at Arncliffe.

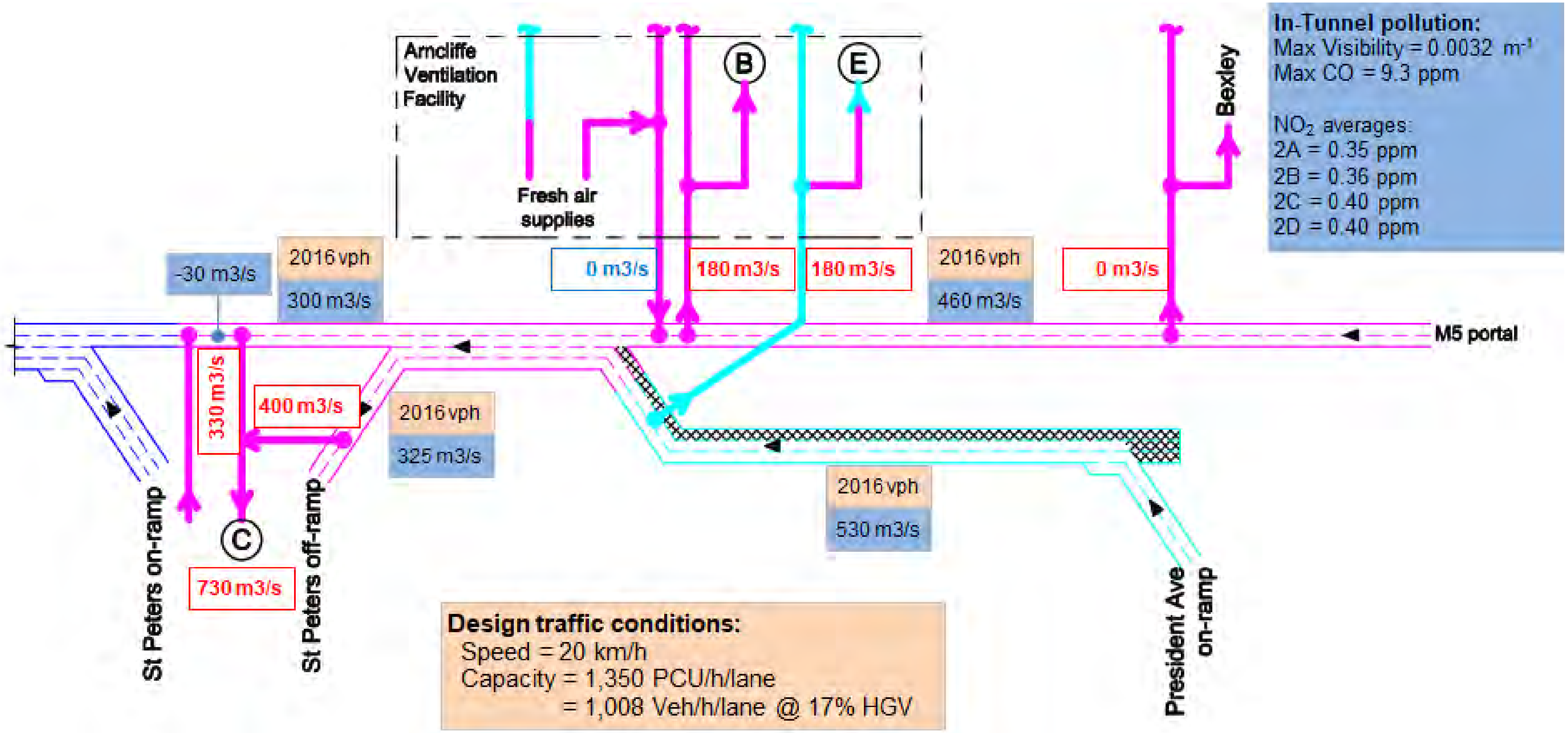


Figure 9.6. Ventilation operation for nouthbound tube with traffic moving at 20 km/h [Do something, worst case operations, 20 km/h].

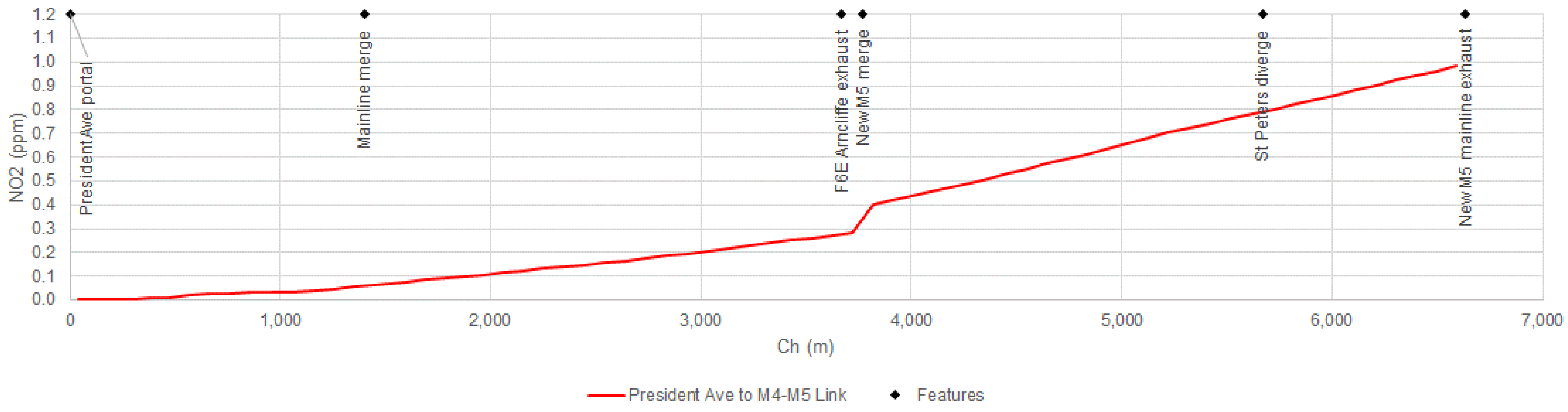


Figure 9.7. In-tunnel NO_2 levels along route 2B from President Ave to M4-M5 Link [Do something, worst case operations, 20 km/h].

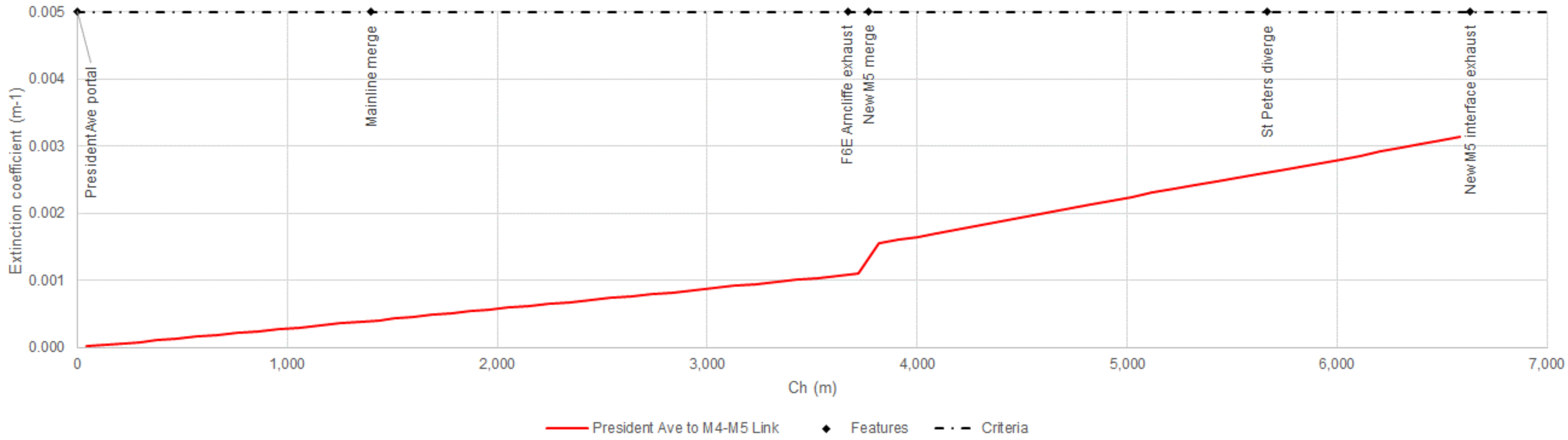


Figure 9.8. In-tunnel visibility along route 2B from President Ave to M4-M5 Link [Do something, worst case operations, 20 km/h].

9.1.3 Southbound normal operation at 80 km/h, maximum traffic volume

This scenario has maximum possible traffic volumes in both F6E and New M5 and represents the traffic which will generate the highest in-tunnel pollution levels. For this scenario, some mainline exchange at St Peters will be necessary to maintain downstream in-tunnel pollution levels within criteria. With equal traffic heading towards the M5 portal and F6E, the natural airflow balance is a roughly equal airflow split at the New M5 / F6E diverge.

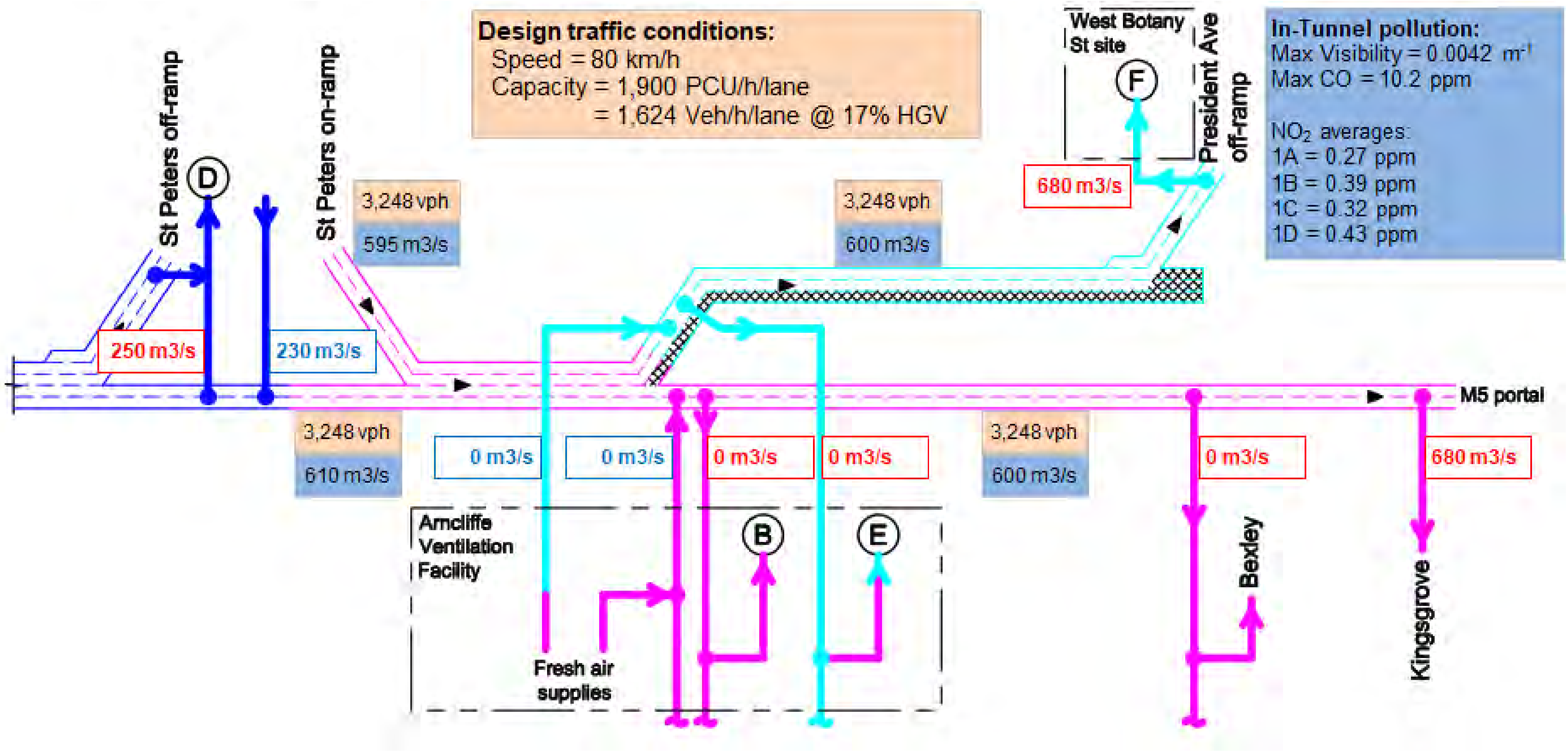


Figure 9.9. Ventilation operation for southbound tube with traffic moving at 80 km/h [Do something, worst case operations, 80 km/h].

