The emissions inventory calculated for the assessed breakdown scenario is summarised in **Table 2-43** for key pollutants. The percentage of these mass emission rates relative to the maximum mass emission rates for the forecast traffic flow scenario in 2029 (refer to Table is also listed. The breakdown scenario has not been assessed further because it would be well within the forecast traffic flow scenario in 2029. Because acceptable ambient air quality outcome have been demonstrated for that scenario (refer to **Section 2.15**), then the breakdown would also have acceptable ambient air quality impacts.

Table 2-43 Emissions inventory – breakdown scenario

Pollutant	Mass emission rate
Carbon monoxide (CO)	3.5 g/s (77.8%)
Nitrogen oxides (NO_x)	4.1 g/s (68.6%)
Particulate matter (PM_{10})	0.27 g/s (71.4%)

Clarification of environmental impact statement emissions inventories

The air quality impact assessment presented in Section 7.3 of the environmental impact statement and the associated Technical Working Paper: Air Quality have been reviewed and confirmed as complete and correct based on the assumptions and inputs that were applied. This includes the ventilation outlet emission rates used in the air dispersion modelling as part of the air quality impact assessment in the environmental impact statement.

However, the tables of data presented in Appendix H of the Technical Working Paper: Air Quality do not represent the data used in the air dispersion modelling.

The summary of ventilation outlet emission rates presented in **Table 2-44** and **Table 2-45** present the actual data as used in the air dispersion modelling included in the environmental impact statement. This data replaces the information in Appendix H of the Technical Working Paper: Air Quality (contained in Appendix G of the environmental impact statement).

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Table 2-44 EIS emissions inventory – forecast traffic volumes 2019 (scenario 2a)

Time of day	Flowrate (Nm^3/s)	CO (g/s)	NO_x (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	PAHs (g/s)	VOCs (g/s)
Southbound							
01:00	300	0.177	0.194	0.018	0.017	0.0176	0.000003
02:00	300	0.139	0.153	0.014	0.013	0.0138	0.000003
03:00	300	0.134	0.146	0.014	0.013	0.0133	0.000002
04:00	300	0.187	0.210	0.019	0.018	0.0187	0.000003
05:00	380	0.317	0.355	0.033	0.031	0.0318	0.000006
06:00	460	0.813	0.904	0.084	0.079	0.0812	0.000015
07:00	540	1.717	1.905	0.176	0.167	0.1714	0.000032
08:00	620	2.252	2.494	0.231	0.218	0.2247	0.000042
09:00	620	2.331	2.583	0.239	0.226	0.2327	0.000043
10:00	620	2.064	2.292	0.212	0.200	0.2061	0.000038
11:00	540	1.922	2.131	0.197	0.186	0.1918	0.000036
12:00	540	1.872	2.074	0.192	0.181	0.1868	0.000035
13:00	540	1.781	1.977	0.183	0.173	0.1779	0.000033
14:00	540	1.840	2.042	0.189	0.179	0.1837	0.000034
15:00	540	2.022	2.244	0.208	0.196	0.2019	0.000037
16:00	620	2.272	2.518	0.233	0.220	0.2268	0.000042
17:00	620	2.170	2.405	0.223	0.210	0.2166	0.000040
18:00	540	1.920	2.131	0.197	0.186	0.1917	0.000036
19:00	540	1.426	1.582	0.146	0.138	0.1423	0.000026
20:00	460	0.926	1.025	0.095	0.090	0.0924	0.000017
21:00	380	0.626	0.694	0.064	0.061	0.0625	0.000012
22:00	380	0.533	0.589	0.055	0.052	0.0531	0.000010
23:00	380	0.403	0.444	0.041	0.039	0.0401	0.000007
24:00	380	0.269	0.299	0.028	0.026	0.0268	0.000005
Northbound							
01:00	300	0.248	0.344	0.020	0.0190	0.025	0.000005
02:00	300	0.190	0.266	0.016	0.0147	0.019	0.000004
03:00	300	0.193	0.266	0.016	0.0147	0.019	0.000004
04:00	300	0.316	0.438	0.026	0.0242	0.031	0.000006
05:00	380	0.720	0.988	0.058	0.0547	0.071	0.000013
06:00	460	1.696	2.336	0.137	0.1292	0.168	0.000031
07:00	540	2.336	3.214	0.188	0.1778	0.232	0.000042

08:00	620	2.187	3.010	0.176	0.1665	0.217	0.000040
09:00	620	2.289	3.151	0.184	0.1743	0.227	0.000041
10:00	620	2.991	4.108	0.240	0.2273	0.296	0.000054
11:00	540	2.952	4.061	0.238	0.2246	0.293	0.000053
12:00	540	2.785	3.826	0.224	0.2117	0.276	0.000050
13:00	540	2.688	3.700	0.216	0.2046	0.267	0.000049
14:00	540	2.722	3.747	0.219	0.2072	0.270	0.000049
15:00	540	3.074	4.233	0.248	0.2341	0.305	0.000056
16:00	620	3.534	4.860	0.284	0.2689	0.350	0.000064
17:00	620	3.766	5.175	0.303	0.2863	0.373	0.000068
18:00	540	3.899	5.362	0.314	0.2966	0.387	0.000071
19:00	540	2.790	3.841	0.225	0.2124	0.277	0.000051
20:00	460	1.644	2.258	0.132	0.1250	0.163	0.000030
21:00	380	1.141	1.568	0.092	0.0867	0.113	0.000021
22:00	380	0.947	1.302	0.076	0.0720	0.094	0.000017
23:00	380	0.715	0.987	0.058	0.0546	0.071	0.000013
24:00	380	0.417	0.579	0.034	0.0320	0.042	0.000008

Table 2-45 EIS emissions inventory – forecast traffic volumes 2029 (scenario 2b)

Time of day	Flowrate (Nm^3/s)	CO (g/s)	NO_x (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	PAHs (g/s)	VOCs (g/s)
Southbound							
01:00	300	0.220	0.213	0.021	0.020	0.021	0.000004
02:00	300	0.172	0.169	0.017	0.016	0.017	0.000003
03:00	300	0.166	0.160	0.016	0.015	0.016	0.000003
04:00	300	0.233	0.230	0.023	0.022	0.022	0.000004
05:00	380	0.394	0.389	0.039	0.037	0.038	0.000006
06:00	460	1.010	0.993	0.100	0.094	0.097	0.000016
07:00	620	2.133	2.092	0.210	0.198	0.205	0.000035
08:00	620	2.797	2.740	0.275	0.260	0.269	0.000046
09:00	620	2.896	2.837	0.285	0.269	0.278	0.000047
10:00	620	2.564	2.517	0.253	0.239	0.246	0.000042
11:00	620	2.388	2.341	0.235	0.222	0.229	0.000039
12:00	620	2.325	2.279	0.229	0.216	0.223	0.000038
13:00	620	2.213	2.172	0.218	0.206	0.213	0.000036
14:00	620	2.286	2.243	0.225	0.213	0.220	0.000037
15:00	620	2.512	2.464	0.247	0.234	0.241	0.000041
16:00	620	2.823	2.766	0.278	0.262	0.271	0.000046
17:00	620	2.696	2.642	0.265	0.251	0.259	0.000044
18:00	620	2.385	2.340	0.235	0.222	0.229	0.000039
19:00	540	1.771	1.737	0.174	0.165	0.170	0.000029
20:00	460	1.151	1.126	0.113	0.107	0.111	0.000019
21:00	460	0.778	0.762	0.077	0.072	0.075	0.000013
22:00	460	0.662	0.647	0.065	0.061	0.064	0.000011
23:00	380	0.500	0.488	0.049	0.046	0.048	0.000008
24:00	380	0.334	0.328	0.033	0.031	0.032	0.000005
Northbound							
01:00	300	0.307	0.373	0.023	0.022	0.029	0.000005
02:00	300	0.236	0.288	0.018	0.017	0.023	0.000004
03:00	300	0.240	0.288	0.018	0.017	0.023	0.000004
04:00	380	0.392	0.475	0.030	0.028	0.037	0.000006
05:00	380	0.894	1.070	0.067	0.063	0.085	0.000014
06:00	540	2.105	2.529	0.159	0.150	0.201	0.000033
07:00	540	2.898	3.480	0.218	0.206	0.276	0.000046

08:00	540	2.714	3.259	0.204	0.193	0.259	0.000043
09:00	540	2.840	3.411	0.214	0.202	0.271	0.000045
10:00	620	3.712	4.448	0.279	0.264	0.353	0.000059
11:00	620	3.663	4.396	0.276	0.261	0.349	0.000058
12:00	620	3.456	4.143	0.260	0.246	0.329	0.000055
13:00	620	3.335	4.006	0.251	0.237	0.318	0.000053
14:00	620	3.377	4.056	0.254	0.240	0.322	0.000053
15:00	620	3.815	4.582	0.287	0.271	0.363	0.000060
16:00	620	4.385	5.262	0.330	0.312	0.418	0.000069
17:00	620	4.673	5.603	0.351	0.332	0.445	0.000074
18:00	620	4.838	5.805	0.364	0.344	0.461	0.000076
19:00	620	3.462	4.158	0.261	0.246	0.330	0.000055
20:00	540	2.040	2.445	0.153	0.145	0.194	0.000032
21:00	460	1.415	1.698	0.106	0.101	0.135	0.000022
22:00	460	1.176	1.409	0.088	0.084	0.112	0.000019
23:00	380	0.887	1.069	0.067	0.063	0.085	0.000014
24:00	380	0.518	0.627	0.039	0.037	0.049	0.000008

Ambient air drawn into project tunnels

The pollutant load of ambient air drawn into the project tunnels has a relatively minor influence on pollutant loads of in-tunnel air quality. This includes air drawn into the tunnel via the entry portals (through the piston effect of vehicles entering the tunnel) and via mechanically assisted ventilation (by fans either within the tunnels or within the emergency smoke extraction facilities under certain conditions).

It is recognised that any air drawn into the project tunnels will carry with it a certain level of background pollution, and that the concentration of this pollution will vary over time depending on conditions external to the project tunnels. To demonstrate the effect of drawing ambient pollution into the project tunnels, the air quality model used for the NorthConnex project has been used to consider the implications of this additional pollutant load on the ambient air quality impacts of the project. The model has been run assuming that background pollution at each main alignment tunnel entry portal is added to the emissions inventory within the project tunnels before discharge from the project's ventilation outlets.

This analysis has considered one meteorological year (2009) and has assumed that air within the road corridor near the entry portal is drawn into the main alignment tunnel. Pollutant loads drawn into the entry portal have been modelled for each hour of the day, over an entire year. For the purpose of this analysis, 'background air' has been taken as the predicted background concentration (refer to **Section 2.14.1** of this report) of pollutants predicted at the closest receiver location to the relevant tunnel entry portal (ie the higher of the CAL3QHCR prediction or monitored ambient data from the Prospect/ Lindfield monitoring stations).

Table 2-46 summarises the maximum ground level concentration from either the northern or southern ventilation outlet (whichever concentration is higher) as presented in the environmental impact statement, and then with the addition of background pollutant loads assuming introduction through the main alignment tunnel entry portals. The table shows that with inclusion of ambient pollution drawn into the main alignment tunnels via the entry portals, the predicted ground level concentrations of relevant pollutants increase by a negligible amount compared with the modelling outcomes presented in the environmental impact statement. When compared with relevant ambient air quality criteria and advisory reporting standards, the predicted air quality impacts of the NorthConnex project remain very low at the most affected locations.

