2.15.2 Further analysis of air quality modelling results (increased ventilation outlet height)

This section presents a more detailed analysis and explanation of the factors that have contributed to the counterintuitive results presented in **Section 2.15.1**. In particular the combination of an increase in ventilation outlet heights and the amended model assumptions and inputs that have generated a set of predicted project contributions to ambient air which results in an overall significant reduction in air quality impacts from operation of the project (albeit from an already low base).

A high level review of dispersion modelling outputs suggests that where ground level concentrations of pollutants have increased as a result of increasing the ventilation outlet heights, this is the result of a very small number of events that have affected the predicted peak concentrations for these pollutants. The frequency of these events is around once in the three years of modelling data.

For the purpose of this further analysis, predicted air quality impacts under forecast traffic volumes in 2019 have been considered. It is relevant to note that the factors that may have contributed to the counterintuitive air quality assessment results are common to all of the air quality impact assessment scenarios (ie the meteorological dataset, the amended modelling assumptions and inputs and the increased ventilation outlet heights). Therefore, this analysis is independent of the air quality impact assessment scenario that is considered, with similar conclusions likely to be drawn from analysis of other assessment scenarios.

Contextualisation of the issue(s)

The air quality modelling results presented in **Section 2.15.1** of this report show changes in predicted peak ground level concentrations (project contributions only) that differ from those presented in the environmental impact statement. Changes in predicted ground level concentrations are expected based on changes made to the modelling assumptions and inputs and the increased ventilation outlet heights.

Because each of these factors (ie changes in modelling assumptions and the increase in ventilation outlet heights) will affect predicted ground level concentrations in different ways, modelling results have been considered for three scenarios:

- **EIS15** – this scenario is identical to the assessment presented in the environmental impact statement (EIS). It includes ventilation outlets at 15 metres and no changes to modelling assumptions and inputs.
- **SPIR15 –** this scenario only incorporates changes to modelling assumptions and inputs detailed in this submissions and preferred infrastructure report (SPIR). It includes ventilation outlets at 15 metres (ie no increase in ventilation outlet height).
- **SPIR20** – this scenario incorporates both the changes to the modelling assumptions and inputs and the increase in ventilation outlet heights detailed in this submissions and preferred infrastructure report (SPIR). It includes ventilation outlets at 15 metres.

Table 2-78 in **Section 2.15.1** summarises the change in predicted ground level concentrations between the environmental impact statement (**EIS15**) and the project presented in this report (**SPIR20**).

The expectation for an increase in outlet height would be that ground level concentrations would decrease. However, some peak ground level concentrations of pollutants have been modelled to increase for short term average periods. Analysis of the modelling outputs indicates that these increased peak ground level concentrations are the result of rare events that appear in the modelling outputs at a frequency of around one event in the whole three years of modelling data.

A potentially contributing factor to these unexpected results is the amended modelling inputs and assumptions that have been detailed in this chapter and applied to updated air quality modelling:

- Increasing the resolution of the receiver grid applied around each ventilation outlet (ie reduced receiver spacing) (refer to **Section 2.13.1**).
- Applying higher resolution topographic data (refer to **Section 2.12**).
- Revising future projections of vehicle fleet fuel mix, to reflect an increased use of diesel fuel in the future) (refer to **Section 2.7**).
- Amending the ozone limiting method equation to take into account a NO_2:NO_x ratio of 16 per cent, as recommended by the Environment Protection Authority (refer to **Section 2.14**).

To test whether some or all of these amended assumptions and inputs are a significant contributor to the unexpected ground level concentration results, the **SPIR15** scenario has been modelled. This scenario includes the amended assumptions and inputs, but retains 15 metre high ventilation outlets. By modelling the **SPIR15** scenario, a base line can be established against which to assess only the increase in ventilation height (noting that the **SPIR15** and **SPIR20** include the same amended assumptions and inputs, with the only difference between them being ventilation outlet height).

Table 2-79 summarises the outcomes of modelling **SPIR15** for forecast traffic flows in 2019, and compares these results with the **EIS15** results. The data in the table showing the relative change in ground level concentrations are solely attributable to amended modelling assumptions and inputs (as this is the only difference between **EIS15** and **SPIR15**).

Table 2-79 shows the following:

- For all pollutants and averaging times (with the exception of one hour average NO_2 at the southern ventilation outlet), the **SPIR15** scenario shows lower predicted project contributions than the **EIS15** scenario.
- The reductions in predicted project contributions (designated in green shading in the table) ranged from four per cent to 44 per cent.
- Overall, these observations support the conclusion that amendments to modelling assumptions and inputs are not the cause of increased ground level concentrations when considering the increase in ventilation outlet heights (the **SPIR20** scenario).

Table 2-79 Comparison of EIS15 and SPIR15 results (relative change)

Pollutant	Averaging period	Scenario	Predicted maximum project contribution (µg/m³)	
			Northern ventilation outlet	Southern ventilation outlet
PM_{10}	24 hour maximum	EIS15	0.94	1.2
		SPIR15	0.76	0.91
		Change (SPIR15 relative to EIS15)	-19%	-27%
	Annual average	EIS15	0.08	0.08
		SPIR15	0.06	0.05
		Change (SPIR15 relative to EIS15)	-19%	-43%
$PM_{2.5}$	24 hour maximum	EIS15	0.88	1.21
		SPIR15	0.72	0.86
		Change (SPIR15 relative to EIS15)	-18%	-29%
	Annual average	EIS15	0.07	0.07
		SPIR15	0.06	0.04
		Change (SPIR15 relative to EIS15)	-19%	-43%
NO_2	One hour maximum	EIS15	68.9	61.8
		SPIR15	58.7	76.4
		Change (SPIR15 relative to EIS15)	-15%	+24%
	Annual average	EIS15	1.4	1.2
		SPIR15	0.7	1.0
		Change (SPIR15 relative to EIS15)	-53%	-15%
CO	One hour average	EIS15	86.6	70.1
		SPIR15	83.0	43.2
		Change (SPIR15 relative to EIS15)	-4%	-38%
	Eight hour average	EIS15	32.4	27.3
		SPIR15	22.2	16.8
		Change (SPIR15 relative to EIS15)	-32%	-38%
Total VOCs	One hour, 99.9th percentile	EIS15	3.46	3.45
		SPIR15	3.24	1.91
		Change (SPIR15 relative to EIS15)	-6%	-44%
PAHs	One hour, 99.9th percentile	EIS15	0.0006	0.0006
		SPIR15	0.0006	0.0004
		Change (SPIR15 relative to EIS15)	-4%	-44%

Analysis of the **SPIR15** scenario indicates that changes to modelling assumptions and inputs are not the cause of the predicted increase in ground level concentrations relative to the **EIS15** scenario (as summarised in **Table 2-78**). It should be noted that the increase in NO_2 concentrations an artefact of the application of the ozone limiting method. The effect of the ozone limiting method is analysed and explained later in this section.

