Results for RWR receptors

The ranked annual mean PM_{10} concentrations at the RWR receptors are shown in **Figure 8-56**. The concentration at the majority of receptors was below 20 µg/m^3, with only a very small proportion of receptors having a concentration just above the NSW assessment criterion of 25 µg/m^3. The highest predicted concentration at any receptor in a with-project or cumulative scenario was 26.5 µg/m^3. The surface road contribution was between 0.05 µg/m^3 and 9.8 µg/m^3, with an average of 1.1–1.2 µg/m^3. The largest contribution from tunnel ventilation outlets was 0.37 µg/m^3 in the 2023-DSC scenario.

The changes in the annual mean PM_{10} concentration at the RWR receptors are shown, ranked by change in concentration, in **Figure 8-57**. There was an increase in concentration at 32-36 per cent of the receptors, depending on the scenario. At the majority of receptors the change was relatively small, and where there was an increase, this was greater than 2.5 µg/m^3 at just a single receptor in the 2023-DSC and 2033-DSC scenarios.

Contour plots – all sources

The contour plots for annual mean PM_{10} in the 2023-DM and 2033-DSC scenarios are given in **Figure 8-58** and **Figure 8-59**. As in the case of NO_2, elevated concentrations are evident along the major road corridors. The contour plot for the change in concentration in the cumulative scenario in (**Figure 8-60**) also shows complex spatial changes that are similar to those for NO_2.

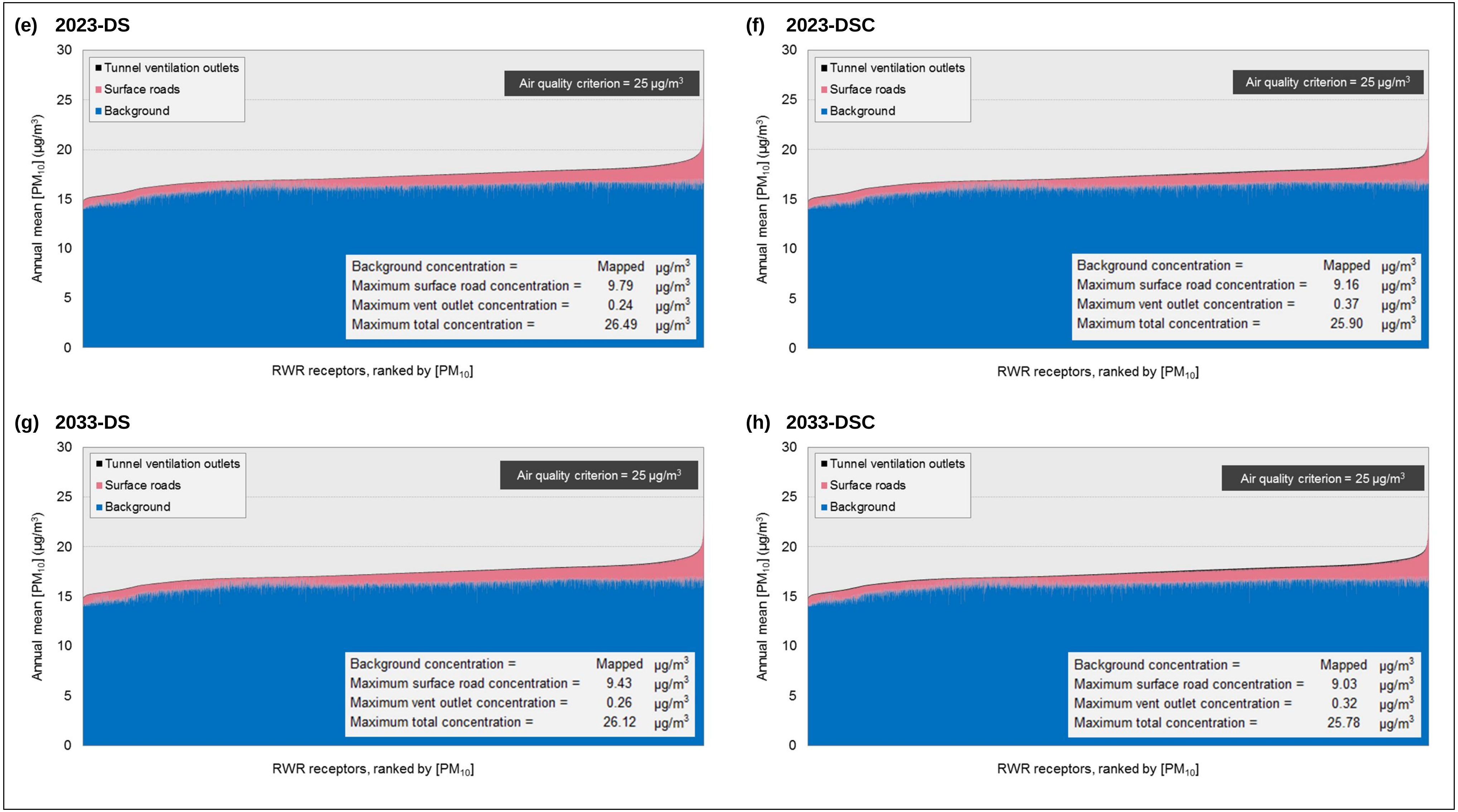

Figure 8-56 Source contributions to annual mean PM_{10} concentration at RWR receptors (with-project and cumulative scenarios)

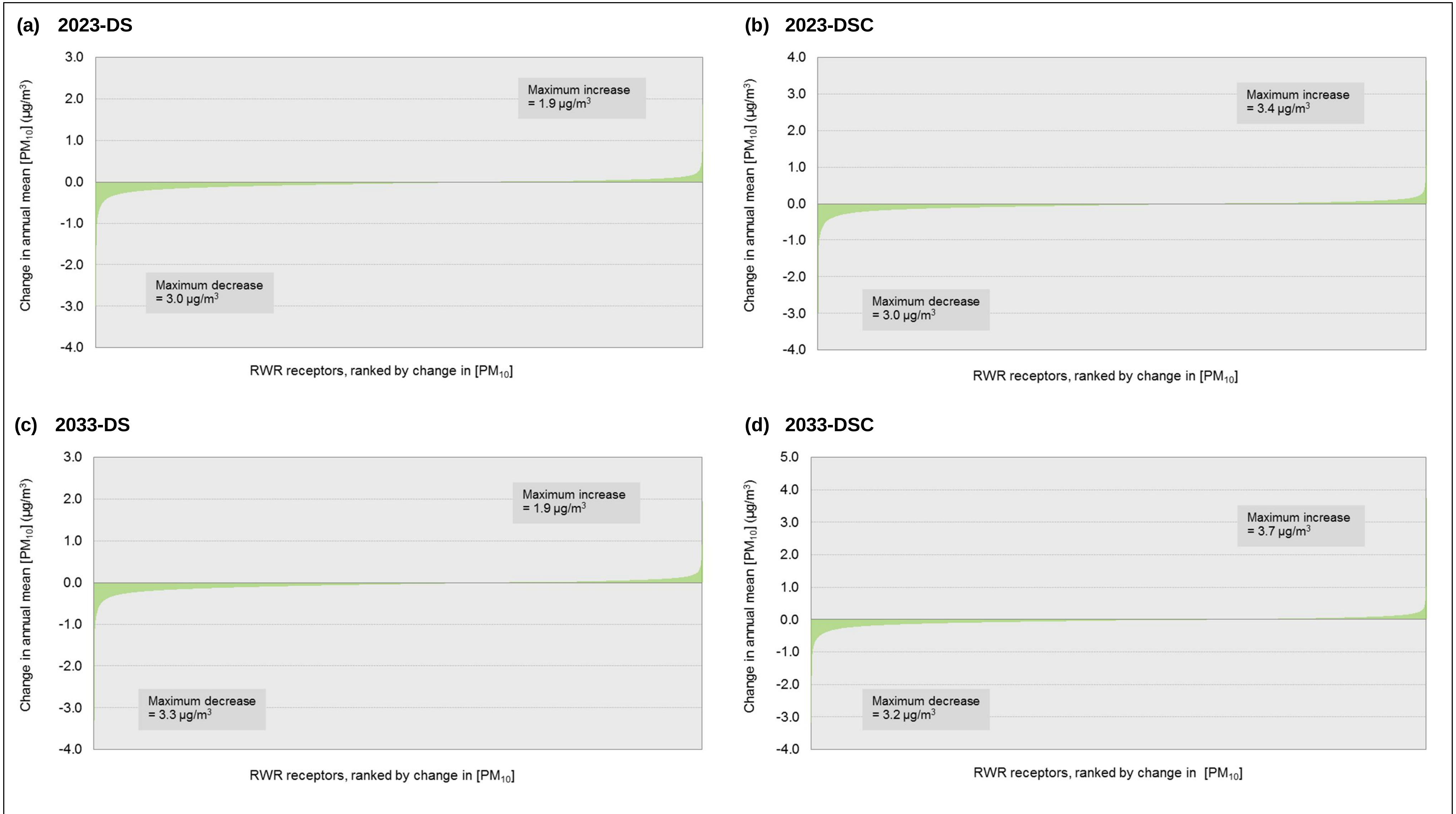

Figure 8-57 Changes in annual mean PM_{10} concentration at RWR receptors (with-project and cumulative scenarios, relative to Do Minimum scenarios)

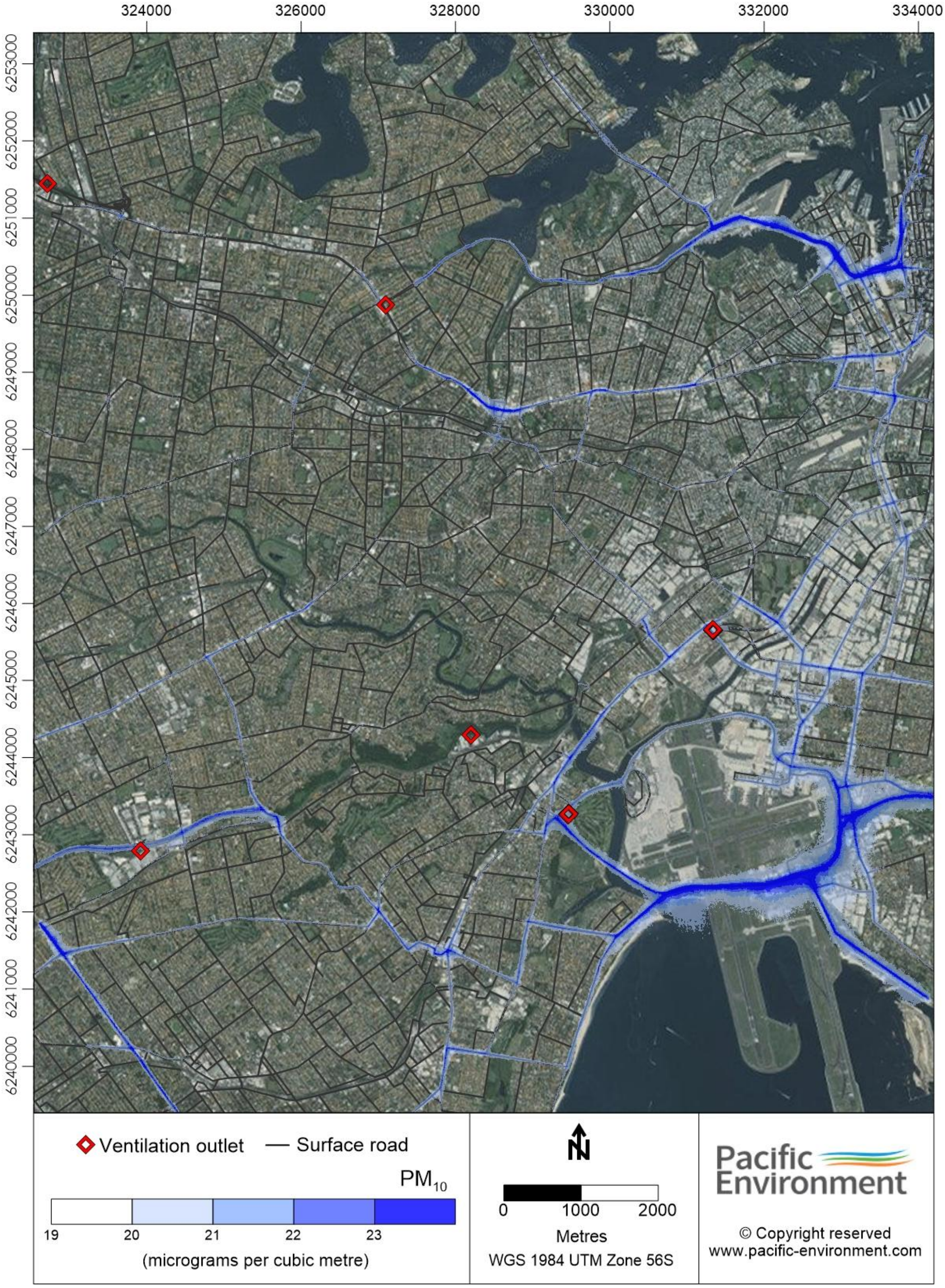

Figure 8-58 Contour plot of annual mean PM_{10} concentration in the 2033 Do Minimum scenario (2033-DM)

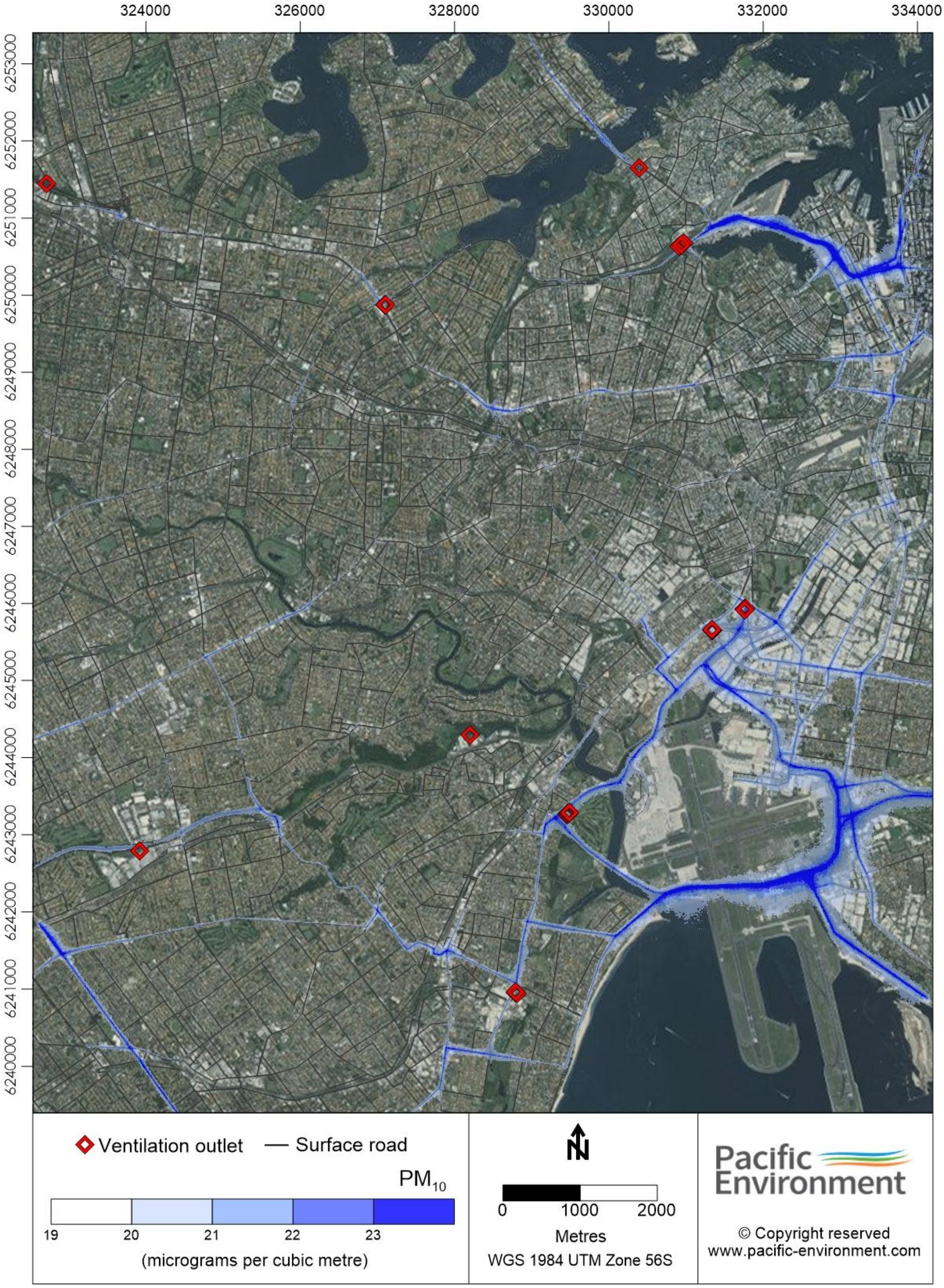

Figure 8-59 Contour plot of annual mean PM_{10} concentration in the 2033 cumulative scenario (2033-DSC)

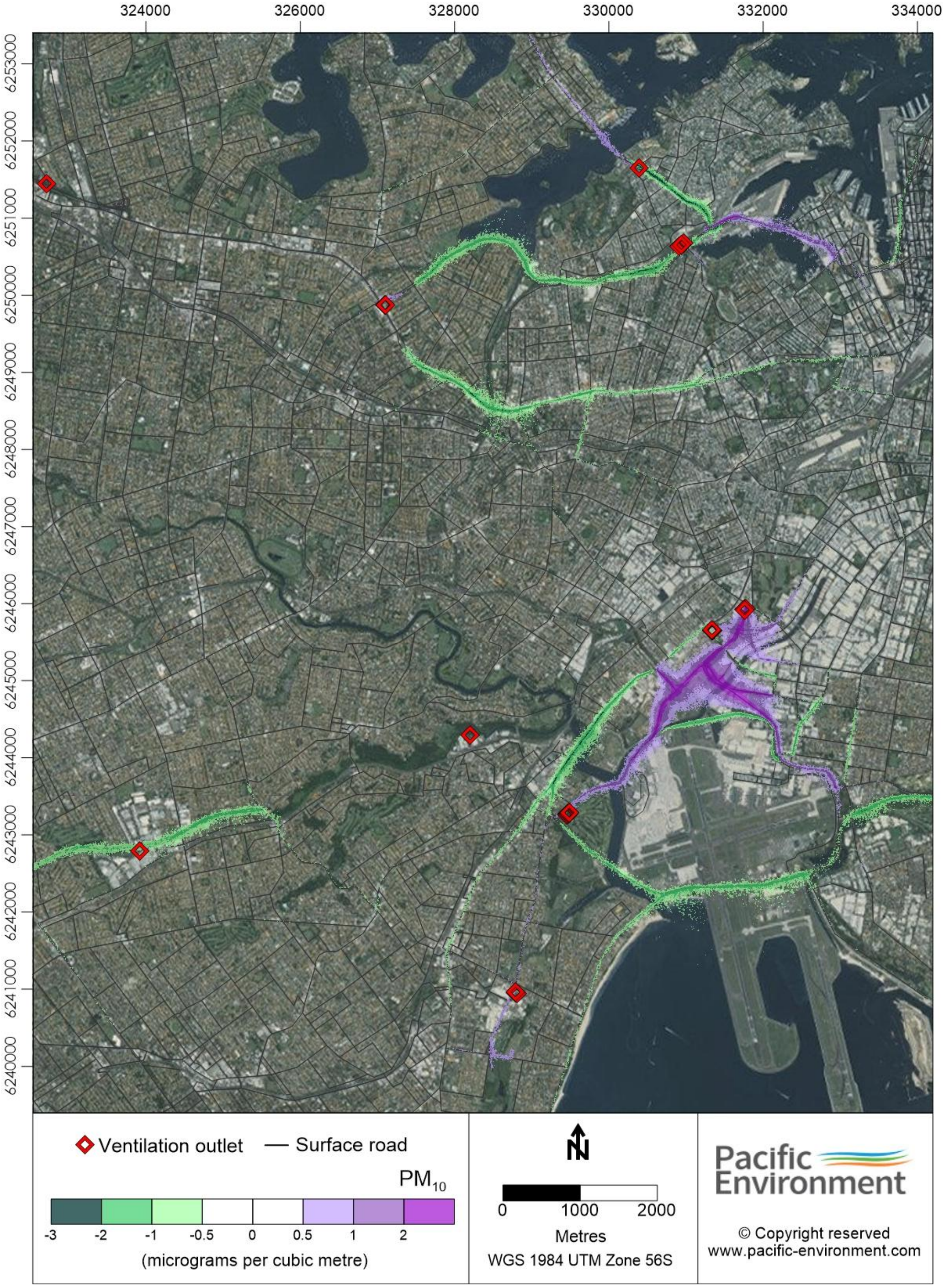

Figure 8-60 Contour plot of change in annual mean PM_{10} concentration in the 2033 cumulative scenario (2033-DSC minus 2033-DM)

Contour plots for ventilation outlets only

The contour plot for the annual mean PM_{10} contribution from the ventilation outlets only in the 2033-DSC scenario is shown in **Figure 8-61**. As with NO_X, the impacts at the three main areas with M4-M5 Link ventilation facilities – Haberfield, Rozelle and St Peters interchange – are low in absolute terms, being at least an order of magnitude below the corresponding criterion of 25 µg/m^3 where there are receptors, and the separate outlets do not combine to produce high cumulative concentrations.

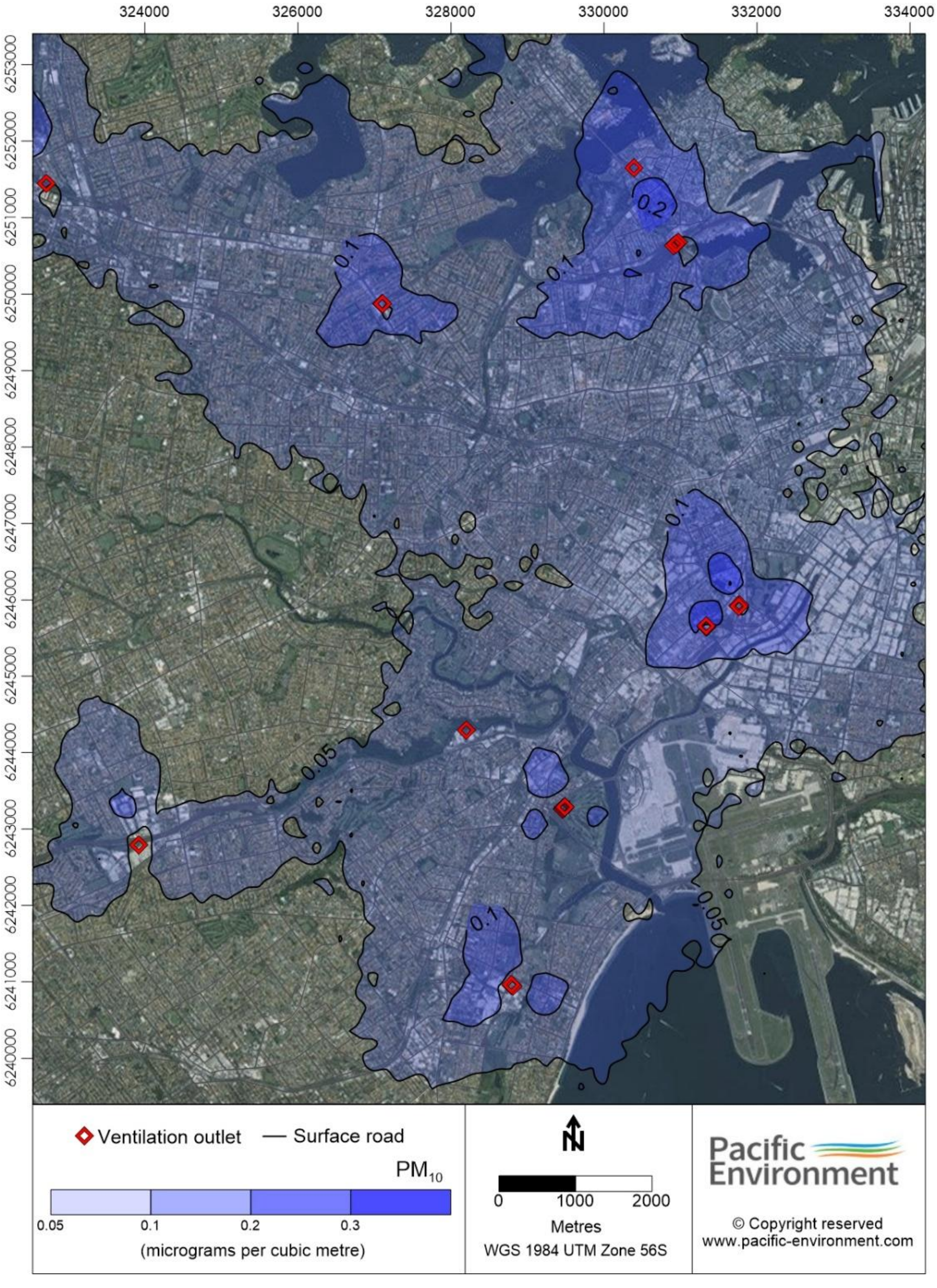

Figure 8-61 Contour plot of annual mean PM_{10} concentration for ventilation outlets only (2033-DSC)

PM_{10} (maximum 24 hour mean)

Results for community receptors

Figure 8-62 presents the maximum 24 hour mean PM_{10} concentrations at the community receptors. At all locations, and in all scenarios, the concentration was close to the NSW impact assessment criterion of 50 µg/m^3, which is also the most stringent standard in force internationally. The number of community receptors with an exceedance of the criterion decreased from 16 in the 2023-DM scenario to 11 in the 2023-DS scenario and 12 in the 2023-DSC scenario. In 2033, the number of receptors exceeding the criterion decreased from 14 in the 2033-DM scenario to 12 in the 2033-DS scenario, but increased to 17 in the 2033-DSC scenario. However, it should be borne in mind that the community receptors only formed a very small subset of all the receptors in the GRAL domain.

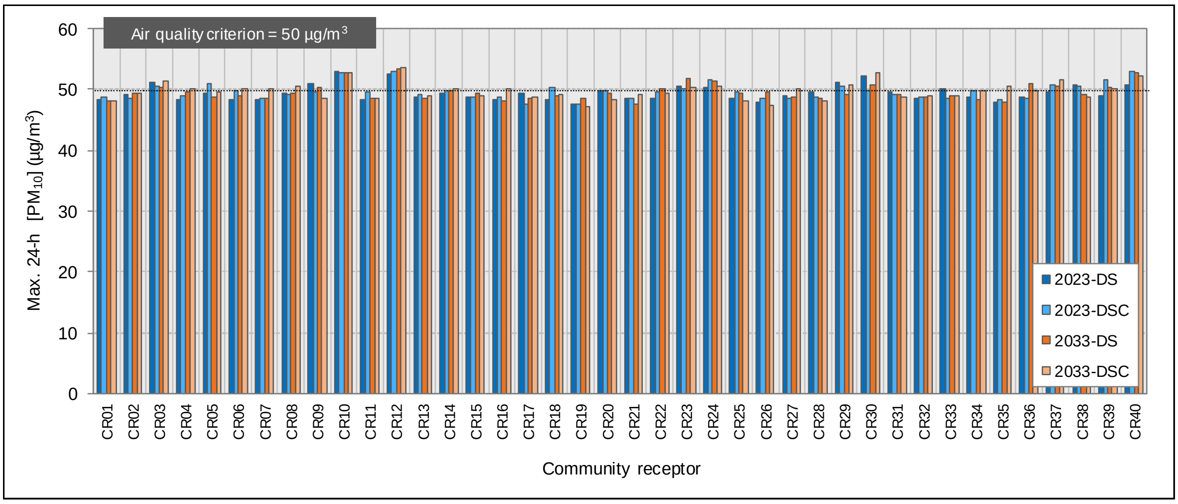

Figure 8-62 Maximum 24 hour mean PM_{10} concentration at community receptors (with-project and cumulative scenarios)

Figure 8-63 shows the changes in concentration in the Do Something scenarios relative to the Do Minimum scenarios for the community receptors. At most receptors, the change was less than 2 µg/m^3, and at all receptors it was less than 4 µg/m^3. There were no systematic changes by year or by scenario.