Table 2-46 Expected effect of background pollution (portal intake) on ground level concentrations from ventilation outlet emissions

Pollutant (averaging period)	Environmental impact statement		With addition of background air drawn into tunnels	
	Concentration (µg/m^3)	Percentage of air quality criteria/ advisory standard	Concentration (µg/m^3)	Percentage of air quality criteria/ advisory standard
NO_2 (annual average)	1.4 µg/m^3	2.3%	1.4 µg/m^3	2.3%
NO_2 (one-hour maximum)	68.9 µg/m^3	28.0%	69.7 µg/m^3	28.3%
PM_{10} (annual average)	0.11 µg/m^3	0.37%	0.12 µg/m^3	0.40%
PM_{10} (24-hour maximum)	1.4 µg/m^3	2.8%	1.8 µg/m^3	3.6%
$PM_{2.5}$ (annual average)	0.11 µg/m^3	1.38%	0.11 µg/m^3	1.38%
$PM_{2.5}$ (24-hour maximum)	1.3 µg/m^3	5.2%	1.4 µg/m^3	5.6%

2.8.3 Surface road emissions inventories

Surface road emissions inventories have been calculated in the same manner as for tunnel emissions inventories. This has include both exhaust and non-exhaust emission sources.

2.9 In-tunnel air quality

This section includes information and discussion of:

- The design and intended operation of the project's ventilation system to maintain acceptable in-tunnel air quality.
- In-tunnel air quality concentrations for the air quality impact assessment scenarios.
- Discussion of the variability of in-tunnel air quality and averaging periods.

2.9.1 Design and intended operation of the ventilation system

Section 2.5.1 of this report details the approach applied to the design of the project's ventilation system, including the design criteria that have been applied. **Table 2-3** in that section details the maximum in-tunnel concentrations that could be expected based on the design of the project's ventilation system and assuming operation at the maximum traffic throughput capacity of the main alignment tunnels at different average traffic speeds. These concentrations represent the maximum concentrations that are considered physically possible given the project's design. These maximum concentrations are also considered to be highly conservative and unlikely to be reached in practice for several reasons, the most significant being:

- The inherent conservatism in the emission factors published by the Permanent International Association of Road Congresses (2012) on which the calculation of in-tunnel air quality has been based.

- The assumption underpinning the concentrations in **Table 2-3**, that the main alignment tunnels would be completely full at each of the average traffic velocities that were considered (ie operation at the maximum throughput capacity of the tunnels). As discussed in **Section 2.7.3**, operation at this traffic throughput is considered unlikely in the foreseeable future and would be well above forecast traffic volumes.

The project has been designed and has committed to achieving the ventilation design criteria specified in **Table 2-2**. The project would also be operated to achieve in-tunnel air quality conditions that may be specified in conditions of approval for the project, if applied by the Minister for Planning.

A detailed ventilation control strategy would be developed during the detailed design phase and implemented during operation of the project to ensure that acceptable in-tunnel air quality is maintained. The control strategy would be developed to include three distinct operational modes:

- **Normal operation** for the management and control of in-tunnel air quality under all traffic scenarios, including fluid free flowing traffic conditions and congestion.
- **Breakdown mode** where a breakdown has caused the tunnel to be blocked or severely restricted.
- **Emergency operation** for the management and control of smoke in the event of a fire, for the safe egress of occupants and access for emergency services.

During normal operation, the project's ventilation system would automatically operate and adjust the ventilation flow rates within the tunnel and at the ventilation outlets to maintain in-tunnel air quality within acceptable limits.

The ventilation system would have a fixed number of ventilation levels which would generally correspond with the number of exhaust fans (at the ventilation outlets) in combination with the supply fans (within the main alignment tunnels and ramps) in the system. For example, a 'level 1' operation may involve the operation of one exhaust fan, and a 'level 5' operation may involve the operation of four exhaust fans. The number of ventilation levels and fan operating combinations would be determined during the detailed design of the project.

Jet fans ('supply fans') in the main alignment tunnels and ramps would operate to maintain longitudinal ventilation and to balance air flow in each tunnel section, such that in-tunnel air quality is maintained within acceptable limits.

The following key inputs would be used to determine the level of ventilation required at any given time and for any given traffic scenario:

- **Time of day** – The ventilation system would activate the level of ventilation required based on the time of day, increasing the level of ventilation in the tunnel in the lead up to peak hours, and reducing the level at off peak times such as during the night.
- **Traffic speed and density** – Vehicle detectors located within the roadway of the project tunnels and approaches would provide real-time input for traffic speed and traffic density in the project tunnels. This combination of vehicle speed and number of vehicles per hour would be used to select and confirm the level of ventilation required, possibly increasing above the level estimated by the 'time of day' schedule, if necessary. The combination of traffic speed, density and ventilation level would be pre-programed into the ventilation system using an algorithm to ensure that acceptable in-tunnel air quality is maintained to prevent emissions from the project's portals.
- **Data from in-tunnel air quality monitoring sensors** - Air quality monitoring sensors would be located throughout the project tunnels to identify and provide a complete

understanding of in-tunnel air quality during operation. As a minimum, these sensors would provide continuous monitoring for carbon monoxide, nitrogen dioxide, visibility and in-tunnel air flow.

If the air quality monitoring sensors detect that vehicle emissions concentrations are approaching the pre-set limits (ie actions triggers below maximum allowable in-tunnel air quality criteria to provide an 'early warning' and action system), feedback would be given to the ventilation system to increase the ventilation rate to the next ventilation level. This would continue in order to maintain in-tunnel air quality and to ensure compliance with the air quality criteria is always achieved.

- **Incident detection** – The project would be equipped with an automatic video incident detection (AVID) system. AVID is a close circuit television (CCTV) system but has the additional capability of detecting and actively alerting tunnel operators to incidents within the tunnel as they occur. The AVID system has the ability to detect a range of tunnel incidents including stopped vehicles, pedestrians or the presence of smoke in the project tunnels.

  The AVID system would quickly alert the tunnel operators to an incident in the project tunnels, so that they can implement the appropriate incident management plan. For example, in the event of a stopped vehicle, the operators can quickly identify its location and respond by implementing a traffic management plan and increasing the level of ventilation if required. It would also assist them to address the driver through the public address system or motorist emergency telephone.

  Unlike surface roads, road tunnels are constantly managed from a central control room with an operations team to ensure that action can be taken quickly and effectively in the event of an alarm or incident. With respect to the emergency devices such as the deluge system, these would be automatically operated in the event of an incident.

  Where there is a major incident such as a crash which results in the tunnel being blocked, the relevant tunnel would be closed and vehicles diverted to surface roads. The close tunnel would only be reopened once the incident is cleared. This action would be taken quickly (response time would be in minutes from alert) to minimise the number of vehicles in the tunnel.

  In the event of a fire incident the whole tunnel in both directions would be closed and vehicles diverted to surface roads until the incident has been dealt with.

- **Traffic and ventilation management** - It is envisaged that congested, slow moving traffic conditions would be rare in the project. However, where average traffic speeds drop below 40km/h, the tunnel operators would have the ability to implement traffic management procedures as a further means to manage vehicle emissions and air quality within the tunnel, in conjunction with the tunnel ventilation system.

Subject to the conditions of approval that may be applied to the project by the Minister for Planning, the NorthConnex project would regularly report (real time) on the performance and compliance with the air quality criteria. This would include in-tunnel air quality, air discharged from the ventilation outlets and ambient air external to the project tunnels.

In-tunnel air quality reporting would provide a direct clear comparison between the actual monitored air quality exposure within the tunnel against the maximum allowable air quality criteria to demonstrate that compliance is achieved at all times.

2.9.2 In-tunnel air quality for air quality impact assessment scenarios

Because emissions have been calculated for each hour of the day in several segments along each main alignment tunnel, it has been possible to use this data to calculate expected in-tunnel concentrations of vehicle emissions. This has been achieved by applying the ventilation flow rate applicable to the particular hour and traffic volume to the emissions calculated in each segment of each main alignment tunnel. Concentrations of pollutants at any point in each main alignment tunnel have been calculated by adding emissions from all tunnel segments up to the point of interest (ie all emissions from the tunnel entry portal up to the point at which the concentration has been calculated).

To provide a more accessible series of concentration data for in-tunnel air quality, calculated concentrations of pollutants within each tunnel segment have been linearly interpolated to provide concentrations at each kilometre along the main alignment tunnels. The outcomes of this process are provided:

- In **Table 2-47** for forecast traffic volumes in 2019 and 2029 (peak hours) for each main alignment tunnel. Data presented in the table shows:
  - The in-tunnel air quality profiles as presented in the environmental impact statement.
  - The in-tunnel air quality profiles based on updated fuel mix assumptions in 2019 and 2029 (refer to **Section 2.8**) and maintain a NO_2:NO_x ratio of 10 per cent, as recommended by PIARC.
  - The in-tunnel air quality profiles based on updated fuel mix assumptions in 2019 and 2029 (refer to **Section 2.8**) and amending the NO_2:NO_x ratio to 16 per cent, as suggested by the Environment Protection Authority in its submission on the environmental impact statement.

    Further discussion of the NO_2:NO_x ratio in the project tunnels is provided in **Section 2.14.2**, including an analysis of experience in other road tunnels and the approach proposed to be taken to management of in-tunnel NO_2 concentrations during operation of the project.

- In **Table 2-48** for a heavy vehicle sensitivity analysis, which assumes a 10 per cent increase in heavy vehicle numbers (ie an increase in heavy vehicle percentage of total traffic in 2019 from 28 per cent to 31 per cent and in 2029 from 25 per cent to 27.5 per cent). **Table 2-48** includes consideration of a NO_2:NO_x ratio of 10 per cent and also 16 per cent.

  As discussed in **Section 2.7.1** of this report, detail traffic forecasting has been conducted for the project. A significant investment is proposed in the NorthConnex project. The commercial viability of this investment is dependent on forecast traffic volumes expected to use the project being reasonable and realistic. Because of this, the Cube model and its outputs have been interrogated in detail to confirm that the project is viable prior to seeking design and construct tenders or lodging an application for environmental planning approval. The forecast heavy vehicles volumes for the project (28 per cent of total traffic in 2019 and 25 per cent of total traffic in 2029) are considered realistic with low risk of significant variance in these forecasts.

  These traffic forecasts for the project have assumed that 95 per cent of through heavy vehicles travelling along the Pennant Hills Road corridor would be directed into the project tunnels with the implementation of regulatory measures (to require heavy vehicles to use the tunnels). There is therefore a very low potential for heavy vehicles using the project to exceed these heavy vehicle percentages.

When considering and interpreting this in-tunnel air quality information, it is important to recognise that this information:

- Presents an estimated maximum concentration at a particular point in each main alignment tunnel within the relevant one hour period (refer to the following section of this report, which discusses variability of in-tunnel air quality and averaging periods).
- Presents a concentration, rather than an exposure for a motorist passing through the main alignment tunnel. To determine an exposure, concentrations along the entire length of the main alignment tunnel need to be considered within the time period during which the motorist's journey occurs (ie around seven minutes at 80 km/h). Where comparisons are to be made for exposure averaging periods greater than the tunnel journey time, then account also needs to be made of the concentration of the relevant pollutant to which the motorist would be exposure prior to/ following the journey (ie ambient air).
- The concentrations (and consequently the exposures that may be calculated from them) do not take into account reductions that may be achieved by closing vehicle windows and recirculating air.
- In-tunnel concentrations have not taken into account additional 'fresh' air that may be drawn into the main alignment tunnels via the exit portal and tunnel ramps (in order to maintain zero portal emission conditions). This air would have the effect of diluting in-tunnel vehicle emissions.
- Based on the variability of background air quality over time, in-tunnel concentrations of pollutants have not included contributions from air drawn into the main alignment tunnels. When considering in-tunnel air quality and motorist exposures, allowance would need to be made for contributions from ambient air. Pollutant loads in ambient air drawn into the main alignment tunnels would affect in-tunnel air quality in the early sections of each main alignment tunnel, before contributions from vehicles within the main alignment tunnels become the dominant contributor to in-tunnel concentrations of vehicle emissions.