To clarify the implications of increasing ventilation outlet heights in isolation, modelling results for **SPIR15** and **SPIR20** have been compared. Both of these scenarios include amended modelling assumptions and inputs, and the only difference between the two is ventilation outlet height. The comparison of modelling results for these two scenarios under forecast traffic flows in 2019 is presented in **Table 2-80**.

- All longer term averaging periods show a decrease in ground level concentrations with an increase in ventilation outlet height.
- All percentile pollutant concentrations (total VOCs and PAH) show a decrease in the ground level pollutant concentrations with an increase in ventilation outlet height.
- Short term averaging periods for CO (one and eight hour averages) show an increase in maximum ground level concentrations whilst the peak short term averaging periods for NO_2 (one hour average) show a decrease in ground level concentrations.
- Short term particulate concentrations (24 hour average) show an increase in concentrations for the northern ventilation outlet and a decrease in concentrations for the southern ventilation outlet.

Based on these observations, it has been identified that the cause of the unexpected air quality outcomes modelled for an increase in ventilation outlet heights is likely to be:

- An infrequent and/ or shorter-term or short duration issue, because it appears to affect short term averaging period concentrations more than longer term averages.
- Affecting the northern and southern ventilation outlets in different ways (despite both ventilation outlets being the same height).

The following sections analyse and explain the reasons for the unexpected modelling outcomes and demonstrate that they are caused by rare and infrequent meteorological conditions. These rare meteorological conditions and infrequent peak ground level concentrations of pollutants would not typically occur during operation of the project.

Table 2-80 Comparison of SPIR15 and SPIR20 results (relative change)

Pollutant	Averaging period	Scenario	Predicted maximum project contribution (µg/m^3) Northern ventilation outlet	Southern ventilation outlet
PM_{10}	24 hour maximum	SPIR15	0.76	0.91
		SPIR20	1.00	0.60
		Change (SPIR20 relative to SPIR15)	+32%	-34%
	Annual average	SPIR15	0.06	0.05
		SPIR20	0.04	0.03
		Change (SPIR20 relative to SPIR15)	-31%	-29%
$PM_{2.5}$	24 hour maximum	SPIR15	0.72	0.86
		SPIR20	0.96	0.60
		Change (SPIR20 relative to SPIR15)	+33%	-30%
	Annual average	SPIR15	0.06	0.04
		SPIR20	0.04	0.03
		Change (SPIR20 relative to SPIR15)	-30%	-29%
NO_2	One hour maximum	SPIR15	58.7	76.4
		SPIR20	54.3	69.0
		Change (SPIR20 relative to SPIR15)	-7%	-10%
	Annual average	SPIR15	0.7	1.0
		SPIR20	0.5	0.7
		Change (SPIR20 relative to SPIR15)	-30%	-31%
CO	One hour average	SPIR15	83.0	43.2
		SPIR20	181.8	48.4
		Change (SPIR20 relative to SPIR15)	+119%	+12%
	Eight hour average	SPIR15	22.2	16.8
		SPIR20	36.0	17.2
		Change (SPIR20 relative to SPIR15)	+62%	+2%
Total VOCs	One hour, 99.9th percentile	SPIR15	3.24	1.91
		SPIR20	2.2	1.5
		Change (SPIR20 relative to SPIR15)	-32%	-22%
PAHs	One hour, 99.9th percentile	SPIR15	0.0006	0.0004
		SPIR20	0.0004	0.0003
		Change (SPIR20 relative to SPIR15)	-31%	-22%

Short term NO_2 and CO concentrations

Why do the short term NO_2 and CO average concentrations not follow the same trend for 15 metre and 20 metre ventilation outlet heights?

The dispersion modelling for CO and the NO_2 are handled in different ways.

Both the NO_X and CO emissions data are entered into the dispersion model and predicted ambient concentrations are generated for the different averaging periods. In the case of NO_x only, these predicted ambient concentrations are further processed following the dispersion modelling to take into account conversion of NO_x to NO_2 (via the ozone limiting method in the case of this assessment).

Based on the different processing requirements for the NO_2 and CO data, a comparison of the trends between NO_2 and CO data is not considered valid. A more valid comparison is the analysis of the CO data and the NO_X data prior to post-dispersion model processing of the NO_x predictions (to calculate NO_2 concentrations). This analysis has been conducted and is presented in **Table 2-81**.

Table 2-81 shows that:

- The NO_X concentrations increase for the one hour average data between the **SPIR15** scenario and the **SPIR20** scenario.
- The short term average trends are now similar for NO_X and CO predictions with the only difference in the trends being that the northern ventilation outlet results show a higher increase that for the southern ventilation.

This analysis indicates that NO_x and CO are being affected in a similar way, and that it is the application of the ozone limiting method during the post-dispersion model processing that is obscuring the similarity of this relationship.