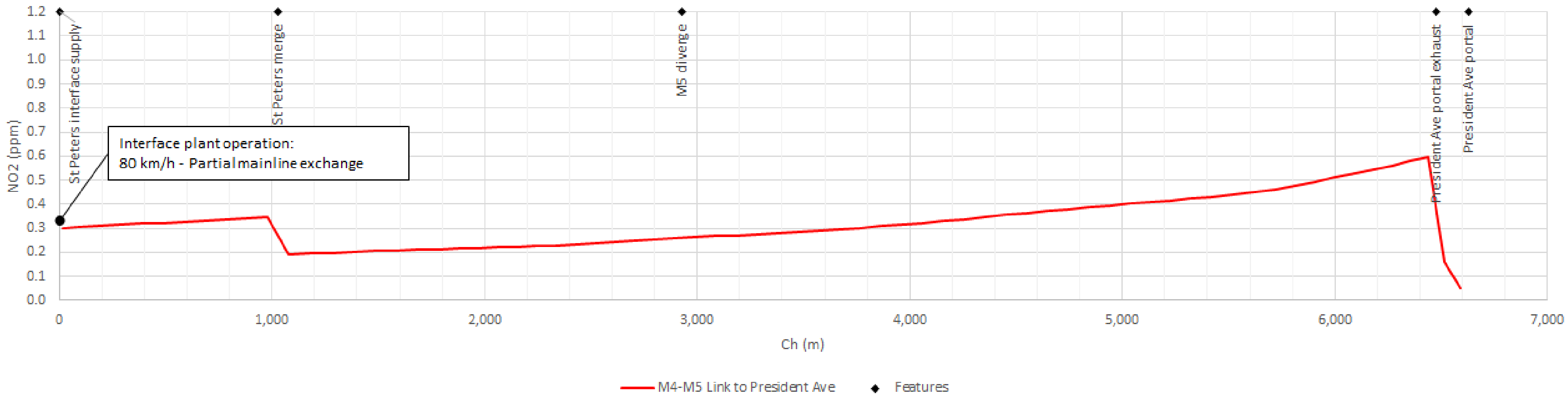


Figure 9.10. In-tunnel NO_2 levels along route 1C from M4-M5 Link to President Ave [Do something, worst case operations, 80 km/h].

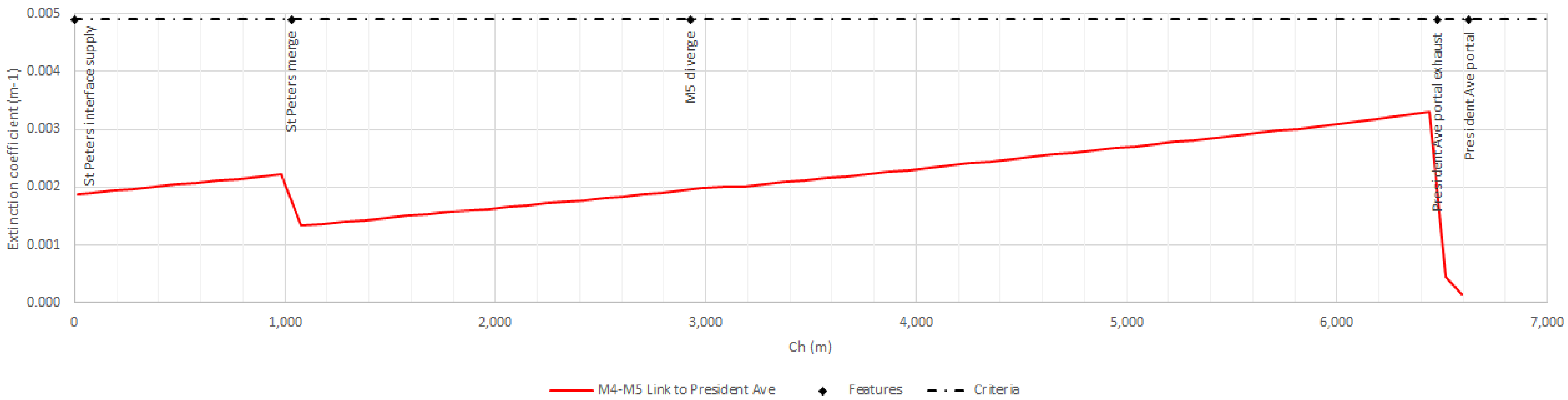


Figure 9.11. In-tunnel visibility along route 1C from M4-M5 Link to President Ave [Do something, worst case operations, 80 km/h].

9.1.4 Northbound normal operation at 80 km/h, maximum traffic volume

This scenario has maximum possible traffic volumes in both F6E and New M5 and represents the most onerous scenario to achieve complete exchange at the interface with M4-M5 Link.

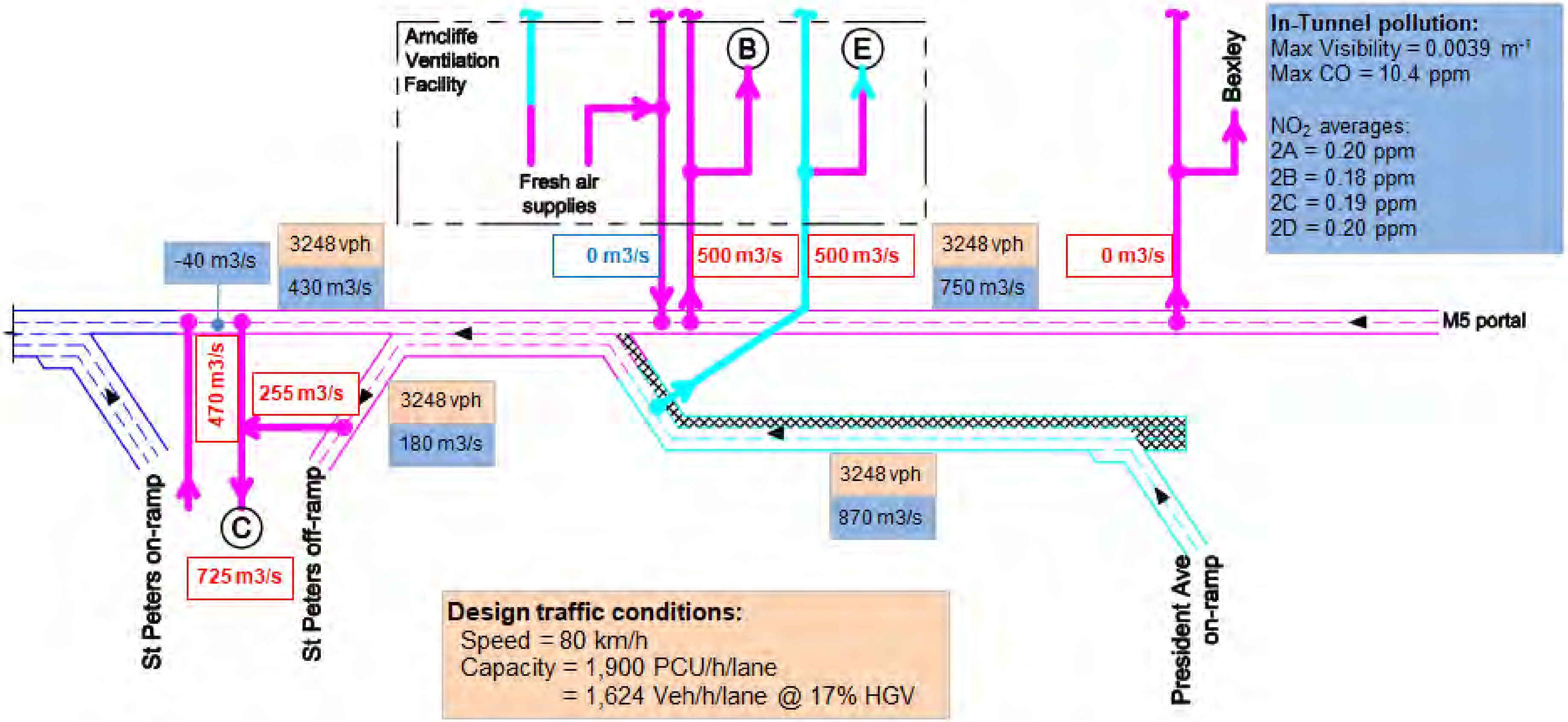


Figure 9.12. Ventilation operation for nouthbound tube with traffic moving at 80 km/h [Do something, worst case operations, 80 km/h].

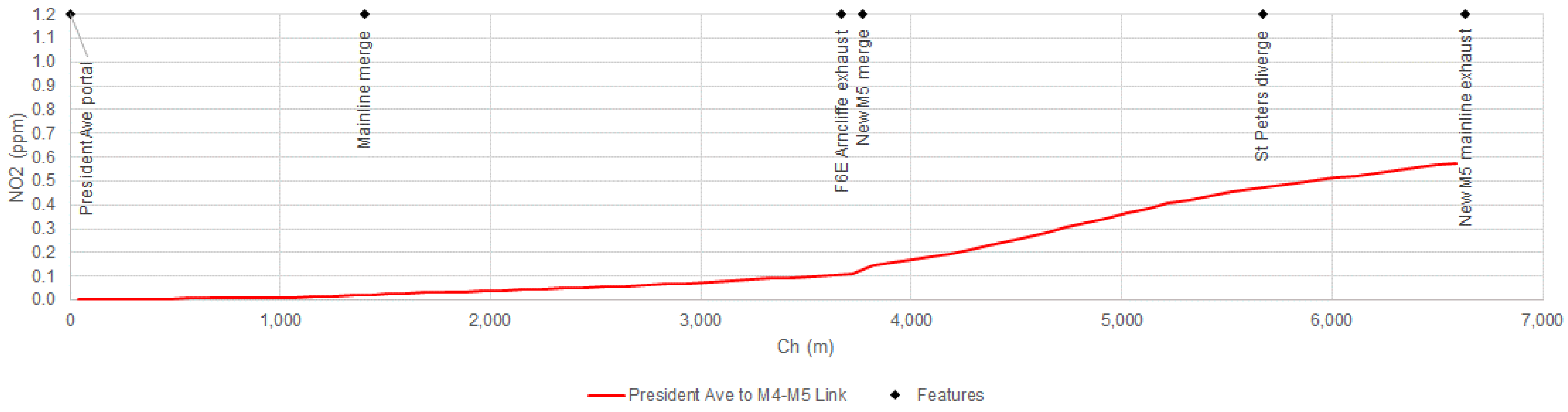


Figure 9.13. In-tunnel NO_2 levels along route 2B from President Ave to M4-M5 Link [Do something, worst case operations, 80 km/h].

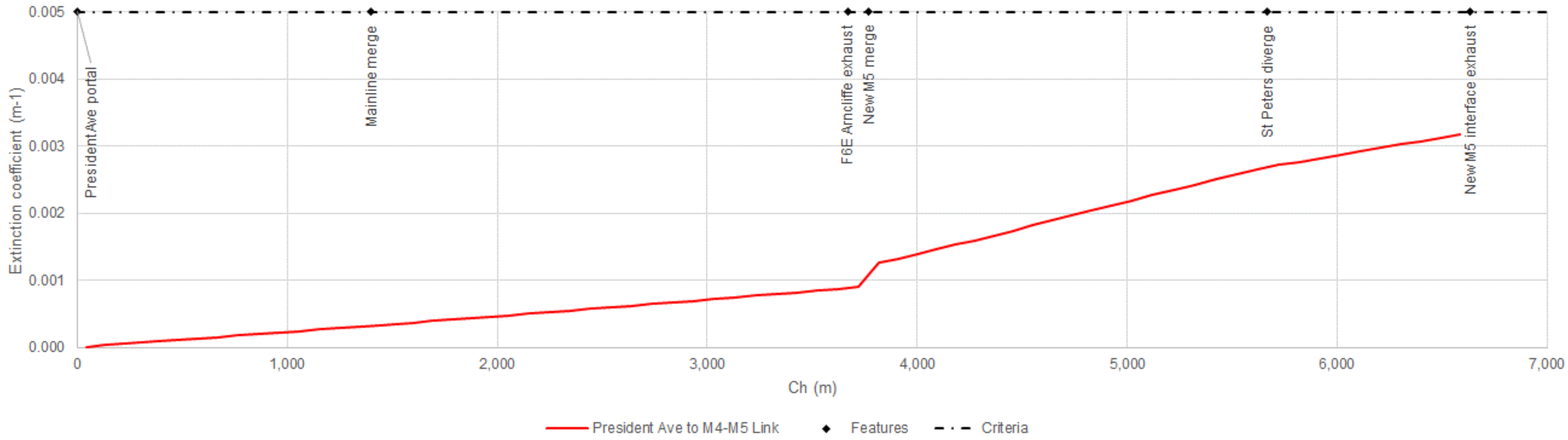


Figure 9.14. In-tunnel visibility along route 2B from President Ave to M4-M5 Link [Do something, worst case operations, 80 km/h].

9.1.5 Southbound normal operation at 80 km/h, maximum airflow to F6 Extension

This scenario has a traffic pattern which creates the maximum demand for the President Ave portal exhaust capture. With no traffic heading towards the M5 portal, the natural airflow balance has F6E receiving the majority of airflow at the New M5 / F6E diverge.