Table 2-47 Calculated in-tunnel air quality for forecast traffic volumes (2019 and 2029) (project contribution) – main alignment tunnels during peak hours

Black – design as presented in the EIS
Blue – design including updates to fuel mix and no change to ratio of NO_2 to NO_x (10%)
Red – design including updates to fuel mix and ratio of NO_2 to NO_x (16%)

	Pollutant concentrations (mg/m^3) (peak hour)								
	Approximate distance along main alignment tunnels								
Pollutant	**1 km**	**2 km**	**3 km**	**4 km**	**5 km**	**6 km**	**7 km**	**8 km**	**9 km**
Southbound main alignment tunnel at 9 am (2019)									
CO	0.331	0.772	1.06	1.34	1.62	1.90	2.17	2.58	3.45
	0.348	0.812	1.12	1.41	1.70	2.00	2.28	2.71	3.63
NO_2	0.039	0.098	0.124	0.144	0.165	0.186	0.206	0.250	0.374
	0.044	0.111	0.140	0.162	0.186	0.210	0.232	0.282	0.422
	0.070	0.177	0.224	0.260	0.298	0.336	0.372	0.451	0.675
PM_{10}	0.039	0.084	0.122	0.158	0.193	0.229	0.265	0.307	0.377
	0.040	0.087	0.127	0.164	0.200	0.238	0.275	0.318	0.391
$PM_{2.5}$	0.037	0.080	0.115	0.149	0.183	0.217	0.251	0.290	0.347
	0.039	0.085	0.122	0.158	0.195	0.231	0.267	0.308	0.369
Southbound main alignment tunnel at 9 am (2029)									
CO	0.411	0.956	1.32	1.67	2.01	2.35	2.70	3.20	4.29
	0.415	0.965	1.33	1.69	2.03	2.37	2.73	3.23	4.33
NO_2	0.043	0.108	0.136	0.159	0.182	0.204	0.227	0.276	0.411
	0.049	0.124	0.156	0.183	0.209	0.235	0.261	0.317	0.473
	0.079	0.199	0.250	0.292	0.335	0.375	0.418	0.508	0.756
PM_{10}	0.047	0.101	0.145	0.189	0.232	0.275	0.319	0.369	0.439
	0.051	0.109	0.156	0.203	0.249	0.296	0.343	0.397	0.472
$PM_{2.5}$	0.046	0.095	0.137	0.178	0.219	0.260	0.301	0.348	0.414
	0.050	0.102	0.148	0.192	0.236	0.280	0.324	0.375	0.446
Northbound main alignment tunnel at 6 pm (2019)									
CO	0.156	0.911	1.76	2.62	3.47	4.32	5.12	5.59	6.26
	0.152	0.890	1.71	2.55	3.38	4.20	4.98	5.44	6.09

NO_2	0.005	0.110	0.231	0.352	0.473	0.594	0.707	0.771	0.860
	0.005	0.112	0.235	0.358	0.481	0.604	0.719	0.784	0.875
	0.008	0.179	0.376	0.573	0.770	0.97	1.15	1.26	1.40
PM_{10}	0.032	0.090	0.153	0.215	0.278	0.340	0.401	0.450	0.504
	0.033	0.092	0.156	0.220	0.284	0.347	0.410	0.460	0.515
$PM_{2.5}$	0.030	0.085	0.144	0.203	0.263	0.322	0.379	0.425	0.477
	0.031	0.087	0.147	0.207	0.269	0.329	0.387	0.434	0.487
Northbound main alignment tunnel at 6 pm (2029)									
CO	0.195	1.13	2.19	3.25	4.31	5.37	6.35	6.94	7.76
	0.183	1.06	2.05	3.04	4.04	5.03	5.95	6.50	7.27
NO_2	0.005	0.119	0.250	0.381	0.512	0.643	0.765	0.834	0.932
	0.005	0.123	0.258	0.393	0.529	0.664	0.790	0.861	0.963
	0.008	0.197	0.413	0.630	0.846	1.06	1.26	1.38	1.54
PM_{10}	0.039	0.106	0.178	0.250	0.323	0.395	0.464	0.521	0.585
	0.041	0.111	0.186	0.261	0.337	0.412	0.484	0.543	0.61
$PM_{2.5}$	0.037	0.100	0.169	0.237	0.305	0.373	0.439	0.497	0.553
	0.039	0.104	0.176	0.247	0.318	0.389	0.457	0.518	0.576

Table 2-48 Calculated in-tunnel air quality – heavy vehicle sensitivity analysis

Blue – design including updates to fuel mix and no change to ratio of NO_2 to NO_x (10%). Heavy vehicles are assumed to be 28 per cent of total traffic in 2019 and 25 per cent in 2029

Green – design including updates to fuel mix and no change to ratio of NO_2 to NO_x (10%). Heavy vehicles are assumed to be 31 per cent of total traffic in 2029 and 27.5 per cent in 2029

Orange – design including updates to fuel mix and a ratio of NO_2 to NO_x (16%). Heavy vehicles are assumed to be 31 per cent of total traffic in 2029 and 27.5 per cent in 2029

	Pollutant concentrations (mg/m^3) (peak hour) Approximate distance along main alignment tunnels								
Pollutant	**1 km**	**2 km**	**3 km**	**4 km**	**5 km**	**6 km**	**7 km**	**8 km**	**9 km**
Southbound main alignment tunnel at 9 am (2019)									
CO	0.348	0.812	1.12	1.41	1.70	2.00	2.28	2.71	3.63
	0.345	0.806	1.11	1.40	1.69	1.98	2.26	2.69	3.60
NO_2	0.044	0.111	0.140	0.162	0.186	0.210	0.232	0.282	0.422
	0.047	0.119	0.151	0.175	0.201	0.226	0.251	0.304	0.455
	0.075	0.190	0.242	0.280	0.322	0.362	0.402	0.486	0.728
PM_{10}	0.040	0.087	0.127	0.164	0.200	0.238	0.275	0.318	0.391
	0.043	0.092	0.133	0.173	0.211	0.250	0.290	0.336	0.412
$PM_{2.5}$	0.039	0.085	0.122	0.158	0.195	0.231	0.267	0.308	0.369
	0.042	0.090	0.129	0.167	0.206	0.244	0.282	0.326	0.390
Southbound main alignment tunnel at 9 am (2029)									
CO	0.415	0.965	1.33	1.69	2.03	2.37	2.73	3.23	4.33
	0.412	0.958	1.32	1.67	2.01	2.36	2.71	3.21	4.30
NO_2	0.049	0.124	0.156	0.183	0.209	0.235	0.261	0.317	0.473
	0.053	0.134	0.169	0.197	0.226	0.253	0.282	0.342	0.510
	0.085	0.214	0.270	0.315	0.362	0.405	0.451	0.547	0.816
PM_{10}	0.051	0.109	0.156	0.203	0.249	0.296	0.343	0.397	0.472
	0.053	0.115	0.164	0.214	0.263	0.312	0.362	0.419	0.498
$PM_{2.5}$	0.050	0.102	0.148	0.192	0.236	0.280	0.324	0.375	0.446
	0.052	0.108	0.156	0.202	0.249	0.295	0.342	0.395	0.470
Northbound main alignment tunnel at 6 pm (2019)									
CO	0.152	0.890	1.71	2.55	3.38	4.20	4.98	5.44	6.09

	0.170	1.01	1.94	2.89	3.83	4.77	5.65	6.17	6.91
NO_2	0.005	0.112	0.235	0.358	0.481	0.604	0.719	0.784	0.875
	0.006	0.139	0.293	0.446	0.600	0.753	0.896	0.977	1.09
	0.010	0.222	0.469	0.714	0.960	1.20	1.43	1.56	1.74
PM_{10}	0.033	0.092	0.156	0.220	0.284	0.347	0.410	0.460	0.515
	0.040	0.113	0.191	0.269	0.348	0.425	0.501	0.563	0.630
$PM_{2.5}$	0.031	0.087	0.147	0.207	0.269	0.329	0.387	0.434	0.487
	0.037	0.106	0.180	0.254	0.329	0.402	0.474	0.531	0.596
Northbound main alignment tunnel at 6 pm (2029)									
CO	0.183	1.06	2.05	3.04	4.04	5.03	5.95	6.50	7.27
	0.181	1.05	2.03	3.01	3.99	4.98	5.88	6.43	7.19
NO_2	0.005	0.123	0.258	0.393	0.529	0.664	0.790	0.861	0.963
	0.006	0.135	0.284	0.433	0.582	0.731	0.870	0.949	1.06
	0.010	0.216	0.454	0.693	0.931	1.17	1.39	1.52	1.70
PM_{10}	0.041	0.111	0.186	0.261	0.337	0.412	0.484	0.543	0.61
	0.043	0.118	0.198	0.279	0.360	0.440	0.517	0.581	0.652
$PM_{2.5}$	0.039	0.104	0.176	0.247	0.318	0.389	0.457	0.518	0.576
	0.041	0.111	0.188	0.264	0.340	0.415	0.489	0.554	0.616

2.9.3 Variability of in-tunnel air quality

The data presented in **Section 2.9.2** have been calculated for peak hour traffic volumes in main alignment tunnel. The concentrations presented in the tables in that section have therefore been calculated on an hourly average basis. A similar approach has been taken for in-tunnel air quality calculations presented in the environmental impact statement.

Air quality within road tunnels is likely to be variable, with the concentration of a particular pollutant at a particular point dependent on the conditions at that point and at a specified time. For example, air quality at a particular point would be different depending on whether a passenger vehicle or a heavy was travelling past that point. Further, the size of vehicles (passenger vehicles or larger heavy vehicles) as well as the number and distribution of vehicles within a particular time period will affect the spatial distribution and mixing of pollutants within the road tunnel. In practice, these effects are seen as variable short term changes in pollutant concentrations around an hourly average (or other averaging period value).

Because motorist journeys through a road tunnel are usually shorter than one hour duration (around 6.75 minutes at 80 km/h through the NorthConnex main alignment tunnels), it is useful to understand the short term variability in in-tunnel pollutant concentrations to gain an appreciation for the range of concentrations that may be experienced by a motorist. It is also useful to understand the likely scale of this variability because exposure standards (where they exist) and in-tunnel air quality criteria are often expressed for shorter averaging periods – often 15 minutes or 30 minutes.

To gain an appreciation of this variability, carbon monoxide monitoring data from the M5 East Motorway tunnels has been analysed for the period April 2013 until December 2013. In-tunnel monitoring data has been used to compared 15-minute average CO concentrations with the one-hour average concentrations calculated from that data. The intention of this comparison was to understand how much higher a 15-minute average concentration may be when compared with an hourly average.

Analysis of the in-tunnel CO monitoring data from the M5 East Motorway indicates that:

- For all of the monitoring data:
  - The maximum 15-minute average CO concentrations were around 18 per cent to 24 per cent higher than the simultaneous hourly average concentrations.
  - The minimum 15-minute average CO concentrations were around zero and 25 per cent below the simultaneous hourly average concentrations.
- For monitoring data in the AM peak (8am to 10am):
  - The maximum 15-minute average CO concentrations were around seven per cent to 15 per cent higher than the simultaneous hourly average concentrations.
  - The minimum 15-minute average CO concentrations were around five per cent to seven per cent below the simultaneous hourly average concentrations.
- For monitoring data in the PM peak (5pm to 7pm):
  - The maximum 15-minute average CO concentrations were around six per cent to 13 per cent higher than the simultaneous hourly average concentrations.
  - The minimum 15-minute average CO concentrations were around five per cent to eight per cent below the simultaneous hourly average concentrations.

2.10 Meteorological data and modelling

This section provides information and discussion of:

- How the MM5 and CALMET models have been set up and used to model meteorology in and around the project.
- Validation of the CALMET model outputs.

2.10.1 Set up of the MM5 and CALMET models

General approach

An advanced diagnostic meteorological model (CALMET) was used to establish local meteorological conditions over a grid around the project corridor measuring 60 kilometres by 62.5 kilometres. The CALMET model constructs three dimensional wind and temperature fields starting from base meteorological data, topography and land use information.