Table 2-81 Comparison of SPIR15 and SPIR20 CO and NO_x results (relative change)

Pollutant	Averaging period	Scenario	Predicted maximum project contribution ($\mu g/m^3$)	
			Northern ventilation outlet	Southern ventilation outlet
NO_x	One hour maximum	SPIR15	119.3	50.3
		SPIR20	261.4	56.4
		Change (SPIR20 relative to SPIR15)	+119%	+12%
	Annual average	SPIR15	1.04	0.49
		SPIR20	0.72	0.35
		Change (SPIR20 relative to SPIR15)	-31%	-30%
CO	One hour average	SPIR15	83.0	43.2
		SPIR20	181.8	48.4
		Change (SPIR20 relative to SPIR15)	+119%	+12%
	Eight hour average	SPIR15	22.2	16.8
		SPIR20	36.0	17.2
		Change (SPIR20 relative to SPIR15)	+62%	+2%

Short term pollutant concentrations increasing with ventilation outlet height

Why do short term pollutant concentrations increase with an increase in ventilation outlet height?

The data presented in **Table 2-80** show peak short term average concentrations increasing with ventilation outlet height. The key exception to this trend is the percentile pollutants (PAHs and total VOCs) which show a reduction in ground level concentration with increased ventilation outlet height. It is important to note that the concentrations of the percentile pollutants are calculated after excluding the eight highest predicted concentrations. A similar trend is also not evident in annual average concentrations, which all show a decrease in ground level concentration with an increase in ventilation outlet height.

These observations suggest that there may be a short term and infrequent meteorological condition leading to unexpected increases in ground level concentrations with increased ventilation outlet height.

To consider this in more detail, the 10 highest predicted concentrations at the three most affected receiver locations have been analysed for both **SPIR15** and **SPIR20** scenarios. Hourly data for the full 2009 modelling year has been analysed, with data ranked by magnitude of predicted ground level concentration. The resultant ranked data is provided in **Table 2-83** (**SPIR15**) and **Table 2-84** (**SPIR20**).

Comparing the data in **Table 2-82** and **Table 2-83** makes it apparent that a small number of individual events (single hours) are leading to an increase in peak one hour average concentrations of CO with an increase in ventilation outlet height. These individual events have been shaded in **Table 2-82** and **Table 2-83**.

Analysis of the data in **Table 2-82** and **Table 2-83** indicates that for:

- A 15 metre ventilation outlet height (**SPIR15**):
  - The peak CO (one hour) concentration is predicted to be 83.03 µg/m^3. The highest impact occurs at 8:00 on day 357.
  - The second highest CO (one hour) concentration is predicted to be 25.71 µg/m^3, which is 69 per cent lower than the peak concentration.
- A 20 metre ventilation outlet height (**SPIR20**):
  - The peak CO (one hour) concentration is predicted to be 181.84 µg/m^3. The highest impact occurs at 17:00 on day 45.
  - The second highest CO (one hour) concentration is predicted to be 52.65 µg/m^3, which is 71 per cent lower than the peak concentration.

Other trends that can be observed from the data in **Table 2-82** and **Table 2-83** include:

- The peak CO (one hour average) concentration for the **SPIR15** scenario, whilst elevated, remains below the predicted air quality impacts presented in the environmental impact statement. The conclusions reached with respect to the acceptability of the predicted air quality impacts presented in the environmental impact statement therefore remain valid and applicable for the **SPIR15** scenario.
- The hour in which the peak concentration for the **SPIR15** scenario modelling occurs is 8:00 on day 337. With the increase in outlet height for the **SPIR20**

scenario, hour 8:00 on day 337 represents the second highest concentration. If the same hour on the same day is compared (ie 8:00 on day 337 at receiver location 337), the increase in ventilation outlet height would decrease the concentration of CO (one hour) from 83.03 µg/m^3 to 52.65 µg/m^3 (ie a 63 per cent reduction as a result of the increased ventilation height).

Analysis of the meteorological data contributing to the results in **Table 2-82** and **Table 2-83** indicates that for both the SPIR15 and SPIR20 scenarios, elevated ground level concentrations are the result of a very small number of meteorological conditions. These rare and infrequent meteorological conditions are considered in more detail in the following sections of this report.

Table 2-82 Ranked CO concentrations (SPIR15) for the three most affected receiver locations

Rank	Receiver location 3286			Receiver location 3284			Receiver location 3258		
	Day	Hour	Concentration ($\mu g/m^3$)	Day	Hour	Concentration ($\mu g/m^3$)	Day	Hour	Concentration ($\mu g/m^3$)
1	337	8:00	83.03	337	8:00	82.58	337	8:00	81.85
2	45	17:00	25.71	45	17:00	26.13	45	17:00	21.65
3	353	9:00	19.62	353	9:00	19.97	353	9:00	19.18
4	65	10:00	15.85	65	11:00	17.10	65	11:00	17.63
5	65	11:00	14.93	65	10:00	16.04	65	10:00	16.44
6	59	11:00	14.58	230	12:00	14.06	248	11:00	15.25
7	319	10:00	14.19	248	11:00	13.43	230	12:00	14.73
8	347	10:00	13.83	59	11:00	13.22	45	16:00	14.36
9	230	12:00	13.80	244	12:00	12.11	325	9:00	13.82
10	244	12:00	13.18	248	10:00	12.04	290	10:00	13.33

Table 2-83 Ranked CO concentrations (SPIR20) for the three most affected receiver locations

Rank	Receiver location 3286			Receiver location 3284			Receiver location 3258		
	Day	Hour	Concentration ($\mu g/m^3$)	Day	Hour	Concentration ($\mu g/m^3$)	Day	Hour	Concentration ($\mu g/m^3$)
1	45	17:00	181.84	45	17:00	129.28	45	17:00	121.97
2	337	8:00	52.65	337	8:00	64.91	45	16:00	91.48
3	45	16:00	32.41	45	21:00	30.51	337	8:00	60.34
4	45	21:00	26.05	45	20:00	22.41	45	20:00	18.52
5	45	20:00	20.60	45	22:00	21.99	45	21:00	8.86
6	45	22:00	18.24	46	17:00	20.27	249	8:00	8.43
7	249	8:00	7.53	45	16:00	13.84	45	22:00	6.06
8	45	23:00	6.47	45	23:00	10.65	343	8:00	5.36
9	343	9:00	4.84	46	15:00	10.47	338	13:00	5.34
10	343	8:00	4.36	45	18:00	8.30	353	10:00	5.31

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Differences in PM_{10} and $PM_{2.5}$ at different ventilation outlets

Why does the short term average PM_{10} and $PM_{2.5}$ data increase at the northern ventilation outlet, but not at the southern ventilation outlet?