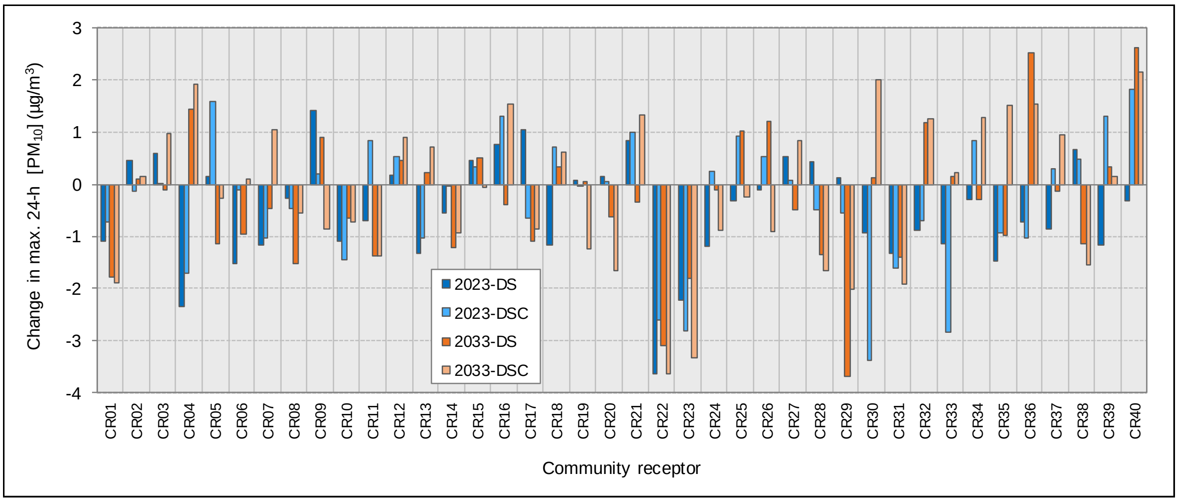

Figure 8-63 Change in maximum 24 hour mean PM_{10} concentration at community receptors (with-project and cumulative scenarios, relative to Do Minimum scenarios)

Figure 8-64 demonstrates that the surface road contribution to the maximum 24 hour PM_{10} concentration at each receptor was small (generally less than around 5 µg/m^3). The exception to this was receptors CR10 (University of Notre Dame, Broadway), which had a road contribution of 15.1 to 21 µg/m^3. This receptor was discussed in **section 8.4.8**. At all community receptors except CR10, the maximum total 24 hour concentration occurred on one day of the year (1 July), and coincided with the highest 24 hour background concentration in the synthetic PM_{10} profile (46.2 µg/m^3).

The tunnel ventilation outlet contribution at the community receptors was negligible, being less than 0.4 µg/m^3 in all cases.

Results for RWR receptors

The ranked maximum 24 hour mean PM_{10} concentrations at the RWR receptors are shown in **Figure 8-65**. The results for the RWR receptors were highly dependent on the assumption for the background concentration. Because this was assumed to be the maximum concentration in the synthetic background profile (i.e. 46.2 µg/m^3), the total concentration at the majority of receptors in the with-project scenarios (77 to 80 per cent) was above the NSW impact assessment criterion of 50µg/m^3.

The proportion of receptors with a concentration above the criterion decreased slightly as a result of the project, such as from 82 per cent in the 2023-DM scenario to 78 per cent in the 2023-DS scenario. The contributions of surface roads and ventilation outlets were not additive. The maximum contribution of tunnel ventilation outlets at any receptor in a scenario was between 1.2 µg/m^3 to 1.9 µg/m^3, depending on the scenario.

The changes in the maximum 24 hour mean PM_{10} concentration with the project and in the cumulative scenarios are ranked – by change in concentration – in **Figure 8-66**. There was an increase in concentration at between 37 and 39 per cent of the receptors, depending on the scenario. The largest predicted increase in concentration at any receptor as a result of the project was 13.3 µg/m^3, and the largest predicted decrease was 11.8 µg/m^3. Where there was an increase, this was greater than 5 µg/m^3 (10 per cent of the criterion) at just 0.1 per cent of receptors.

Contour plots – all sources

The contour plots for maximum 24 hour average PM_{10} in the 2033-DM and 2033-DSC scenarios are given in **Figure 8-67** and **Figure 8-68**. The changes in maximum 24 hour PM_{10} are shown in **Figure 8-69**.

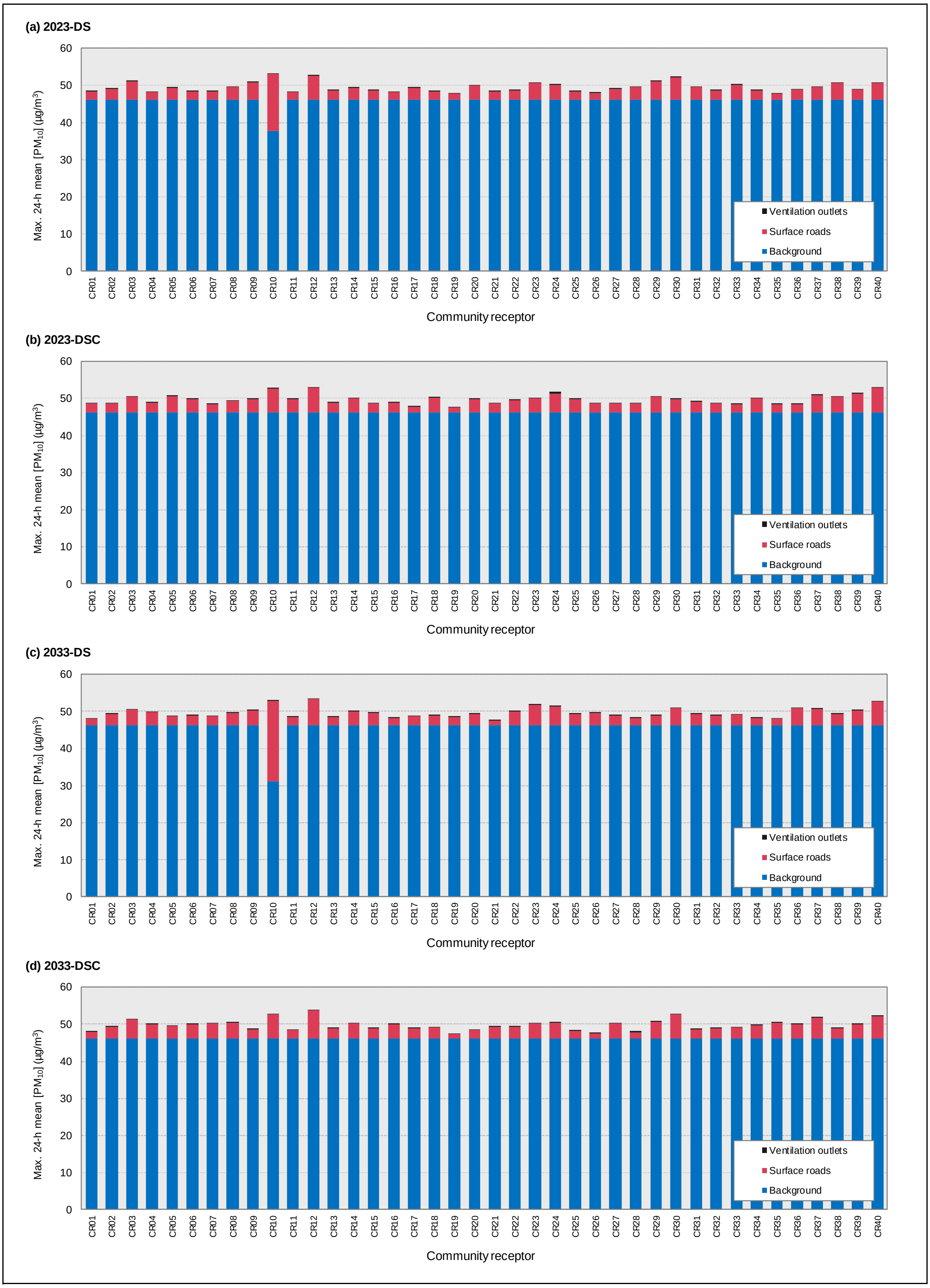

Figure 8-64 Source contributions to maximum 24 hour mean PM_{10} concentration at community receptors (with-project and cumulative scenarios)

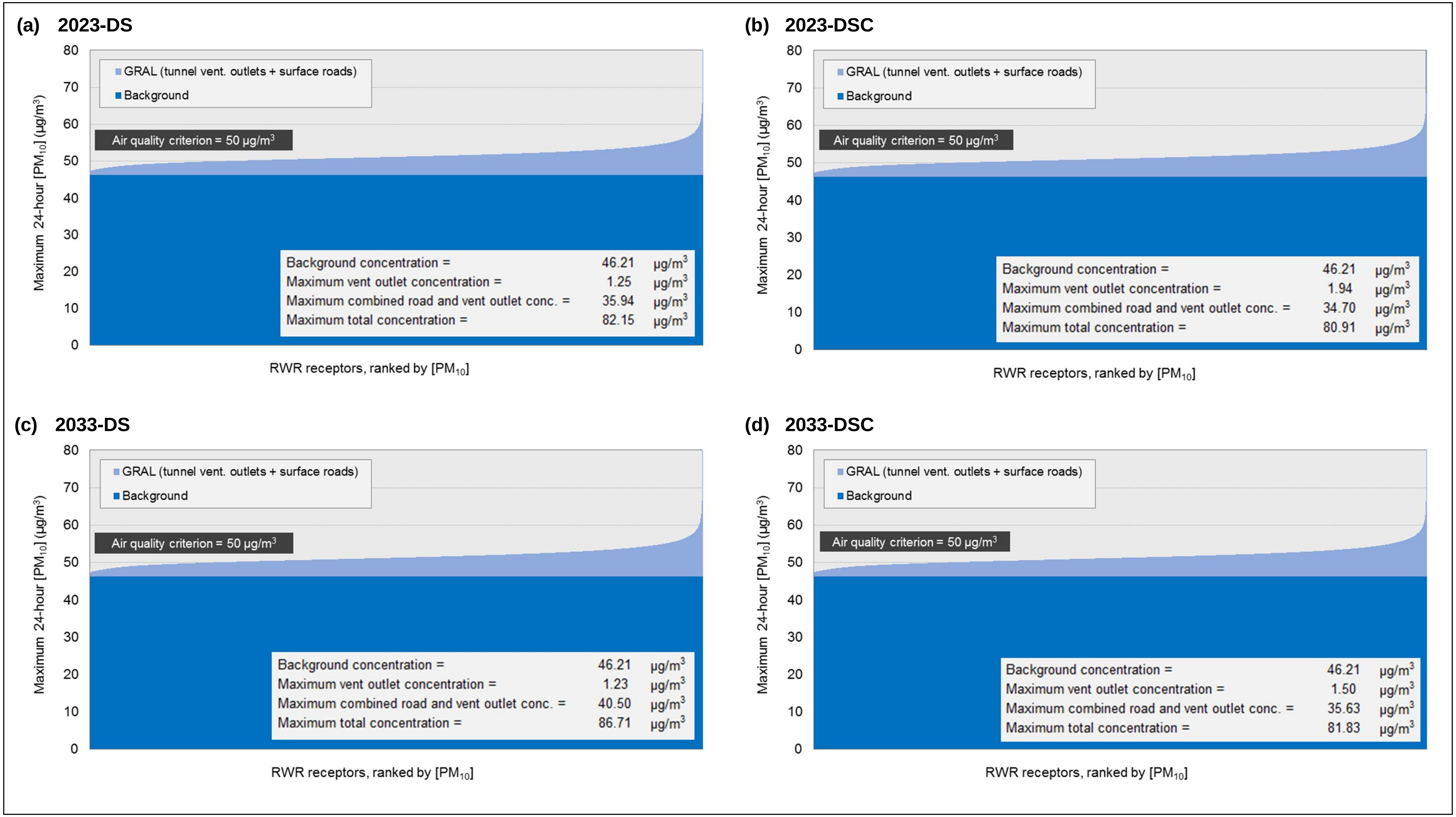

Figure 8-65 Source contributions to maximum 24 hour mean PM_{10} concentration at RWR receptors (with-project and cumulative scenarios)

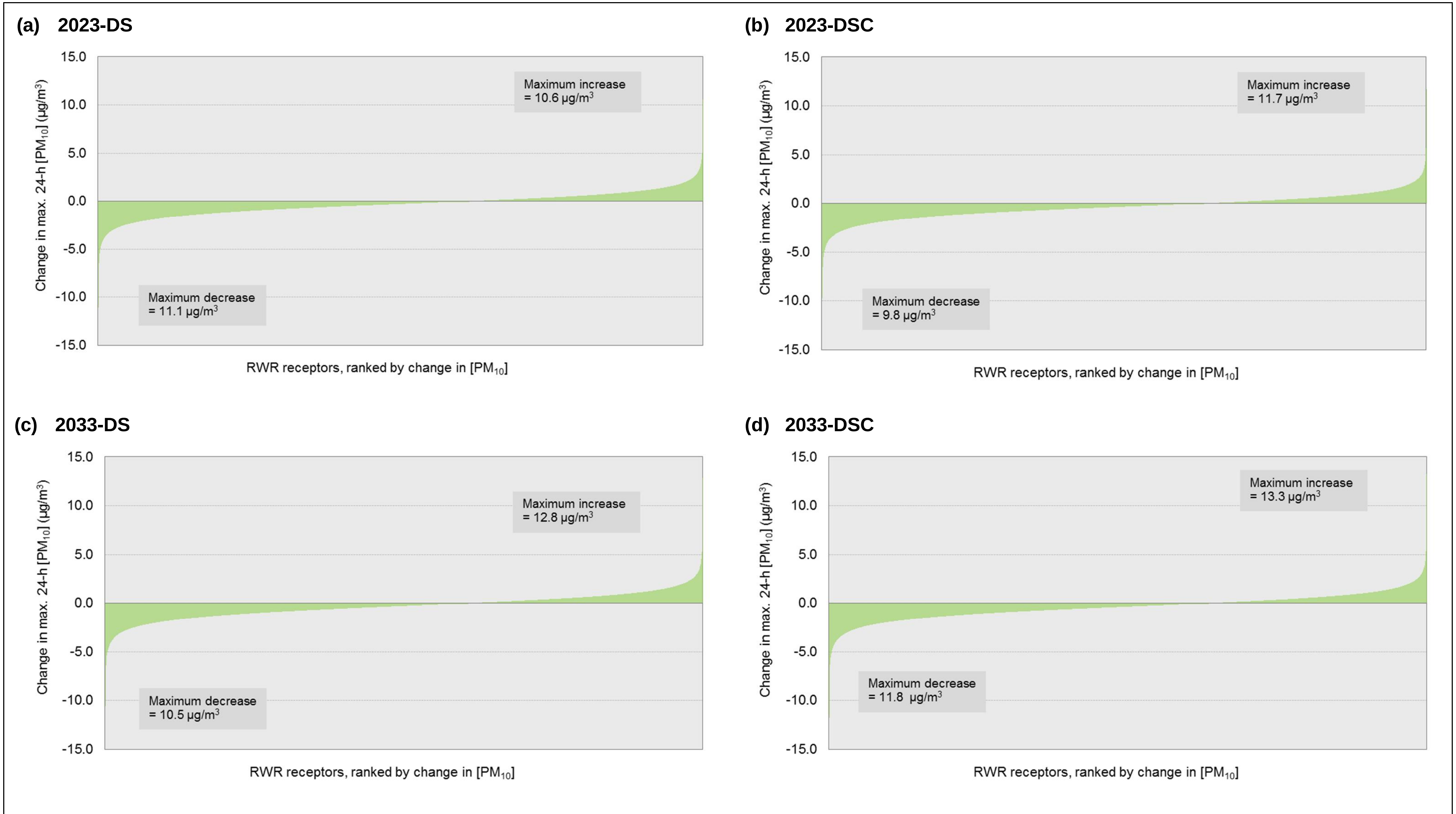

Figure 8-66 Change in maximum 24 hour mean PM_{10} concentration at RWR receptors (with-project and cumulative scenarios, relative to Do Minimum scenarios)

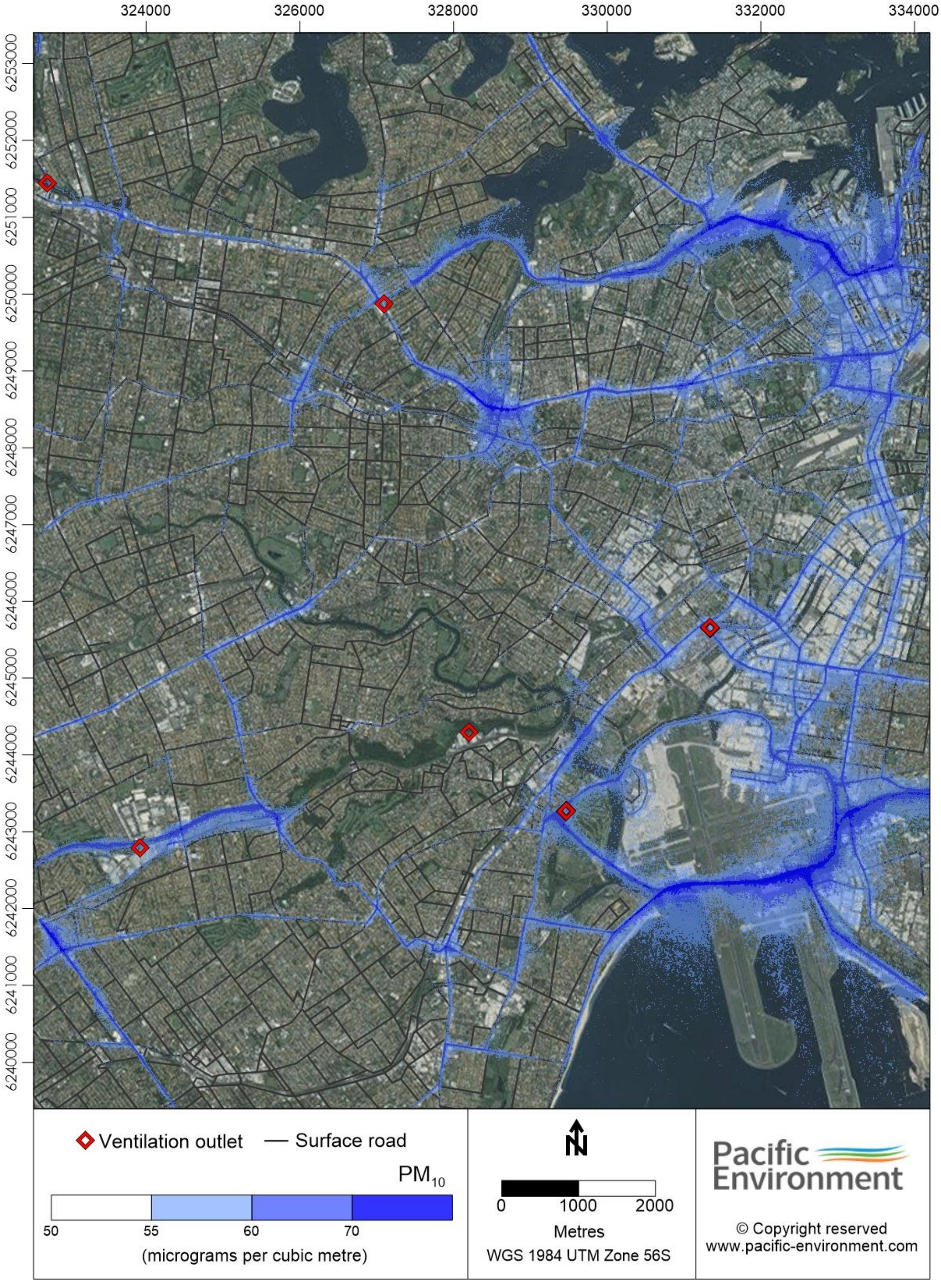

Figure 8-67 Contour plot of maximum 24 hour average PM_{10} concentration in the 2033 Do Minimum scenario (2033-DM)

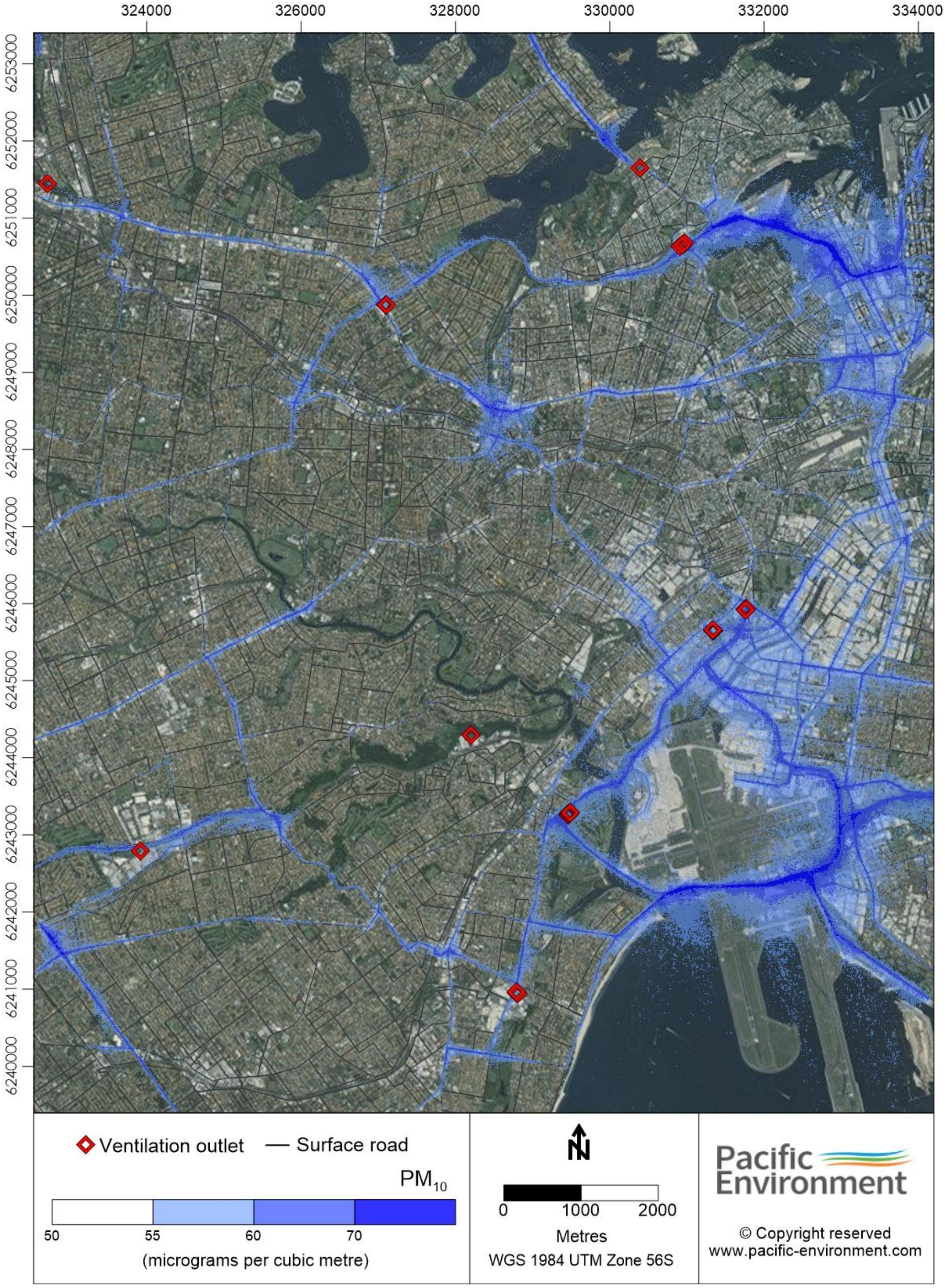

Figure 8-68 Contour plot of maximum 24 hour average PM_{10} concentration in the 2033 cumulative scenario (2033-DSC)

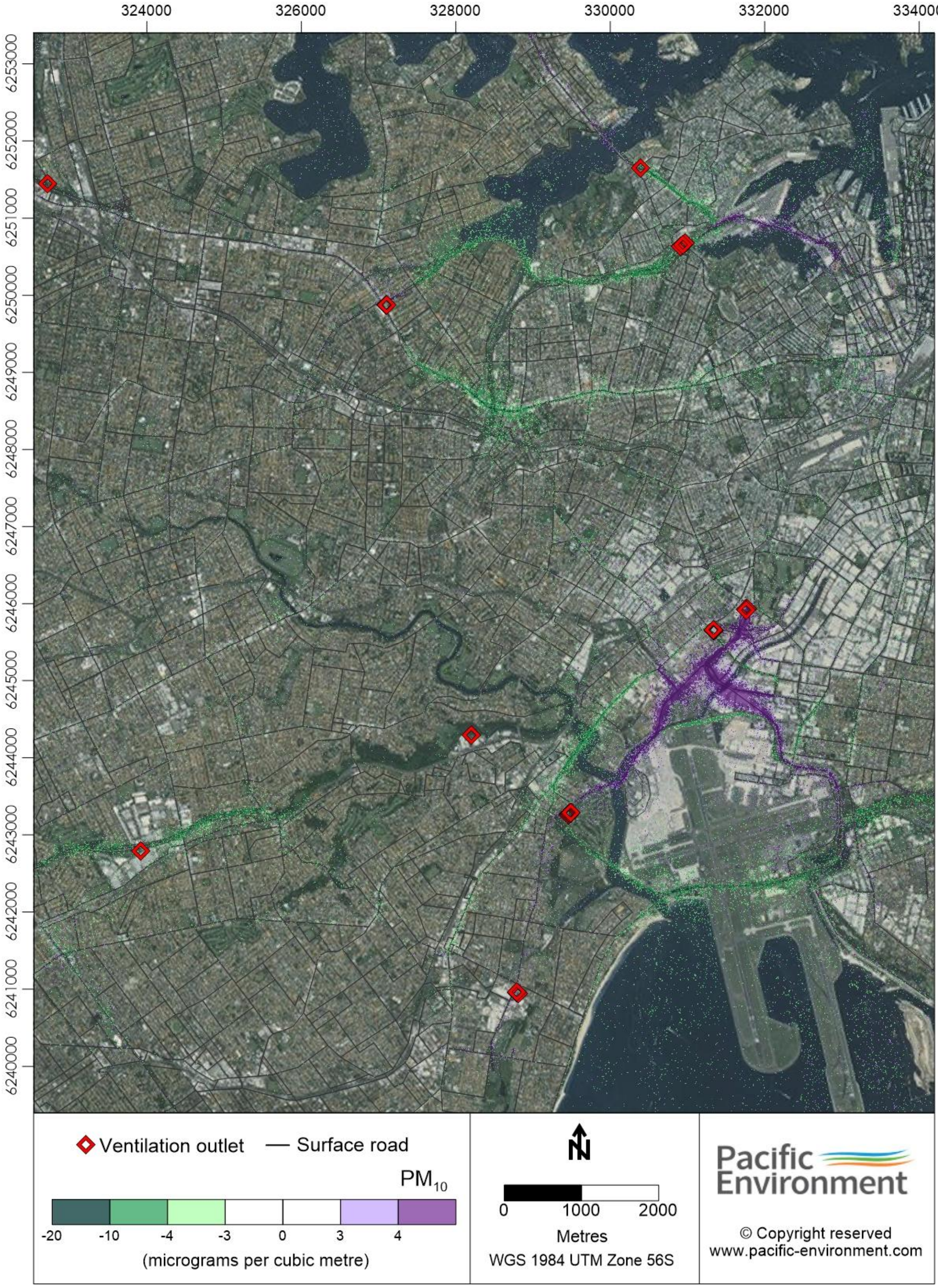

Figure 8-69 Contour plot of change in maximum 24 hour mean PM_{10} concentration in the 2033 cumulative scenario (2033-DSC minus 2033-DM)

Contour plots for ventilation outlets only

The contour plot for the maximum 24 hour PM_{10} contribution from the ventilation outlets only in the 2033-DSC scenario is shown in **Figure 8-70**.