The CALMET model used meteorological inputs from the MM5 prognostic meteorological model (the Fifth-Generation Penn State/ NCAR Mesoscale Model), which is a regional scale model used to create weather forecasts and climate projections. To ensure that the MM5 model generated meteorological data that was representative of actual conditions, the outputs from the MM5 model were compared with and calibrated against actual monitoring data from five existing meteorological monitoring stations across Sydney: at Lindfield, Terrey Hills, Richmond, Prospect and the Sydney Kingsford Smith Airport.

Prognostic meteorological data from MM5 were used to define the meteorological parameters for the upper air levels (which are required by the CALPUFF model but are not measured at most Bureau of Meteorology and Office of Environment and Heritage monitoring stations) and to provide the initial wind field information at the surface level.

CALMET then used the Bureau of Meteorology and Office of Environment and Heritage meteorological monitoring station data to modify those initial wind fields to be more representative of actual measured conditions.

Meteorological modelling using MM5 and CALMET, within inputs from meteorological monitoring data is a two-step process:

- In the first step, the CALMET model uses the meteorological monitoring data and the MM5 prognostic data to develop a flow field across the entire modelling domain. In this first step, the surface meteorological monitoring stations 'assist' in nudging the MM5 data towards their solution.
- In the second step, fine scale terrain and land use inputs are introduced (across the CALMET model model), with these inputs used to further nudge the initial wind field generated based on the MM5 and meteorological monitoring data.

The CALMET/ MM5 model can be run very well without meteorological monitoring, but meteorological monitoring data ensures a more robust numerical data output.

Meteorological parameters have been modified in CALMET based on the data recorded by the Bureau of Meteorology and Office of Environment and Heritage meteorological monitoring stations, terrain and land use data to produce site-representative wind fields, which were used by the CALPUFF model to predict pollutant movements in the atmosphere. Examples of these wind fields are shown in **Figure 2-6** and **Figure 2-7** for onshore and offshore wind flows, respectively.

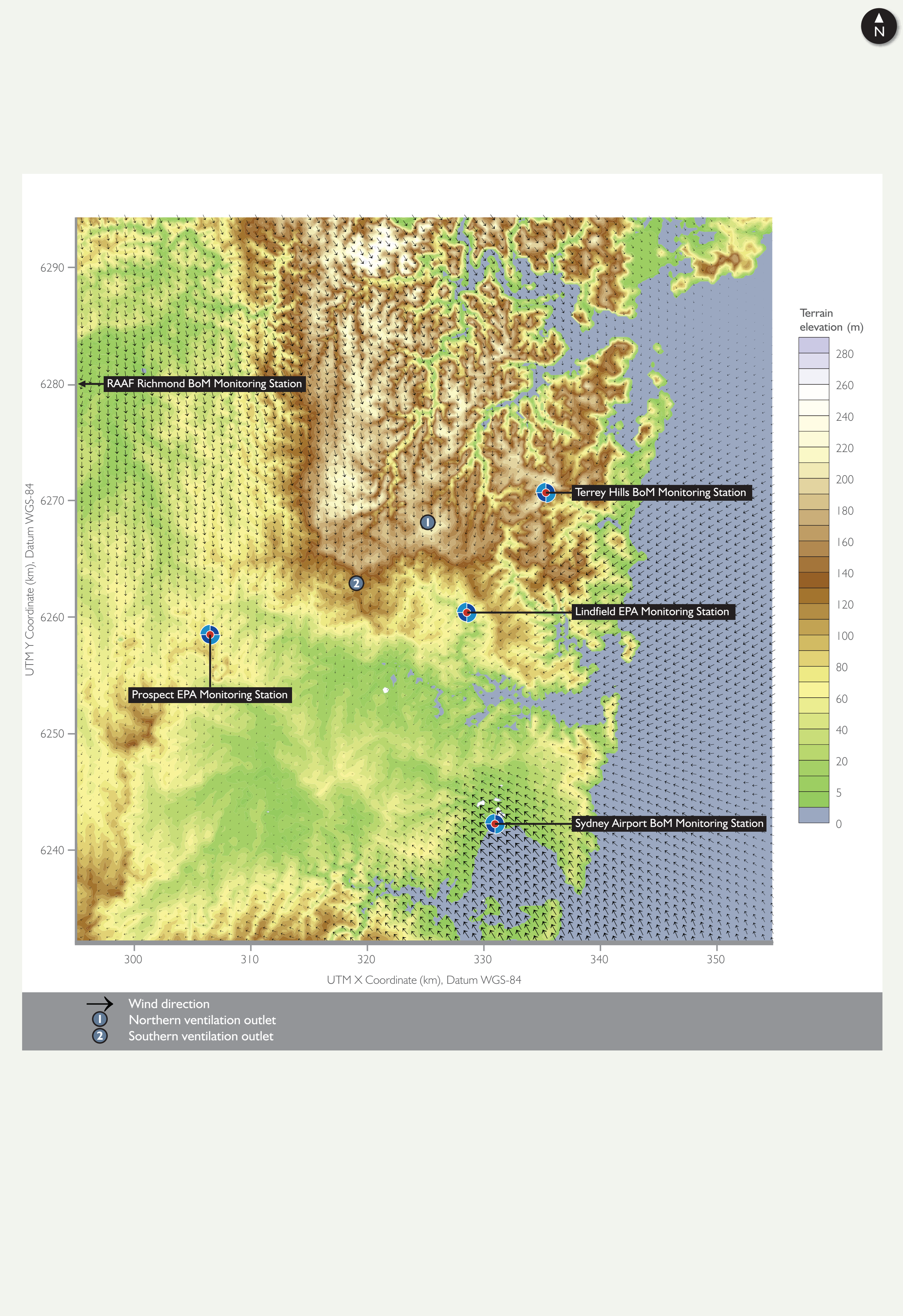

Figure 2-6 Example wind field (onshore flow, October 2011, 4:00am)

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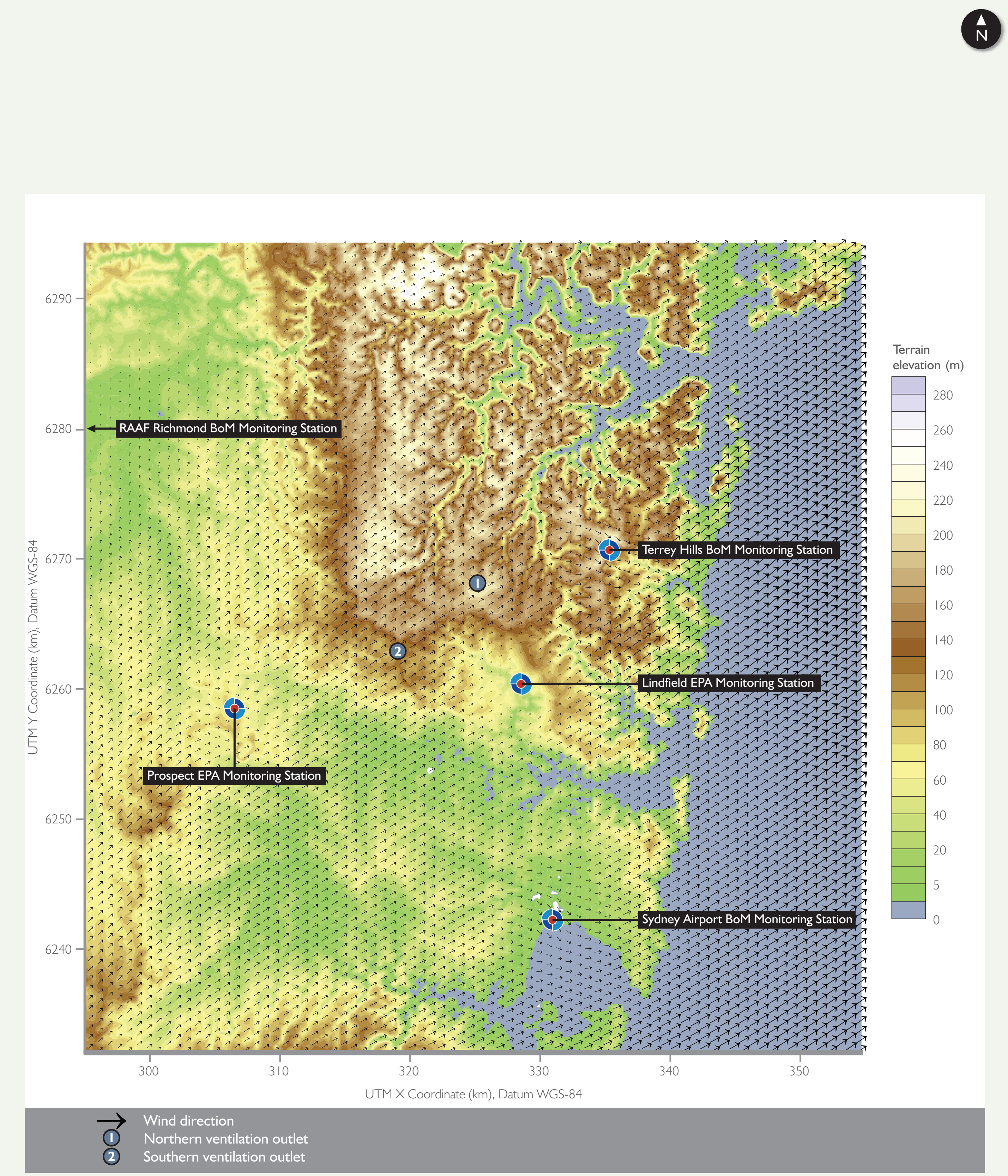

Figure 2-7 Example wind field (offhore flow, October 2011, 4:00am)

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CALMET and MM5 model parameters

The model input parameters used in the CALMET model and the MM5 model are summarised in **Table 2-49** and **Table 2-50**, respectively.

The seven critical parameters of the CALMET model and their values used in the air quality impact assessment for the project are:

- TERRAD – six kilometres.
- RMAX1 – four kilometres.
- RMAX2 – not used as prognostic data were used to determine the temperature field above 20 metres.
- R1 – 2.5 kilometres.
- R2 – not used as prognostic data were used to determine the temperature field above 20 metres.
- IEXTRP – no extrapolation was done.
- BIAS – no bias was done.

It should also be noted that ten vertical levels were used in CALMET, defined as the levels between 0, 20, 40, 80, 160, 320, 700, 1300, 1700, 2300 and 3000 metres above ground level. Cloud cover and cloud ceiling height were determined from the prognostic data (MM5).

The values described above have been chosen consistent with the guidance provided in in Generic Guidance and Optimum Model Settings for the CALPUFF Modeling System for Inclusion into the 'Approved Methods for the Modeling and Assessment of Air Pollutants in NSW, Australia' (OEH, 2011). The final parameters used in the air quality impact assessment, as listed above, were determined following an iterative process of investigation of the effects of different values on the resultant wind fields. This iterative process considered parameters in the following ranges:

- TERRAD values between four kilometres and 10 kilometres.
- RMAX1 values between one kilometre and eight kilometres.
- R1 values between one kilometre and six kilometres.
- IEXTRP switched both on and off. For this air quality impact assessment, it was switched off due to confidence in the MM5 data in determining the initial guess wind fields.