Table 2-80 shows that with an increase in ventilation outlet height, 24-hour average concentrations of particulate matter (PM_{10} and $PM_{2.5}$) increase at the northern ventilation outlet, but decrease at the southern ventilation outlet.

Analysis of the data for the two ventilation outlets shows that the peak PM_{10} and $PM_{2.5}$ concentrations at the northern ventilation outlet both occur on day 45. The same effect is not seen in data for the southern ventilation outlet.

The meteorological conditions leading to the peak particulate matter concentrations at the northern ventilation outlet are characterised by high wind speeds which lead to outlet tip downwash on day 45 of the modelling. This situation is a very unusual occurrence in the meteorology and is not considered to be representative of normal meteorological conditions in the area surrounding the northern ventilation outlet. In this case, the difference in air quality outcomes at the northern and southern ventilation outlets is a consequence of infrequent meteorological conditions (refer to the following sections of this report for discussion of these conditions).

Meteorological conditions as a potential cause

What are the rare and infrequent meteorological conditions that result in elevated ground level concentrations?

Based on the summary presented in **Table 2-82** and **Table 2-83**, day 337 and day 45 have been identified as most frequently experiencing elevated ground level concentrations. Wind conditions on those days, and for the times at and around those identified in **Table 2-82** and **Table 2-83** are summarised in the table below.

Table 2-84 Wind conditions leading up to and during predicted peak ground level concentrations

Day 337		Day 45	
Hour of day	**Scalar wind speed (m/s)**	**Hour of day**	**Scalar wind speed (m/s)**
6:00	1.9	14:00	2.8
7:00	0.8	15:00	4.3
8:00	0.1	16:00	9.5
9:00	1.2	17:00	11.9
10:00	1.8	18:00	13.6

Given predicted increases in short term average ground level concentrations with increased ventilation outlet height, and the relatively high wind speeds identified on day 45 in the table above, outlet tip downwash has been identified as a potential cause of unexpectedly high ground level concentrations. Outlet tip downwash can occur when the ratio between the outlet discharge velocity and ambient wind speed at the outlet height is less than 1.5.

To explore the potential for outlet tip downwash further, the hours of interest (from 15:00 to 23:00) on day 45 have been analysed for the northern ventilation outlet. For these hours, the ratio of outlet discharge velocity to ambient wind speed has been plotted and is show in **Figure 2-29**. The figure shows that the ratio of outlet discharge velocity to ambient wind speed is less than 1.5 for all hours analysed, suggesting that outlet tip downwash is likely to be a key contributing factor to elevated short term ground level concentrations during these times.

This hypothesis has been tested qualitatively by plotting the locations of the three most affected receiver locations for the **SPIR15** and **SPIR20** scenarios (for the northern ventilation outlet). These receiver locations are shown in **Figure 2-30**. All six locations lie within the road reserve of the M1 Pacific Motorway and do not impact on surrounding residential receivers.

Ordinarily an increase in the height of a ventilation outlet is expected to move the location of peak ground level impacts away from the ventilation outlet (ie discharge at a greater height increases the length of time before the peak effects of a plume are experience at ground level). **Figure 2-30** shows that the converse is true around the northern ventilation outlet, with the most affected receiver locations for the **SPIR20** scenario being located closer to the northern ventilation outlet than for the **SPIR15** scenario. This suggests that under certain conditions, the discharge plume is reaching ground level faster than anticipated, which is consistent with the effects of outlet tip downwash.