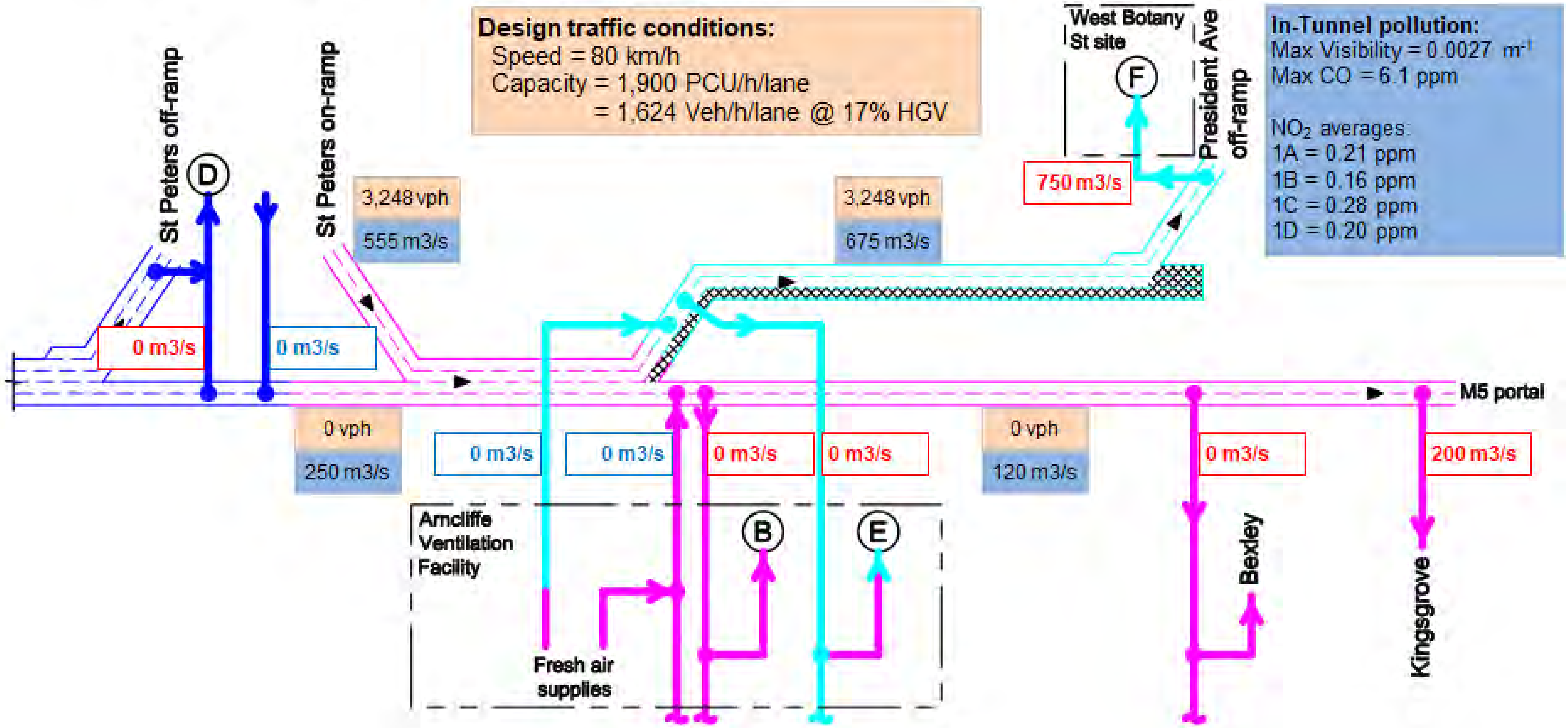


Figure 9.15. Ventilation operation for southbound tube with traffic moving at 80 km/h [Do something, worst case operations, 80 km/h].

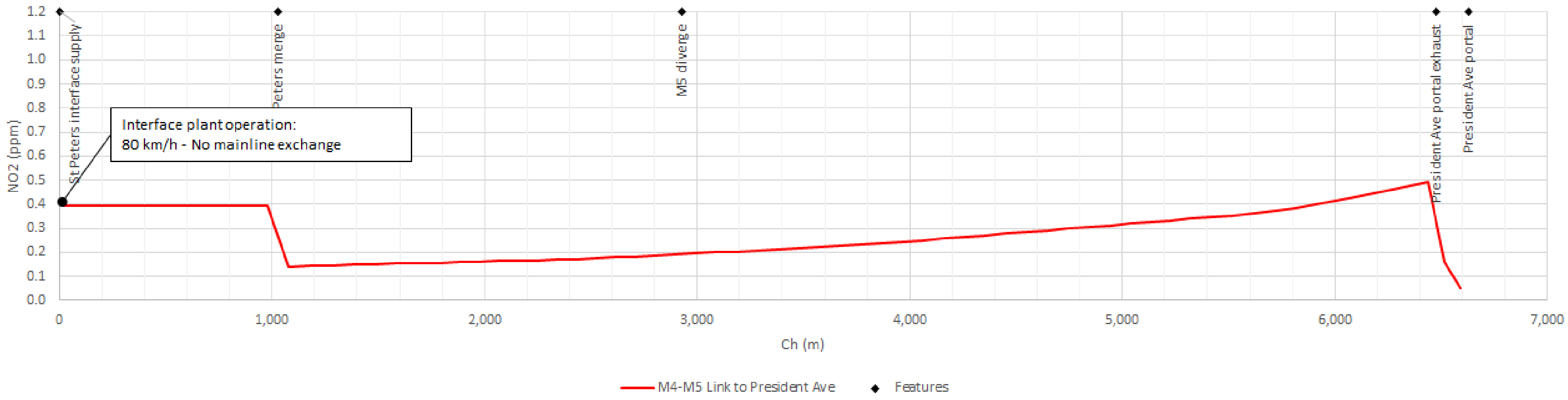


Figure 9.16. In-tunnel NO_2 levels along route 1C from M4-M5 Link to President Ave [Do something, worst case operations, 80 km/h].

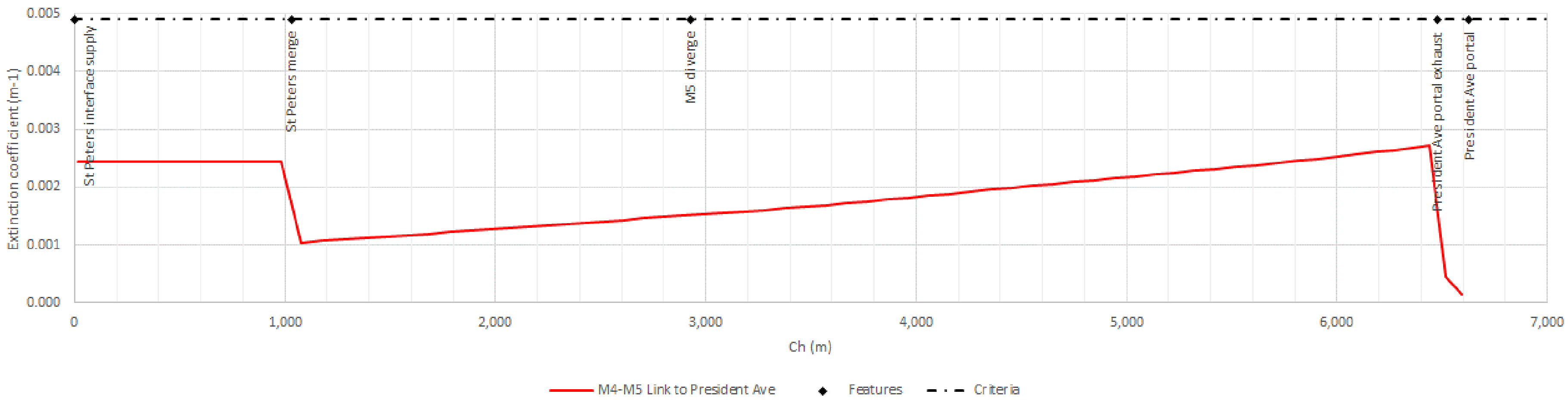


Figure 9.17. In-tunnel visibility along route 1C from M4-M5 Link to President Ave [Do something, worst case operations, 80 km/h].

9.1.6 Southbound Smart Motorways operation, maximum traffic to F6 Extension

This scenario has maximum possible traffic volumes towards F6E during Smart Motorways operation. For this scenario, partial mainline exchange at St Peters will be necessary to maintain pollution levels within criteria.

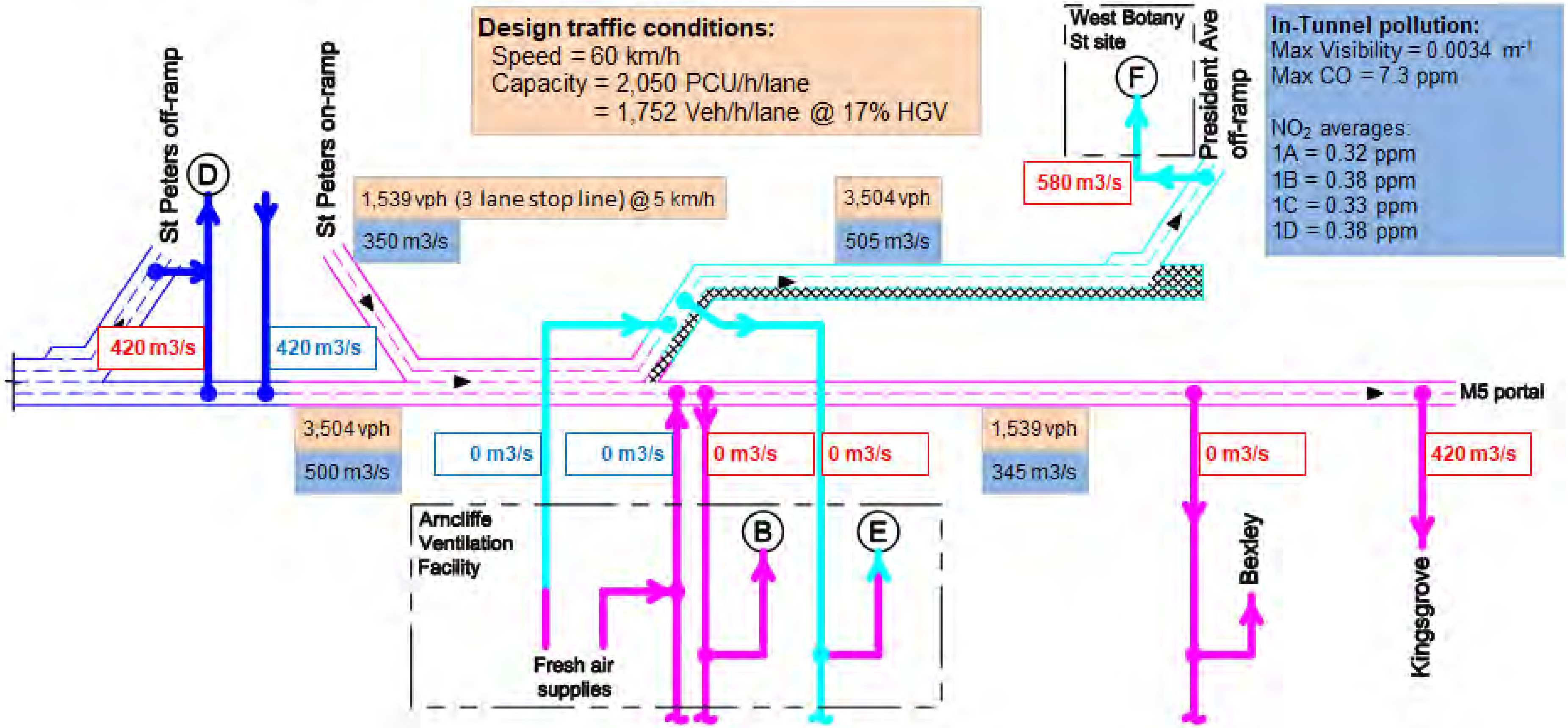


Figure 9.18. Ventilation operation for southbound tube with Smart Motorways [Do something, worst case operations, Smart Motorways].

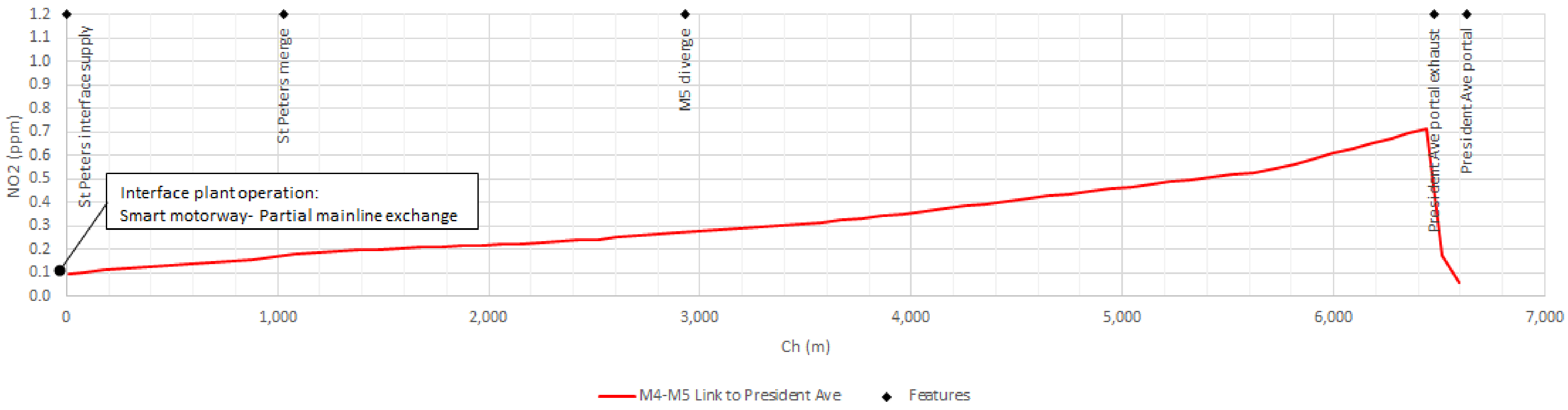


Figure 9.19. In-tunnel NO_2 levels along route 1C from M4-M5 Link to President Ave [Do something, worst case operations, Smart Motorways].