Table 2-49 CALMET model input parameters

Parameter	Input
Meteorological grid domain	60 kilometres x 62.5 kilometres
Meteorological grid resolution	250 metre resolution (240 x 250 grid cells)
Reference grid coordinate of southwest corner	295.000 E, 6232.000 S
Cell face heights in vertical grid	0, 20, 40, 80, 160, 320, 700, 1300, 1700, 2300 and 3000 m
Years of analysis	2009, 2010 and 2011
Simulation length	3 years (62,280 hours/1,095 days)
Surface meteorological stations	CALMET Hybrid Mode: Run using a combination of MM5 gridded numerological data supplemented by data from five surface meteorological stations operated by BOM and OEH (described below). **Lindfield OEH Monitoring Station** Hourly data: Temperature, precipitation, humidity, wind speed and wind direction. MGA Coordinates (km): 328.711 E, 6260.391 S **Terry Hills BOM Monitoring Station** (Station No. 066059) Hourly data: Temperature, precipitation, humidity, wind speed and wind direction. MGA Coordinates (km): 335.509 E, 6270.714 S **Richmond RAAF BOM Monitoring Station** (Station No. 067105) Hourly data: Temperature, precipitation, humidity, pressure, wind speed and wind direction. MGA Coordinates (km): 293.651 E, 6279.933 S **Prospect OEH Monitoring Station** Hourly data: Temperature, precipitation, humidity, wind speed and wind direction. MGA Coordinates (km): 306.745 E, 6258.646 S **Sydney Airport BOM Monitoring Station** (Station No. 066307) Hourly data: Temperature, precipitation, humidity, pressure, wind speed and wind direction. MGA Coordinates (km): 331.173 E, 6242.272 S
Upper air meteorological station	No upper air stations. The three-dimensional gridded prognostic data from MM5 were used as the initial guess wind-field for CALMET.
Terrain data	For the assessment presented in the environmental impact statement, terrain elevations were extracted from the NASA Shuttle Radar Topography Mission data set (SRTM 90 metre, 3-arc sec). Terrain data has been updated as part of the air quality impact assessments presented in this report (refer to **Section 2.12**). Terrain data have been re-extracted using five metre resolution Land and Property Information (LPI) data. The elevations of the discrete receivers and the ventilation outlet locations have been identified using this revised data.

Table 2-50 MM5 model input parameters

Parameter	Input
Horizontal resolution	12 kilometres; four tiles with each tile covering approximately 120 kilometres by 120 kilometres.
Model Configuration	Full non-hydrostatic model Analysis nudging on outer domain One-way nesting Microphysics – Reisner2 scheme Cumulus – Kain-Fitsch scheme Moisture parameterisation – Reisner Graupel scheme Planetary boundary layer scheme – Mellor-Yamada scheme
Vertical levels	40 vertical half sigma levels, 16 vertical levels below 1000 metres; nine vertical levels above 1000 metres and below 3500 metres; 15 levels above 3500 metres
Three-dimensional variables	Wind speed; wind direction; temperature; relative humidity; pressure; mixing ratios of water vapours, cloud water, rain water, ice and snow
Two-dimensional variables	Precipitation amount, short wave and long wave solar radiation, snow cover, two metre temperature and specific humidity, 10 metre wind speed and direction
Land use data	Land use information was derived from the OEH land use data set between June 2000 and June 2007 for NSW. The data set has a resolution of 150 square metres over the modelling domain.

2.10.2 Wind data from the Sydney airport

For the purpose of the air quality impact assessment presented in the environmental impact statement, the three years of data from the Bureau of Meteorology Sydney Airport station used as inputs in the meteorological modelling were compared to the long term (30 year) statistics from this site in order to show the suitability of these years for the assessment (Section 4.2.4 of the Technical Working Paper: Air Quality in the environmental impact statement).

Sydney Airport data were used in this analysis as this monitoring location it is one of several key surface meteorological stations used in the meteorological modelling. Monthly summaries of temperature, relative humidity and wind speed were provided for 9 am and 3 pm conditions. The data used in the modelling (2009 – 2011) were different to the long term (30 year) average data from Sydney Airport. This difference is attributed to the anemometer at the monitoring station (Potts, Monypenny & Middleton, 1997).

From 1939 to 1994, wind reports at the airport were taken from a Dines pressure-tube anemometer. The Dines anemometer, which was sited in a number of different locations during its operational period, was replaced by a Synchrotac anemometer in August 1994. The new anemometer, which is the new Bureau of Meteorology standard wind vane and rotating cup anemometer, was sited in a location that is more exposed to winds from all directions.

Before its decommissioning, operational staff at the airport indicated concern that the anemometer was recording wind speeds lower than those reported by pilots or indicated by other anemometers on site and wind socks. Since the upgrade, higher average wind speeds have been recorded at the site. These higher wind speeds affect the modelling data since the modelling period occurred after the replacement of the anemometer, and, as such, the wind speeds during modelling period were higher than the 30 year average data.

The effect of the anemometer replacement is illustrated in **Figure 2-8**, which shows the 3 pm average wind speeds for the old and new anemometers and the 30 year average. As can be seen, the average wind speed for the period 1995 – 2011 was higher than the 30 year average. The 3 pm annual average wind speed for the modelling period (2009 – 2011) was 7.3 m/s, which closely aligns with the 16 year average (1995 – 2011) of 7.2 m/s shown in **Figure 2-8**.

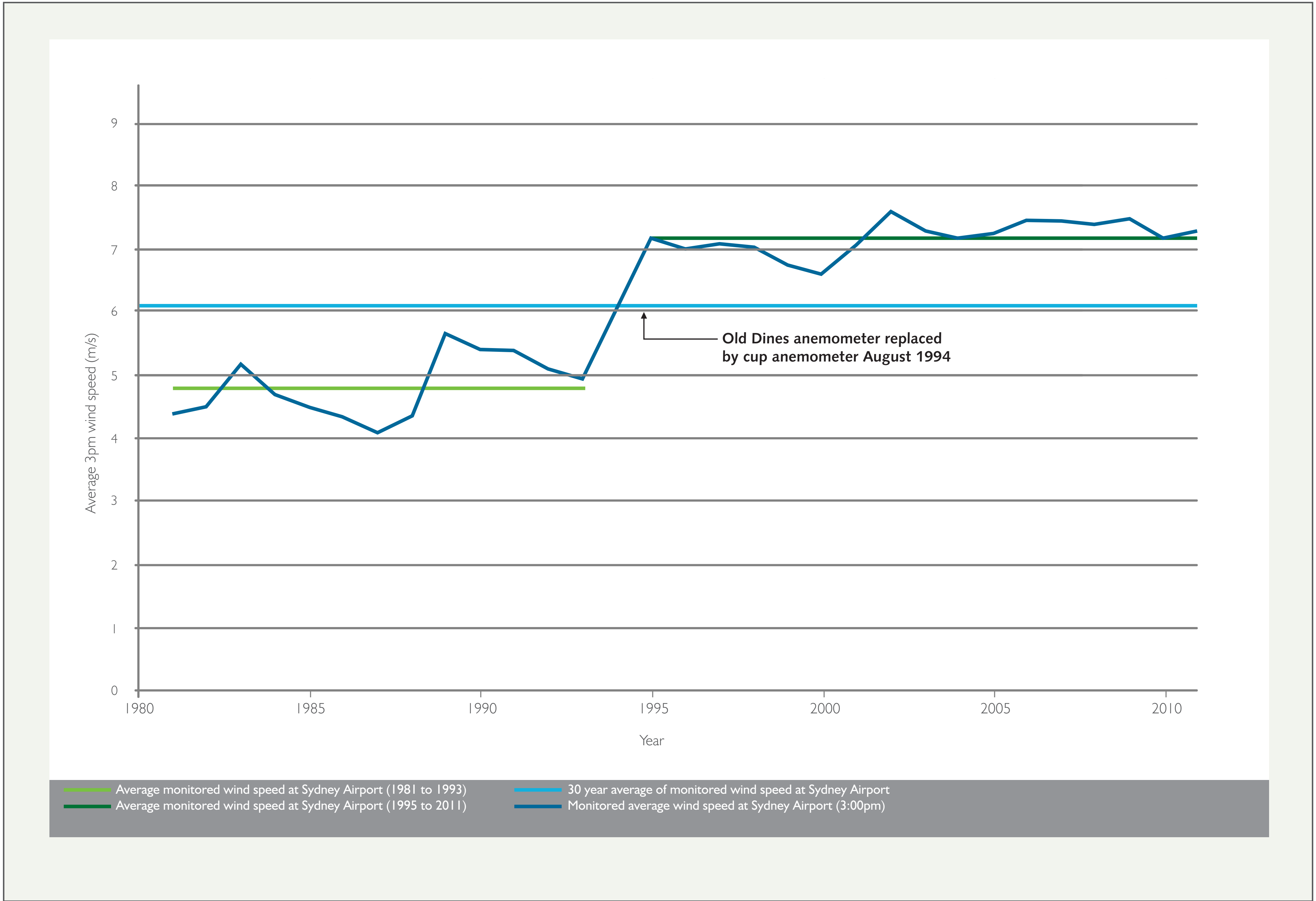

Figure 2-8 Effect of anemometer replacement at Sydney Airport

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2.10.3 Validation of the CALMET and MM5 models

The outputs of the CALMET and MM5 models have been validated using observed meteorological data from the Earlwood meteorological monitoring station operated by the Office of Environment and Heritage. Data from this station has not been previously used in the CALMET or MM5 modelling.

The outputs of the CALMET and MM5 models have been validated by comparing the results from the model at the Earlwood site, with actual monitoring data from that station.

A comparison of the wind directions and speeds of the CALMET monitoring data extracted for the suburb of Earlwood (generated using MM5 prognostic data and surface monitoring stations) (referred to as modelled) and data from the Earlwood monitoring station is provided in **Appendix B**, in the form of seasonal and annual wind roses.

From the comparison of CALMET/ MM5 generated wind roses and wind roses based on monitoring data at the Earlwood monitoring stations, the following observations can be made:

- The annual average comparison shows that the general spread of wind directions is generally uniform for all years, although the monitoring data from the Earlwood station does show a stronger portion of winds from the west north-west. The modelled data also shows relatively higher wind speeds.
- The summer data shows a strong correlation between wind trends, both showing a strong proportion of north east to south winds. These winds are likely to represent sea breezes. The modelled data shows generally stronger wind conditions.
- The autumn data correlation is not as strong as the other seasons, although still shows similar trends between data sets. The observed data shows lower wind conditions with a marginal west north-west and east south-east axis. The modelled data shows more winds from the south east to west south-west. Both data sets show minor winds from the north-west to east quadrants.
- The winter shows a good correlation between data sets, with winds predominantly blowing between the south west and north west, with minor winds from the other directions. As seen in the annual comparison, the monitoring data has a stronger portion of winds from the west north-west.
- The spring data shows a good correlation, with winds prevalent from most wind directions from both data sets. Again, the modelled data shows generally stronger wind conditions.

The comparison of the observed to modelled data shows a reasonable correlation between the data sets, although the modelled data tends to predict higher winds and may underestimate winds blowing from the west south-west. In general, the data shows a good correlation and is considered appropriate for the use in the air quality impact assessment.

2.10.4 Calm and low wind speed conditions

Based on the observation that modelled meteorology generally produced less frequent calm and low wind speeds than monitoring data (refer to the validation of the CALMET and MM5 models, above), and in response to concerns raised in public submissions, further analysis of calm and low wind speed conditions has been conducted.

The CALMET data used in the air quality modelling have been analysed to determine the frequency of calm and light wind conditions. Data at the northern ventilation outlet is presented here, although it is highlighted that analysis of data for the southern ventilation outlet produces essentially the same observations.

For the 2009 meteorological modelling year, there were 81 calm wind periods (hours) present in the CALMET file for the northern ventilation outlet, representing 0.9 per cent of the modelling period. For 2010 and 2011, there were 65 and 44 calm periods respectively.

Low wind speeds between zero and one metre per second have been predicted for approximately three per cent of 2009 and 2011 and 3.4 per cent of 2010. Low wind speeds between one and 2.5 metres per second occurred for approximately 36 per cent of 2009 and 2011 and 38 per cent of 2010.

It is well known that prognostic meteorological data typically under-predict the number of calm events. Actual meteorological conditions at the ventilation outlet sites would be expected to have a slightly greater number of low wind speed classes and fewer stronger winds. It should be noted, however, that apart from a single peak concentration of NO_2 that occurred during a calm period, the highest pollutant concentrations from the project's ventilation outlets have been predicted to occur during high wind speeds (refer to analysis of this issue below). As such, the meteorological data are considered adequate for this assessment.