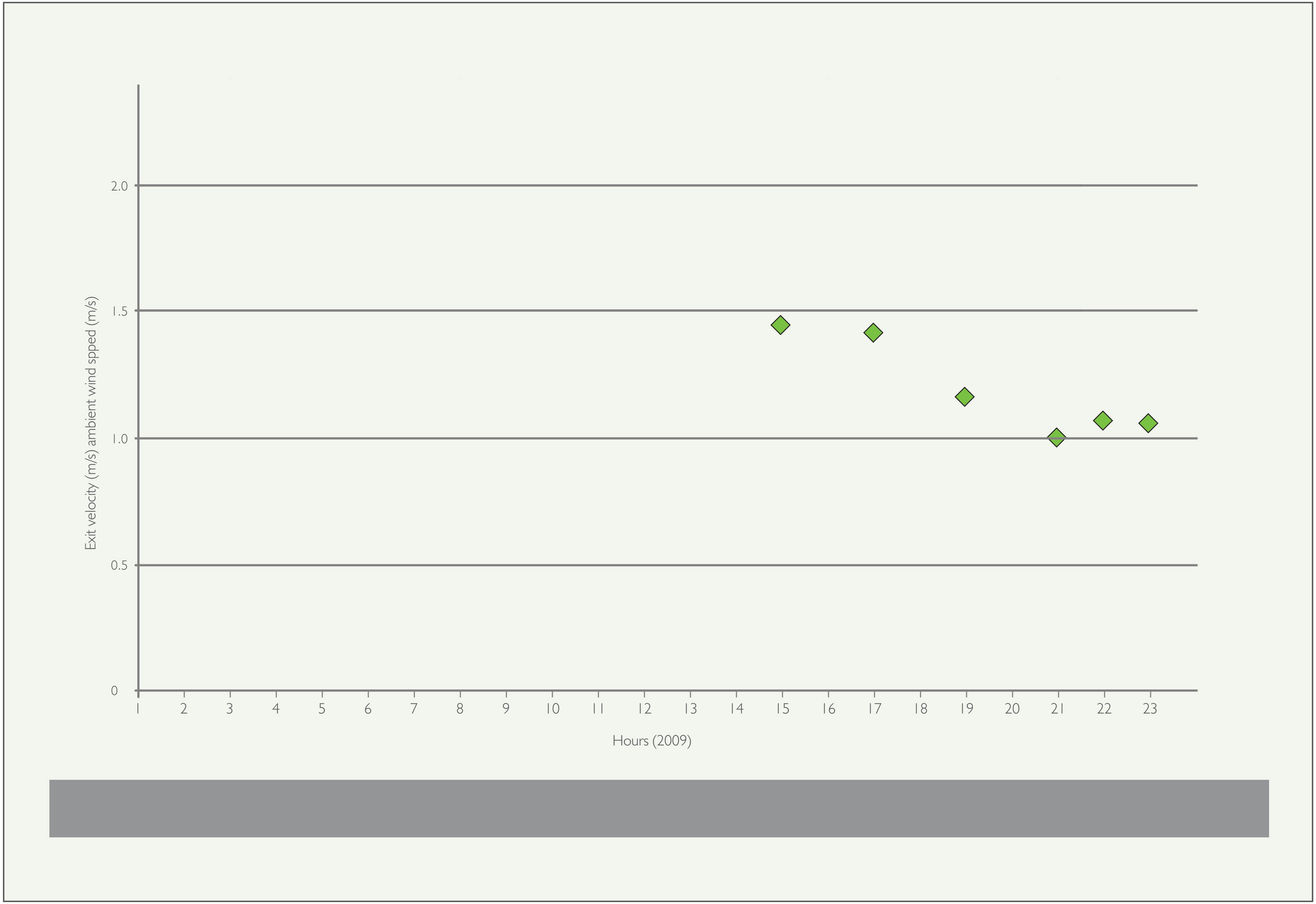

Figure 2-29 Ratio of discharge velocity to wind velocity on day 45 (hour 15:00 to hour 23:00)

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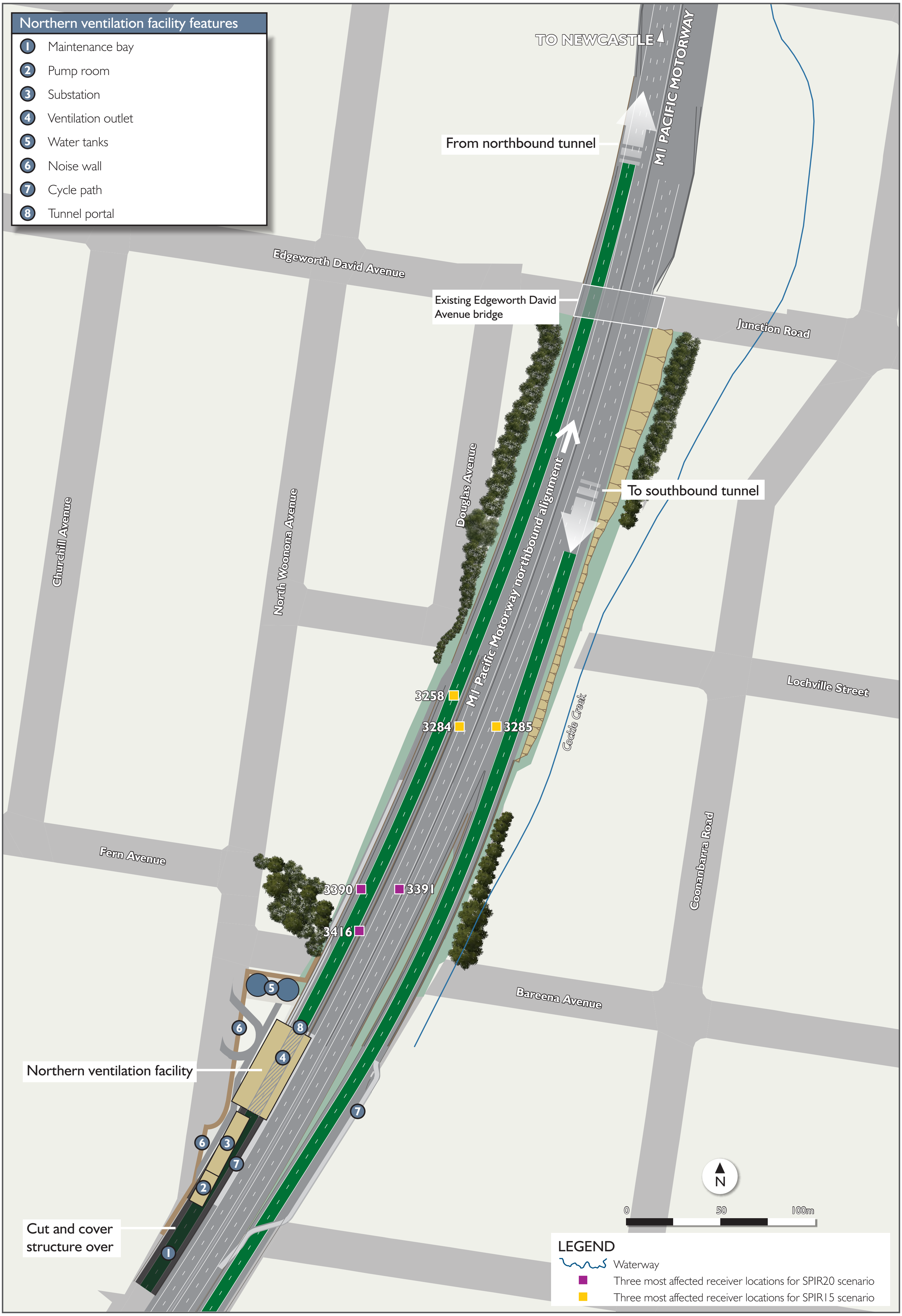

Figure 2-30 Three most affected receiver locations for SPIR15 and SPIR20

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The reality of meteorological conditions

Are the identified rare and infrequent meteorological conditions that result in elevated ground level concentrations real?

Further consideration has been given to rare and infrequent meteorological identified as contributing elevated ground level concentrations for short term averaging periods, and in particular:

- Hour 17:00 on day 45.
- Hour 8:00 on day 337.

Meteorological conditions at these times have been analysed to established whether they could plausibly occur in practice.