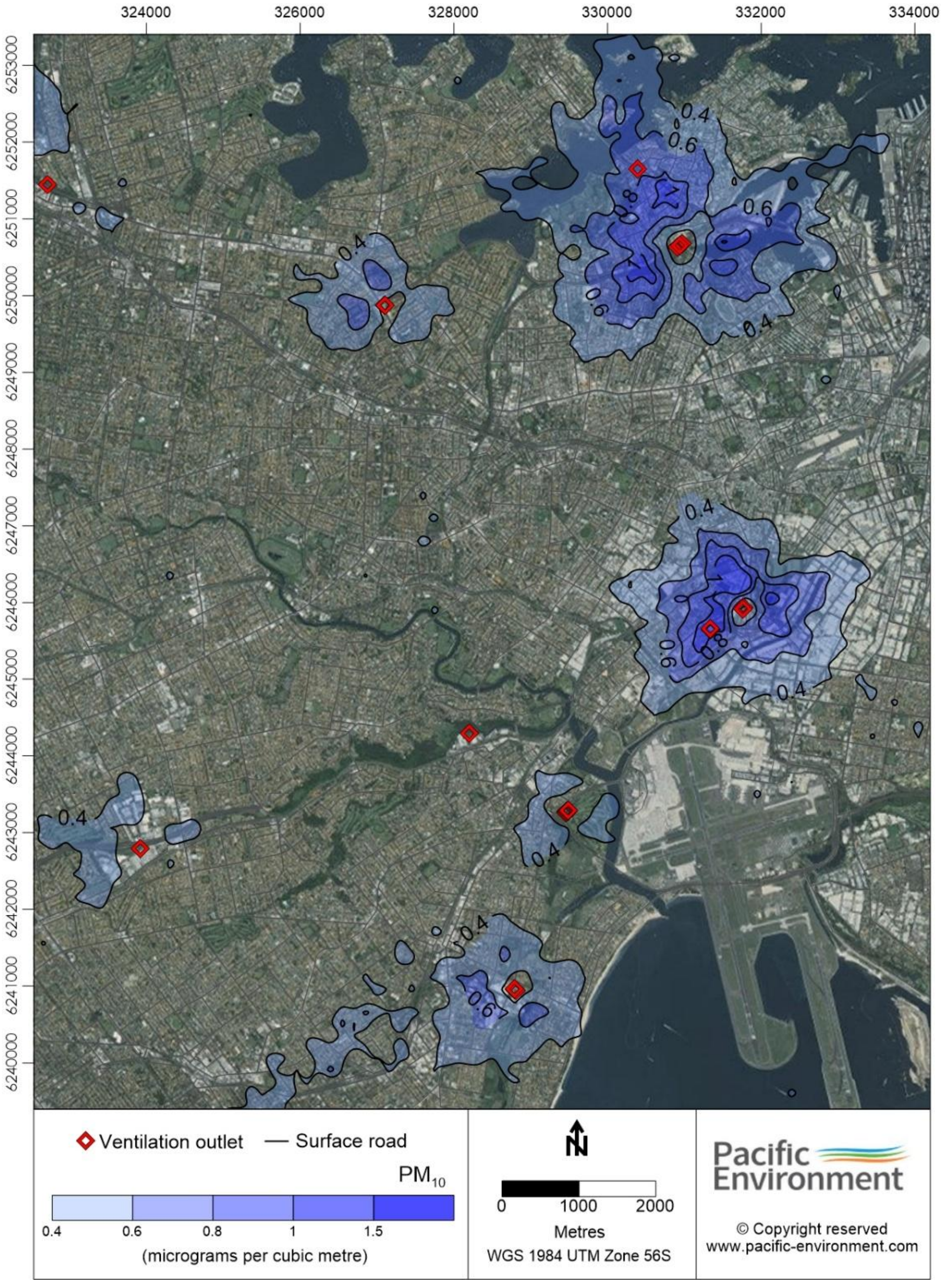

Figure 8-70 Contour plot of maximum 24 hour PM_{10} concentration for ventilation outlets only (2033-DSC)

$PM_{2.5}$ (annual mean)

Results for community receptors

Figure 8-71 presents the annual mean $PM_{2.5}$ concentrations at the community receptors. The results are based on an assumed background concentration of 8 µg/m^3 (the AAQ NEPM standard), and therefore the Figure shows exceedances at all receptors. Clearly, there would also be exceedances of the NSW target of 7 µg/m^3. Internationally, there are no standards lower than 8 µg/m^3 for annual mean $PM_{2.5}$. The next lowest is 12 µg/m^3 (California, Scotland).

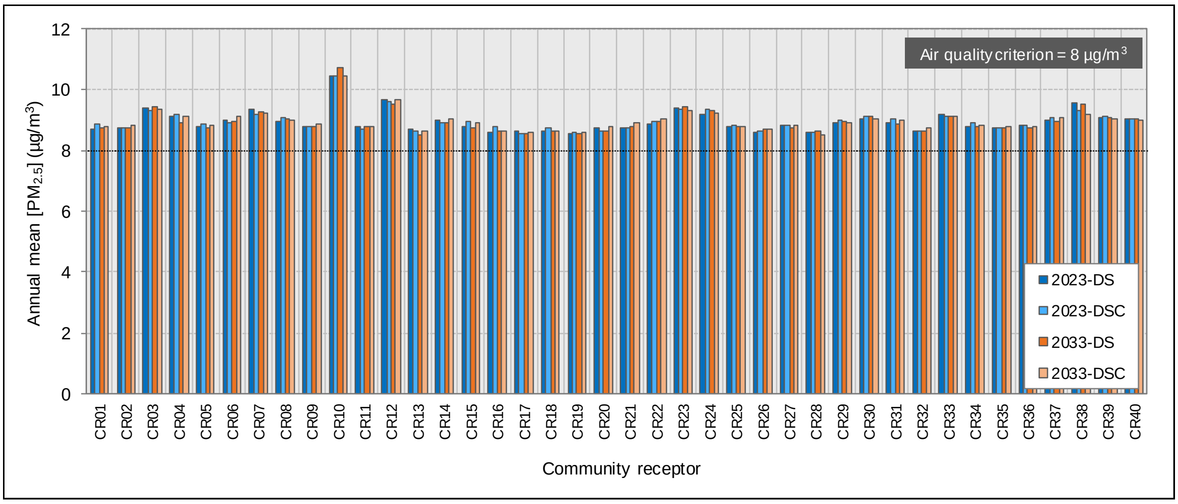

Figure 8-71 Annual mean $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios)

Figure 8-72 presents the changes in annual mean $PM_{2.5}$ with the project and in the cumulative scenarios at the community receptors. At the majority of receptors, there was a decrease in concentration. Any increases were generally less than 0.2 µg/m^3; the largest increase (0.56 µg/m^3 at receptor CR38 in the 2033-DS scenario) equated to seven per cent of the air quality criterion.

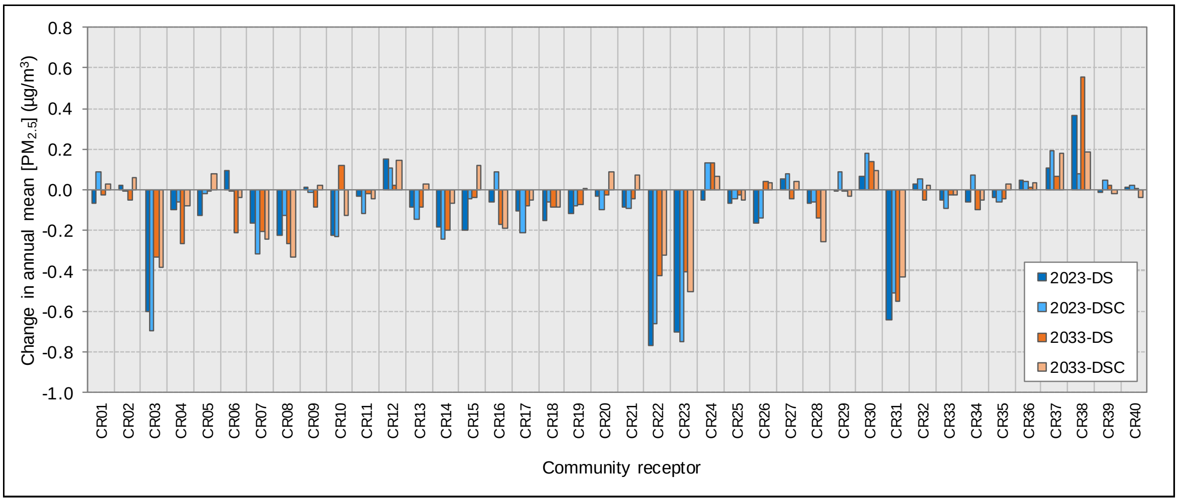

Figure 8-72 Change in annual mean $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios, relative to Do Minimum scenarios)

Figure 8-73 shows that concentrations were again dominated by the background contribution. The surface road contribution was between 0.5 µg/m^3 and 2.7 µg/m^3. The largest contribution from tunnel ventilation outlets at any receptor was just 0.14 µg/m^3.

Figure 8-73 Source contributions to annual mean $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios)

Results for RWR receptors

The ranked annual mean $PM_{2.5}$ concentrations at the RWR receptors in the with-project and cumulative scenarios are shown in **Figure 8-74**, including the contributions of surface roads and ventilation outlets. As the background concentration was taken to be the same as the NSW criterion of 8 µg/m^3, the total concentration at all receptors was above this value. The highest concentration at any receptor was 14.2 µg/m^3 but, as with other pollutants and metrics, the highest values were only predicted for a small proportion of receptors and are unlikely to be realistic. In the with-project and cumulative scenarios, the largest surface road contribution at any receptor was 5.4 µg/m^3. The largest contribution from tunnel ventilation outlets in these scenarios was 0.25 µg/m^3.

The change in the annual mean $PM_{2.5}$ concentration at the RWR receptors in the with-project and cumulative scenarios are ranked in **Figure 8-75**. There was an increase in concentration at between 29 per cent and 37 per cent of the receptors, depending on the scenario. The largest predicted increase in concentration at any receptor as a result of the project was 2.3 µg/m^3, and the largest predicted decrease was also 2.3 µg/m^3. Where there was an increase, this was greater than 0.1 µg/m^3 at around 2-3 per cent of receptors.

As noted in **section 5.5.3**, the increase in annual mean $PM_{2.5}$ at sensitive receptors with the project ($\Delta PM_{2.5}$) is a key metric for assessing the risk to human health. For the M4-M5 Link project, the acceptable value of $\Delta PM_{2.5}$ was determined to be 1.8 µg/m^3. Only one receptor (RWR-46456, with the increase of 2.3 µg/m^3 noted above) had a predicted change in $PM_{2.5}$ above this value. However, this receptor is a commercial building that is very close to the indicative alignment of Sydney Gateway (refer to discussion in **section 8.4.14**).

For the Option B construction scenario, the removal of the 25 RWR receptors that were inside the associated project footprint had little effect on the overall results. As explained earlier, all 25 receptors were commercial premises. The values for $\Delta PM_{2.5}$ at these receptors are summarised in **Table 8-23**. These covered a large portion of the results for all RWR receptors, ranging from low percentiles to high percentiles. However, none of the values were at the extreme ends of the distribution.

Table 8-23 Changes in annual mean $PM_{2.5}$ at 25 receptors in Option B construction ancillary facilities

Statistic	Change in annual mean $PM_{2.5}$			
	2023-DS minus 2023-DM	2023-DSC minus 2023-DM	2033-DS minus 2033-DM	2033-DSC minus 2033-DM
Minimum (µg/m^3)	-0.29	-0.25	-0.23	-0.14
Ranking of minimum (out of 86,375 RWR receptors	1,296th (1.5th percentile)	1,900th (2.2nd percentile)	1,987th (2.3rd percentile)	6,565th (7.6th percentile)
Maximum (µg/m^3)	0.10	0.13	0.12	0.11
Ranking of maximum (out of 86,375 RWR receptors	84,907th (98.3rd percentile)	84,993rd (98.4th percentile)	85,079th (98.5th percentile)	84,129th (97.4th percentile)

Contour plots – all sources

The contour plots for total annual mean $PM_{2.5}$ are given in **Figure 8-76** (2033-DM) and **Figure 8-77** (2033-DSC). The contour plot for the associated change in concentration in this cumulative scenario is shown in **Figure 8-78**.

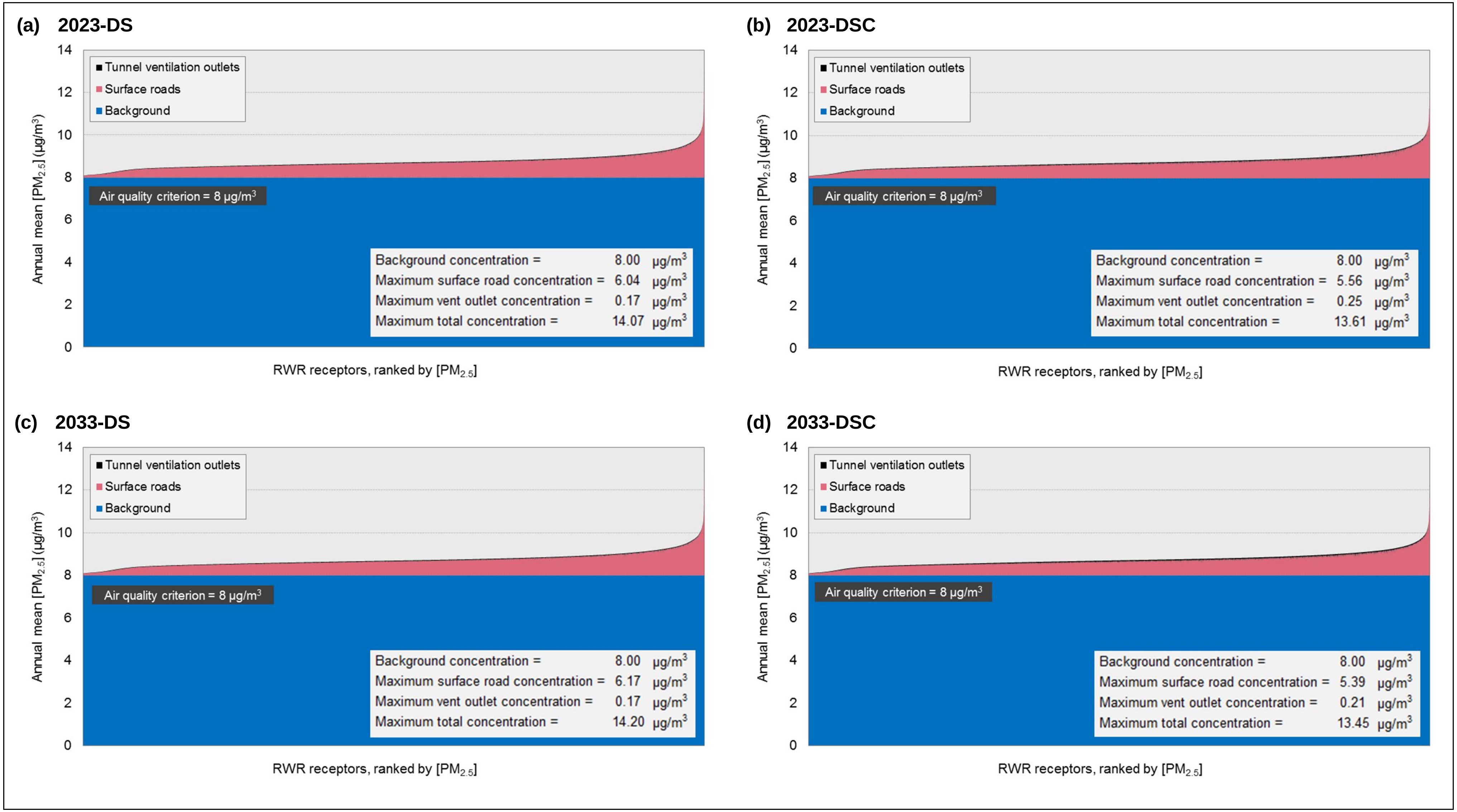

Figure 8-74 Source contributions to annual mean $PM_{2.5}$ concentration at RWR receptors (with-project and cumulative scenarios)

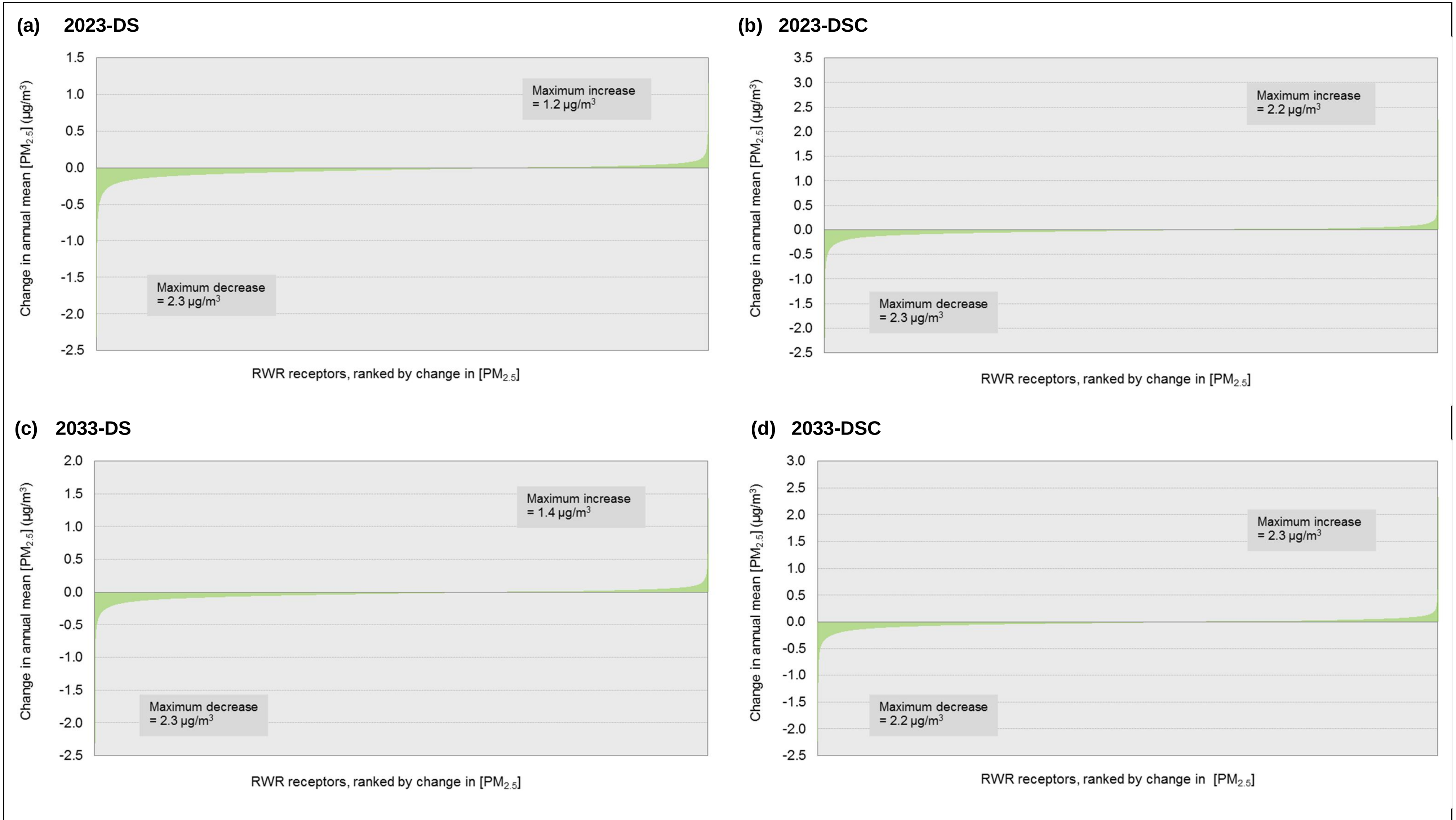

Figure 8-75 Change in annual mean $PM_{2.5}$ concentration at RWR receptors (with-project and cumulative scenarios, relative to Do Minimum scenarios)

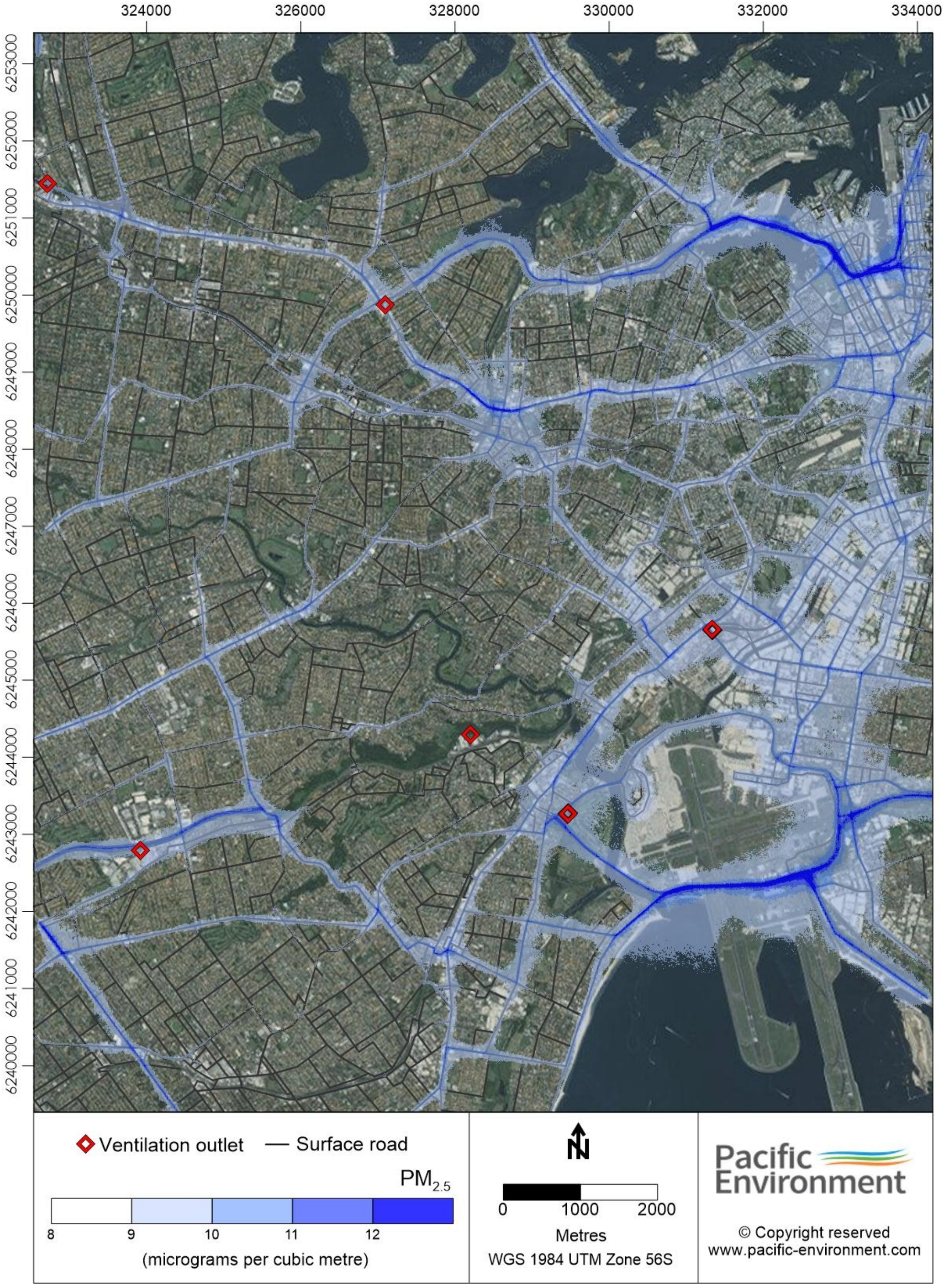

Figure 8-76 Contour plot of annual mean $PM_{2.5}$ concentration in the 2033 Do Minimum scenario (2033-DM)

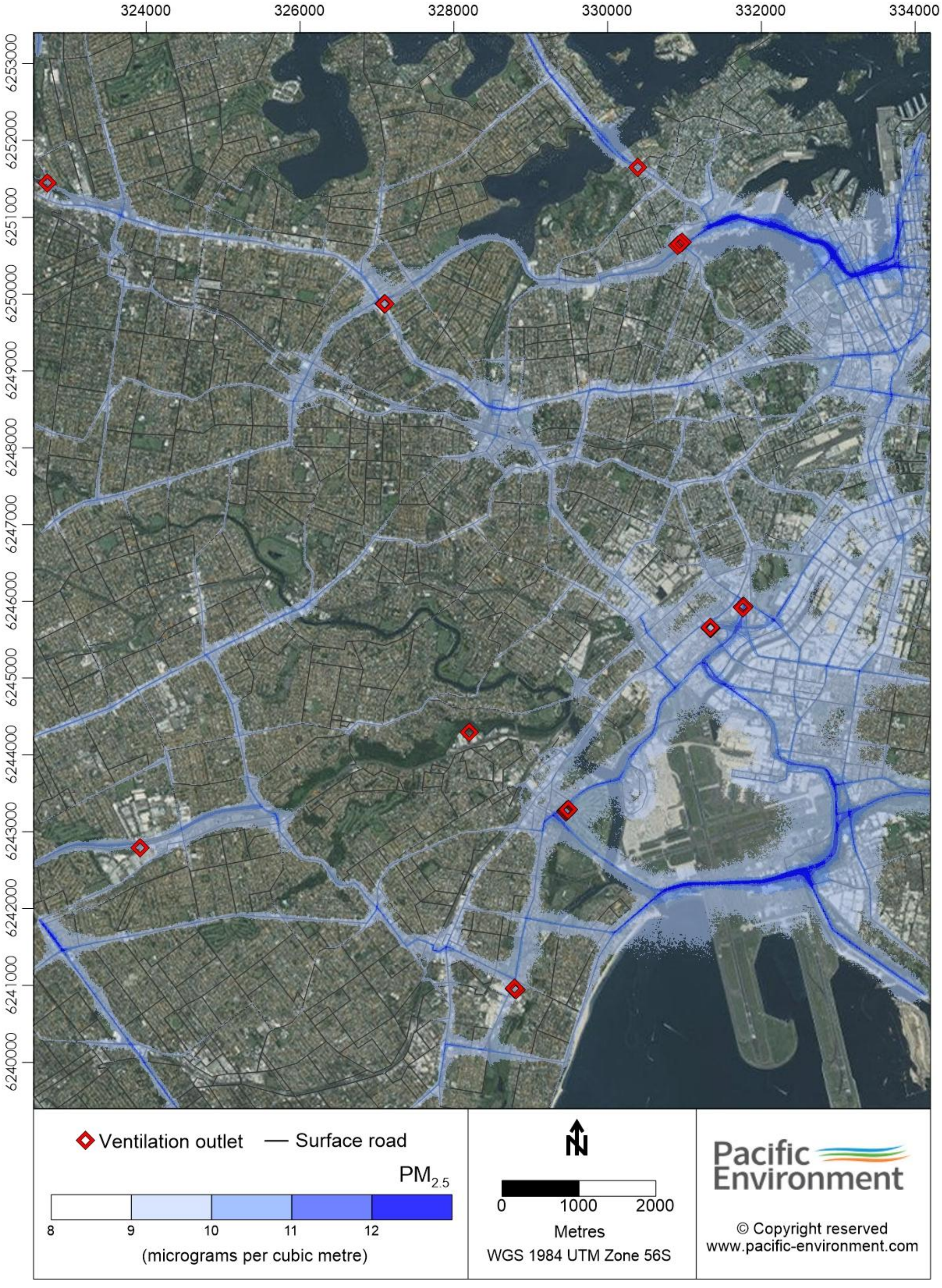

Figure 8-77 Contour plot of annual mean $PM_{2.5}$ concentration in the 2033 cumulative scenario (2033-DSC)