Figure 2-9 and **Figure 2-10** show the frequency and distribution of calm and low wind speeds at the northern ventilation outlet for the zero to one metre per second wind speed band, and the one to 2.5 metres per second wind speed band. These data have been generated by the CALMET and MM5 models used for the air quality impact assessment.

Wind speeds less than one metre per second are relatively consistent across all wind directions, but are more common in the west-southwesterly direction and least frequent in the easterly direction. Winds between one and 2.5 metres per second most commonly occur in the southerly and westerly directions and least commonly in the northerly directions. It can be seen from **Figure 2-9** and **Figure 2-10** that low wind speed conditions are distributed across all the directions/ receiver locations.

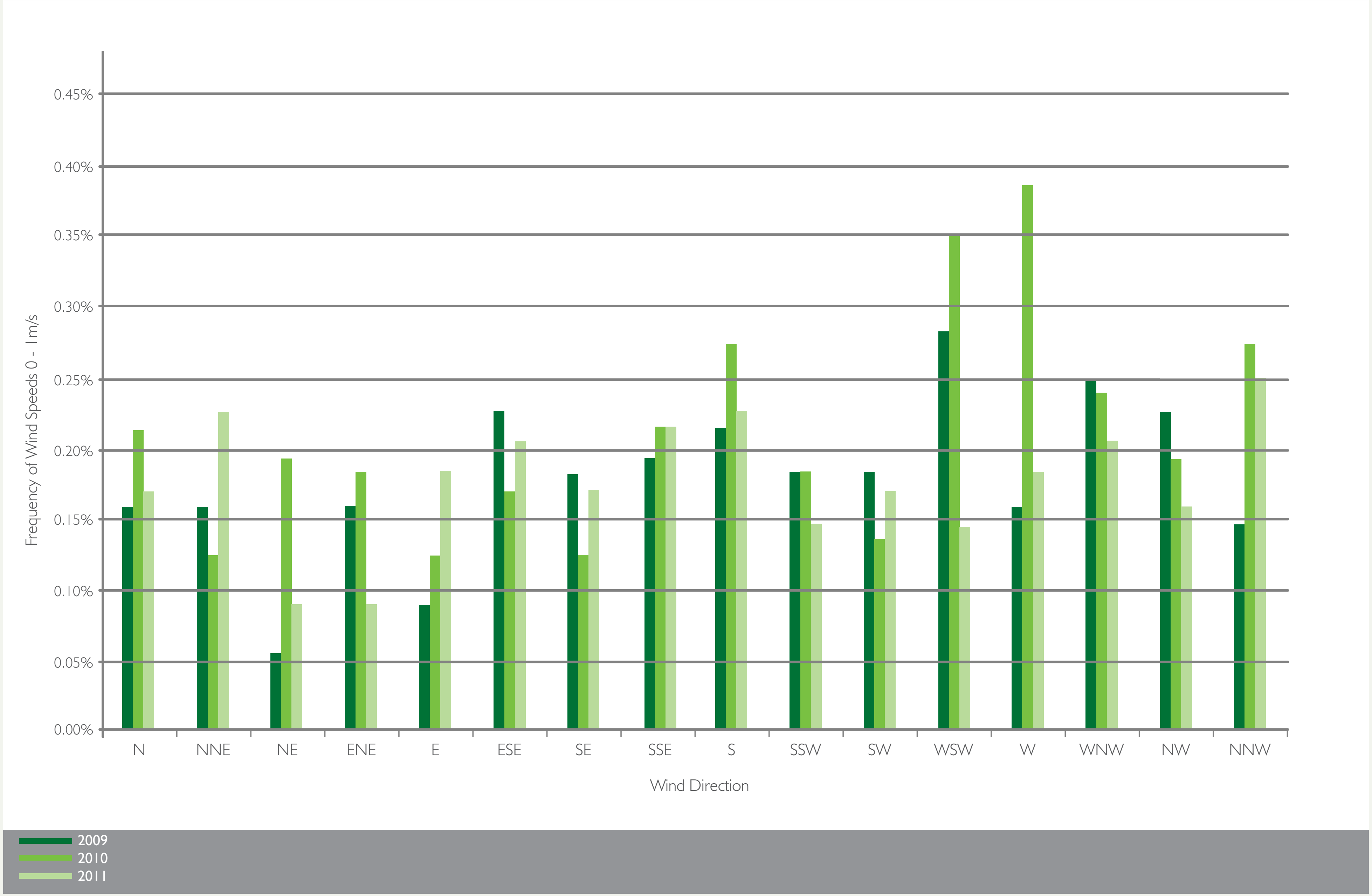

Figure 2-9 Winter low wind frequency and distribution

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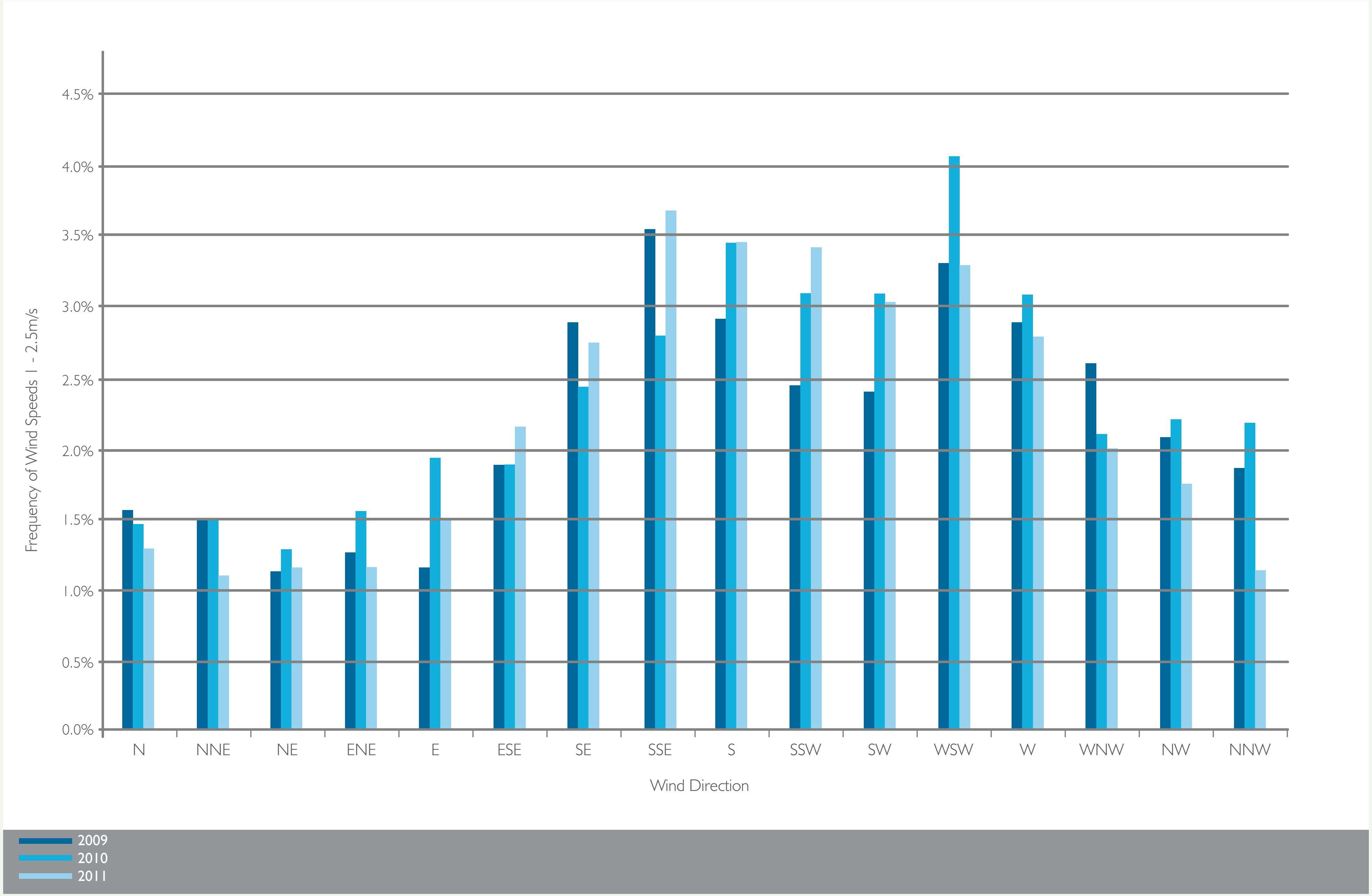

Figure 2-10 Summer low wind frequency and distribution

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2.10.5 Sensitivity to calm and low wind speed conditions

To test the sensitivity of the air quality impact assessment to changes in the percentage of calm meteorological conditions, further analysis of dispersion modelling results has been carried out. This analysis has considered predicted maximum and second highest ground level concentrations of oxides of nitrogen (NO_x) as a function of wind speed.

Concentrations of NO_x at ground level around the northern ventilation outlet under forecast traffic volumes in 2019 have been analysed. The northern ventilation outlet has been considered based on predictions in the environmental impact statement that maximum ground level concentrations would be higher than around the southern ventilation outlet. Ground level concentrations have been analysed for the most affected location, based on the 2009 meteorological modelling year (during which the maximum impacts were predicted to occur).

Table 2-51 summarises the maximum, the second highest and the average NO_x concentration around the northern ventilation outlet by wind speed. The number of modelled hours at the relevant wind speeds is also listed.

Table 2-51 shows that the predicted peak concentration of NO_x would occur under calm conditions. However, comparison of this value with the second highest prediction under calm conditions highlights a significant difference in concentrations, which suggests that the peak NO_x concentration occurred during a single hour during which a rare combination of meteorological conditions was experienced. This rare combination of meteorological conditions is discussed further in **Section 2.15.2** as part of the analysis of predicted air quality impacts. The unusually high maximum NO_x concentration under calm condition has also skewed the average value.

The maximum NO_x concentration for the single hour under calm conditions is also significantly higher than all other ground level concentrations predicted through the air dispersion modelling, reinforcing the conclusion that this value is more likely to be an unusual, infrequent outcome rather than an outcome characteristic of typical calm conditions. This is supported by the further analysis conducted in response to issues raised by the Environment Protection Authority (refer to **Section 7.1.1.3** of this report) that identifies a single unusual hour of meteorological data (out of three years of data used in the air quality impact assessment) that has contributed to a distinct and elevated (but very rare) air quality impact.

With the exception of the single elevated NO_x prediction, **Table 2-51** shows that:

- NO_x concentrations under calm conditions and light wind conditions (up to 1 m/s) are very low. NO_x concentrations under these conditions are lower than predicted concentrations under higher wind speeds.
- The wind speeds with the highest NO_x concentrations when considering maximum and second highest predicted values lie within the range 1 m/s to 5 m/s.
- Annual average ground level concentrations of NO_x are highest at high wind speeds (more than 5 m/s).

On this basis, peak ground level air quality impacts are not expected to occur under calm and light wind conditions. Peak ground level concentrations are expected to occur when winds are between 1 m/s and 5 m/s (3.6 to 18 km/h). These wind speeds are well represented in the meteorological monitoring data used in the air quality impact assessment of the project (around 90 per cent of the time based on modelled hours of wind speeds summarised in **Table 2-51**).

To the extent that calm and light winds may have been underestimated in the meteorological modelling for the project, this is likely to have led to an overestimate of air quality impacts (based on an overestimate of higher wind conditions). The air quality impact assessment and the meteorological modelling conducted for the project is therefore conservative (ie over predicted).