Hour 17:00 on day 45

Wind flow fields for hour 17:00 on day 45 are shown in **Figure 2-31** (at 10 metres), **Figure 2-32** (at 30 metres) and **Figure 2-33** (at 60 metres).

Based on the analysis of the wind field figures there does not appear to be anything erroneous or unrealistic with the meteorology. The day in question appears to be a windy day with winds at the northern ventilation outlet of 2.8 m/s at hour 14:00, 4.3 m/s at hour 15:00, 9.5 m/s at hour 16:00, 11.9 m/s at hour 17:00 and 13.6 m/s at hour 18:00. The wind speeds increase significantly with height. There is neutral stability so convective velocity is not responsible for the observed elevated ground level concentrations at these times.

In short, the meteorology on day 45 appears plausible and there is no reason to consider it as erroneous or unrealistic.

Hour 8:00 on day 337

Wind flow fields for hours around the hour of interest (ie before and after hour 8:00 on day 337) are shown in **Figure 2-34** (hour 7:00), **Figure 2-35** (hour 9:00), **Figure 2-36** (hour 10:00) and **Figure 2-37** (hour 11:00). Each of these wind fields is shown at 10 metres.

Based on analysis of these wind fields, the peak prediction CO concentrations (one hour average) at the northern ventilation outlet at hour 8:00 on day 337 (3 December 2009) is the result of the switch in flow from nocturnal offshore flow to onshore flow at that hour. The diurnal pattern of sea breeze giving way to land breeze happens every morning and evening. A series of spatial wind field plots from 7:00 to 11:00 shows relatively moderate onshore flow at Sydney airport and supported by MM5 data over the ocean, whilst inland stations at Terrey Hills and Lindfield show offshore flow consistent with the decaying land breeze. At 8:00 the interface between the land and sea breeze lies over the northern ventilation outlet and tunnel portals. The meteorology at the northern ventilation outlet and tunnel portals experiences a significant switch in meteorological conditions around this time.

Given the likelihood of wind shifts in the area around the project corridor, it is considered likely that these conditions would occur regularly. The potential implications of regular occurrence of these conditions are considered further in the following section. Despite these conditions potentially producing elevated ground level concentrations, the concentrations themselves are considered acceptable (in the context of the overall air quality impacts being lower than the environmental impact statement predictions which were considered acceptable).

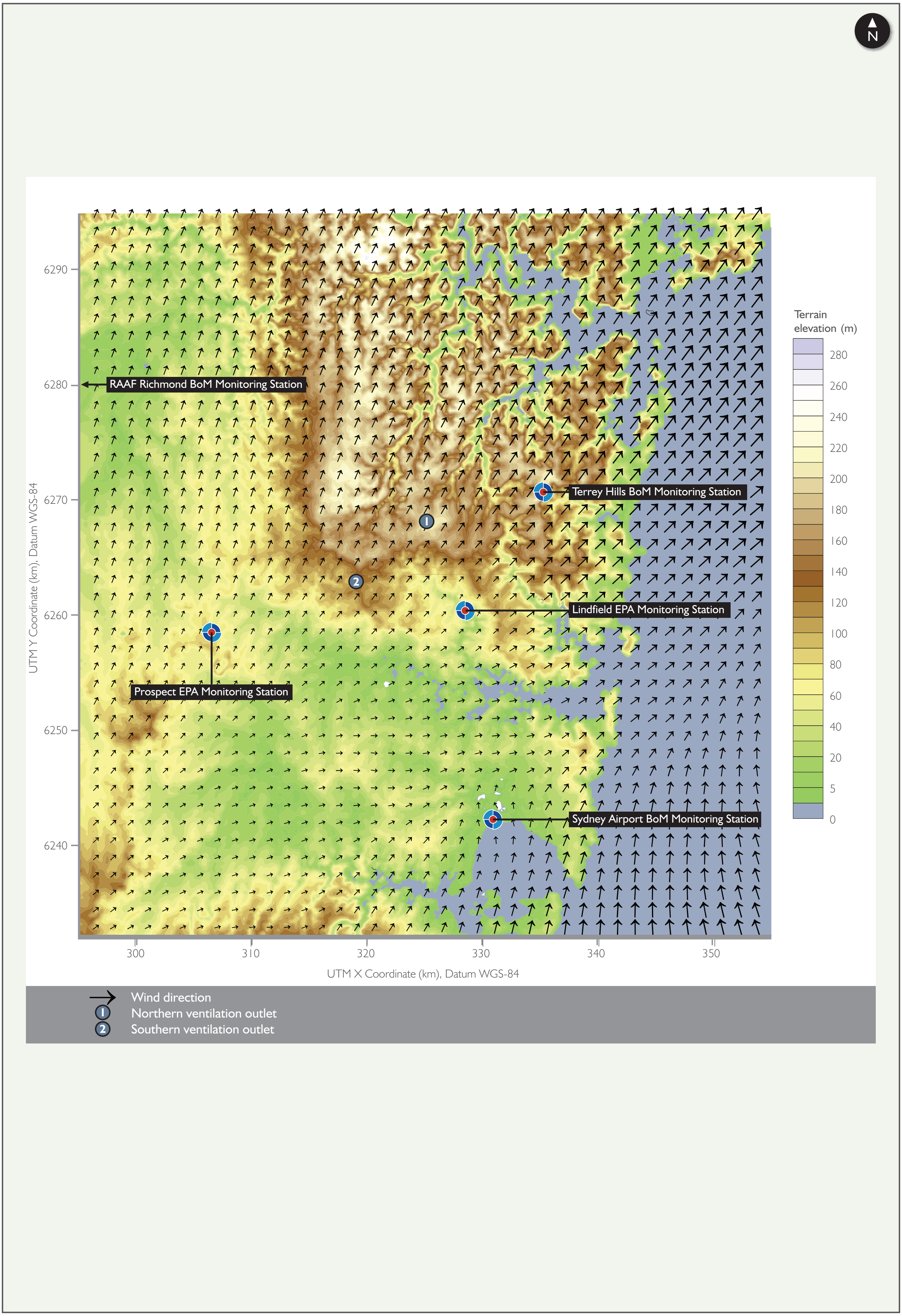

Figure 2-31 Wind flow field at hour 17:00 on day 45 (10 metres)