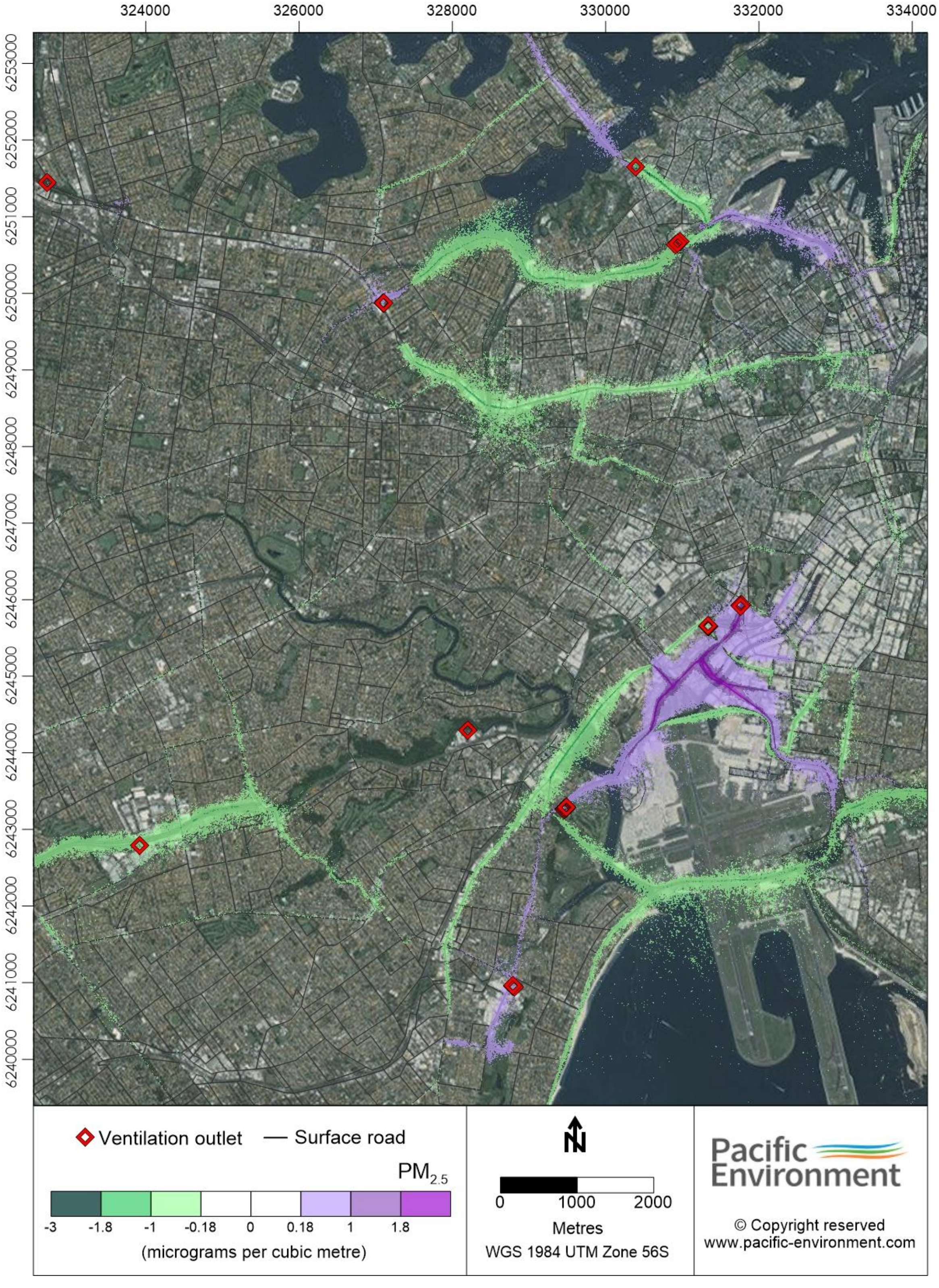

Figure 8-78 Contour plot of change in annual mean $PM_{2.5}$ concentration in the 2033 cumulative scenario (2033-DSC minus 2033-DM)

Contour plots - ventilation outlets only

The contour plot for the annual mean $PM_{2.5}$ contribution from the ventilation outlets only in the 2033-DSC scenario is shown in **Figure 8-79**.

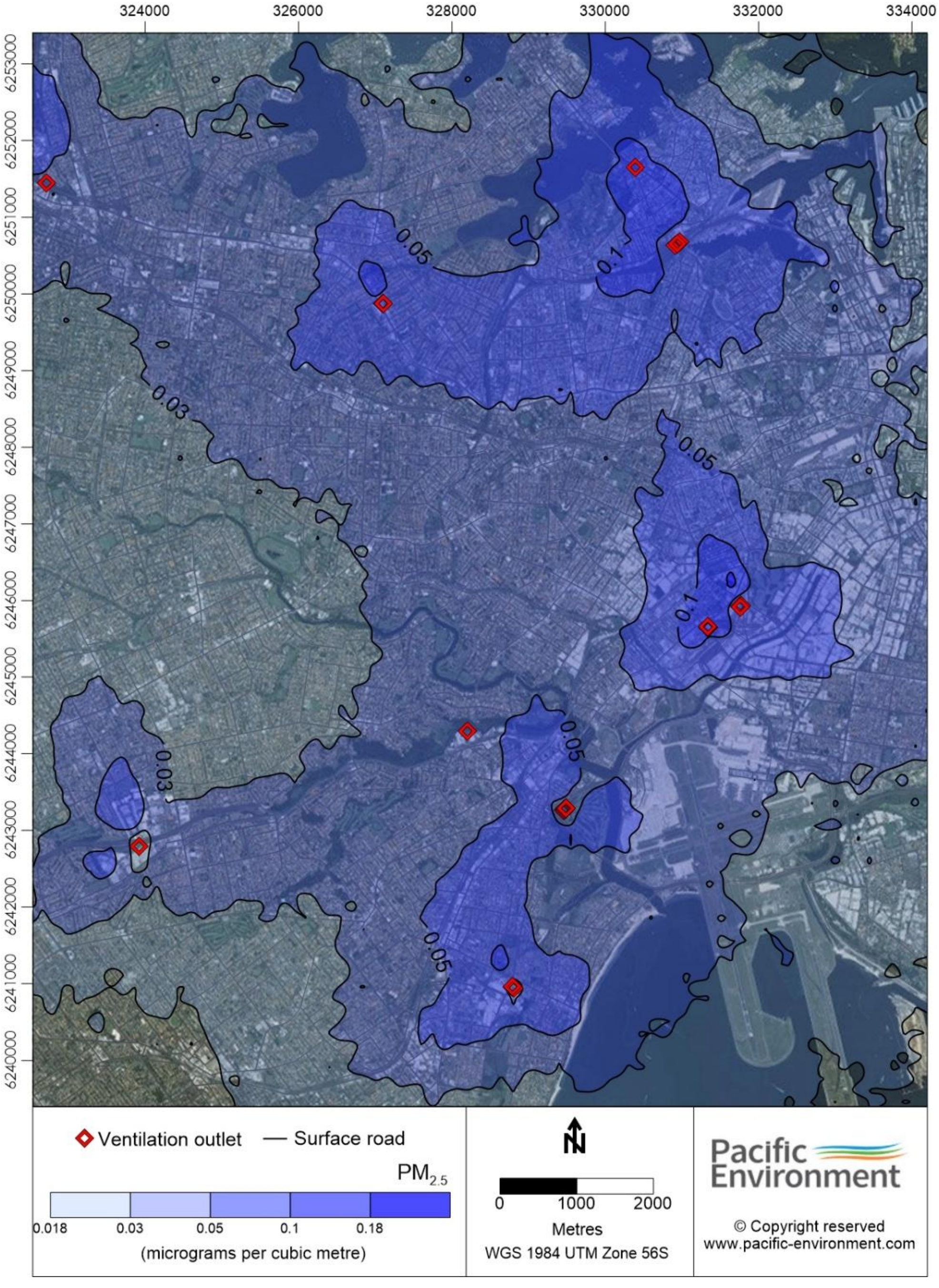

Figure 8-79 Contour plot of annual mean $PM_{2.5}$ concentration for ventilation outlets only (2033-DSC)

$PM_{2.5}$ (maximum 24 hour mean)

Results for community receptors

The maximum 24 hour mean $PM_{2.5}$ concentrations at the community receptors with the project and in the cumulative scenarios are presented in **Figure 8-80**. At all receptor locations, the maximum concentration was above the NSW impact assessment criterion of 25 µg/m^3, although exceedances were already predicted without the project. Internationally, there are no standards lower than 25 µg/m^3 for 24 hour $PM_{2.5}$. However, the AAQ NEPM includes a long-term goal of 20 µg/m^3, and the results suggest that this would be difficult to achieve in the study area at present.

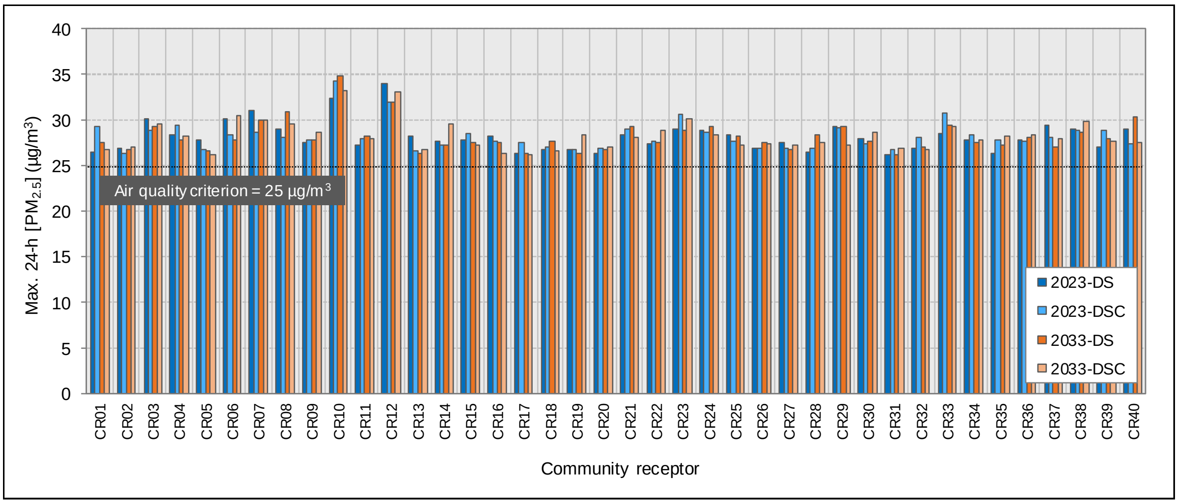

Figure 8-80 Maximum 24 hour $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios)

Figure 8-81 presents the changes in maximum 24 hour PM2.5 with the project and in the cumulative scenarios at the community receptors. At the majority of receptors, there was a decrease in concentration. Most of the increases in concentration were less than 2 µg/m3. The largest increase (2.9 µg/m3 at receptor CR40 in the 2033-DSC scenario) equated to 11 per cent of the air quality criterion.

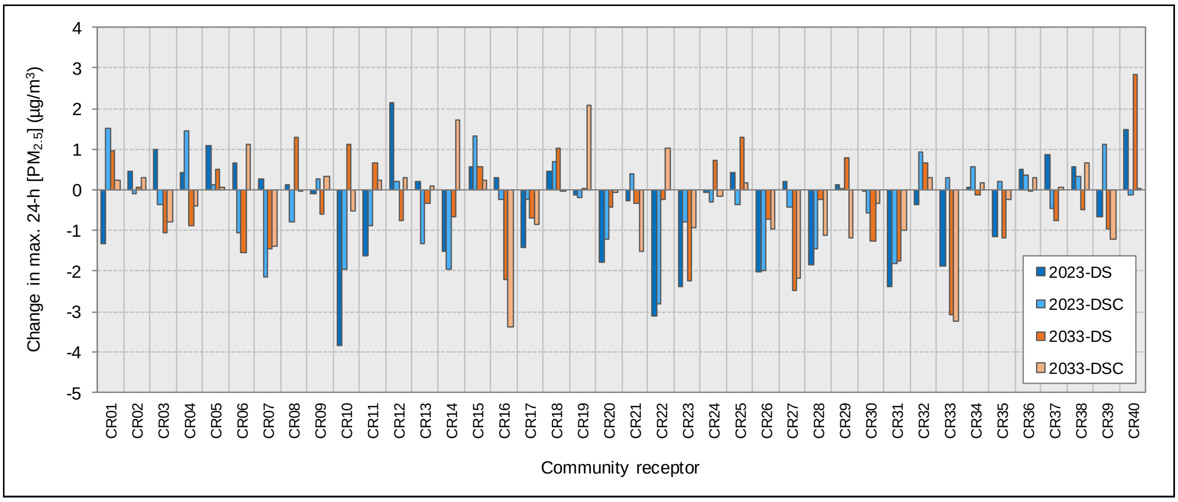

Figure 8-81 Change in maximum 24 hour $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios, relative to Do Minimum scenarios)

The combined road/outlet contributions to the maximum 24 hour $PM_{2.5}$ concentration at the community receptors were relatively small, as shown in **Figure 8-82**. The tunnel ventilation outlet contributions alone were negligible in all cases (<0.15 µg/m^3).

At all community receptors, the maximum total 24 hour concentration occurred on one of two dates, and two of these dates coincided with the highest 24 hour background concentrations in the synthetic $PM_{2.5}$ profile (25.1 and 23.9 µg/m^3).

Figure 8-82 Source contributions to maximum 24 hour mean $PM_{2.5}$ concentration at community receptors (with-project and cumulative scenarios)

Results for RWR receptors

The ranked maximum 24 hour mean $PM_{2.5}$ concentrations at the RWR receptors in the with-project and cumulative scenarios are shown in **Figure 8-83**. The concentration at all receptors was above the NSW impact assessment criterion of 25 µg/m^3. As with PM_{10}, the contributions of surface roads and ventilation outlets are not shown separately as these were not additive. The maximum contribution of tunnel outlets at any receptor was 1.2 µg/m^3.

The changes in the maximum 24 hour mean $PM_{2.5}$ concentration at the RWR receptors in the with-project and cumulative scenarios are ranked in **Figure 8-84**. There was an increase in concentration at between 36 per cent and 39 per cent of the receptors, depending on the scenario. The largest predicted increase in concentration at any receptor as a result of the project was 8.7 µg/m^3 (2023-DSC scenario), and the largest predicted decrease was 8.2 µg/m^3. For most of the receptors the change in concentration was small; where there was an increase in concentration, this was greater than 2.5 µg/m^3 at only around 0.2-0.3 per cent of receptors.

Contour plots – all sources

The contour plots for maximum 24 hour $PM_{2.5}$ in the 2033-DM and 2033-DSC scenarios are given in **Figure 8-85** and **Figure 8-86** respectively. The changes with the project and in the cumulative scenarios are shown in **Figure 8-87**.

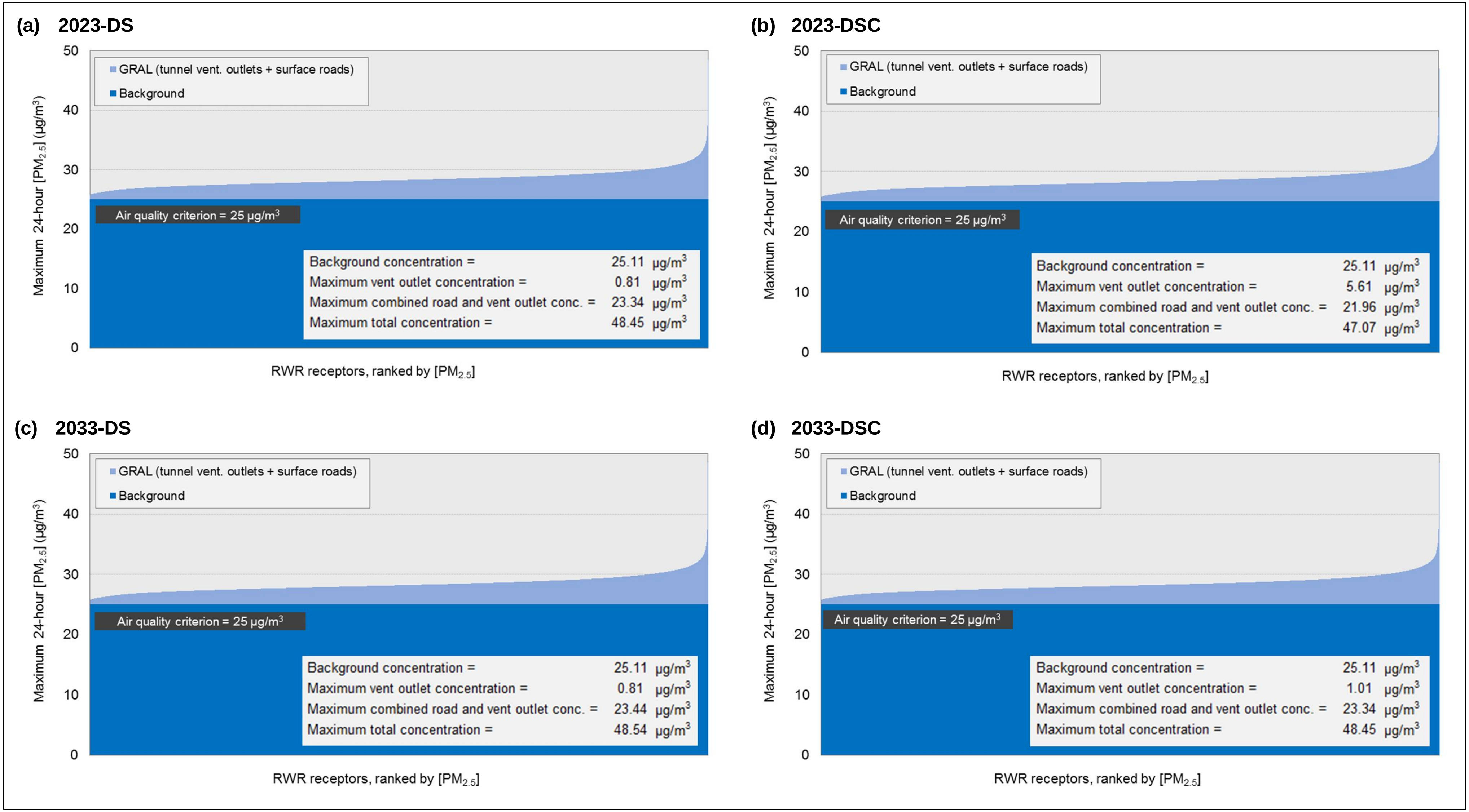

Figure 8-83 Source contributions to maximum 24 hour mean $PM_{2.5}$ concentration at RWR receptors (with-project and cumulative scenarios)

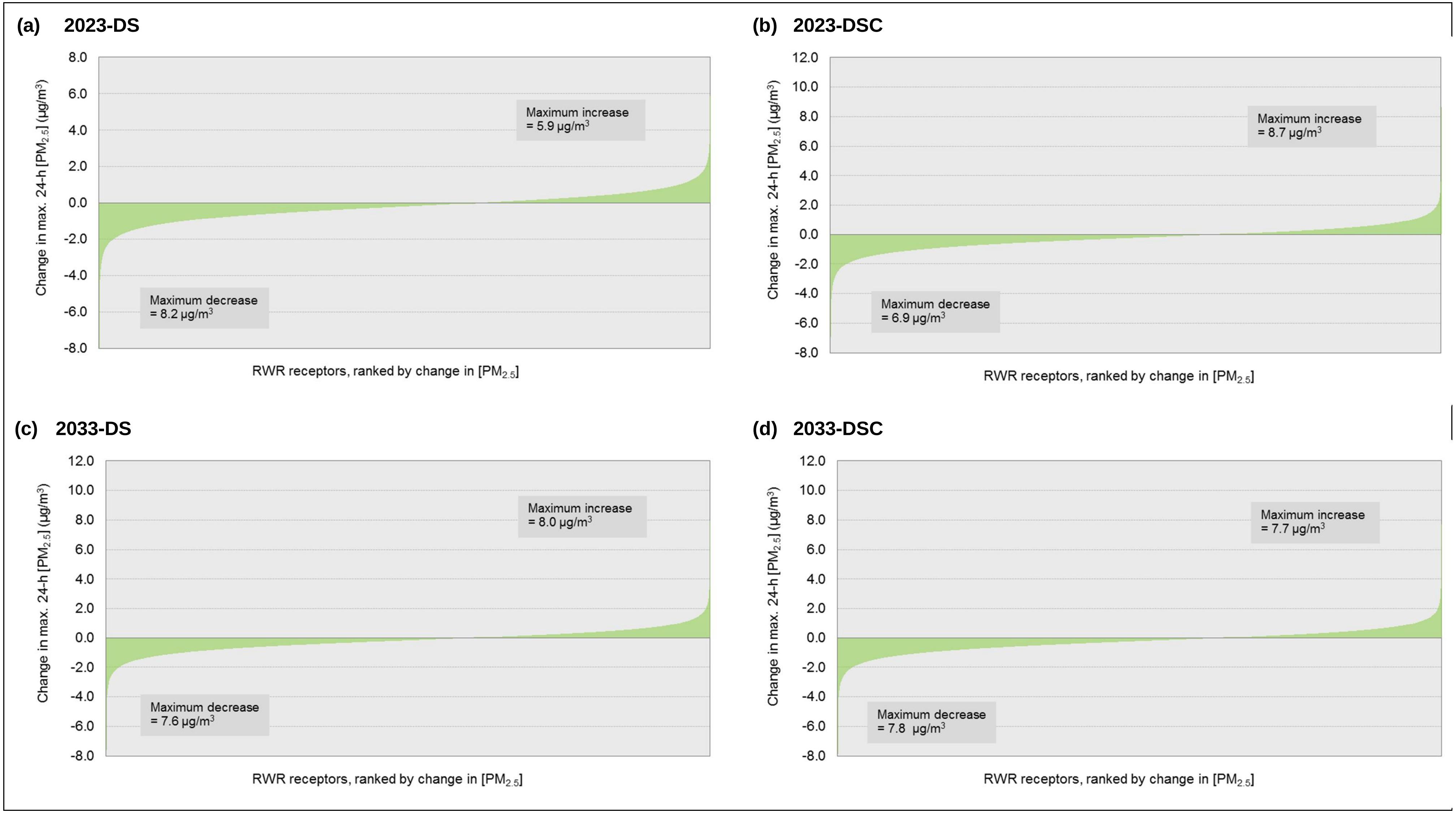

Figure 8-84 Change in maximum 24 hour mean $PM_{2.5}$ concentration at RWR receptors (with-project and cumulative scenarios, relative to Do Minimum scenarios)

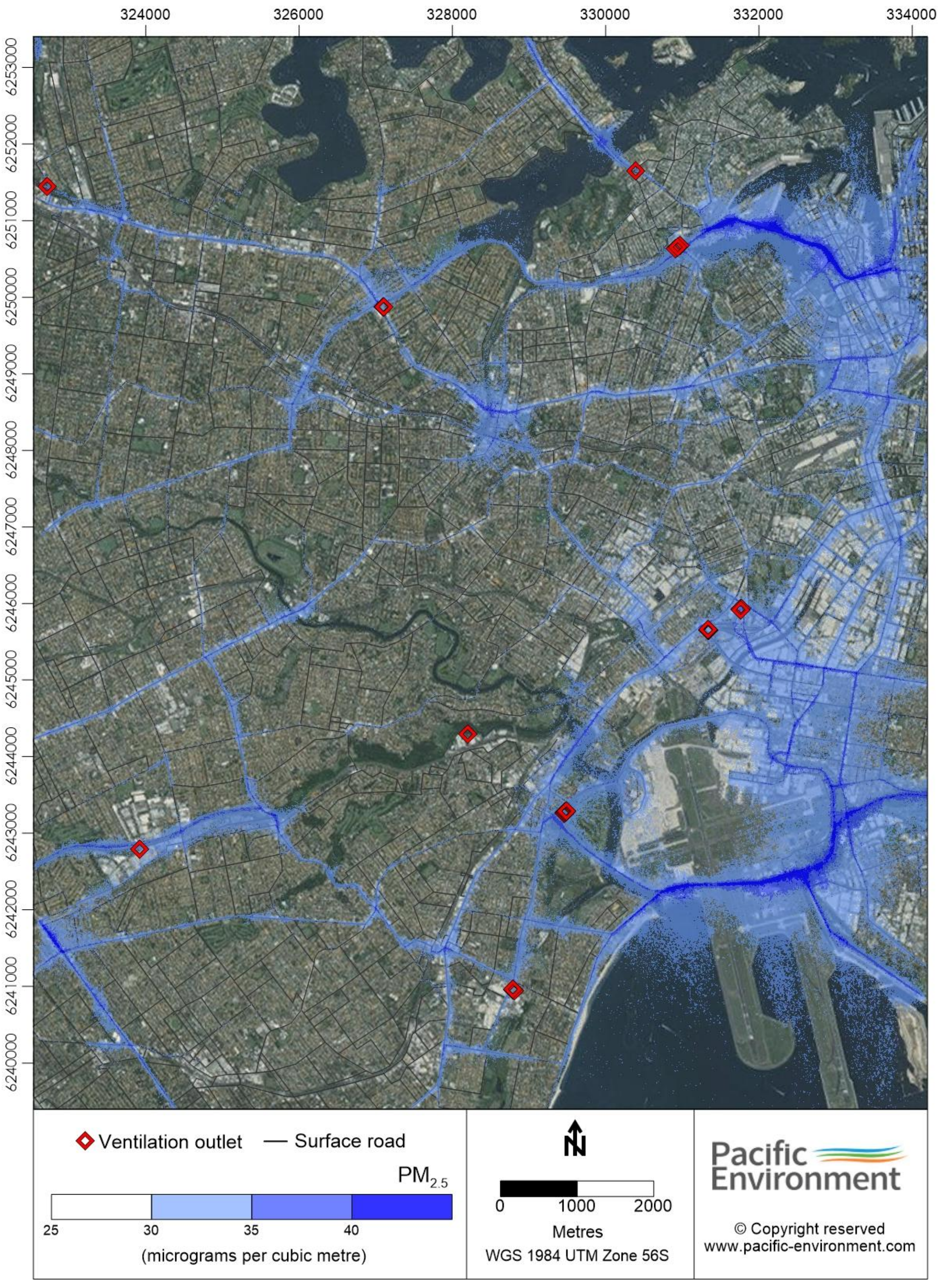

Figure 8-85 Contour plot of maximum 24 hour average $PM_{2.5}$ concentration in the 2033 Do Minimum scenario (2033-DM)