Table 2-51 Correlation between peak NO_x concentration and wind speed

Scalar wind speed (m/s)	Predicted NO_x concentration (one hour) ($\mu g/m^3$)			Number of modelled hours of wind speed
	Maximum	Second highest	Average	
0 to 0.5	119.0*	14.8	2.9	49
0.5 to 1	16.3	6.6	0.3	208
1 to 2	42.5	34.9	0.5	1,293
2 to 3	38.1	37.7	0.2	3,941
3 to 5	35.6	34.7	0.7	2,657
5 to 7	29.2	24.7	1.1	521
7 to 9	32.9	28.5	1.3	69
>9	79.2	23.0	7.4	22

* One hour in three years of modelling (refer to discussion in Section 2.15.2).

2.10.6 Local meteorological monitoring data

This section includes information and discussion of:

- Quality requirements for meteorological monitoring.
- Community meteorological monitoring data.
- Meteorological monitoring data from the monitoring stations installed along the project corridor.

Quality requirements for meteorological data

Meteorological data used in the air quality impact assessment for the project were sourced from meteorological stations operated by the Bureau of Meteorology (BoM) and the New South Wales Office of Environment and Heritage (NSW OEH). All stations from which data were sourced are operated in accordance with Australian Standard AS 3580.14-2011 Meteorological Monitoring for ambient air quality monitoring applications. The purpose of this standard is to ensure that meteorological parameters are accurately defined and representative of the wider area.

Location of instruments is critical for the measurement of meteorological parameters. The Australian Standard stipulates that wind should be measured at 10 metres above ground level, and must be at a distance of at least 10 times the height of all obstructions (trees, buildings etc.) within a defined distance. This is because obstructions may influence measured wind by -50% to +100% in speed and more than 90° in direction when compared with wind representative of the wider area.

The Australian Standard also sets a schedule for critical performance checks and calibrations to ensure that instrumentation is in operable condition and measurements are within specified tolerances. It is also critical that data recorded during calibration or maintenance procedures are removed from the final validated data set. This is because meteorological data cannot be accurately validated unless correct calibration, maintenance and checks are performed on the instrumentation at regular intervals.

Non-conformance to the Australian Standard may result in meteorological data that significantly deviates from actual conditions. If such data are used as input in an air dispersion model, predictions made with the model may also deviate significantly from reality. As such, the Environment Protection Authority requires meteorological equipment used for the collection of data used in dispersion modelling to be established, sited, operated and maintained in accordance with Australian Standards

The National Association of Testing Authorities (NATA) is the authority responsible for the accreditation of laboratories, inspection bodies, calibration services, technical operators, producers of certified reference materials and proficiency testing scheme providers throughout Australia.

The NorthConnex project monitoring stations are all operated to NATA standards by experienced industry specialists. Monitoring stations operated by the Office of Environment and Heritage are also to NATA standards.

Community meteorological monitoring data

Several submissions received in response to the exhibition of the environmental impact statement made reference to a community meteorological monitoring station in Wahroonga.

Reasonable endeavours have been made to identify the location of this meteorological monitoring station, but without success. Efforts to locate the monitoring station have included:

- Attendance at the location of the Wahroonga monitoring station site (at the coordinates listed on the Weather Underground website (http://www.wunderground.com/personal-weather-station/dashboard?ID=INEWSOUT355#history) (-33.712, 151.139)). This location is within Cherrywood Reserve, located on land between Cherrywood Avenue and Bunyana Avenue, Wahroonga. No evidence of a monitoring station could be identified at this location.
- Doorknocks of properties around the listed location of the monitoring station. None of the local residents who were spoken to were aware of or knew the location of a local meteorological monitoring station.

Based on the coordinates listed on the Weather Underground website, the Wahroonga monitoring station appears to be located in an area surrounded by medium density residential development and a large number of mature trees. Based on this and the lack of visibility of a monitoring station tower during attendance at the site, it is considered likely that the station is not sited in accordance with AS 3580.14-2011 due to the number of obstacles (trees) within a short distance of the listed location of the station. The presence of obstacles can significantly affect wind readings, and it is likely that data from this station will not be representative of the winds in the wider local area.

Despite uncertainty over the quality of data from community meteorological monitoring stations in the area, the data that is available on the Wunderground website from several of those stations has nonetheless been analysed. Community weather stations in the vicinity of the northern ventilation outlet have been identified at Wahroonga, Asquith, Florence Cotton Reserve, Normanhurst, Turramurra and St Ives. Due to differences in the types of data collected at the stations and limitations on website data availability, the only data that could be compared between the community stations and the project monitoring station at James Park were average wind speed and average temperature.

The average temperature data recorded at community monitoring stations between January and August 2014 are shown in **Figure 2-11**. In contrast to the wind speed data discussed below, there was a high degree of consistency in average temperatures measured at each of the community weather stations and the project monitoring station at James Park. The average temperatures recorded at James Park were typically within one degree of the average temperatures from the community weather stations. This is not unexpected because temperature is not as dependent on location as wind speed in the area of investigation.

The average wind speed data collected between January 2014 and August 2014 are shown in **Figure 2-12**. It should be noted that, due to the inconsistent formatting of monthly data on the community weather station website, the available monitoring station data does not correspond exactly to calendar months. The data has, however, been investigated in a manner that provides a summary of each stations interpretation of the conditions within the month.

As shown in **Figure 2-12**, the average wind speeds measured at the project monitoring station at James Park were consistently higher than the wind speeds measured at each of the community weather stations. The highest wind speeds at community weather stations were recorded at Florence Cotton Reserve and Asquith. There is, however, great variability between the average wind speeds measured at the community weather stations. As such, it can be concluded that wind conditions within the area of investigation are likely to be heavily influenced by near field obstructions, further strengthening the likelihood that the community stations are not sited in accordance with AS 3580.14-2011, so that their wind measurements reflect very local conditions and not, for example, those in the vicinity of the ventilation outlets. Therefore in accordance with Environment Protection Authority requirements, the community stations cannot be used in the dispersion modelling assessment.

The Wahroonga community monitoring station available on the Weather Underground website is identified as the closest community monitoring station to the northern ventilation outlet. The site is located around 2.2 kilometres to the east of the ventilation outlet.

A high-level comparison has been undertaken to attempt to identify any trends and similarities between data collected at the Wahroonga community monitoring station and the James Park project monitoring station.

The James Park project monitoring station is operated as part of the NorthConnex project by a NATA certified and experienced company. The collected data is processed through a vigorous validation procedure prior to being released. The station is compliant with Australian Standard AS 3580.14-2011 Meteorological Monitoring for ambient air quality monitoring applications. The site is located within an open park area, approximately 1.1 kilometres from the northern ventilation outlet.

The Wahroonga station data is only available from May 2014 and the validated James Park project station data from January to August 2014. As such the review is limited to the period from May 2014 to August 2014.

Monitoring data for the entire May to August period, 9am and 3pm at the James Park monitoring station show a predominant wind direction from the west with minor winds from all other directions, and an average wind vector of 261 degrees. Winds were predominantly from the west at 9am and from the west and south east at 3pm.

Figure 2-11 Temperature data from community monitoring stations

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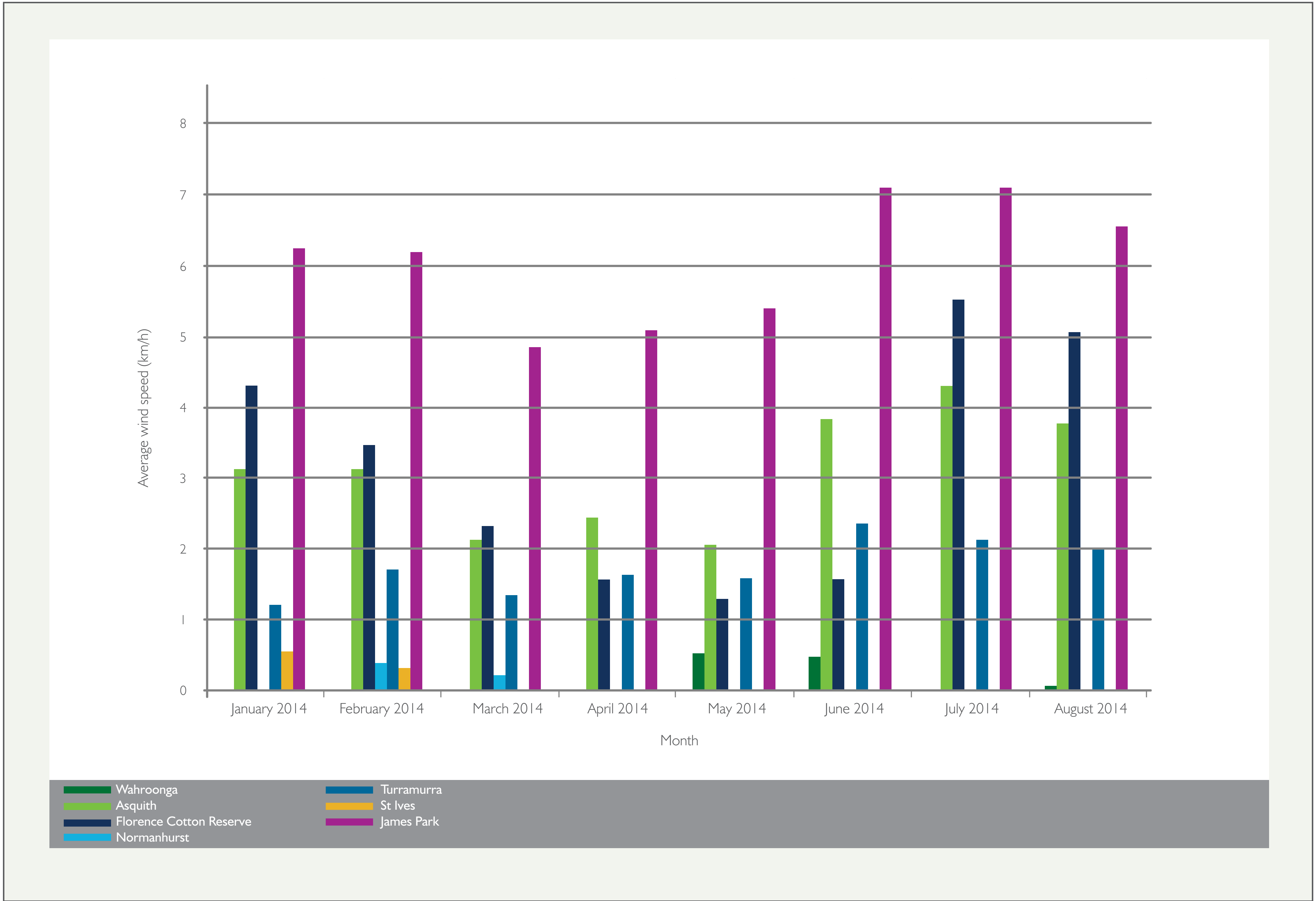

Figure 2-12 Wind speed data from community monitoring stations

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The Wahroonga data show winds predominately from the north, with an average wind vector of 357 degrees. Winds were predominantly from the north west at 9am and from the west and south at 3pm. During periods of inconsistent and missing data within the Wahroonga dataset the wind direction typically defaulted to a northerly direction. This default to a northerly direction in low to zero wind speed conditions consequently introduced a high likelihood of a northerly bias into the monitoring data that is probably inconsistent with actual conditions.

The two data sets do not seem to correlate wind direction well for the entire period or 9am wind roses. They do show some, albeit low, correlation for the 3pm wind rose with both showing a higher proportion of westerly data and some scatter to the south and south east.

The calm percentage (wind speeds less than 0.5 m/s) for the May to August period for James Park was nine per cent compared to 90 per cent for Wahroonga. The data show that the maximum hourly average wind speed for the James Park data was 8.5 m/s while for the Wahroonga data it was 2.0 m/s. The wind speed trends show no real correlation between datasets. The James Park data show a more typical trend with decreasing wind counts as wind speed increases. The Wahroonga data shows the majority of the wind speed range is calm, with no wind counts greater than 2 m/s.