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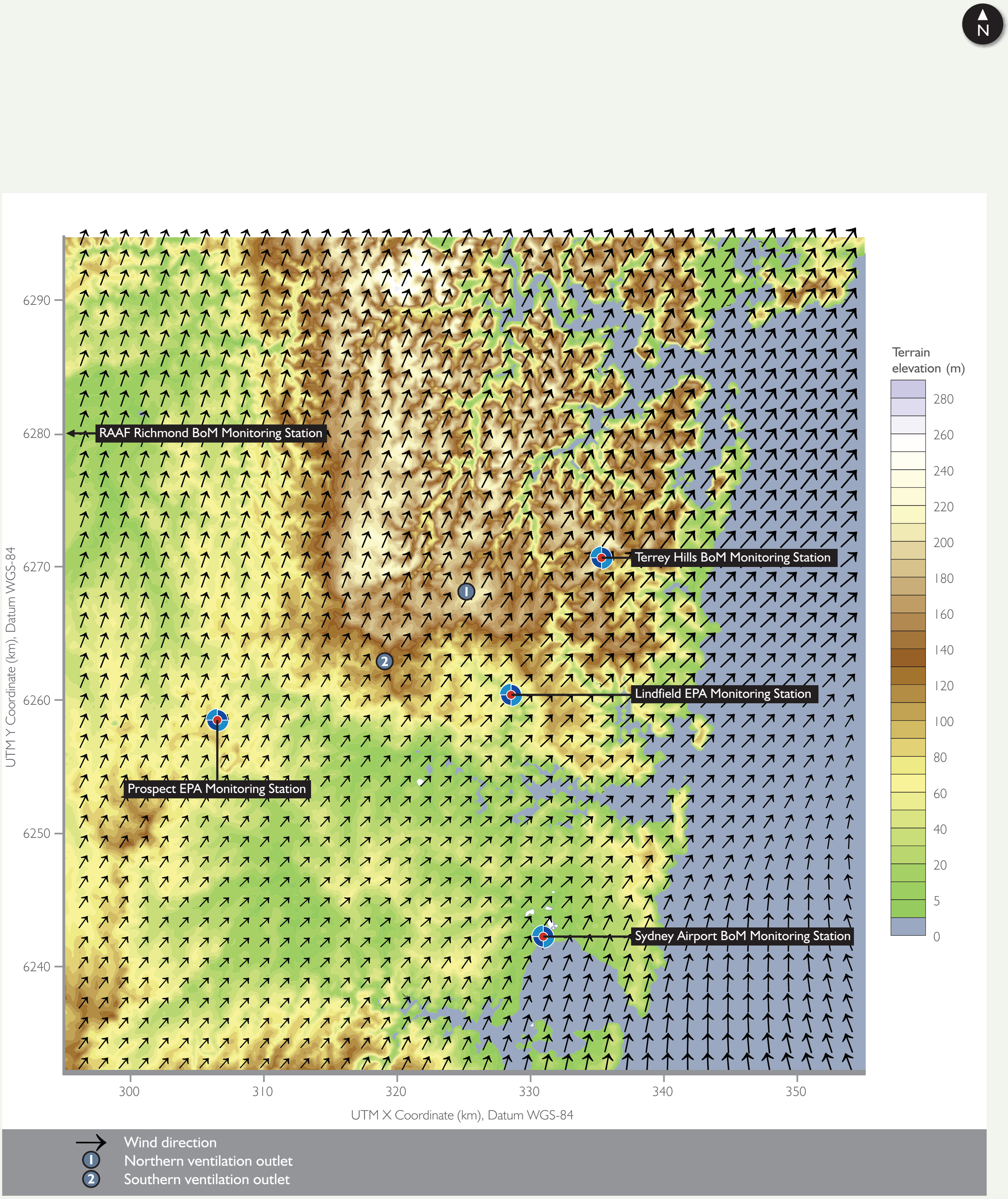

Figure 2-32 Wind flow field at hour 17:00 on day 45 (30 metres)