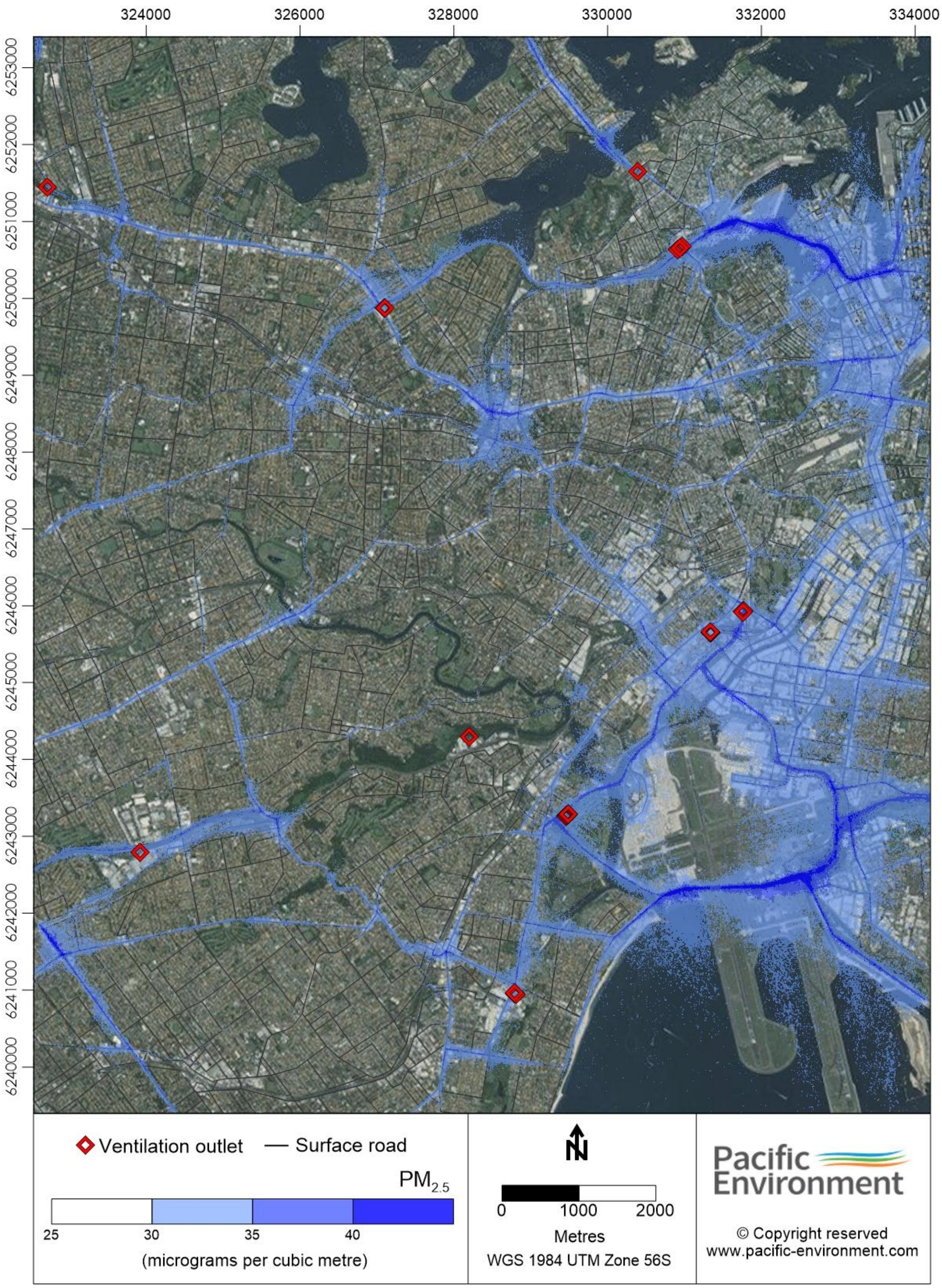

Figure 8-86 Contour plot of maximum 24 hour average $PM_{2.5}$ concentration in the 2033 cumulative scenario (2033-DSC)

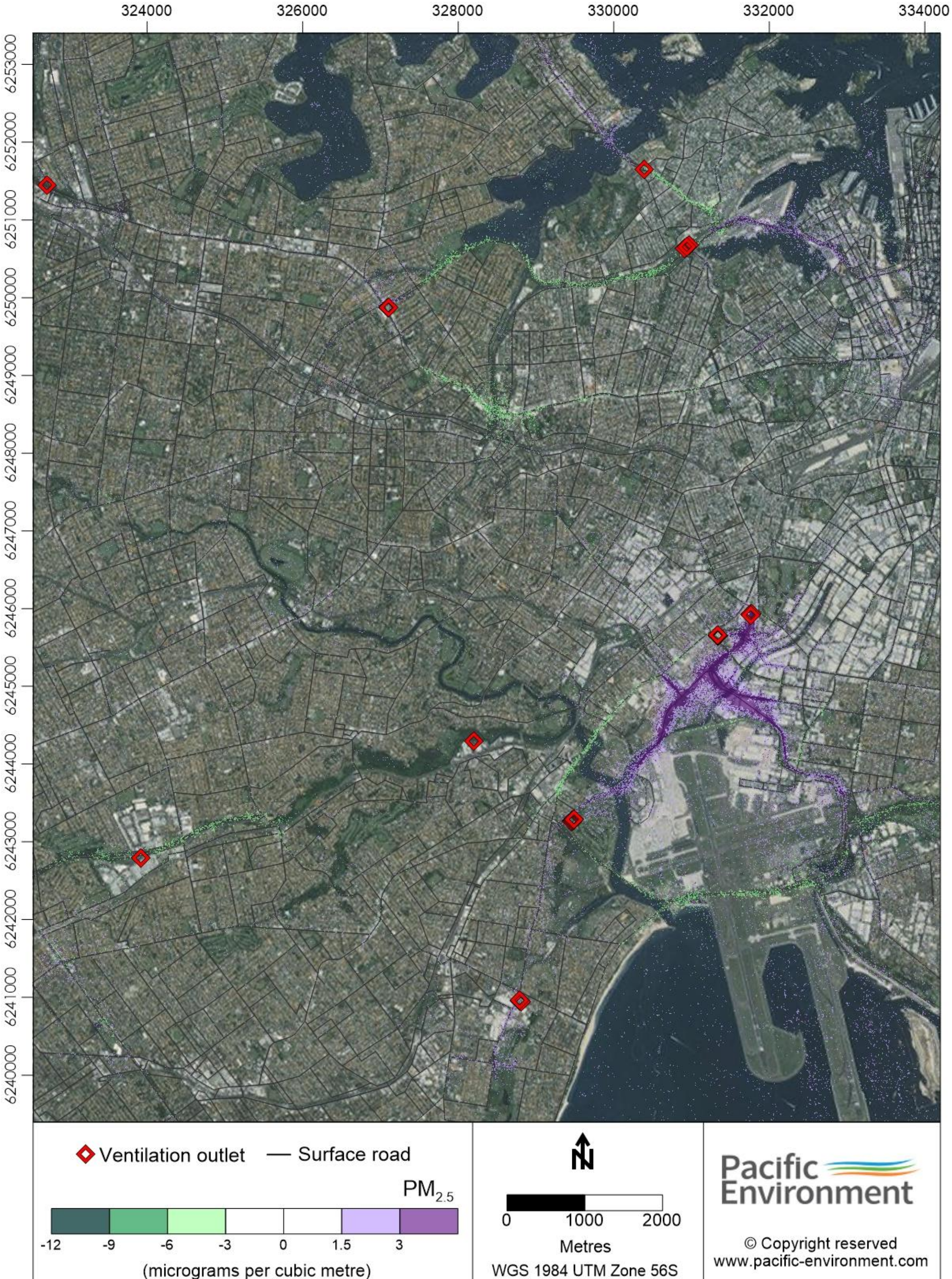

Figure 8-87 Contour plot of change in maximum 24 hour $PM_{2.5}$ concentration in the 2033 cumulative scenario (2033-DSC minus 2033-DM)

Contour plots – ventilation outlets only

The contour plot for maximum 24 hour mean $PM_{2.5}$ contribution from the ventilation outlets only in the 2033-DSC scenario is shown in **Figure 8-79, Figure 8-88**.

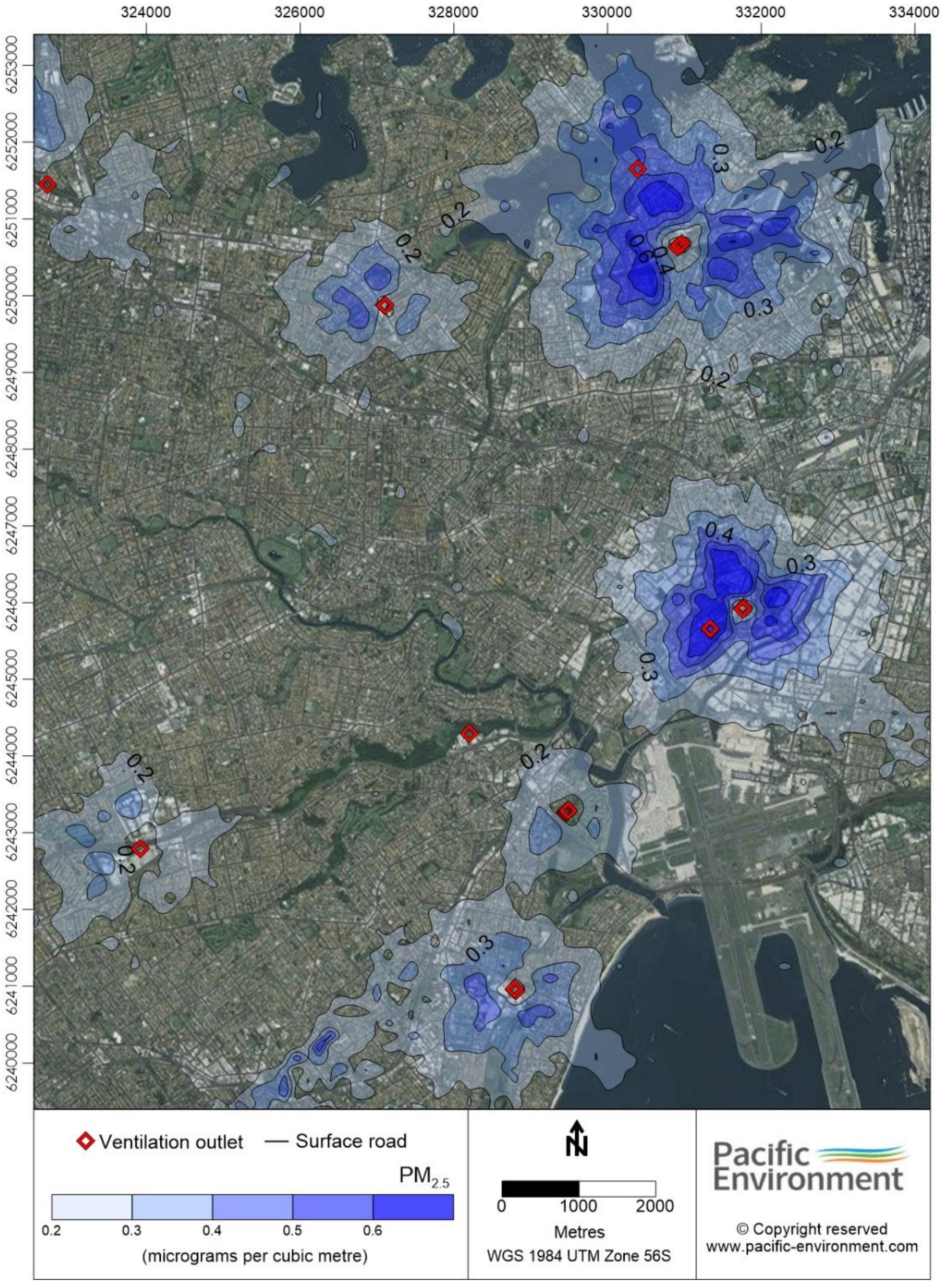

Figure 8-88 Contour plot of maximum 24 hour $PM_{2.5}$ concentration for ventilation outlets only (2033-DSC)

Air toxics

Four air toxics - benzene, PAHs (as BaP), formaldehyde and 1,3-butadiene – were considered in the assessment. These compounds were taken to be representative of the much wider range of air toxics associated with motor vehicles, and they have commonly been assessed for road projects.

The changes in the maximum one hour benzene concentration at the community receptors as a result of the project are shown in **Figure 8-89**, where they are compared with the NSW impact assessment criterion from the Approved Methods. These changes took into account emissions from both surface roads and tunnel ventilation outlets. It can be seen from the Figure that there where there was an increase in the concentration, this was well below the assessment criterion. The changes in the maximum one hour BaP, formaldehyde and 1,3-butadiene concentration are presented in **Figure 8-90**, **Figure 8-91**, and **Figure 8-92** respectively. For each compound, where there was an increase in the concentration, this was well below the NSW impact assessment criterion. The largest increases for the community receptors were also representative of the largest increases for the RWR receptors.

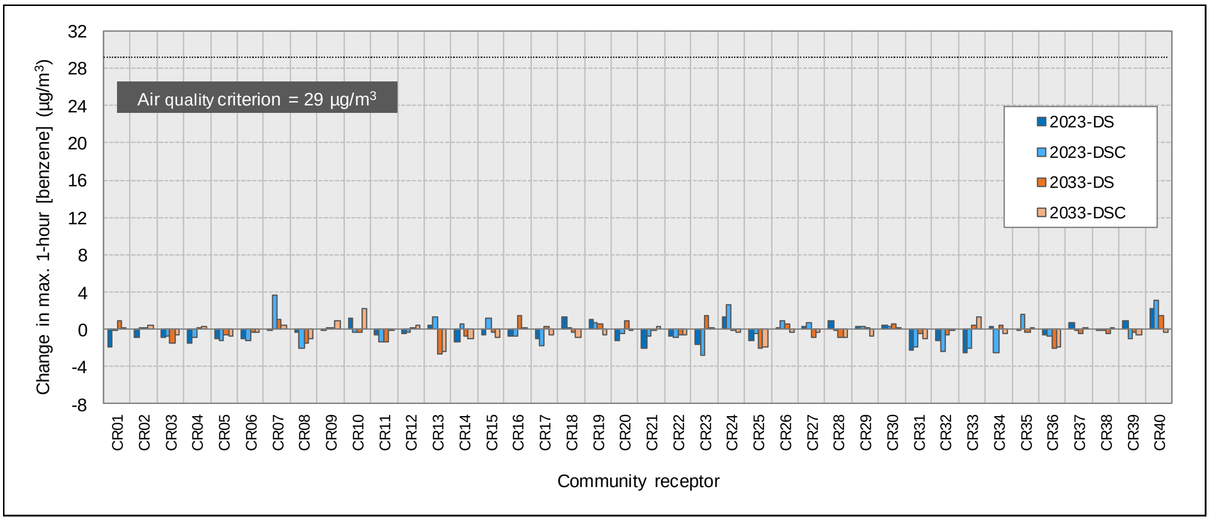

Figure 8-89 Change in maximum one hour mean benzene concentration at community receptors (with-project and cumulative scenarios)

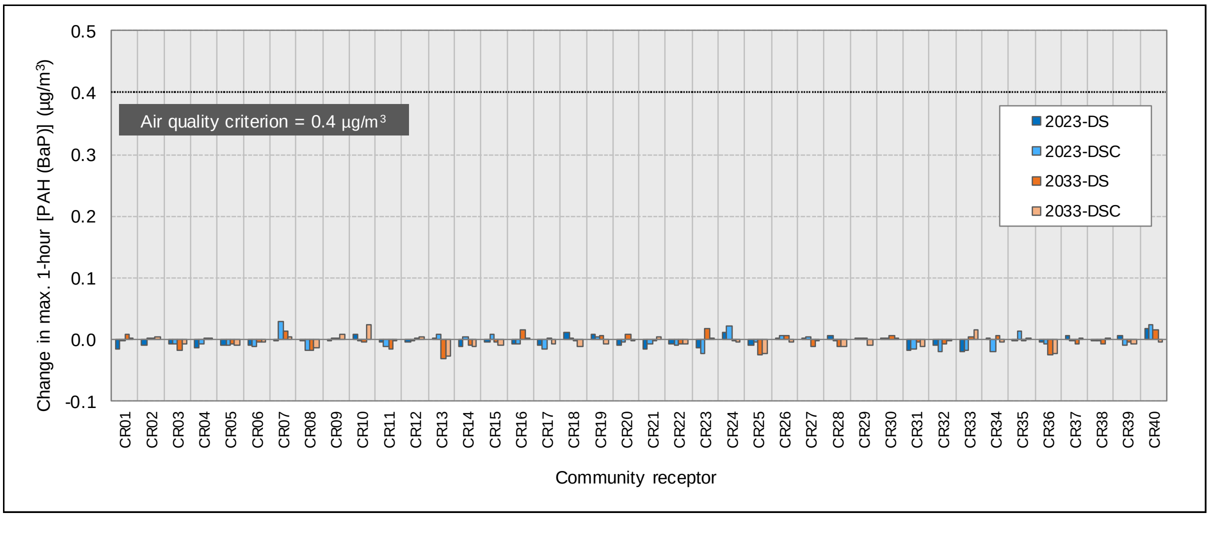

Figure 8-90 Change in maximum one hour mean b(a)p concentration at community receptors (with-project and cumulative scenarios)

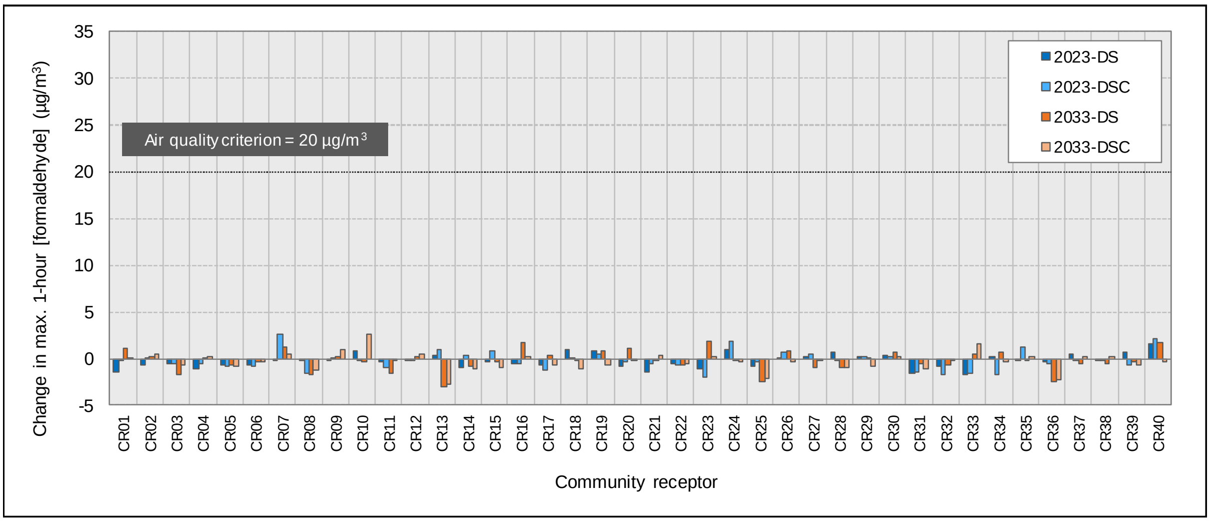

Figure 8-91 Change in maximum one hour mean formaldehyde concentration at community receptors (with-project and cumulative scenarios)

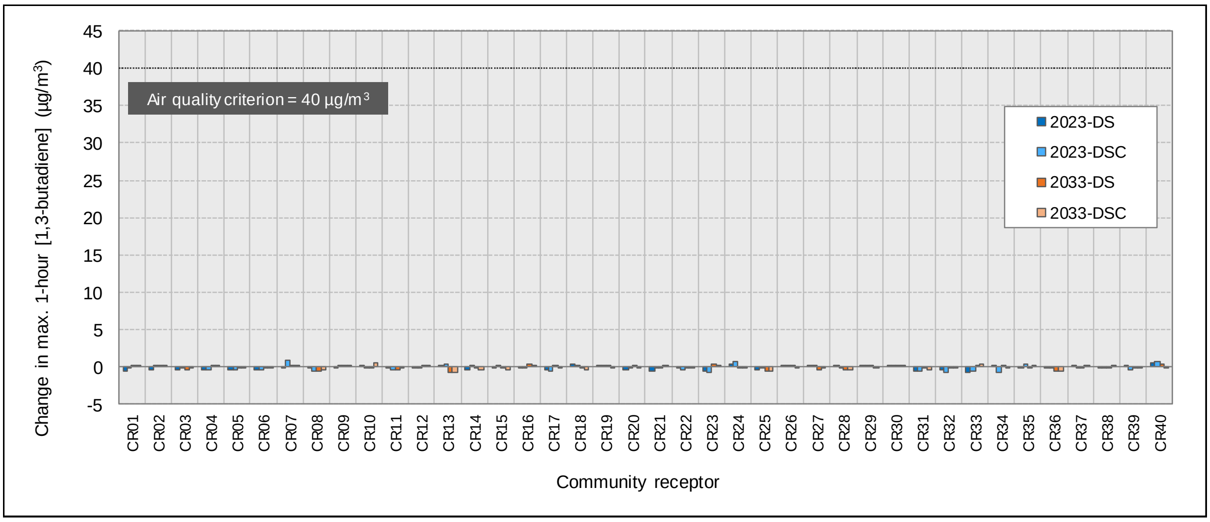

Figure 8-92 Change in maximum one hour mean 1,3-butadiene concentration at community receptors (with-project and cumulative scenarios)

8.4.11 Results for expected traffic scenarios (elevated receptors)

Annual mean $PM_{2.5}$

Figure 8-93 and **Figure 8-94** present contour plots for the changes in annual mean $PM_{2.5}$ concentration in the 2033-DSC scenario, and for receptor heights of 10 metres and 30 metres respectively. These plots can be compared with the changes in ground-level annual mean concentration for the same scenario (**Figure 8-78**). It should be noted that, for the 10 metre and 30 metre outputs, it was not necessarily the case that there were existing buildings at these heights at the receptor locations.

The reduced influence of surface roads at a receptor height of 10 metres compared with ground level can be seen in **Figure 8-93**. However, because the influence of surface roads in the Do Minimum case at 10 metres was also reduced, the distributions of changes in annual average $PM_{2.5}$ concentration at 10 metres and ground level were quite similar. For example, where there was an increase in annual mean $PM_{2.5}$ at the height of 10 metres, this was greater than 0.1 µg/m^3 for 2.9 per cent of receptors (compared with 3.2 per cent at ground level). However, the largest changes in concentration at 10 metres were smaller than those at ground level. The largest increase at the height of 10 metres for the RWR receptors was 0.79 µg/m^3, which can be compared with the maximum increase for any ground-level receptor in the 2033-DSC scenario of 2.3 µg/m^3. This was probably because the large changes at ground-level receptors were exaggerated (**section 8.4.14)**.

Figure 8-94 show that the situation was quite different at a receptor height of 30 metres. At this height the changes in annual mean $PM_{2.5}$ associated with surface roads appeared to be negligible at all locations. The increase in $PM_{2.5}$ was greater than 1.8 µg/m^3 at just one industrial receptor. The largest increases for residential receptors were between 1.41 and 1.43 µg/m^3 for a small group of receptors close to the location of the M4-M5 Link ventilation facility at St Peters interchange. However, the height of these receptors (<5 metres) was considerably lower than that of the ventilation outlets.

Maximum 24 hour $PM_{2.5}$

Figure 8-95 and **Figure 8-96** show the contour plots showing the changes in maximum 24 hour PM2.5 concentration in the 2033-DSC scenario at receptor heights of 10 metres and 30 metres respectively. These plots can be compared with the changes in ground-level concentration for the same scenario (**Figure 8-87**). As mentioned in the previous section, it is not necessarily the case that there would be existing buildings with heights of 10 metres or 30 metres at the RWR receptor locations.

At a receptor height of 10 metres, the maximum changes in concentration were slightly lower than at ground level but, as with the annual mean, the distributions of changes were quite similar. The largest increase in 24 hour $PM_{2.5}$ at the height of 10 metres for the RWR receptors was 6.0 µg/m^3, which can be compared with the maximum increase for any ground-level RWR receptor in the 2033-DSC scenario of 7.7 µg/m^3. Where there was an increase in $PM_{2.5}$ at the height of 10 metres, this was greater than 2.5 µg/m^3 (10 per cent of the assessment criterion) for 0.1 per cent of receptors (compared with 0.2 per cent at ground level).

At the height of 30 metres the largest increases in the maximum 24 hour $PM_{2.5}$ concentrations were again in the vicinity of the ventilation outlets, and these largest increases were greater than those at 10 metres and ground level. Again, there was a large increase of 36.6 µg/m^3 at one industrial receptor. There was predicted to be an increase in maximum 24 hour $PM_{2.5}$ of more than 2.5 µg/m^3 (10 per cent of the assessment criterion) at 86 (0.1 per cent) receptors. Of these, 67 were at residential locations, and of the 67 the ones with the largest increases were close to the location of the M4-M5 Link ventilation facility at St Peters interchange. Again, the actual height of these receptors was considerably lower than that of the ventilation outlets.