It should be noted that there was a great deal of inconsistent and missing data from the community weather stations as well as inconsistent averaging periods and data that appeared to be invalid in accordance with AS 3580.14-2011. The Wahroonga monitoring station, for example, was estimated to have a data capture rate of about 50%. It has an average wind speed of zero kilometres per hour for the month of July compared to 7.1 kilometres per hour at James Park. The Wahroonga station data shows 30 out of 31 days as having a zero kilometre per hour reading for this month. It is highly unlikely that the Wahroonga station had no measurable winds for 96 per cent of the month; it is more likely that the station's measuring sensitivity is not appropriate, the stall speed is too high, the station was malfunctioning and recording zero, or that the station siting is not appropriate. During these periods of inconsistent and data missing the wind direction typically defaults to a northerly direction. This default to a northerly direction in low to zero wind speed conditions consequently introduced a high likelihood of a northerly bias into the monitoring data that is probably inconsistent with actual conditions.

Based on the analysis above, it is concluded that the Wahroonga data set does not represent the winds in the project area but rather just those in the very close vicinity of the measuring instrument, i.e. it is not sited in accordance with AS 3580.14-2011. Furthermore, there appear to be significant uncertainties in the recorded wind speeds (far too many calms, probably due to high start/stall speeds) and wind directions (due to the default to north when the wind speed was measured to be zero).

Project meteorological monitoring data

As discussed in the environmental impact statement and earlier in this report, a series of five monitoring stations have been installed and operated along the project corridor since late 2013. The monitoring stations have collected background air quality and meteorological data.

Two of the monitoring stations – at James Park, Hornsby and at Rainbow Farm Reserve, Carlingford – are the closest project monitoring stations to the northern and southern ventilation outlets, respectively. The Rainbow Farm Reserve monitoring station is located reasonably close to the site for the southern ventilation outlet, and is representative of local meteorological conditions. The James Park site is further distanced from the northern ventilation site, but is nonetheless reasonably representative of local meteorological conditions.

Both the James Park and the Rainbow Farm Reserve monitoring stations record temperature, relative humidity, wind direction and wind speed. At the time of conducting the air quality impact assessment presented in the environmental impact statement, data were available from:

- The Rainbow Farm Reserve monitoring station from 16 January 2014 to 30 April 2014.
- The James Park data monitoring station from 3 December 2013 to 31 May 2014.

An initial review and comparison of meteorological data (wind speed, direction and frequency) has been conducted based on CALMET data used in the air dispersion modelling for the project and monitored data from each of the Rainbow Farm Reserve and James Park monitoring stations. From this comparison, the CALMET data shows a greater range in wind directions that project monitoring data. A higher percentage of calm conditions and very low wind speeds have also been recorded at the project monitoring stations than have been predicted in the CALMET data. This is consistent with the broader discussion about calm and low wind conditions presented earlier in this section.

Observations that can be made from the comparison of CALMET and project monitoring data include:

- The Rainbow Farm Reserve data shows a relatively high proportion of wind from the north-west, which are not similarly reflected in the CALMET data. Most of the Rainbow Farm Reserve data shows winds from the south-west to the north. In comparison, most of the CALMET data shows wind from the west-southwest to the south-southeast.
- The James Park meteorological data and the CALMET meteorological data are similar in terms of wind direction. However, the CALMET data show a greater spread of wind directions.

Overall, the CALMET data shows higher wind speeds and a lower percentage of calm conditions than recorded at James Park or at Rainbow Farm Reserve.

It is important to note the following regarding the James Park and Rainbow Farm Reserve meteorological monitoring data:

- Missing data – A substantial amount of data are missing for the monitoring period (more than 20 per cent of data are missing from James Park and < 20 per cent for Rainbow Farm Reserve).
- Interference– Based on the expected wind patterns and the measured winds at Rainbow Farm Reserve, there appears to be some interference by the large trees located to the west of the Rainbow Farm Reserve monitoring station (despite the station being located in accordance with AS3580.14-2011). Winds from the west are usually the dominant flow for the region, but were rarely recorded by this monitoring station.
- Wind speed - The measured wind speeds at Rainbow Farm Reserve and James Park are unusually low. At Rainbow Farm Reserve, more than 38 per cent of all measured wind speeds fell between 0.5 and 1 m/s (1.8 to 3.6 km/h). At James Park, 30 per cent of the winds were less than 1 m/s (3.6 km/h) and 48 per cent of the winds were between 1 and 3.3 m/s (11.8 km/h). The fastest wind speed recorded at both Rainbow Farm Reserve and James Park was 5.4 m/s (19.4 km/h).

Based on available data from project monitoring stations and the limitations referred to above, a conclusive comparison between project monitoring station data and CALMET data is not possible. However, there is sufficient information to form a general view that there is likely to be a higher percentage of calm and very low wind conditions experienced around the northern and southern ventilation outlets than reflected in the CALMET meteorological data.

The tendency for calm conditions to be under predicted by the CALMET meteorological is recognised, and typically taken into account when analysing and interpreting related air dispersion modelling predictions. As part of this analysis and interpretation, it is important to recognise that plume behaviour is influenced by two significant factors:

- Plume velocity and buoyancy, which drive the vertical component of a plume, pushing it into the atmosphere. Some of this upward energy will contribute to dispersion of the plume as it rises.
- Ambient winds, which drive the horizontal or lateral component of plume, pushing it away from a straight vertical ascent. Energy from ambient winds will contribute to dispersion of the plume.

The balance between the vertical and horizontal forces affecting a plume will determine how high it rises before 'bending' from its vertical ascent, and the degree to which the plume 'bends'. Under high winds, a plume is more likely to be dominated by a horizontal component, leading to early plume 'bending' and increased horizontal dispersion. In the case of calm or very light winds, a plume is likely to ascend much higher before being affected by significant horizontal dispersion. Depending on the specific situation, it is therefore often moderate winds, rather than high wind speeds or calm conditions that are of particular interest when considering peak ground level air quality impacts.

In the case of the NorthConnex project, a preliminary analysis suggests that the plumes could rise up to around 100 metres above each of the ventilation outlets in calm conditions. Under high wind conditions, the plumes are expected to rise by up to around 30 metres above the ventilation outlets before being significantly affected by the horizontal component of ambient winds. This would suggest that calm conditions and low wind speeds may not be the limiting factor when assessing the potential peak air quality impacts of the project. This issue is considered further in the analysis in the following section.

2.11 Ambient air quality

This section provides information and discussion of:

- The approach taken to selecting background (ambient) air quality data for use in the air quality impact assessment for the project.
- Consideration of the representativeness of background air quality data having regard to local data collected from project monitoring stations.

2.11.1 Approach taken for the project

The air quality impact assessment for the project has been carried out in accordance with the Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (DEC, 2005a) (the Approved Methods guidelines). This involved preparing a dispersion model with site-specific background air quality data and meteorological data inputs.

The Approved Methods guidelines require a minimum of one year of background air quality data and meteorological data in the dispersion model. The NorthConnex dispersion model has used three years of background air quality and meteorological data, to provide a more rigorous and comprehensive analysis of potential air dispersion scenarios.

The Approved Methods guidelines recognise that it is ideal to gather background air quality monitoring data from the site of a proposed development. The Approved Methods guidelines recognise that it is 'extremely rare' for one year of background air quality monitoring data to be available. Where it is available, the Approved Methods guidelines recommend that data be sourced from a location as close as possible to the proposed development site where the sources of air pollution resemble the existing sources at the proposed development site.

At the time of conducting the air quality impact assessment for the project, background air quality and meteorological data was available from:

- Several years of background air quality and meteorological data available from an existing network of monitoring stations operated by the Office of Environment and Heritage and the Australian Bureau of Meteorology across the Sydney Metropolitan Area. There are 15 monitoring stations in the Sydney region (including the Southern Highlands), the two nearest monitoring stations to the project being Prospect and Lindfield.
- Around four months of background air quality and meteorological data from five monitoring stations installed along the NorthConnex project corridor. The two road monitoring stations were positioned close to Pennant Hills Road (to monitor air quality for receivers significantly affected by traffic emissions along the Pennant Hills Road corridor) and the three ambient monitoring stations were positioned away from Pennant Hills Road (to monitor air quality for receivers away from and not significantly affected by traffic emissions along the Pennant Hills Road corridor, or from other major road sources). Air quality and meteorological data have continued to be collected from these monitoring stations, with data up to and including August 2014 available at the time of preparation of this report (around nine months of data in total).

The background air quality and meteorological data from the Office of Environment and Heritage and the Australian Bureau of Meteorology was identified as satisfying the requirements of the Approved Methods guidelines. The first requirement is satisfied because more than a year's worth of data was available and the sources of air pollution resemble existing sources in the project area. Relevantly, areas around Lindfield and Prospect exhibit similar land use patterns and development types as exists along the project corridor, with principal sources of air pollution similar in scale and nature.

For the second requirement of the Approved Methods guidelines, the background air quality data from the Office of Environment and Heritage monitoring stations has been compared with data collected from the ambient monitoring stations installed along the Pennant Hills Road corridor to determine whether it is representative of background air quality around the NorthConnex project. These data are presented in **Table 2-52**.

Receivers in proximity to Pennant Hills Road and other major roads are recognised as likely to experience higher levels of background air pollution compared to receivers further removed from those major roads. This can be seen by comparing the data presented in **Table 2-52**, from the project road monitoring stations (located close to Pennant Hills Road), with the data from the project ambient monitoring stations (located away from Pennant Hills Road). In all cases, concentrations of relevant air pollutants are markedly higher at monitoring stations close to Pennant Hills Road.

To adequately account for the influence of vehicle emissions along Pennant Hills Road and other major roads, background air quality along major road corridors was modelled at more than 6,900 locations using an advance dispersion model (CAL3QHCR) developed for application to linear sources such as roads. Full details of this modelling are provided in the Technical Paper: Air Quality (Appendix G to the environmental impact statement).

The results of this air quality modelling were compared to the background air quality measured for receivers away from the influence of vehicle emissions from major roads (ie data from existing monitoring stations). Where the major road air quality modelling results were higher than background air quality data, the modelled background air quality results were applied rather than background air quality data from monitoring stations.

In relation to cumulative pollutant concentrations, Table 7-97 of the environmental impact statement provides the peak cumulative concentration of all assessed pollutants (ie the project contribution plus the background concentration).

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Table 2-52 Background air quality monitoring data

Pollutant (averaging period)	Statistic	Project road monitoring stations (December 2013 – August 2014)		Project ambient monitoring stations (December 2013 – August 2014)			OEH monitoring stations – Prospect and Lindfield		
		Observatory Park	Brickpit Park	Headen Sports Park	Rainbow Farm Reserve	James Park	Year 1	Year 2	Year 3
PM_{10} (24-hour) (µg/m^3)	Maximum	50	47	40	35	41	222	48	42
	95th percentile	32	29	26	22	25	36	27	28
	Average	20	18	14	13	16	21	16	16
$PM_{2.5}$ (24-hour) (µg/m^3)	Maximum	38	32	30	29	27	78	17	15
	95th percentile	20	17	16	16	15	13	10	10
	Average	12	9	10	8	9	7	6	6
NO_2 (1-hour) (µg/m^3)	Maximum	155	109	90	107	87	100	81	75
	95th percentile	89	62	44	58	48	47	49	47
	Average	42	29	17	26	18	22	23	22
CO (1-hour) (µg/m^3)	Maximum	2,251	1,373	2,205	1,884	1,693	3,625	3,250	2,875
	95th percentile	1,138	678	577	789	514	1,125	1,000	1,000
	Average	453	314	216	302	214	451	419	419
O_3 (1-hour) (µg/m^3)	Maximum	119	162	156	154	173	218	204	247
	95th percentile	49	61	68	61	67	86	76	71
	Average	19	28	35	26	35	36	32	32

Project NO_2, CO and O_3 values have been converted to µg/m^3 @ 0ºC, using the conversion factors in Section 12, Table 12.1 of the Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (DEC, 2005a)

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