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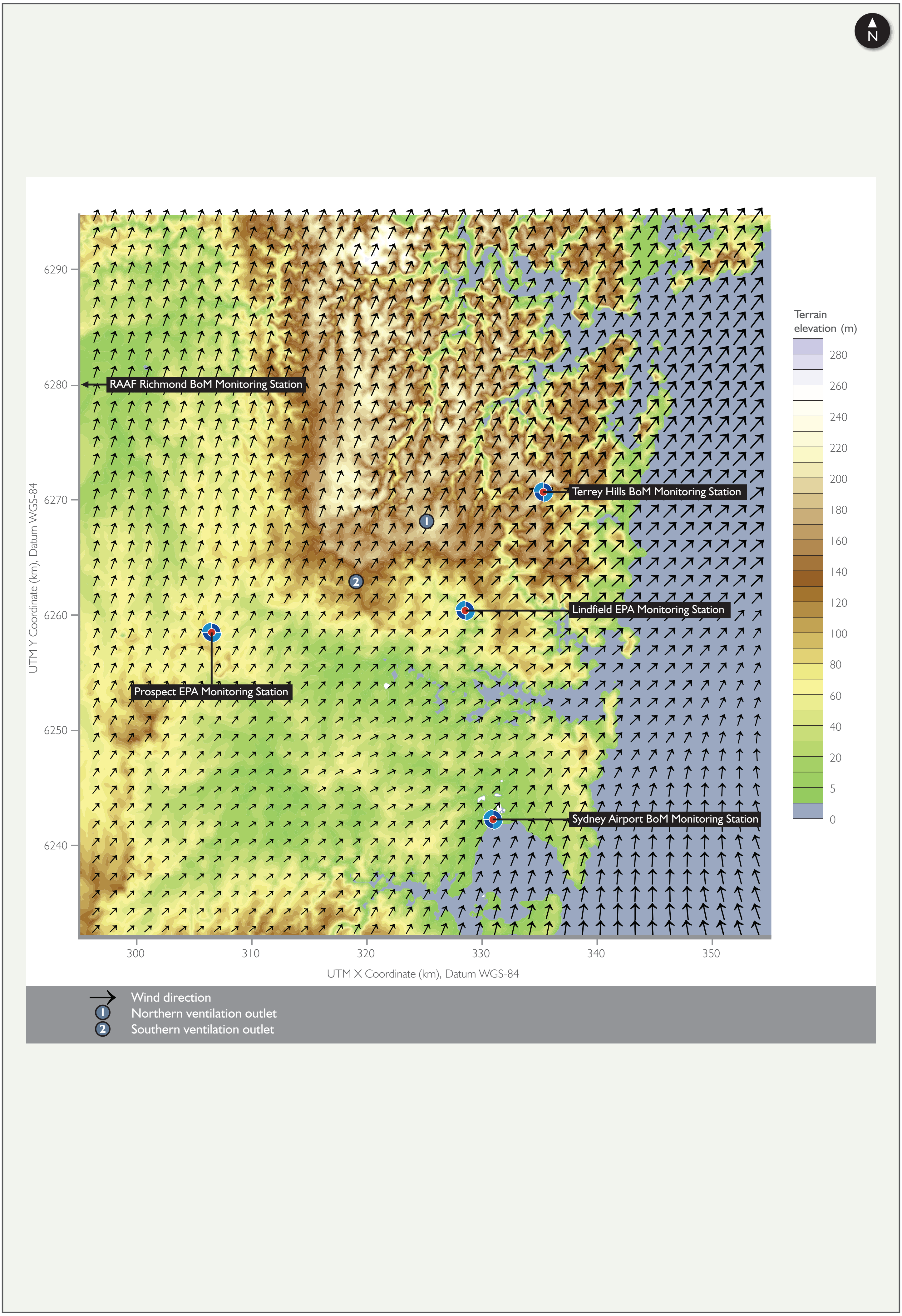

Figure 2-33 Wind flow field at hour 17:00 on day 45 (60 metres)

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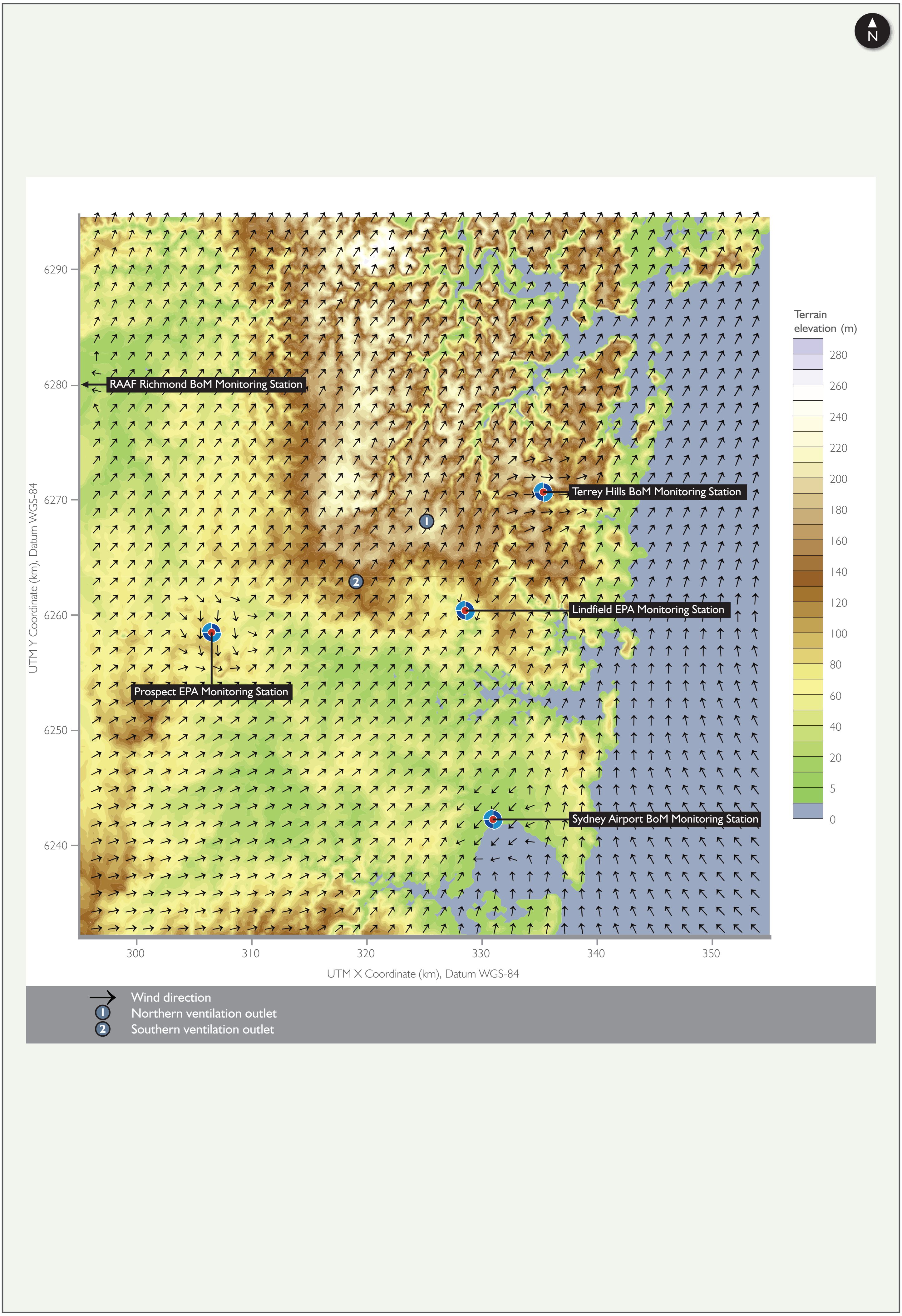

Figure 2-34 Wind flow field at hour 07:00 on day 337 (10 metres)

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