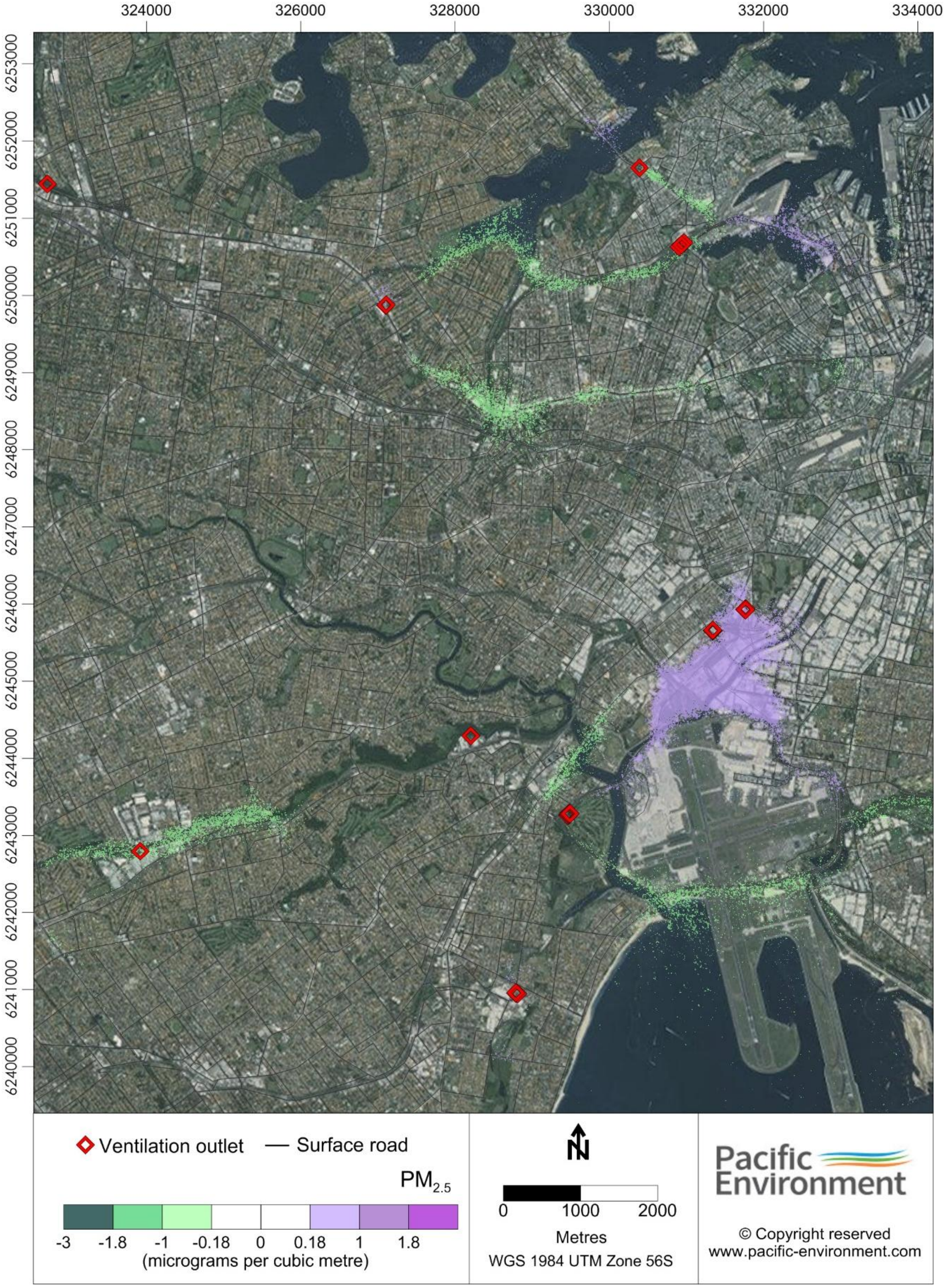

Figure 8-93 Contour plot of change in annual mean $PM_{2.5}$ concentration at 10 metre receptor height in 2033 Cumulative scenario (2033-DSC minus 2033-DM)

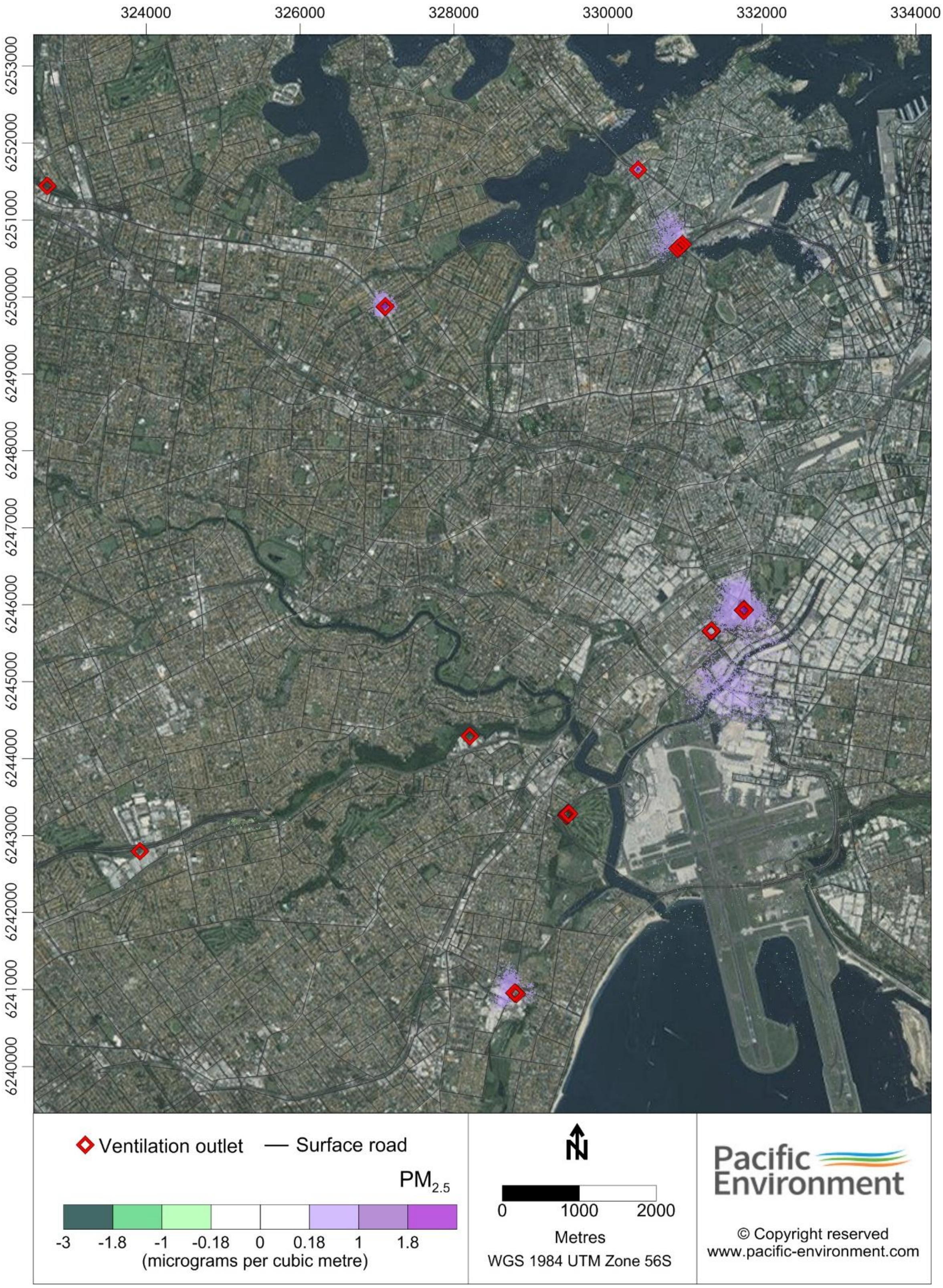

Figure 8-94 Contour plot of change in annual mean $PM_{2.5}$ concentration at 30 metre receptor height in 2033 Cumulative scenario (2033-DSC minus 2033-DM)

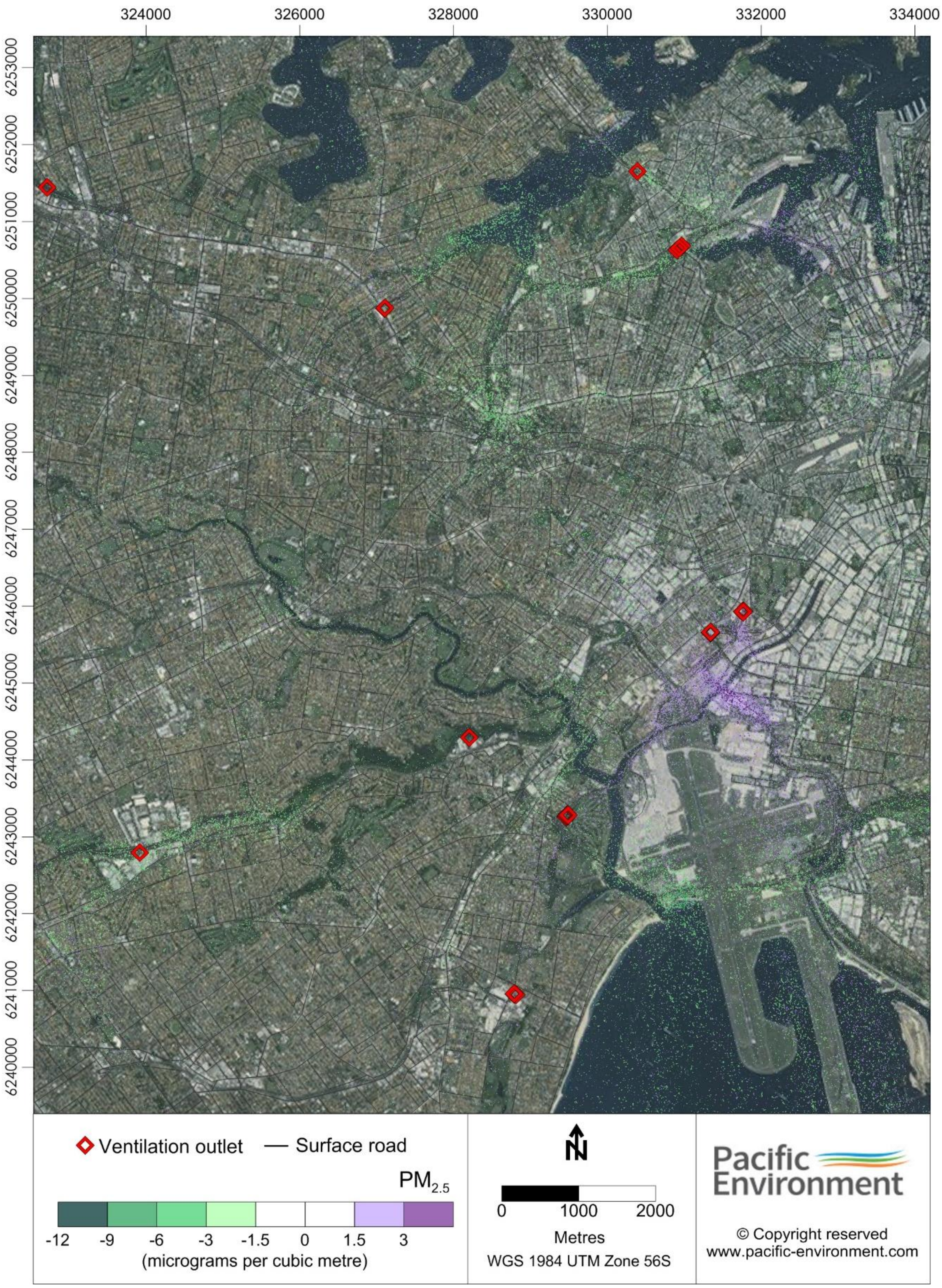

Figure 8-95 Contour plot for change in maximum 24 hour $PM_{2.5}$ concentration at 10 metre receptor height in 2033 Cumulative scenario (2033-DSC minus 2033-DM)

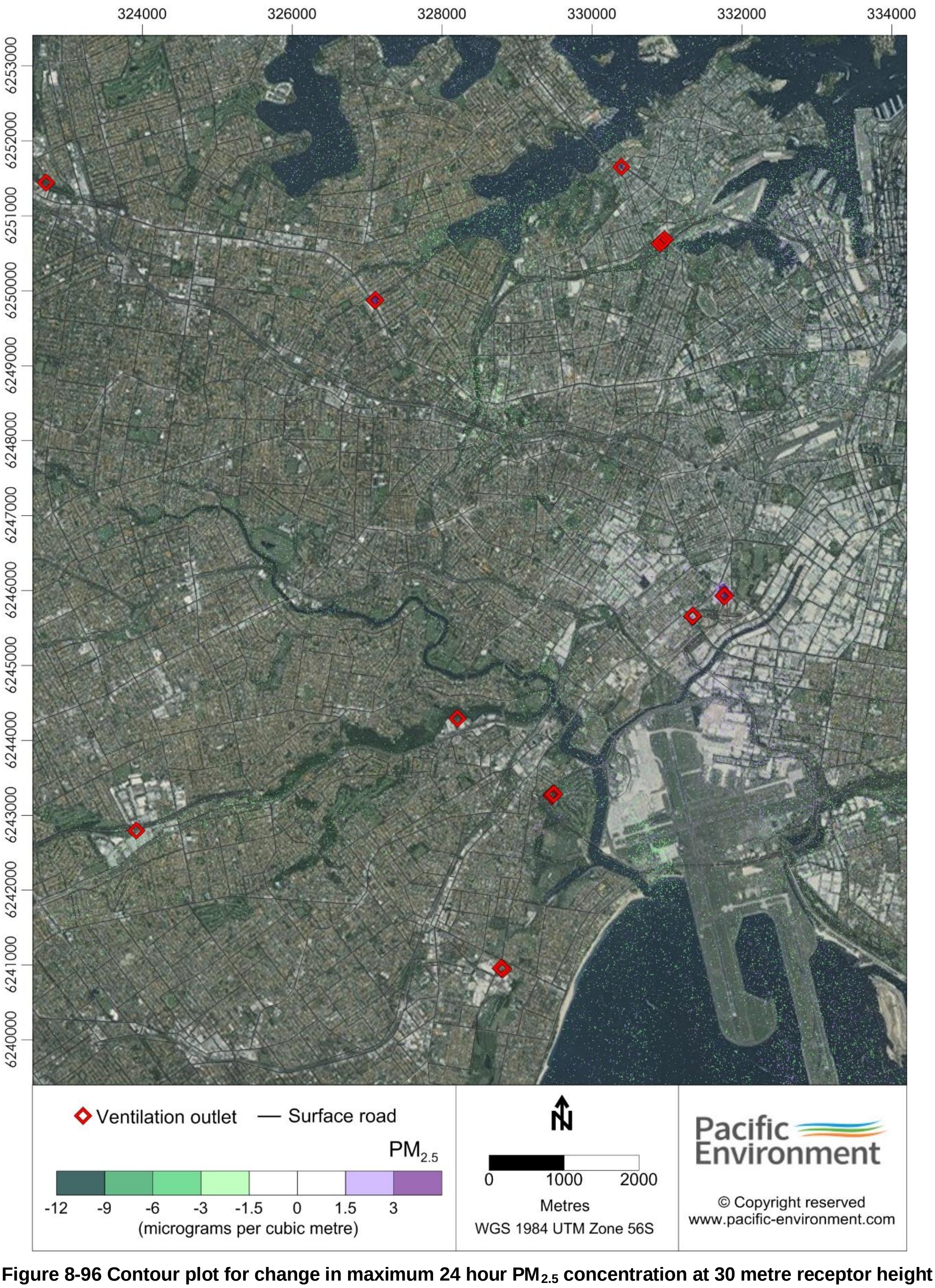

Figure 8-96 Contour plot for change in maximum 24 hour $PM_{2.5}$ concentration at 30 metre receptor height in 2033 Cumulative scenario (2033-DSC minus 2033-DM)

Summary

The implications of these results can be summarised as follows:

- For all existing receptor locations, the changes in $PM_{2.5}$ concentration at 10 metres are likely to be acceptable. This assumes that the changes in $PM_{2.5}$ concentration for heights between ground level and 10 metres are also acceptable
- Future developments to the height of 10 metres should be possible at all locations in the GRAL domain
- The contour plots do not seem to impose any significant restrictions on future developments to 30 metres height, except in the immediate vicinity of ventilation outlets, especially at St Peters interchange. The ventilation outlets would not adversely impact any existing receptors, as there are no existing buildings 30 metres or higher located close to the proposed ventilation facilities. However, planning controls should be developed in the vicinity of St Peters interchange to ensure future developments at heights 10 metres or higher are not adversely impacted by the ventilation outlets. Development of planning controls would be supported by detailed modelling addressing all relevant pollutants and averaging periods.

8.4.12 Results for regulatory worst case scenario

The following sections highlight the results of this scenario for the receptors with the largest impacts. As noted in the methodology, a more detailed approach was required for NO2 than for the other pollutants.

CO and PM

The results for CO, PM_{10} and $PM_{2.5}$ in the regulatory worst case scenario (RWC-2033-DSC only) are given in **Table 8-24**. The Table shows the maximum contribution of tunnel ventilation outlets at any of the RWR receptors in this scenario, as well as the maximum contribution at any residential receptor. For most of the pollutant metrics, the results were the same in both cases.

Table 8-24 Results of regulatory worst case assessment (RWR receptors) – CO and PM

Pollutant and period	Units	Maximum ventilation outlet contribution at any receptor					
		Regulatory worst case scenario (RWC-2033-DSC)		Expected traffic scenarios			
		All receptors	Residential receptors	2023-DS	2023-DSC	2033-DS	2033-DSC
CO (one hour)	(mg/m^3)	0.50	0.50	0.06	0.07	0.06	0.07
PM_{10} (annual)	($\mu g/m^3$)	1.01	1.01	0.24	0.37	0.24	0.30
PM_{10} (24-h)	($\mu g/m^3$)	4.51	4.06	1.25	1.94	1.23	1.50
$PM_{2.5}$ (annual)[(a)]	($\mu g/m^3$)	1.01	1.01	0.17	0.25	0.17	0.21
$PM_{2.5}$ (24-h)[(a)]	($\mu g/m^3$)	4.51	4.06	0.81	1.23	0.81	1.01

(a) The same emission rates were used for PM_{10} and $PM_{2.5}$.

The concentrations in the regulatory worst case scenario were, of course, higher than those for the expected traffic scenarios in all cases, and the following points are noted for the former:

- The maximum one hour CO concentration was negligible, especially taking into account the fact that CO concentrations are well below the NSW impact assessment criterion. For example, the maximum one hour outlet contribution in the regulatory worst case scenario (0.50 mg/m^3) was a very small fraction of the criterion (30 mg/m^3). The maximum background one hour CO concentration (3.27 mg/m^3) was also well below the criterion. Exceedances of the criterion are therefore highly unlikely to occur

- For PM_{10} the maximum contribution of the ventilation outlets would have been small. For both the annual mean and maximum 24 hour metrics the outlet contributions were less than 10 per cent of the respective criteria. This would be significant for some receptors, but any exceedances of the criteria would be dominated by background concentrations
- The ventilation outlet contribution would be most important for $PM_{2.5}$, with the maximum contributions equating to 13 per cent and 18 per cent of the annual mean and 24 hour criteria respectively. Again, any exceedances of the criteria would be dominated by background concentrations.

NO_X and NO_2

The results of the more detailed assessment for NO_2 at the M4-M5 Link ventilation facilities in the with-project and cumulative scenarios are shown in **Figure 8-97** to **Figure 8-108**. In each figure:

- The first plot (a) shows the different source contributions when the maximum one hour NO_2 concentration occurs during the year. During these periods the tunnel ventilation contributions are zero or close to zero
- The second plot (b) shows the NO_2 concentrations when the maximum ventilation outlet concentrations occur; under these circumstances, the background and surface road concentrations tend to be lower than in plot (a), and therefore the total NO_2 concentrations are well below the criterion.

For some receptors, the same maximum outlet concentration occurred in more than one hour of the year. Where this was the case the hour having the largest total NO_X concentration has been presented.

In some cases the ventilation outlet contributions appear to be substantial. This is deceptive, as the background and surface road contributions (and hence total NOx) increase, there is a pronounced reduction in the contribution of the outlets to NO_2. In other words, as the total NO_2 concentration tends towards the 'maximum' situation in plot (a) of each figure, the outlet contribution to NO_2 decreases dramatically, indicated by the black 'ventilation outlet' contribution being imperceptible in the plots. This is because as the concentration of NO increases the amount of ozone available for NO_2 production decreases. Plot (b) of each figure shows that the maximum outlet contribution occurs when other contributions are low, such that overall NO_2 concentrations are well below the criterion or even the current maximum.

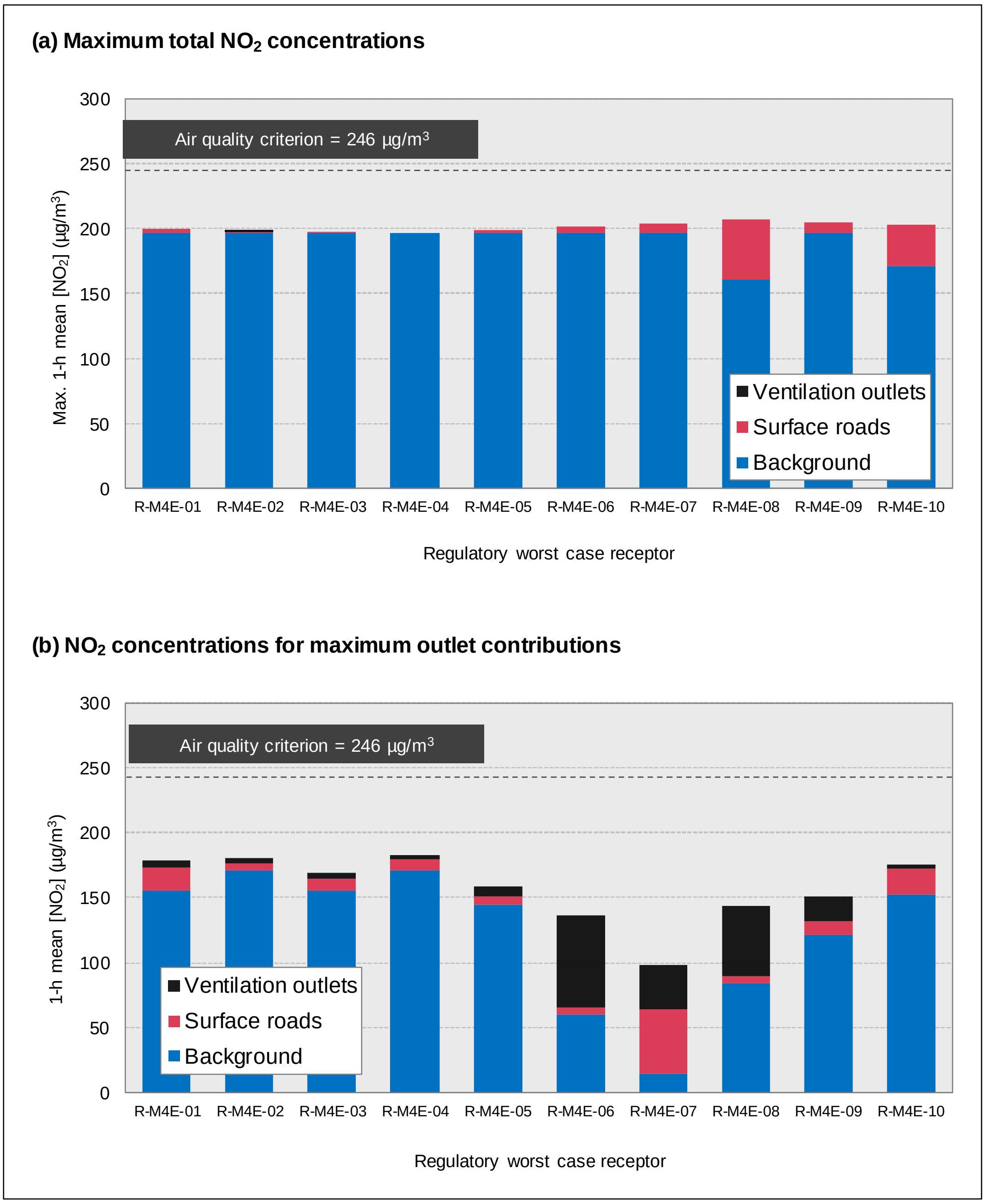

Figure 8-97 Regulatory worst case: one hour mean NO_2 concentrations (2023-DS, Parramatta Road facility)

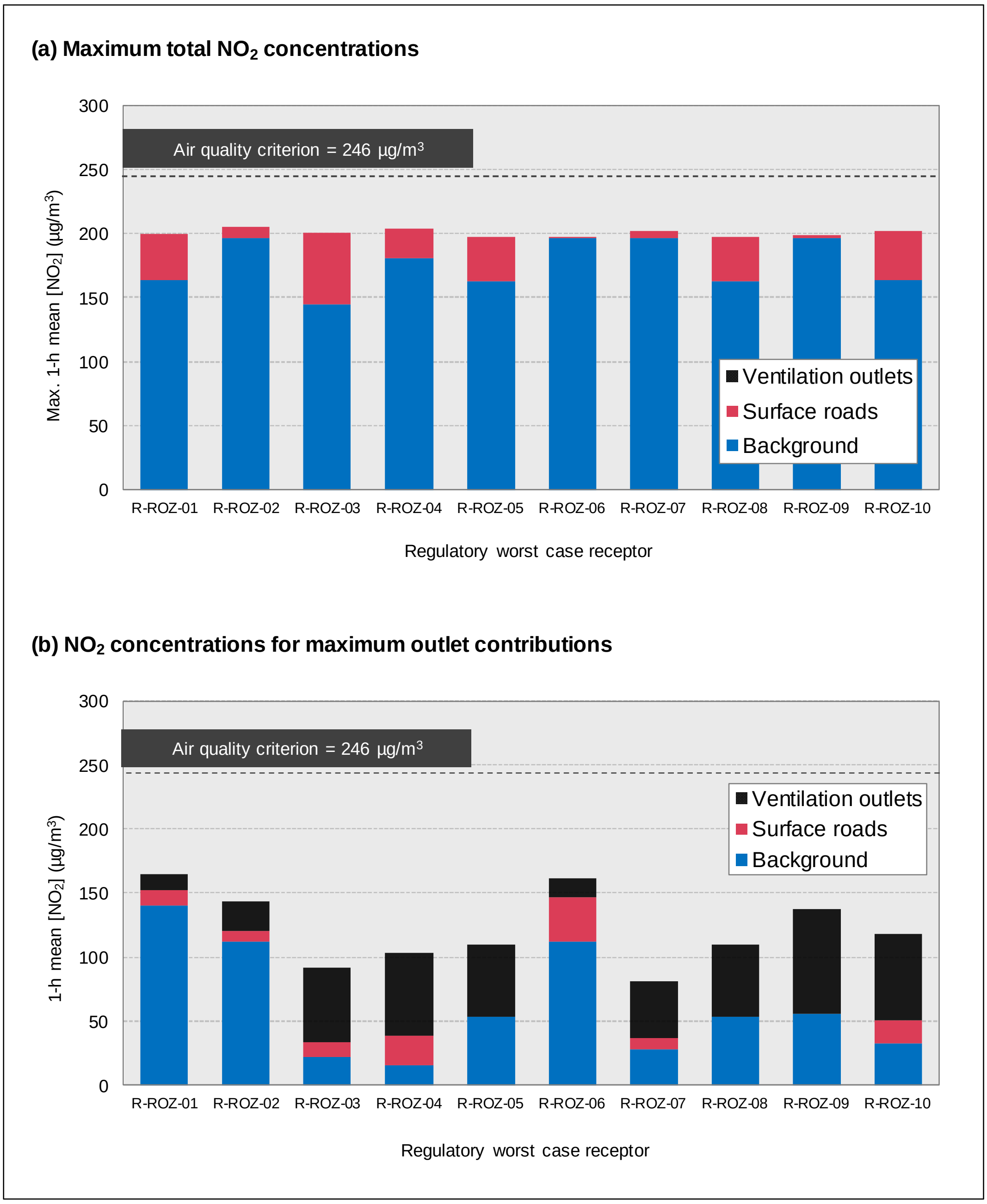

Figure 8-98 Regulatory worst case: one hour mean NO_2 concentrations (2023-DS, Rozelle facilities)

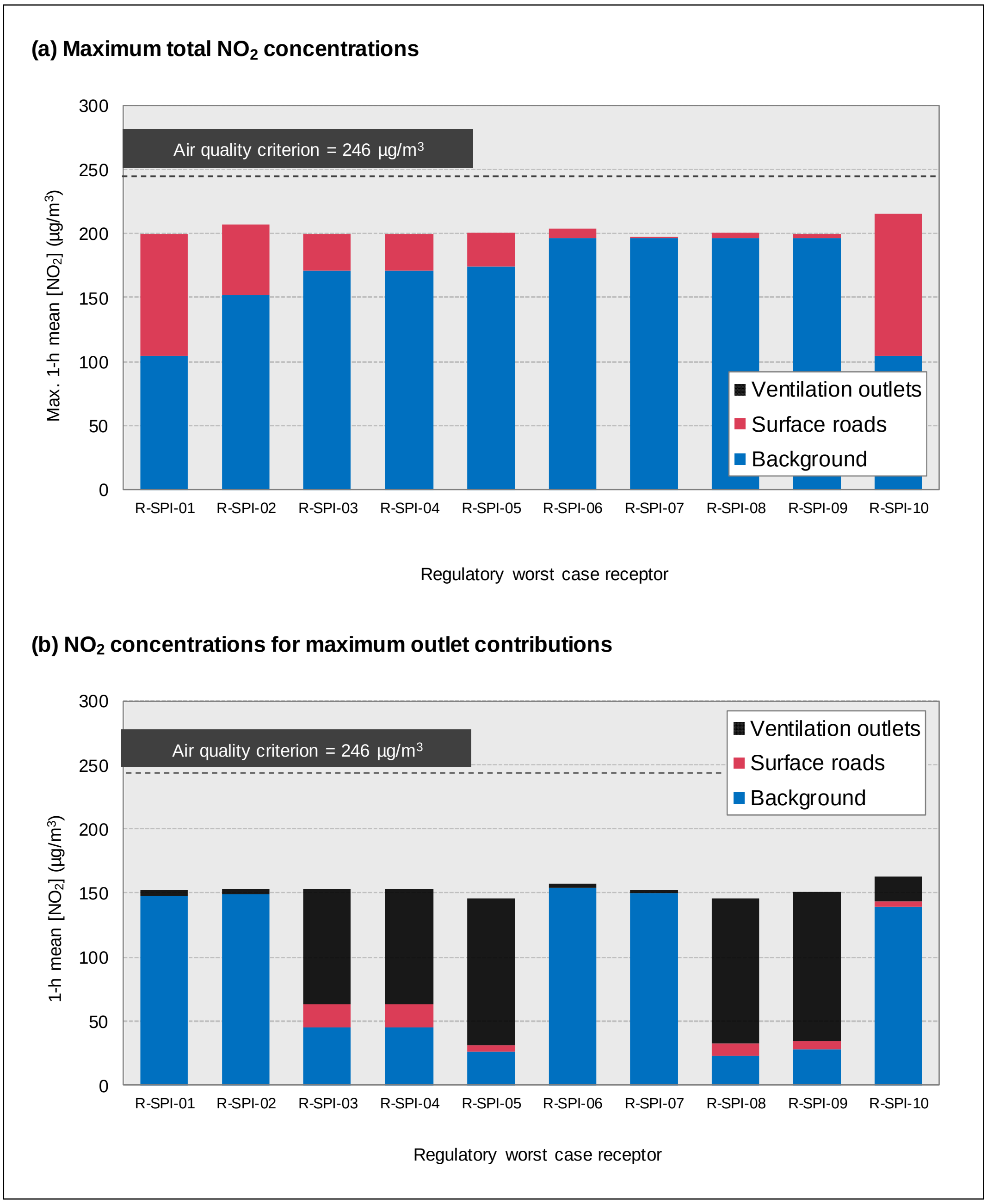

Figure 8-99 Regulatory worst case: one hour mean NO_2 concentrations (2023-DS, SPI facilities)