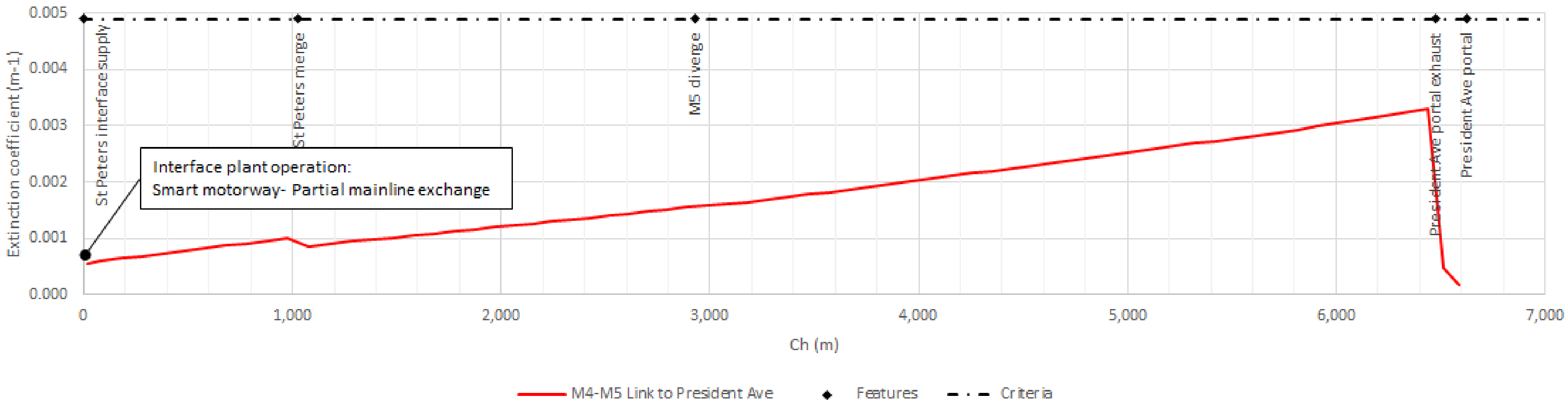


Figure 9.20. In-tunnel visibility along route 1C from M4-M5 Link to President Ave [Do something, worst case operations, Smart Motorways].

9.1.7 Southbound Smart Motorways operation, maximum traffic to M5 Portal

This scenario has maximum possible traffic volumes towards M5 portal during Smart Motorways operation. With New M5 representing a longer uphill run, this is more onerous on the combined ventilation system than the previous scenario. For this scenario, partial mainline exchange will be necessary at St Peters to maintain pollution levels within criteria. An alternative arrangement using less mainline exchange at St Peters but using New M5 supply at Arncliffe would also be feasible.

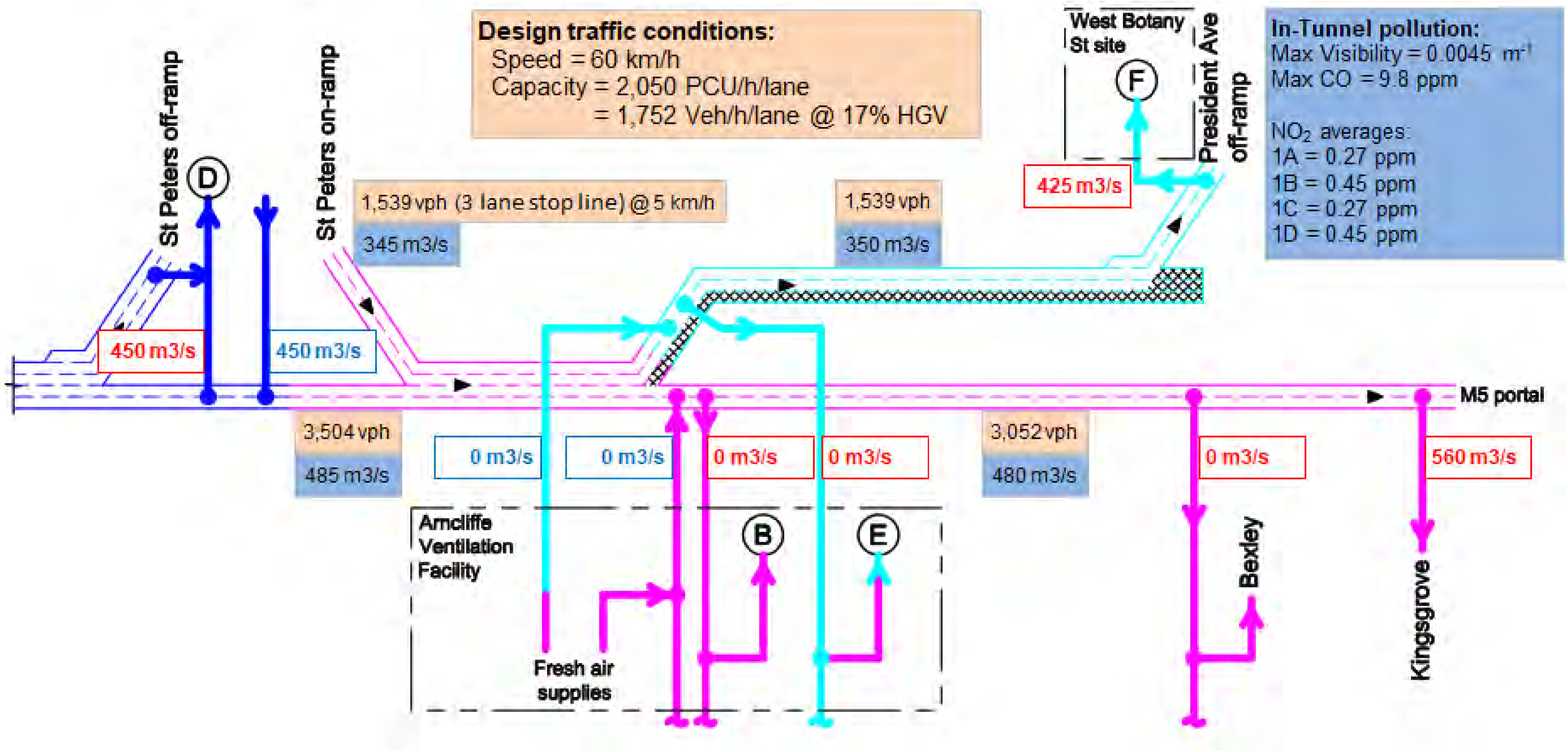


Figure 9.21. Ventilation operation for southbound tube with Smart Motorways [Do something, worst case operations, Smart Motorways].

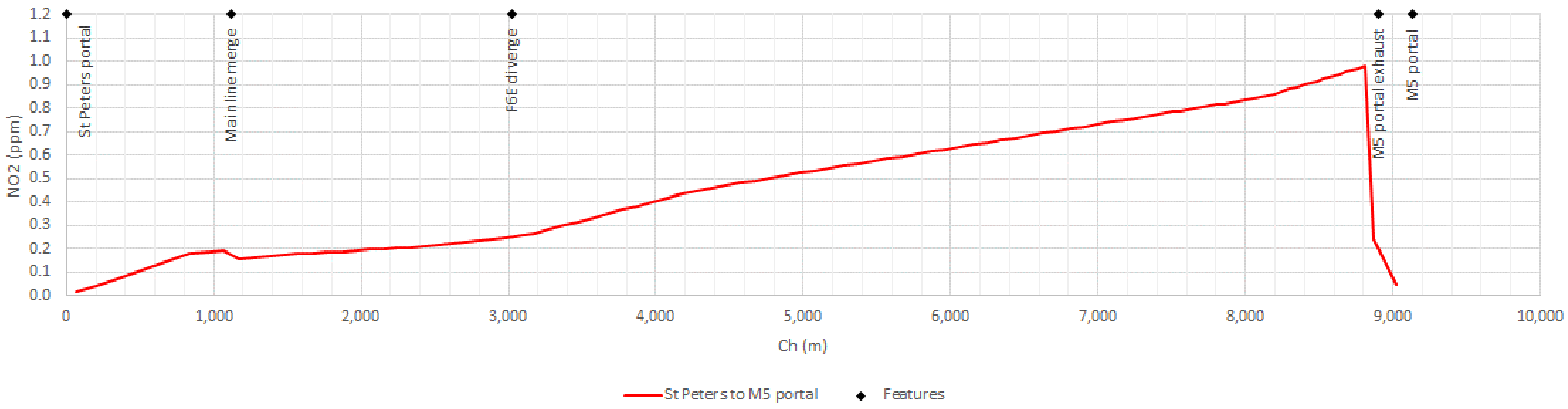


Figure 9.22. In-tunnel NO_2 levels along route 1B from St Peters to M5 portal [Do something, worst case operations, smart motorways].

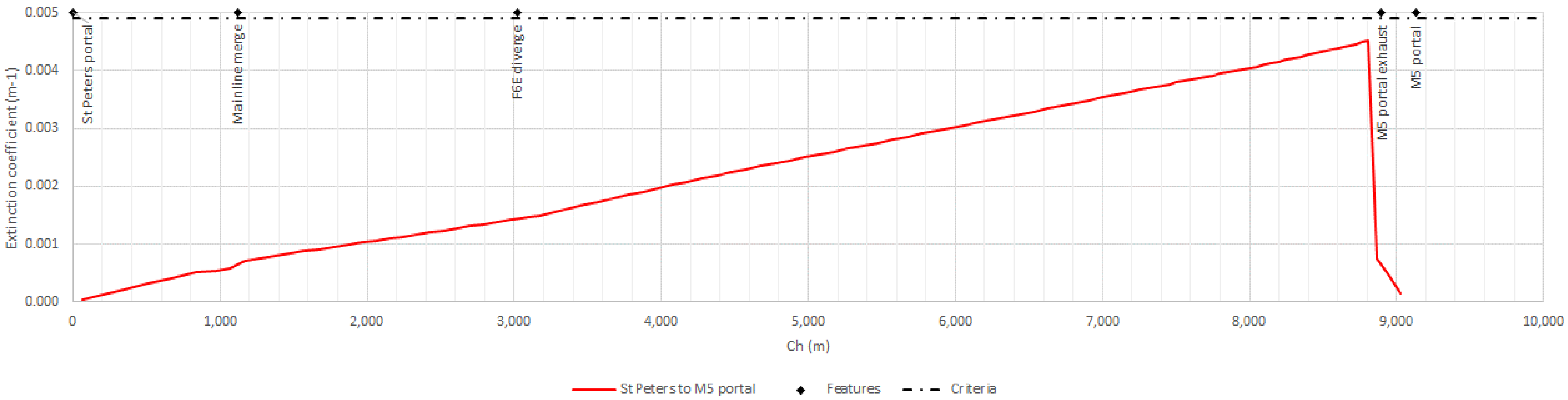


Figure 9.23. In-tunnel visibility along route 1B from St Peters to M5 portal [Do something, worst case operations, Smart Motorways]

9.1.8 Northbound Smart Motorways operation

This scenario has maximum possible traffic volumes in both F6E and New M5 with Smart Motorways operational. It must be noted that metering in the President Ave on-ramp is somewhat unwarranted in this scenario. There is no merge after this ramp for the F6E Stage 1 arrangement so the metering would only serve to create unnecessary queuing in the ramp, though it may assist in the downstream merge with New M5.