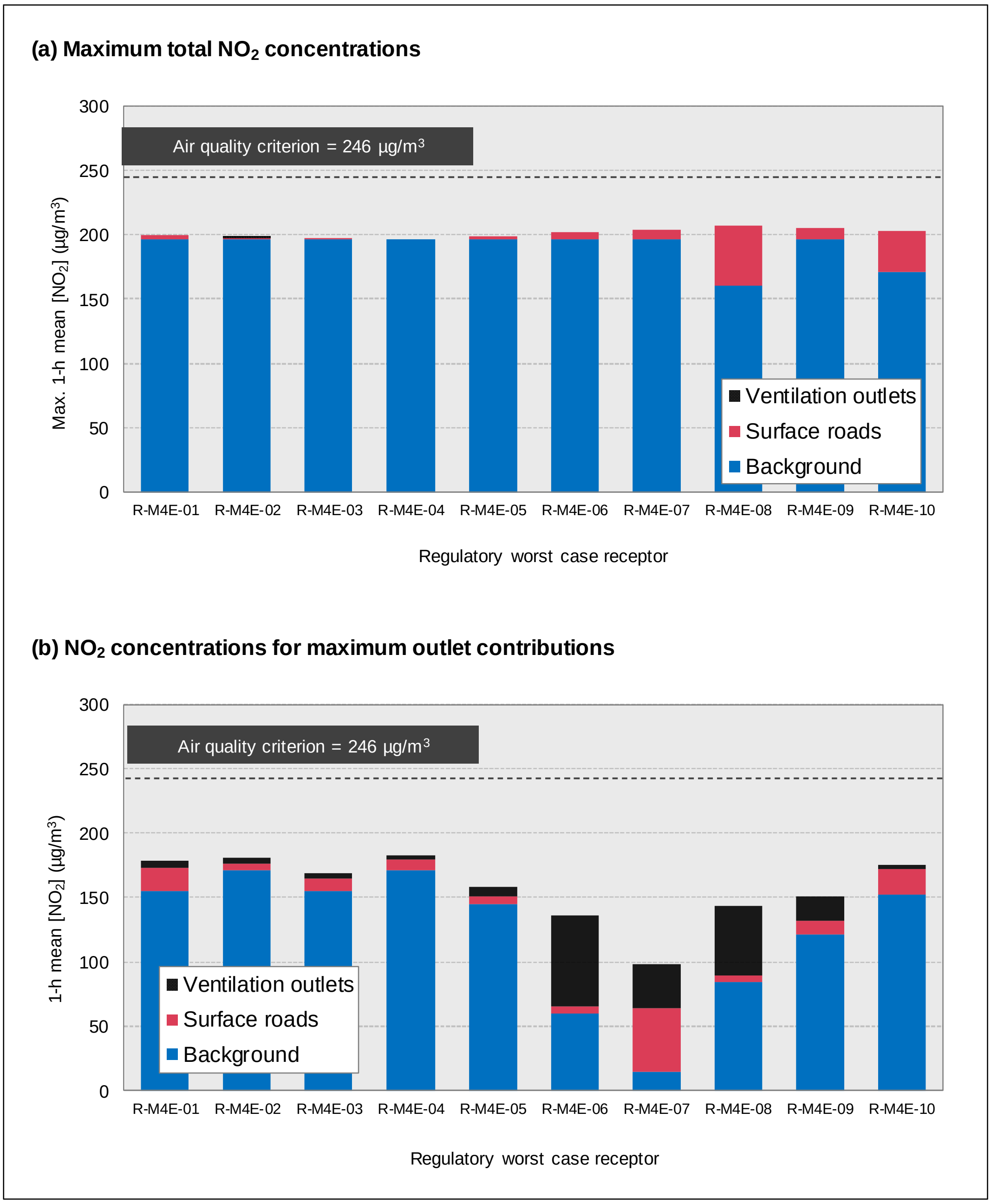

Figure 8-100 Regulatory worst case: one hour mean NO_2 concentrations (2023-DSC, Parramatta Road facility)

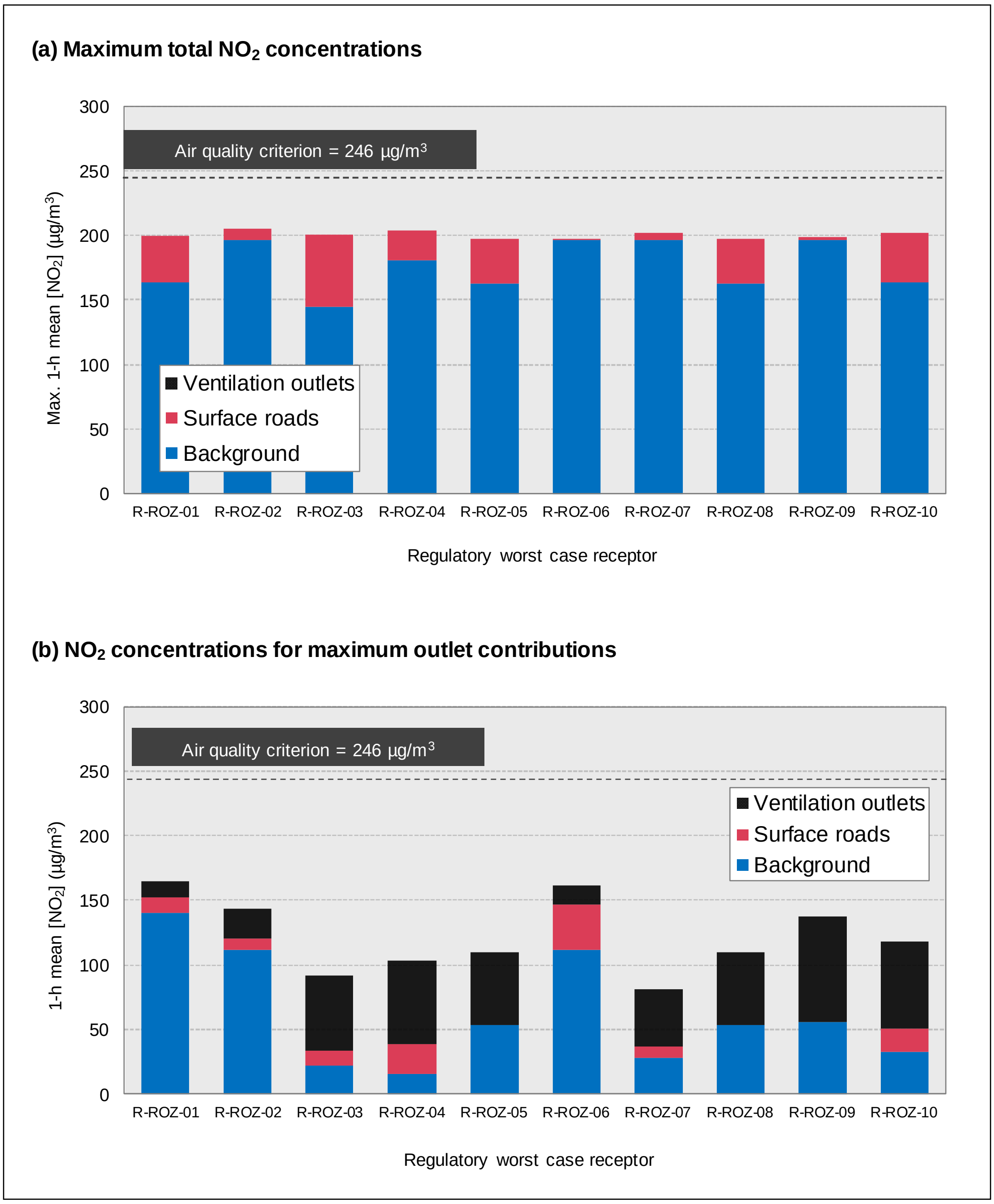

Figure 8-101 Regulatory worst case: one hour mean NO_2 concentrations (2023-DSC, Rozelle facilities)

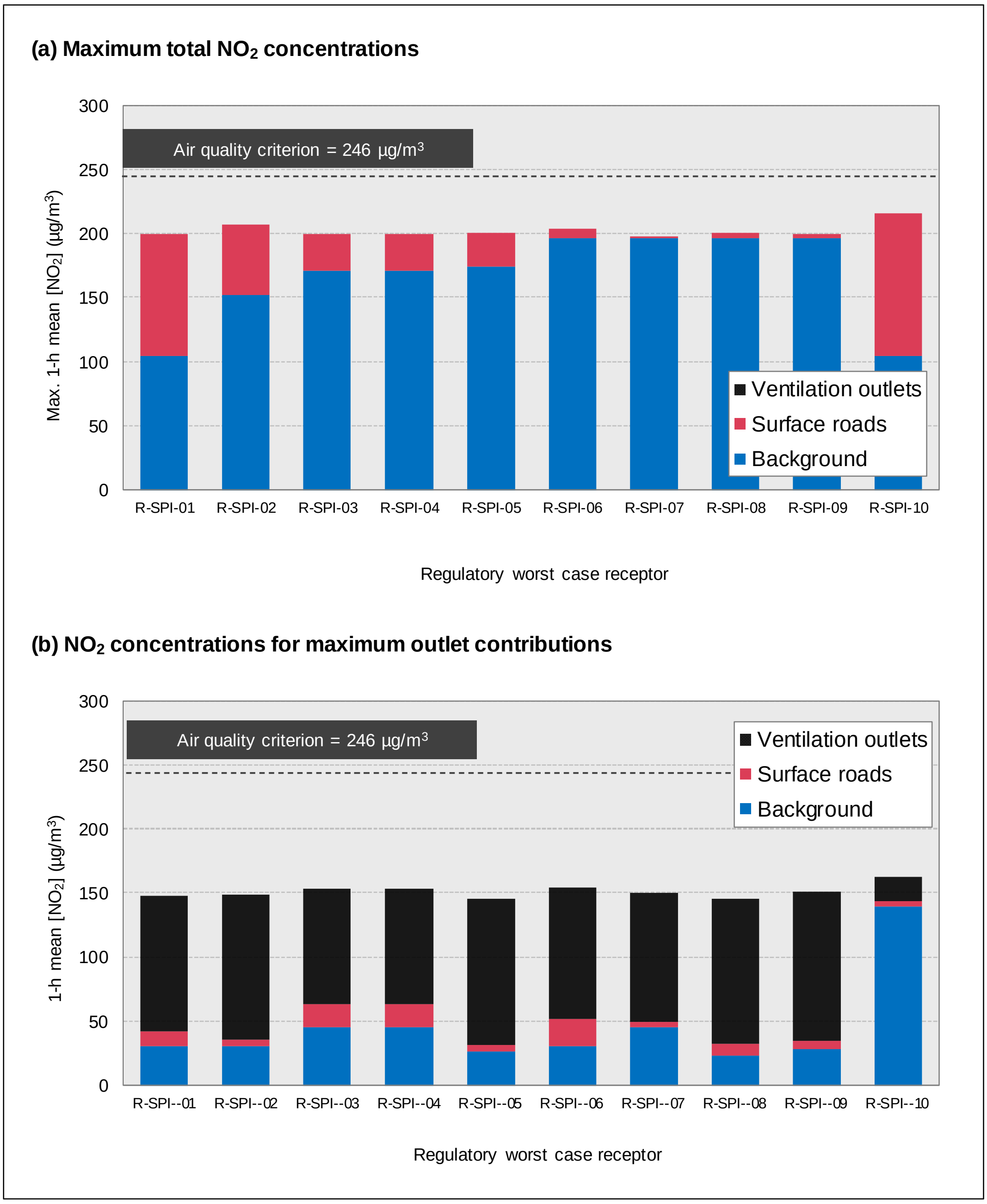

Figure 8-102 Regulatory worst case: one hour mean NO_2 concentrations (2023-DSC, SPI facilities)

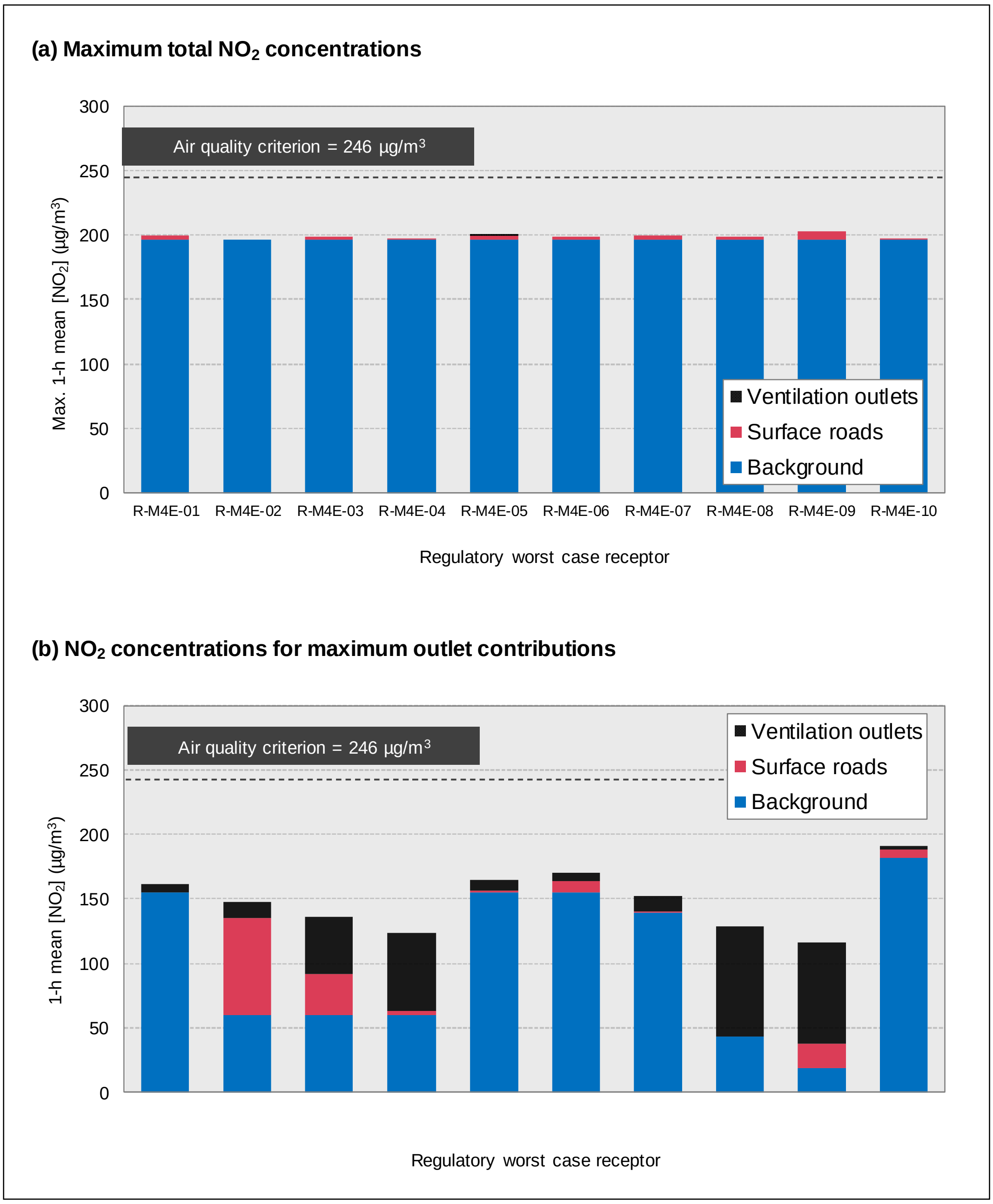

Figure 8-103 Regulatory worst case: one hour mean NO_2 concentrations (2033-DS, Parramatta Road facility)

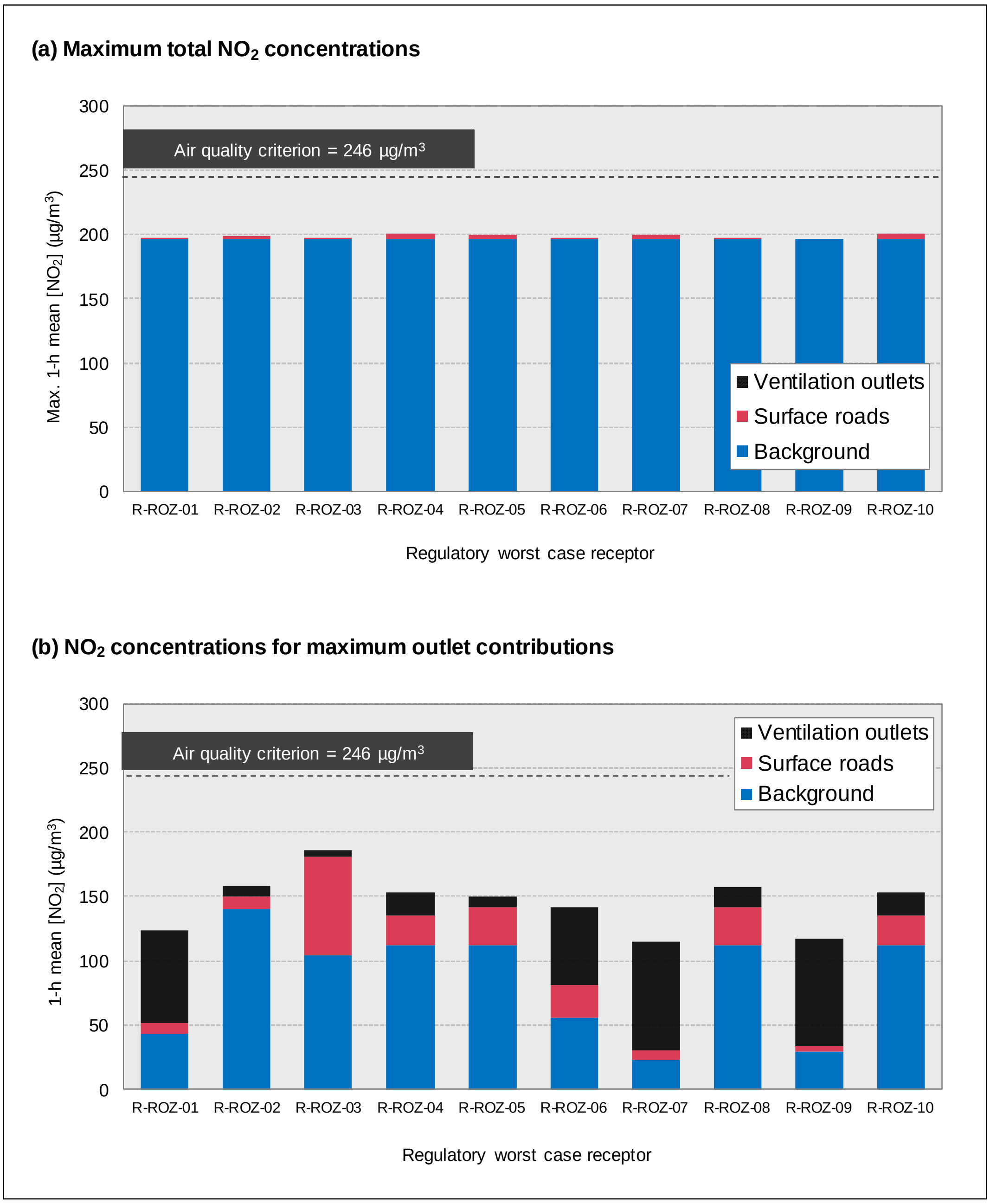

Figure 8-104 Regulatory worst case: one hour mean NO_2 concentrations (2033-DS, Rozelle facilities)

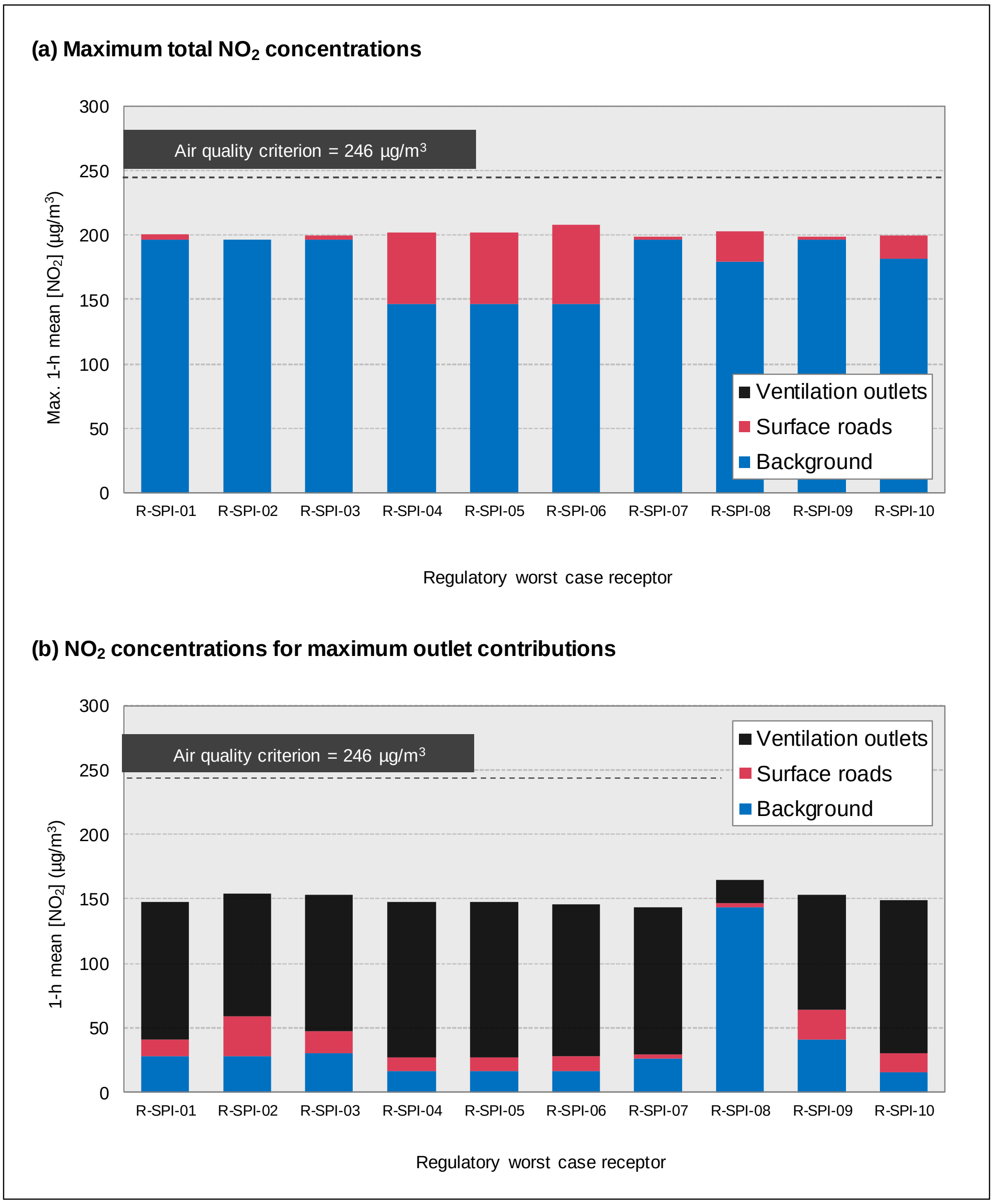

Figure 8-105 Regulatory worst case: one hour mean NO_2 concentrations (2033-DS, SPI facilities)

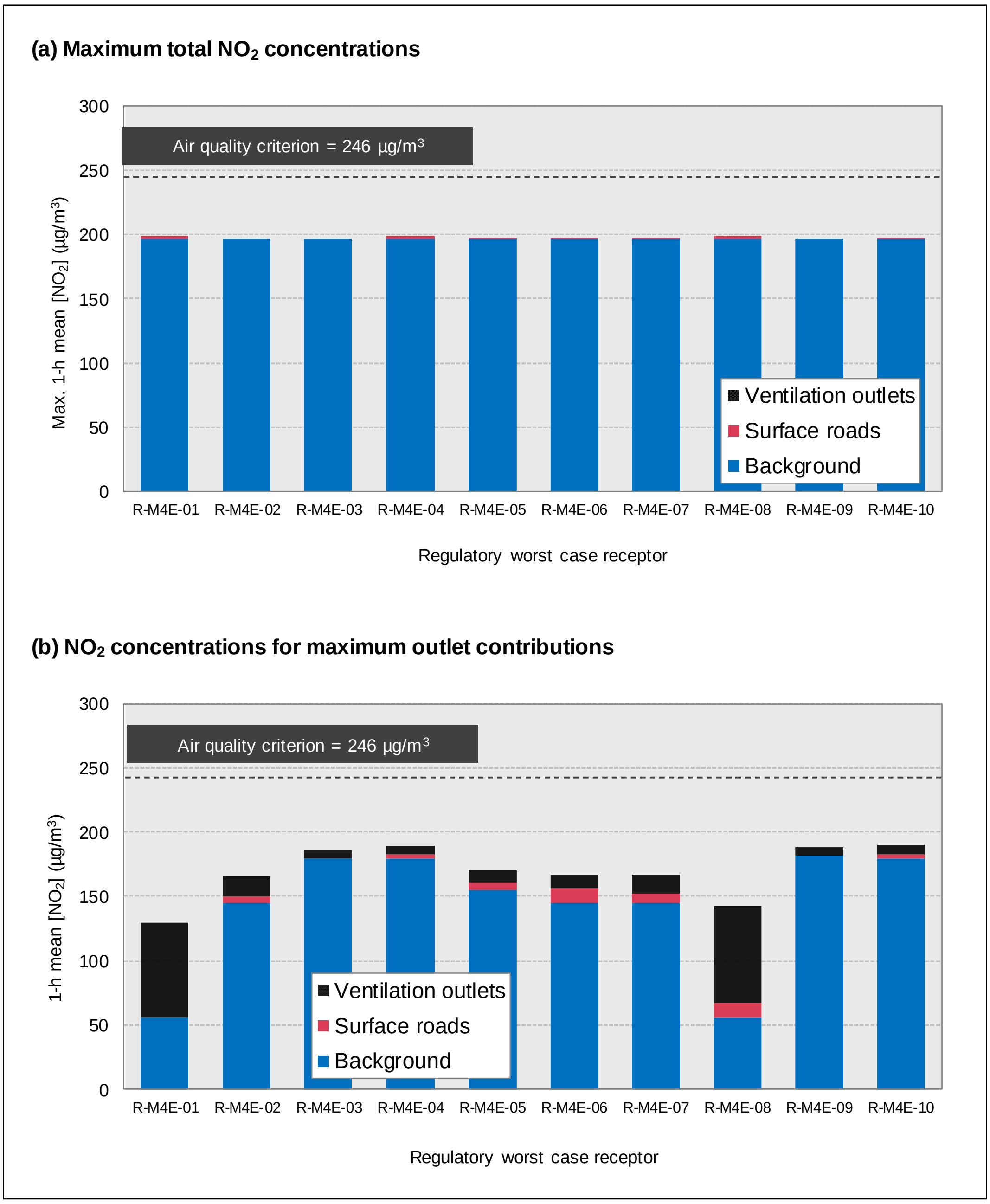

Figure 8-106 Regulatory worst case: one hour mean NO_2 concentrations (2033-DSC, Parramatta Road facility)