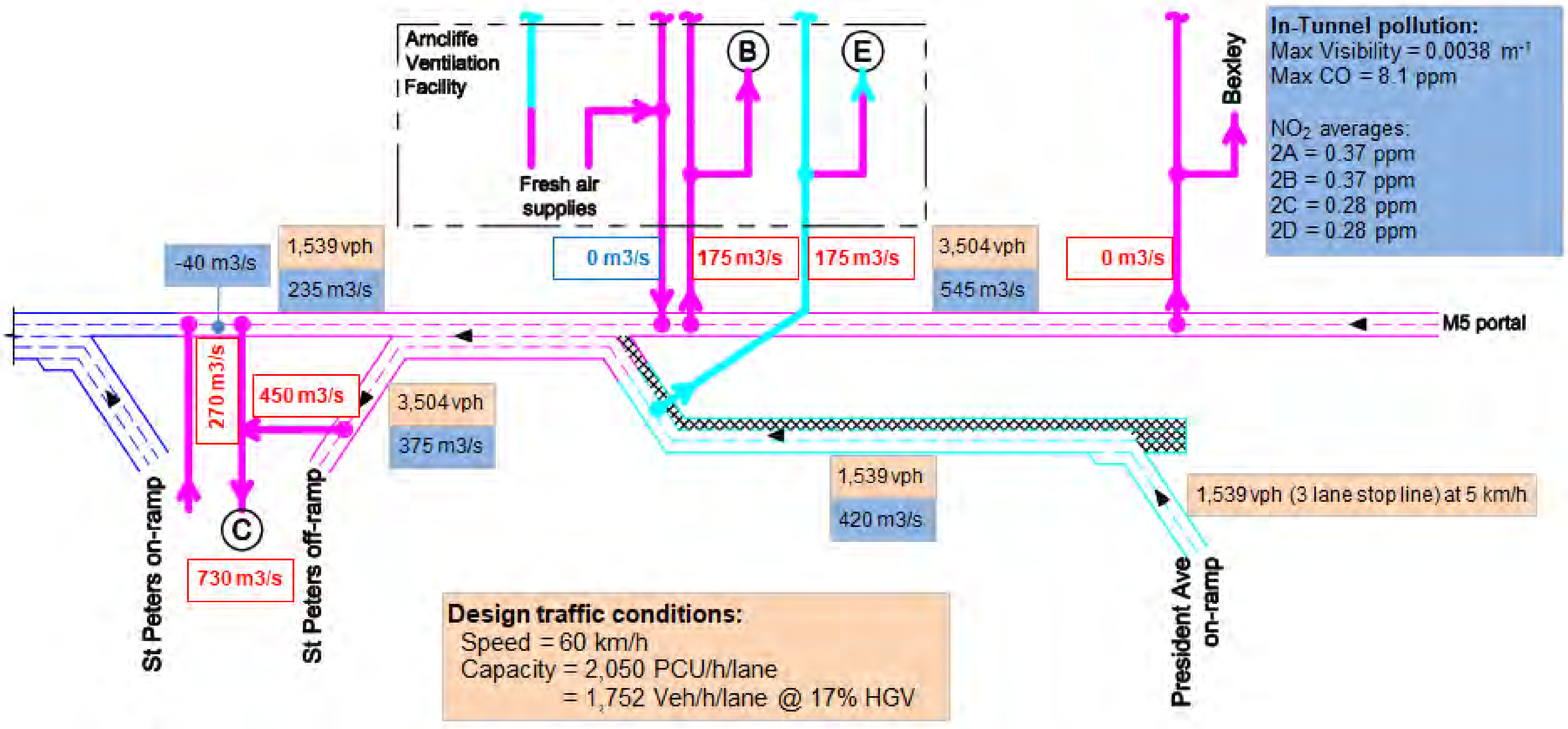


Figure 9.24. Ventilation operation for nouthbound tube with Smart Motorways [Do something, worst case operations, Smart Motorways].

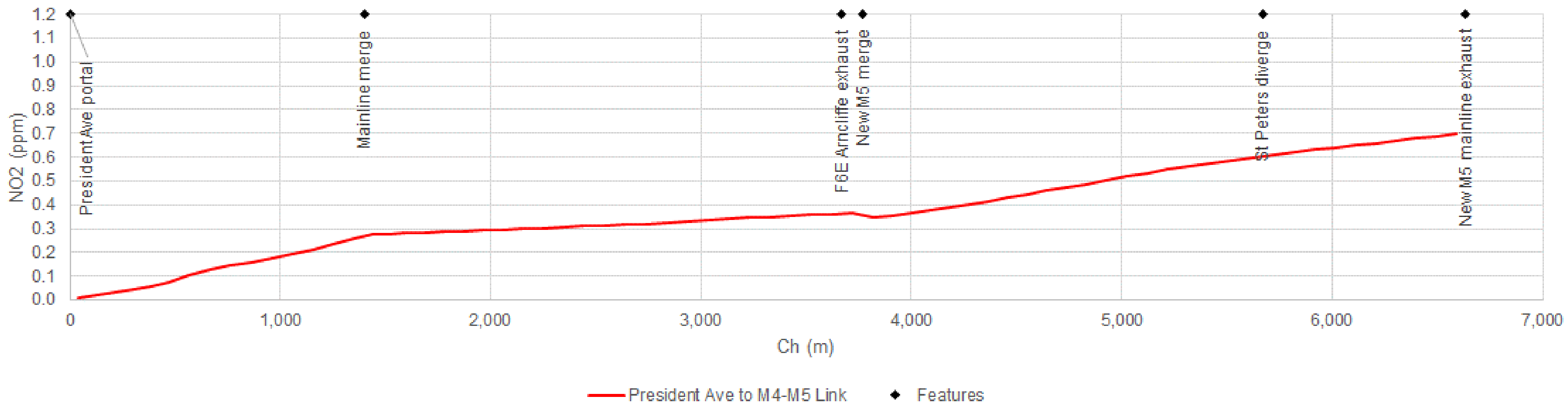


Figure 9.25. In-tunnel NO_2 levels along route 2B from President Ave to M4-M5 Link [Do something, worst case operations, Smart Motorways].

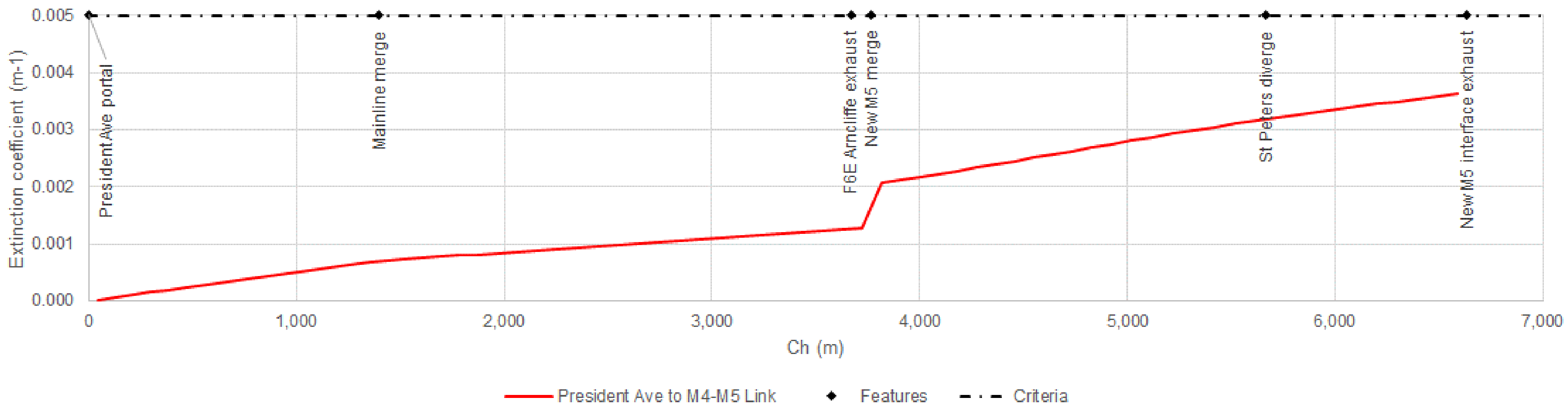


Figure 9.26. In-tunnel visibility along route 2B from President Ave to M4-M5 Link [Do something, worst case operations, Smart Motorways].

9.2 Cumulative arrangement (with F6 Extension Stage 1 and future stages)

The results and analysis in this section describe the ventilation system operation with F6 Extension including future stages, integrated with the WestConnex tunnel systems as shown in Figure 9.2.

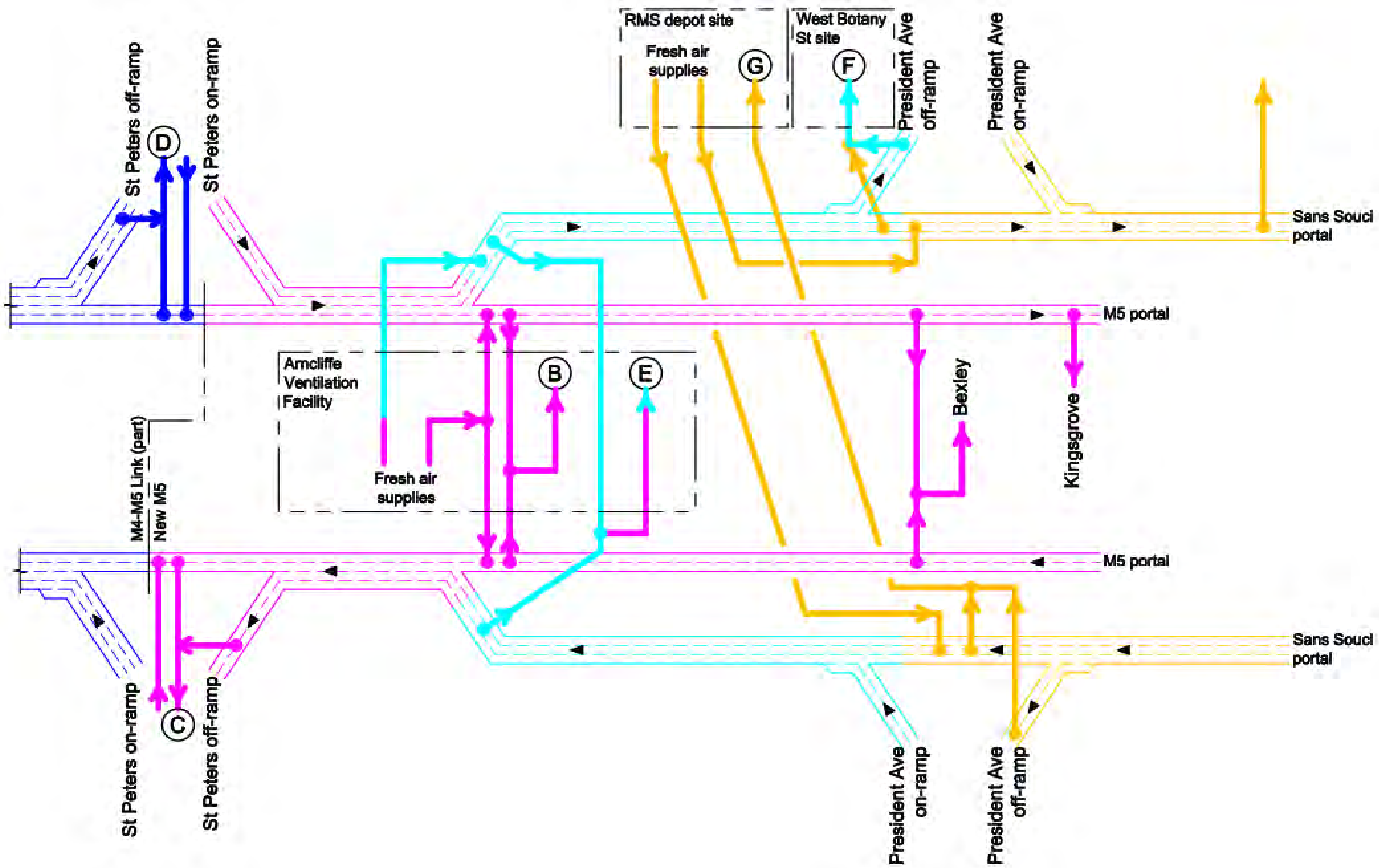


Figure 9.27. Ventilation schematic, worst case operations with F6 Extension Stage 1 and future stages.

Stacey Agnew

9.2.1 Southbound normal operation at 20 km/h

This scenario has a traffic pattern with maximum possible traffic volumes in F6E, with the balance of traffic heading to the M5 portal. It represents the traffic which will generate the highest in-tunnel pollution levels within F6E. For this scenario, complete mainline exchange at St Peters will be necessary to maintain pollution levels within criteria.

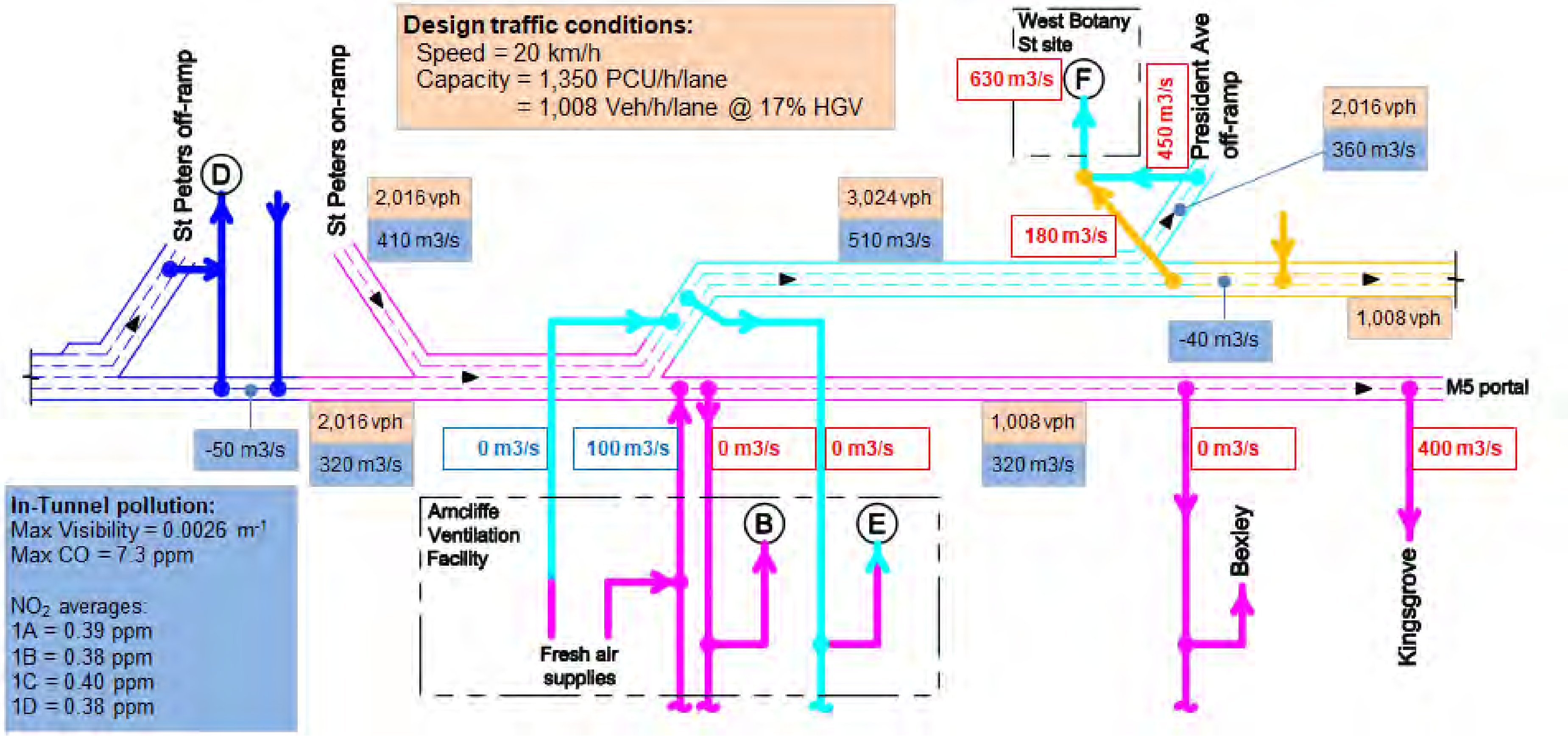


Figure 9.28. Ventilation operation for southbound tube with traffic moving at 20 km/h [Cumulative, worst case operations, 20 km/h].

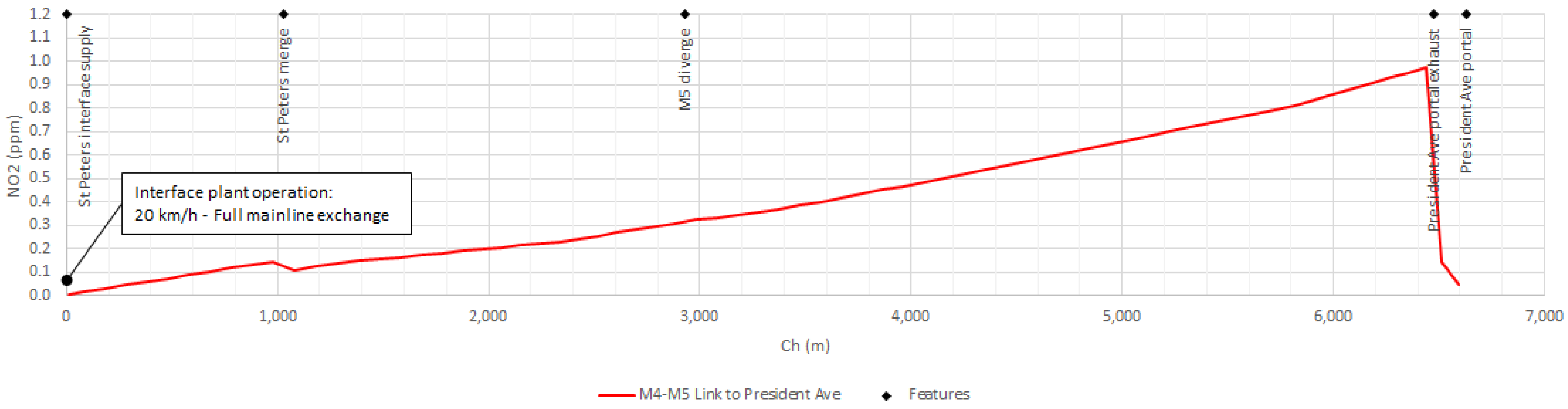


Figure 9.29. In-tunnel NO_2 levels along route 1C from M4-M5 Link to President Ave [Cumulative, worst case operations, 20 km/h].

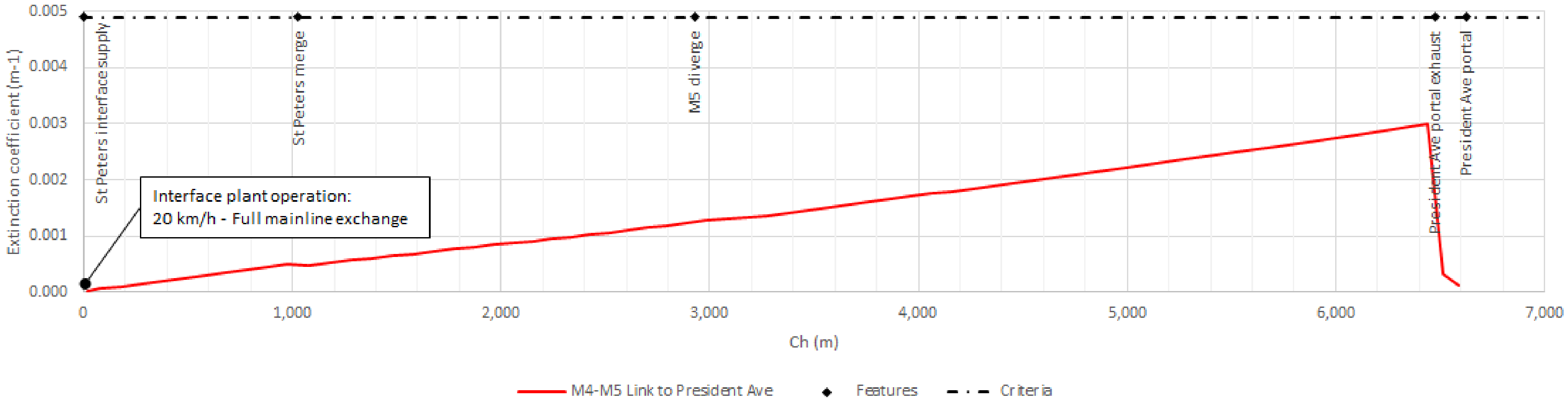


Figure 9.30. In-tunnel visibility along route 1C from M4-M5 Link to President Ave [Cumulative, worst case operations, 20 km/h].

9.2.2 Northbound normal operation at 20 km/h

This scenario has a traffic pattern with maximum possible traffic volumes in F6E, and the balance of traffic within continuity through New M5. For this scenario, complete mainline exchange at St Peters can be achieved using only exhaust operation at Arncliffe.

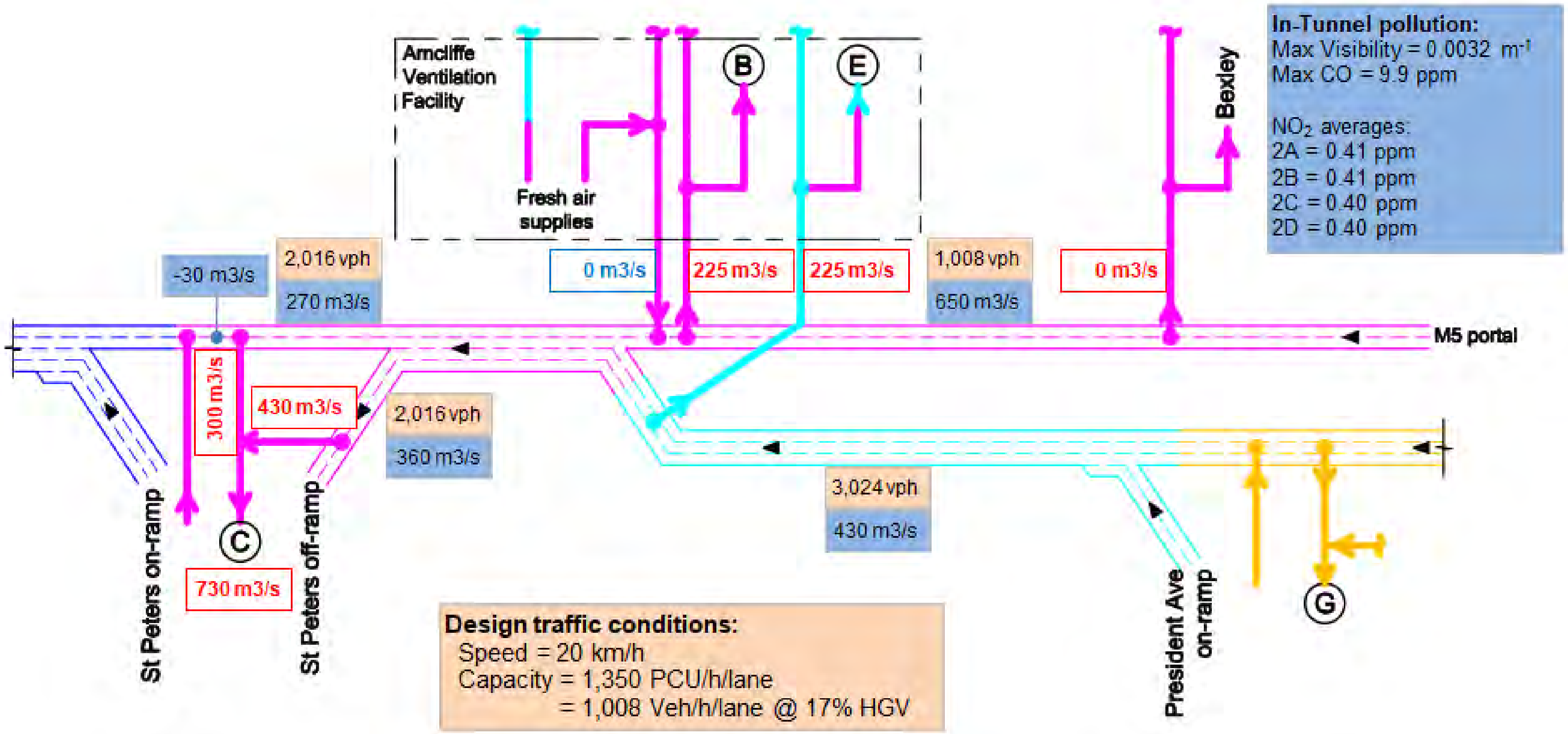


Figure 9.31. Ventilation operation for nouthbound tube with traffic moving at 20 km/h [Cumulative, worst case operations, 20 km/h].

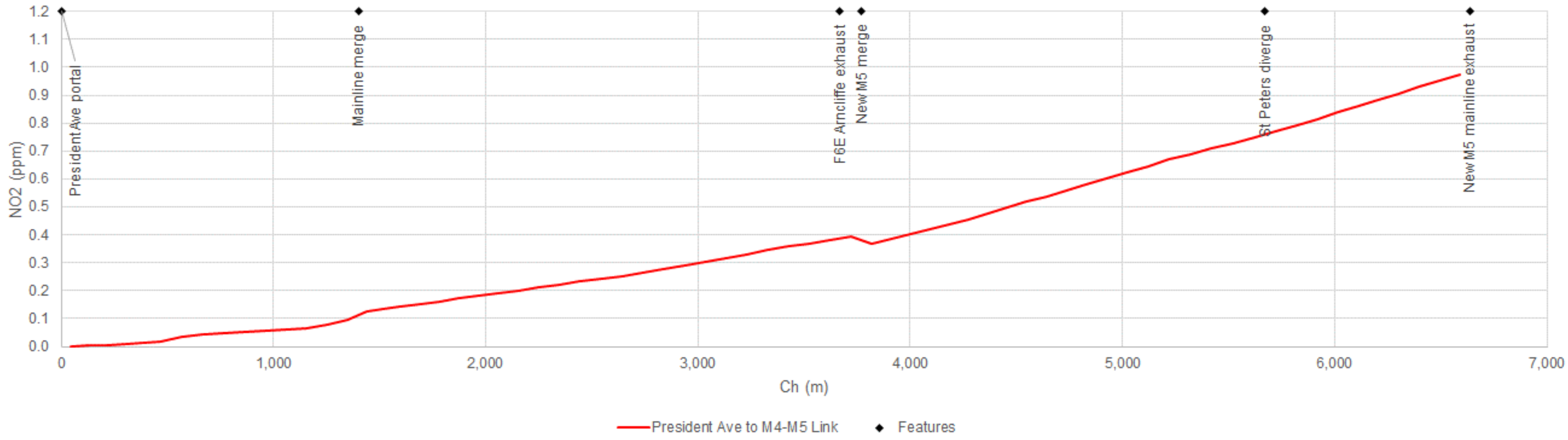


Figure 9.32. In-tunnel NO_2 levels along route 2B from President Ave to M4-M5 Link [Cumulative, worst case operations, 20 km/h].

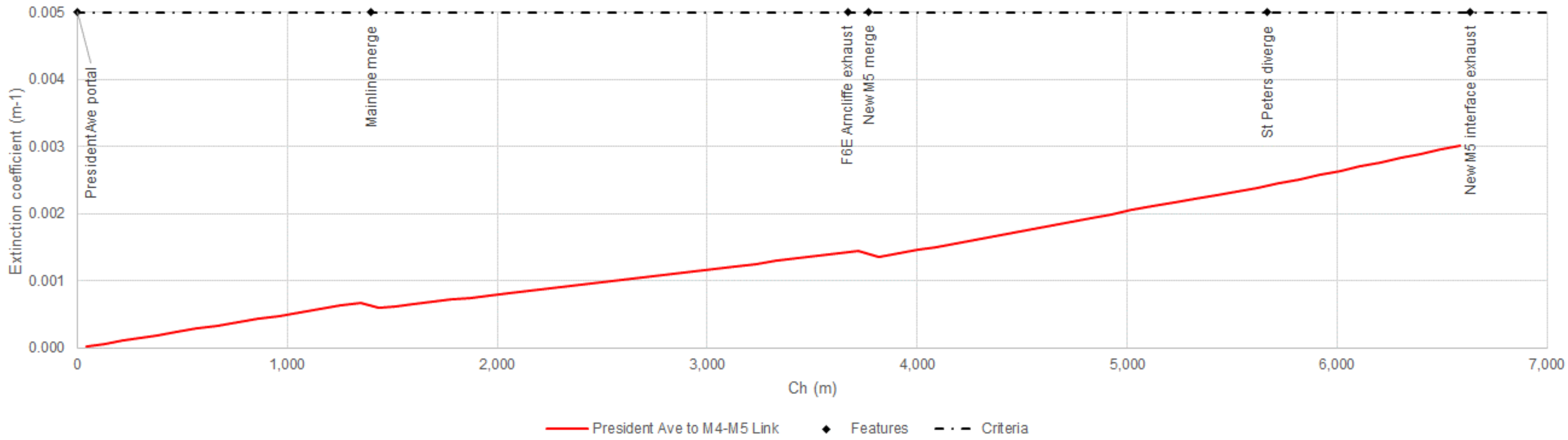


Figure 9.33. In-tunnel visibility along route 2B from President Ave to M4-M5 Link [Cumulative, worst case operations, 20 km/h].

9.2.3 Southbound normal operation at 80 km/h

This scenario has a traffic pattern with maximum airflow demand for the F6E Stage 1 outlet at President Ave. Similar scenarios with different flow splits at the President Ave diverge have similar requirements to achieve complete exchange at the interface between F6E Stage 1 and future stages. For this scenario, no mainline exchange at St Peters will be necessary to maintain pollution levels within criteria.

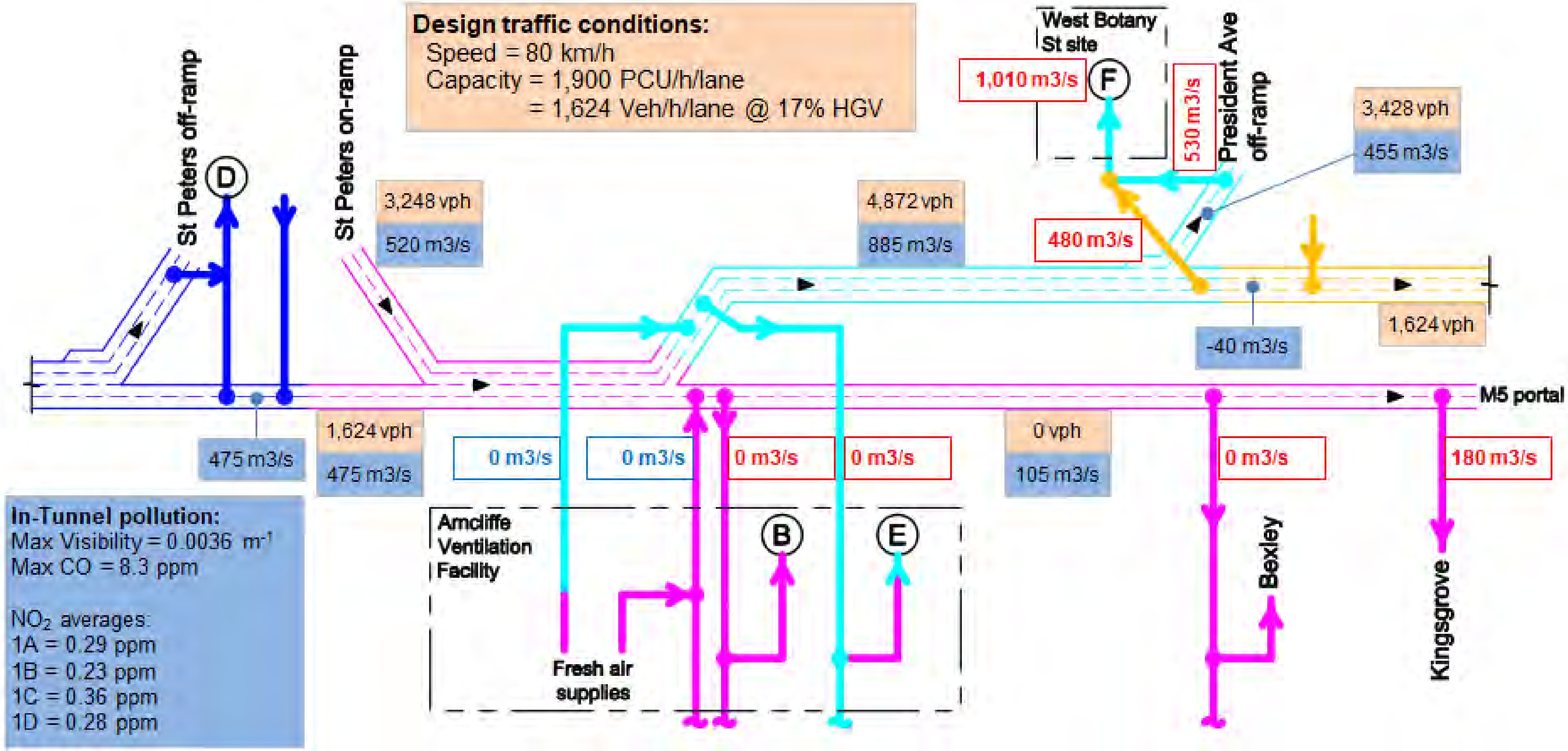


Figure 9.34. Ventilation operation for southbound tube with traffic moving at 80 km/h [Cumulative, worst case operations, 80 km/h].

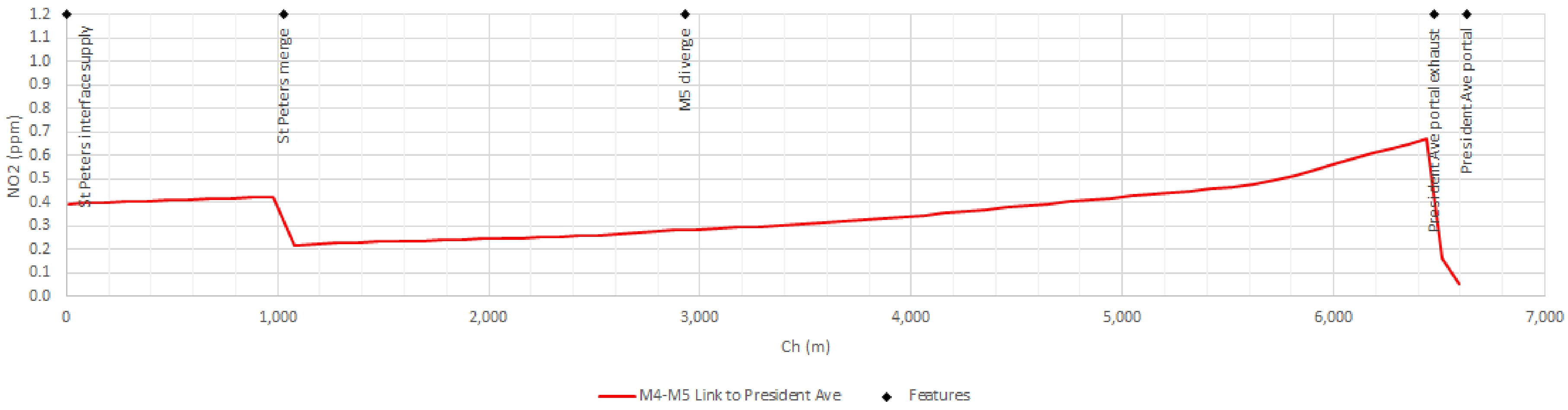


Figure 9.35. In-tunnel NO_2 levels along route 1C from M4-M5 Link to President Ave [Cumulative, worst case operations, 80 km/h].

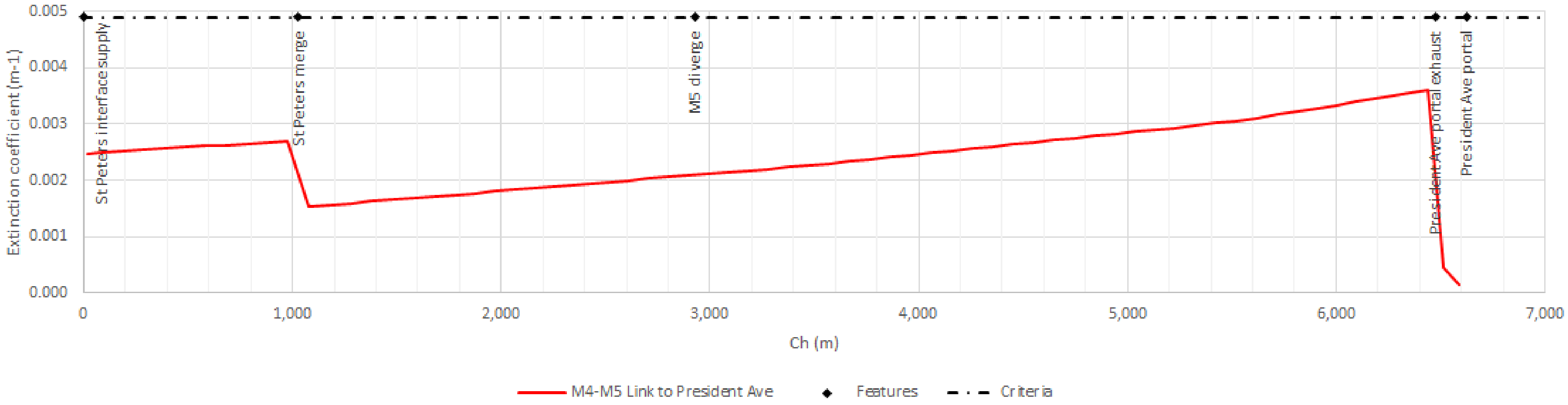


Figure 9.36. In-tunnel visibility along route 1C from M4-M5 Link to President Ave [Cumulative, worst case operations, 80 km/h].

9.2.4 Northbound normal operation at 80 km/h

This scenario has a traffic pattern with maximum possible traffic volumes in F6E, and balance of traffic within continuity through New M5. For this scenario, complete mainline exchange at St Peters can be achieved using only exhaust operation at Arncliffe.

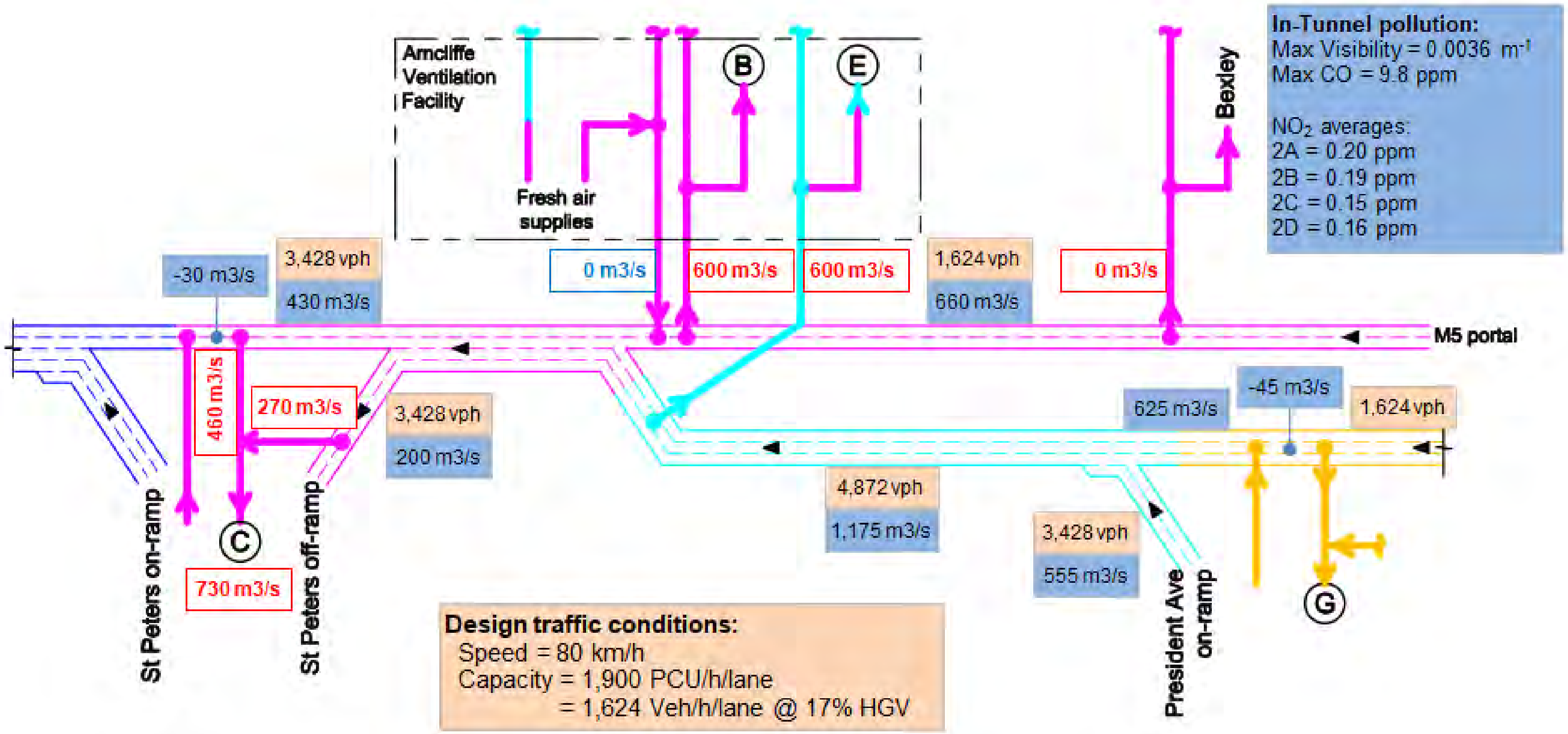


Figure 9.37. Ventilation operation for nouthbound tube with traffic moving at 80 km/h [Cumulative, worst case operations, 80 km/h].

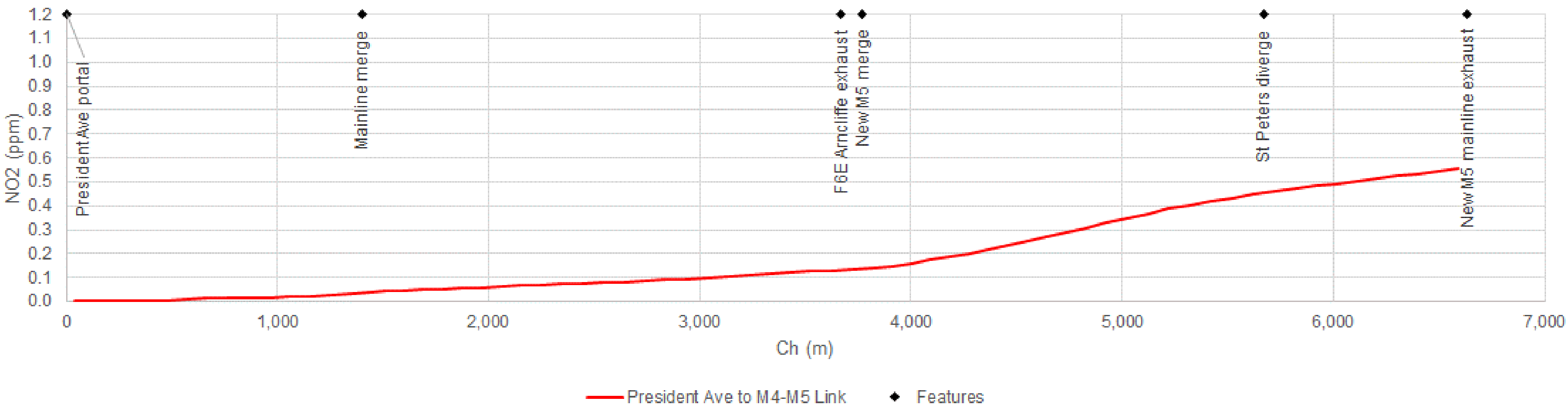


Figure 9.38. In-tunnel NO_2 levels along route 2B from President Ave to M4-M5 Link [Cumulative, worst case operations, 80 km/h].

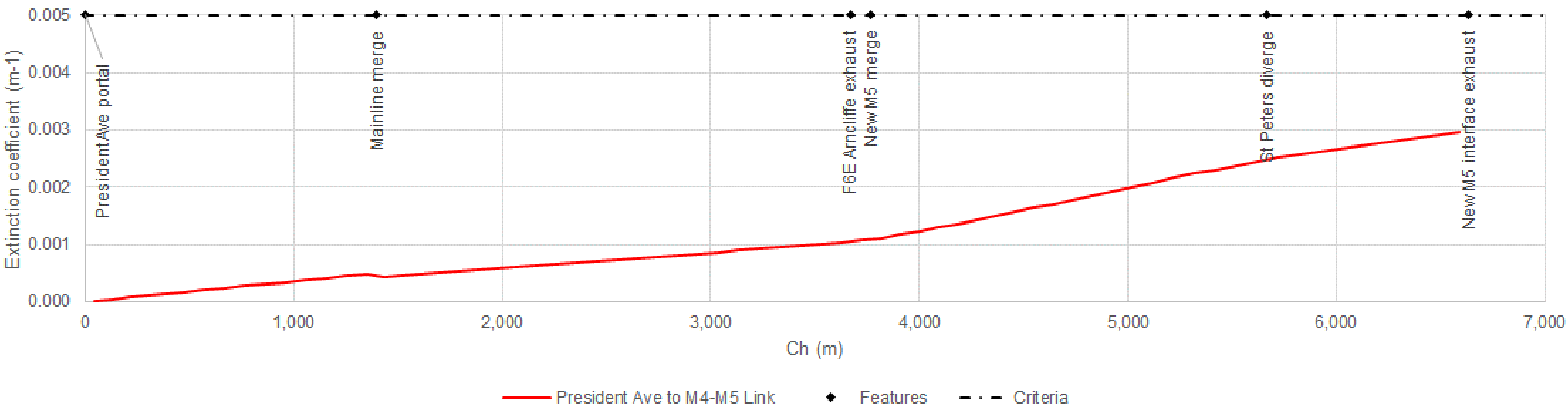


Figure 9.39. In-tunnel visibility along route 2B from President Ave to M4-M5 Link [Cumulative, worst case operations, 80 km/h].

9.3 Conclusion

The concept ventilation scheme meets the in-tunnel air quality criteria for all design traffic cases. The limiting traffic cases analysed in the worst case operations are more onerous on the ventilation system compared to the expected traffic cases.

For the northbound direction of travel, the New M5 and F6 Extension ventilation system is capable of operating without any carry-over into M4-M5 Link for all design traffic cases. That exceeds the functional requirements which formed the basis of the WestConnex integrated ventilation analysis documented in the M4-M5 Link EIS. It is further noted that it is possible to achieve that level of performance without requiring the (New M5) fresh air supply into the northbound (New M5 eastbound) tube at Arncliffe. As the New M5 supply is shared between both the New M5 tubes at Arncliffe this creates an interdependence in ventilation between the two directions of travel under some traffic conditions. The ability to meet ventilation criteria without supply in the northbound tube allows the ventilation do be effectively de-coupled between the two directions of travel which would be expected to simply the ventilation control algorithms.

In the southbound direction of travel, complete mainline exchange at St Peters is required during heavily congested traffic conditions (20 km/h cases) to meet air quality criteria. However, some carry-over during the high speed traffic cases (80 km/h, 60 km/h smart motorways) would not prevent the project (and New M5) from achieving in the tunnel air quality criteria. Combined with the northbound outcomes, the integrated analysis of the overarching WestConnex tunnels, as documented in the M4-M5 Link EIS, remains valid.

APPENDIX A – INCORPORATION OF SEARS AND COMMENTS

This appendix describes how the SEARs and comments on the SEARS relevant to in-tunnel air quality and design are, or will be, addressed. It is not exhaustive in that generic comments that are discussed within the body of this report, such as “describe the ventilation system” are not discussed further in this appendix.

Table A.1. SEARS – air quality

Desired Performance Outcome	SEARs	Where addressed in the EIS
The project is designed, constructed and operated in a manner that minimises air quality impacts (including nuisance dust and odour) to minimise risks to human health and the environment to the greatest extent practicable.	1. The Proponent must undertake an air quality assessment (AQIA) for construction and operation of the project in accordance with the current guidelines;	Appendix F. Air Quality Technical Report.
	2. The Proponent must ensure the AQIA also includes the following: (a) demonstrated ability to comply with the relevant regulatory framework, specifically the *Protection of the Environment Operations Act 1997* and the *Protection of the Environment Operations (Clean Air) Regulation 2010;*	Appendix F. Air Quality Technical Report.
	(b) the identification of all potential sources of air pollution including details of the location, configuration and design of all potential emission sources including ventilation systems and tunnel portals;	Within the scope of ventilation, the sources of pollution are the vehicles. This report assesses in-tunnel and emitted concentrations for pollutants with defined in-tunnel air quality criteria, being CO, NO_2 and particulates (see Section 6.9). NO_X emissions from outlets are also calculated, and provided for ambient air quality assessment (Appendix F. Air Quality Technical Report). Other pollutants may be inferred approximately by their typical proportions in vehicle exhaust, if known. That is not done within the scope of this report.

Desired Performance Outcome	SEARs	Where addressed in the EIS
	(c) a review of vehicle emission trends and an assessment that uses or sources best available information on vehicle emission factors;	The fleet characterization used for in-tunnel vehicle emissions has been updated by Roads and Maritime to incorporate the current understanding in implementation of emissions standards within Australia, refer Section 6.5.1. Fleet average NO_2:NO_X ratios used for estimating in-tunnel NO_2 emissions have been updated to the most recent available data, refer Section 6.5.2.
	(d) an assessment of impacts (including human health impacts) from potential emissions of PM10, PM2.5, CO, NO2 and other nitrogen oxides and volatile organic compounds (e.g. BTEX) including consideration of short and long - term exposure periods;	Appendix F. Air Quality Technical Report.
	(e) consider the impacts from the dispersal of these air pollutants on the ambient air quality along the proposal route, proposed ventilation outlets and portal, surface roads, ramps and interchanges and the alternative surface road network;	Appendix F. Air Quality Technical Report.
	(f) a qualitative assessment of the redistribution of ambient air quality impacts compared with existing conditions, due to the predicted changes in traffic volumes;	Appendix F. Air Quality Technical Report.

Desired Performance Outcome	SEARs	Where addressed in the EIS
	(g) assessment of worst case scenarios for in-tunnel and ambient air quality, including a range of potential ventilation scenarios and range of traffic scenarios, including the worst case design maximum traffic flow scenario (variable speed) and worst case breakdown scenario, and discussions of the likely occurrence of each;	This report assesses a range of worst case traffic scenarios ranging from highest occupancy traffic flows at the posted speed limit at 80 km/h, to highest occupancy traffic flows at the minimum design speed of 20 km/h. The likelihood of these scenarios is not considered, with the concept design ventilation system capable of handling all traffic scenarios with average speeds above 20 km/h. The likely occurrence frequency for various traffic conditions may be considered during future design stages, which may lead to optimisation of plant capacities.
	(h) details of the proposed tunnel design and mitigation measures to address –in-tunnel air quality and the air quality in the vicinity of portals and any mechanical ventilation systems (ie ventilation outlets and air inlets) including details of proposed air quality monitoring (including frequency and criteria);	In-tunnel air quality is proposed to be continuously monitored by permanently installed sensors placed at strategic locations within the tunnel. The type, number and location of sensors will be determined during detailed design. The ventilation systems are described in Section 3 and Section 5.

Desired Performance Outcome	SEARs	Where addressed in the EIS
	(i) a demonstration of how the project and ventilation design ensures that concentrations of air emissions meet NSW, national and international best practice for in-tunnel and ambient air quality, and taking into consideration the approved criteria for the New M5 project and the In-Tunnel Air Quality (Nitrogen Dioxide) Policy;	This report presents predicted in-tunnel air quality for a range of tunnel configuration and years of operation when subjected to the demand traffic predicted by SMPM. The results presented in Section 8 demonstrate that the ventilation system will meet the nominated in-tunnel air quality criteria. Further analysis of worst case traffic scenarios is presented in Section 8.4, to similarly show that the ventilation system can ensure compliance with criteria. The nominated in-tunnel air quality criteria are identical to the approved criteria for New M5 project. This report provides estimated emissions from outlets to enable assessment of external air quality by others.
	(j) details of any emergency ventilation systems, such as air intake/exhaust outlets, including protocols for the operation of these systems in emergency situations, potential emissions of air pollutants and their dispersal, and safety procedures;	Refer Section 5.3.2 of this report. The specific protocols and operation will be determined during later stages of design.
	(k) details of in-tunnel air quality control measures considered, including air filtration, and justification of the proposed measures;	Appendix F. Air Quality Technical Report.
	(j) details of the proposed mitigation measures to prevent the generation and emission of dust (particulate matter and TSP) and air pollutants (including odours) during the construction of the proposal, particularly in relation to ancillary facilities (such as concrete batching plants), the use of mobile plant, stockpiles and the processing and movement of spoil; and	Chapter 10 of the EIS and Appendix F. Air Quality Technical Report.

Desired Performance Outcome	SEARs	Where addressed in the EIS
	(m) a cumulative assessment of the in-tunnel, local and regional air quality from the operation of the project and due to the operation of and potential continuous travel through existing and committed future motorway tunnels and surface roads.	Refer to Section 8 for in-tunnel air quality. Regional air quality is addressed in Chapter 10 of the EIS and Appendix F. Air Quality Technical Report.