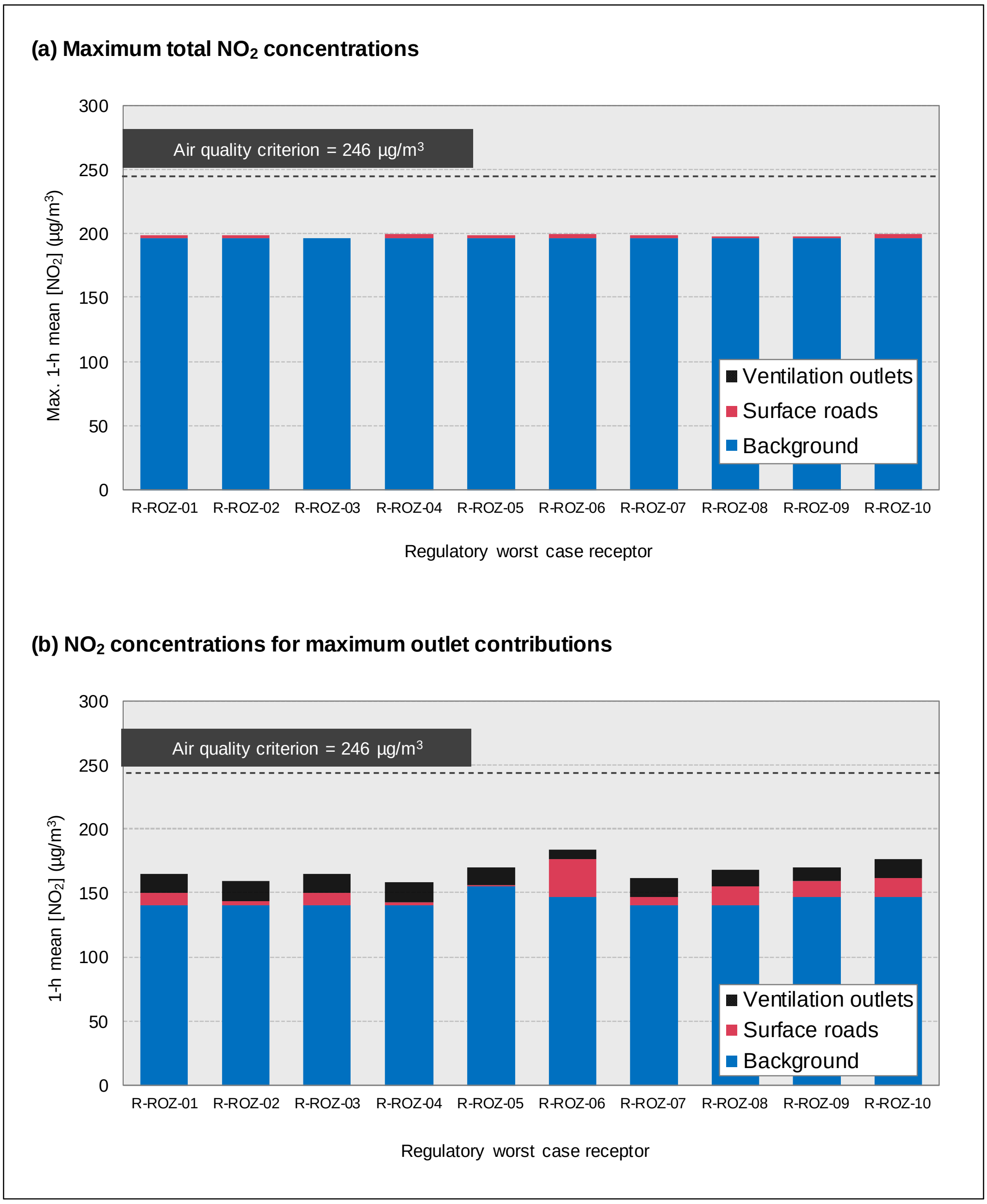

Figure 8-107 Regulatory worst case: one hour mean NO_2 concentrations (2033-DSC, Rozelle facilities)

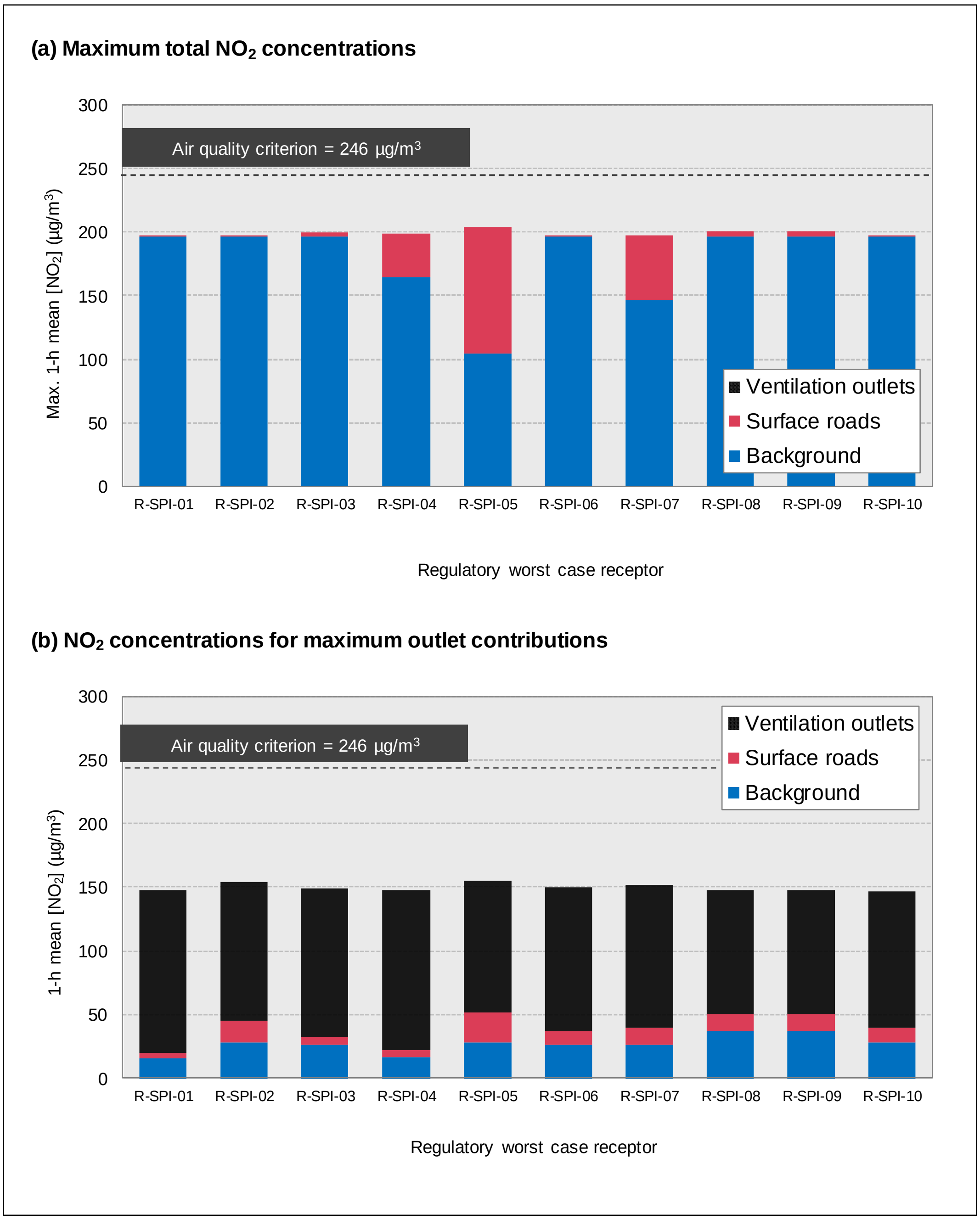

Figure 8-108 Regulatory worst case: one hour mean NO_2 concentrations (2033-DSC, SPI facilities)

THC and air toxics

The maximum outlet concentrations for the four specific air toxics considered in the regulatory worst case assessment (scenario RWC-2033-DSC only) were determined using the THC predictions in conjunction with the speciation profiles stated in **Table 8-18**. The results are given in **Table 8-24**. The Table shows the maximum contribution of tunnel ventilation outlets at any of the RWR receptors in this scenario (for most of the pollutant metrics these were residential receptors). The outlet contributions to the specific air toxics are well below the impact assessment criteria in the *Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales*.

Table 8-25 Results of regulatory worst case assessment (RWR receptors) – air toxics (ventilation outlets only)

Pollutant and period	Units	Maximum ventilation outlet contribution at any receptor	
		Regulatory worst case scenario (RWC-2033-DSC)	Impact assessment criterion (µg/m^3)
THC (annual)	(µg/m^3)	3.65	-
THC (one hour)	(µg/m^3)	55.29	-
Benzene (1 hour)	(µg/m^3)	2.20	*29*
PAH (BaP) (1 hour)	(µg/m^3)	0.016	*0.4*
Formaldehyde (1 hour)	(µg/m^3)	1.83	*20*
1,3-butadiene (1 hour)	(µg/m^3)	0.59	*40*

Table 8-26 shows that, even if the maximum outlet contribution is added to the maximum increase in concentration in the cumulative scenario (which implies some double counting), the results are still comfortably below the impact assessment criteria.

Table 8-26 Results of regulatory worst case assessment (RWR receptors) – air toxics (ventilation outlets plus traffic)

Pollutant and period	Units	Maximum outlet contribution at any receptor	Maximum increase due to project (outlet + expected traffic)	Sum	Impact assessment criteria
THC (1 hour)	(µg/m^3)	55.29	-	-	-
Benzene (1 hour)	(µg/m^3)	2.20	3.08	5.28	*29*
PAH (BaP) (1 hour)	(µg/m^3)	0.016	0.035	0.051	*0.4*
Formaldehyde (1 hour)	(µg/m^3)	1.83	3.59	5.42	*20*
1,3-butadiene (1 hour)	(µg/m^3)	0.59	0.84	1.43	*40*

8.4.13 Key assumptions

The assumptions in the local air quality impact assessment for the project that were likely to have had the most influence on the outcomes of the assessment are discussed in this Section. This discussion is provided to clarify the level of uncertainty and conservatism in the assessment, and consequently the total conservatism in the predicted air quality impacts of the project.

Table 8-27 Summary of key assumptions and implications for conservatism

Topic and sub-topic		Method and assumptions	Implications for conservatism
1	Background (ambient) air quality		
1.1	General	Background concentrations of air pollutants were derived using the data from OEH and RMS air quality monitoring stations in the study area.	The monitoring sites were considered to reflect background air quality in the study area accurately.
		Pollutant concentrations at background monitoring stations in 2015 were assumed to be representative of background concentrations in 2023 and 2033.	The implications of this cannot be quantified. It could be argued that concentrations in the future would decrease as emission controls improve (across all sectors of activity). However, any improvements could also be offset by increases in population and activity.
		It was assumed that there would be no contribution from the road network to the concentrations at these sites. The GRAL model actually gave non-zero (but generally small) values at the locations of the background monitoring sites.	Total predicted concentrations (GRAL + background) would generally be overestimated across the GRAL domain. The maximum annual mean GRAL predictions at background sites were: - CO 0.06 mg/m^3 - NO_X 28.3 µg/m^3 - PM_{10} 1.5 µg/m^3 This added an element of conservatism to the total concentration predictions.
1.2	Community receptors *CO, rolling 8 hour mean*	Hourly monitoring data from several OEH and RMS monitoring stations in 2015 were combined, and the highest monitored concentration in each hour was selected as the background value for that hour.	This resulted in an average concentration that was higher than the average for any individual station, and a distribution of concentrations that was shifted towards higher values than for any individual station.
1.3	Community and RWR receptors *NO_X, annual mean*	Background annual mean NO_X concentrations were mapped across the GRAL domain.	Notwithstanding the comments under item 1.1, this approach can be viewed as accurate rather than conservative.
1.4	Community receptors *NO_X, 1 hour mean*	Hourly monitoring data several OEH and RMS monitoring stations in 2015 were combined, and the highest monitored concentration in each hour was selected as the background value for that hour.	This resulted in an average concentration that was higher than the average for any individual station, and a distribution of concentrations that was shifted towards higher values than for any individual station.

Topic and sub-topic		Method and assumptions	Implications for conservatism
1.5	Community and RWR receptors *PM_{10}, annual mean*	Background annual mean PM_{10} concentrations were mapped across the GRAL domain.	Notwithstanding the comments under item 1.1, this approach can be viewed as accurate rather than conservative.
1.6	Community receptors *PM_{10}, 24 hour mean*	24 hour monitoring data from several OEH and RMS monitoring stations in 2015 were combined, and the highest monitored concentration in each hour was selected as the background value for that hour.	This resulted in an average concentration that was higher than the average for any individual station, and a distribution of concentrations that was shifted towards higher values than for any individual station.
1.7	Community and RWR receptors *$PM_{2.5}$, annual mean*	A single value of 8 µg/m^3 was assumed for the whole GRAL domain.	The measurement of $PM_{2.5}$ is rather uncertain, and therefore it cannot be stated with confidence that this approach is either accurate or conservative.
1.8	Community receptors *$PM_{2.5}$, 24 hour mean*	24 hour monitoring data from three OEH monitoring stations in 2015 were combined, and the highest monitored concentration in each hour was selected as the background value for that hour.	This resulted in an average concentration that was higher than the average for any individual station, and a distribution of concentrations that was shifted towards higher values than for any individual station.
1.9	RWR receptors only *Short-term metrics*	For 1 hour NO_X, 24 hour PM_{10} and 24 hour $PM_{2.5}$, the maximum value from the corresponding synthetic background profile was used as the background for all RWR receptors.	This would be reasonable accurate for receptors with a low road traffic contribution. For receptors with a large road traffic contribution, the total concentration would be overestimated. The approach would be very conservative for a small proportion of receptors.
2	Traffic forecasts		
2.1	Traffic volumes for tunnels and surface roads	Traffic volumes were taken from WRTM. The traffic data for a typical weekday were applied to every day of the year in the dispersion model.	This resulted in overestimates of concentrations at weekends.
3	Emission model (surface roads)		
3.1	Model selection	Emissions from vehicles on surface roads were calculated using a model that was adapted from the NSW EPA's inventory model.	The NSW EPA model is not designed to be conservative for surface roads, but the analysis presented in **Annexure E** indicates that for the conditions in the LCT (and probably more widely for tunnels in Sydney during normal operation), the NSW EPA emission factors overestimate real-world emissions (see below).

Topic and sub-topic		Method and assumptions	Implications for conservatism
3.2	CO emission factors	NSW EPA model	LCT analysis indicated an overestimation of real-world emissions in 2013 by a factor of 2.0 to 2.8
3.3	NO_X emission factors	NSW EPA model	LCT analysis indicated an overestimation of real-world emissions in 2013 by a factor of 2.2 to 3.3
3.4	PM_{10} emission factors	NSW EPA model, includes both exhaust and non-exhaust sources	LCT analysis indicated an overestimation of real-world emissions in 2013 by a factor of 1.8-3.2
3.5	$PM_{2.5}$ emission factors	NSW EPA model, includes both exhaust and non-exhaust sources	LCT analysis indicated an overestimation of real-world emissions in 2013 by a factor of 1.7-2.9
3.6	THC emission factors	NSW EPA model. Exhaust emissions only (no evaporation)	Not included in LCT analysis
4	Emission model (tunnels)		
The assumptions concerning in-tunnel emissions are provided in **Annexure L**.			
5	Dispersion modelling (general)		
5.1	Terrain	Terrain data were taken from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) website. A 30-metre resolution was used for the modelling of meteorology.	The terrain data were assumed to reflect the study area accurately.
5.2	Meteorology	Data from the BoM Canterbury Racecourse AWS meteorological station were chosen as the input to GRAMM for modelling.	The site was considered to be representative of the meteorology in the domain.
6	Dispersion modelling (ventilation outlets)		
6.1	Portal emissions	The assessment has been conducted assuming zero emissions from the tunnel portals; that is, all vehicle emissions have been assumed to be vented via the tunnel ventilation outlets near the end of each tunnel.	-
6.1	Ventilation outlet heights	The ventilation outlet heights were optimised to minimise the concentration increments at sensitive receptors, with a particular emphasis on annual mean $PM_{2.5.}$	A basic sensitivity analysis for the M4 East and New M5 projects showed that the total predicted concentrations are not likely to be very sensitive to ventilation outlet height, based on a sensitivity range of 25 to 35 metres.
6.2	Ventilation outlet exit diameter	The dispersion modelling involved either time-varying or fixed ventilation outlet diameters, depending on the outlet.	-

Topic and sub-topic		Method and assumptions	Implications for conservatism
6.3	Volumetric flow rates	Volumetric flow rates were initially calculated for each hour of the day based on predicted traffic volumes.	-
6.4	Road gradient	The total tunnel emissions have been calculated based on the sum of each tunnel section's emissions, factoring in the length of each section, the time taken for vehicles in the tunnel to pass through each section, the density of vehicles in the tunnel and the respective gradients.	-
6.5	Outlet temperature	An annual average outlet temperature was used for each ventilation outlet modelled in GRAL, based on the tunnel ventilation calculations (**Annexure L**).	A basic sensitivity analysis for the M4 East and New M5 projects showed that the total predicted concentrations are not likely to be very sensitive to ventilation outlet temperature, based on a sensitivity range of 15 to 35^{0}C.
7	Post-processing (NO_2) – community receptors		
7.1	NO_X-to-NO_2 conversion, annual mean	A 'best estimate' empirical approach was used, which gave the most likely annual mean NO_2 concentration for a given annual mean NO_X concentration.	The approach used was not inherently conservative.
7.2	NO_X-to-NO_2 conversion, maximum 1 hour mean	A 'detailed' contemporaneous approach was used. This involved the use of a conservative upper bound empirical function which gave the maximum likely 1 hour mean NO_2 concentration for a given 1 hour mean NO_X concentration.	Given the wide range of possible NO_2 concentrations for a given NO_X concentration, this approach was used to estimate the maximum 1 hour mean NO_2 concentrations conservatively. The dispersion modelling evaluation showed, however, that this method was less conservative than the OLM.
8	Post-processing (NO_2) – RWR receptors		
8.1	NO_X-to-NO_2 conversion, annual mean	A 'best estimate' approach was used, which gave the most likely annual mean NO_2 concentration for a given annual mean NO_X concentration.	The approach used was not inherently conservative.
8.2	NO_X-to-NO_2 conversion, maximum 1 hour mean	A 'simple' statistical (non-contemporaneous) approach was applied to determine the maximum 1 hour NO_X concentrations for the much larger number of residential, workplace and recreational' (RWR) receptors. The maximum 1 hour mean NOx value predicted by GRAL was added to the 98th percentile NOx value for the background in the synthetic profile for 2015. The conversion of NO_X to NO_2 was then based on the functions used in the detailed approach.	In general, the simple method performed in a similar manner to the detailed method, giving slightly lower maximum NO_2 values.

8.4.14 Reasons for unrealistically high concentrations at some RWR receptors

The predicted maximum one hour NO_2 concentrations were very high at some RWR receptor locations. In addition, a small number of receptors had predicted increases in annual mean $PM_{2.5}$ that were more than 10 per cent of the air quality criterion (ie greater than 0.8 $\mu g/m^3$), and one receptor had a predicted increase that was above the health risk criterion of 1.8 $\mu g/m^3$. For both NO_2 and $PM_{2.5}$, it is unlikely that these extreme results are realistic, and the reasons for this are explained below.

Maximum one hour NO_2

For maximum one hour NO_2 the highest values were considerably higher than those obtained in the M4 East and New M5 assessments. For example, the maximum concentrations at RWR receptors (DS and DSC scenarios) in the three assessments are as follows:

- M4 East between 274 and 359 $\mu g/m^3$, depending on the scenario
- New M5 between 312 and 458 $\mu g/m^3$, depending on the scenario
- M4-M5 Link between 415 and 516 $\mu g/m^3$, depending on the scenario.

However, in all three assessments these very high values were only obtained for only a very small proportion of the receptors. The much larger number of receptors in the M4-M5 Link assessment (around 86,000, compared with around 10,000 for M4 East and around 46,000 for New M5), combined with an additional scenario, has made the likelihood of obtaining such high values much greater.

The following general points should also be noted:

- A maximum value of anything is inherently difficult to predict, and when modelling there is a tendency to avoid under-prediction by assuming worst-case conditions at several stages
- Dispersion model performance is known to deteriorate as the averaging period decreases. In the WestConnex ambient air quality assessments, one hour is the shortest time period considered
- No exceedances of the one hour NO_2 criterion have been measured at ambient air quality monitoring stations in Sydney in recent years, and the measured peak one hour concentrations, even at near-road sites in Sydney, are typically less than 150 $\mu g/m^3$ (refer to **Annexure F**). However, the predictions in the assessment are for a wider range of site types than those currently used for monitoring. None of the monitoring sites are at kerbside, or as close to major roads as some of the receptors in the assessments, and concentrations fall off quite sharply with distance from a road. Peak concentrations above 150 $\mu g/m^3$ would therefore occur in reality.

Nevertheless, the results of the assessment suggest that exceedances may be happening at some non-monitored locations, and it is important to understand why such high predicted values were obtained.

The high predicted one hour NO_2 values were due to a combination of the following conservative assumptions:

- Potential overestimation of traffic volumes or HDVs, or potential errors in speed. This is an issue for the traffic model, but also for the assumed traffic patterns in the dispersion modelling. For example, the traffic volume may have been overestimated during poor dispersion conditions
- Potential conservatism in the emission factors. The evaluation of the NSW EPA model in the Lane Cove Tunnel suggested a general overestimation of NO_X emissions
- Potential conservatism in GRAMM-GRAL. The results in **Annexure J** suggest that GRAMM and GRAL tended to slightly overestimate NO_X concentrations
- Inaccuracy in the spatial representation of sources/receptors (which would affect all pollutants). The spatial relationship between the source and receptor could not be accurately represented

everywhere across the domain, such as where there was a difference in height, or where a road did not follow the true real-world alignment exactly

- Conservatism in the synthetic background profile. The synthetic background profile assumed that, in any given hour, the maximum value at any monitoring station was applicable to all locations
- Addition of modelled NO_X component to background NO_X component. For the RWR receptors the maximum model prediction was added to the maximum background value from the synthetic profile. It is very unlikely that these two values would coincide in time in reality, and for some RWR receptors this approach would clearly be very conservative
- Conservatism in the conversion of NO_X to NO_2. The equation for converting one hour NO_X to NO_2 was an outer envelope of many hourly measurements over the last decade (refer to **Annexure G**). Some further conservatism was then added to allow for a potential future increase in the NO_2/NO_X ratio in vehicle exhaust, and the assumption that this would be reflected in ambient measurements. It is possible that this conversion method was rather too conservative. For example, the predicted background NO_2 concentration at receptors in 2023/2033 was around 200 µg/m^3, which was well above the maximum value in existing measurements. The background NO_X contribution at RWR receptors was assumed to be around 800 µg/m^3, which gave a NO_2/NO_X ratio of around 0.25 using the future year conversion function in **Annexure G**, and hence a NO_2 background of around 200 µg/m^3. However, the conversion based on the base year function would have given a NO_2/NO_X ratio of 0.18, equating to a background NO_2 of around 145 µg/m^3. This values is closer to the measurements to date, although it cannot be stated definitively that it would also be appropriate for future years.

The locations of receptors with a very high maximum one hour NO_2 concentration in any scenario were examined in more detail. The cut-off for this was taken to be 400 µg/m^3. These receptors were mostly in the vicinity of Anzac Bridge, especially at the western end (**Figure 8-109**), with a small number alongside King Georges Road and inside the boundary of Sydney Airport (not shown). There was also one receptor to the north of Sydney Airport (not shown). None of the receptors were especially sensitive in nature, being either ‘industrial’, ‘commercial’ or ‘other’, and most of the highest values occurred in 2023.

Figure 8-109 Receptors in Anzac Bridge area with a maximum one hour NO_2 concentration above 400 µg/m^3 in any scenario

The receptors at the western end of Anzac Bridge included the receptor with the highest concentration (516 µg/m^3). This was very probably an example of a height mismatch between the road and the receptor. In the model Anzac Bridge effectively follows the terrain at ground level, whereas in reality it is elevated. This contributed to the overestimation of concentrations at ground-level receptors in the area. However, there were also some elevated receptors at the eastern end of the bridge for which the predicted concentrations would be more relevant, although here the background concentration could well have been lower than at ground level, thus reducing the likely overall impact.

Following on from this, an additional round of NO_X/NO_2 modelling was undertaken at 18 discrete receptors to investigate the likely magnitude of the NO_2 overestimation. These 18 receptors are listed in Table 8-29. They were selected to represent the range of concentrations across the domain. At each receptor the contemporaneous approach was used to calculate NO_2 concentrations, as with community receptors.

Table 8-28 Discrete receptors used for NO_2 tests (grid system MGA94)

Receptor code	Corresponding RWR receptor	Reason for inclusion	type	Receptor location	
				x	y
NO2-01	RWR-69026	Receptors with highest 1 hour NO_2 (all non-residential). Selected from receptors with NO_2 >300 µg/m^3)	Other	332039.9	6250939.3
NO2-02	RWR-47908		Park/sport/recreation	332463.3	6250751.1
NO2-03	RWR-08053		Commercial	322775.9	6241674.3
NO2-04	RWR-74277	Receptors with highest 1 hour NO_2 (residential). Selected from receptors with NO_2 >300 µg/m^3)	Residential	329755.2	6252269.7
NO2-05	RWR-81676		Residential	329754.4	6252194.6
NO2-06	RWR-48996		Residential	332056.5	6245854.4
NO2-07	RWR-28441		Residential	330404.3	6241989.0
NO2-08	RWR-86595	Receptors with large changes in NO_2	Residential	331144.6	6248818.3
NO2-09	RWR-86385		Child care/pre-school	331080.1	6249142.3
NO2-10	RWR-86404		Child care/pre-school	327268.3	6250487.4
NO2-11	RWR-83940		Residential	330113.6	6250368.0
NO2-12	RWR-67506	Other receptors (with lower concentrations) across the project area	Residential	331126.9	6250411.2
NO2-13	RWR-72496		Residential	330825.7	6251861.2
NO2-14	RWR-64759		Residential	331008.7	6249631.1
NO2-15	RWR-83302		Residential	332102.7	6247719.5
NO2-16	RWR-56673		Residential	331233.8	6247949.9
NO2-17	RWR-60251		Residential	331031.5	6248651.8
NO2-18	RWR-64141		Residential	330036.5	6249602.5

The results of the additional modelling are shown for annual mean and maximum one hour NO_2 concentrations in **Figure 8-110** and **Figure 8-111** respectively. The annual mean NO_2 concentrations were very similar for the two methods, and in most cases the difference being less than 5 per cent. These differences are associated with the interpolation of the GRAL predictions in the statistical (RWR) method. However, the statistical method predicted significantly higher maximum one hour NO_2 concentrations (up to 70% higher) than the contemporaneous method, with the difference being most pronounced for the receptors with relatively high predicted concentrations. This supports the contention that the extreme one hour NO_2 predictions for RWR receptors are unlikely to be realistic.

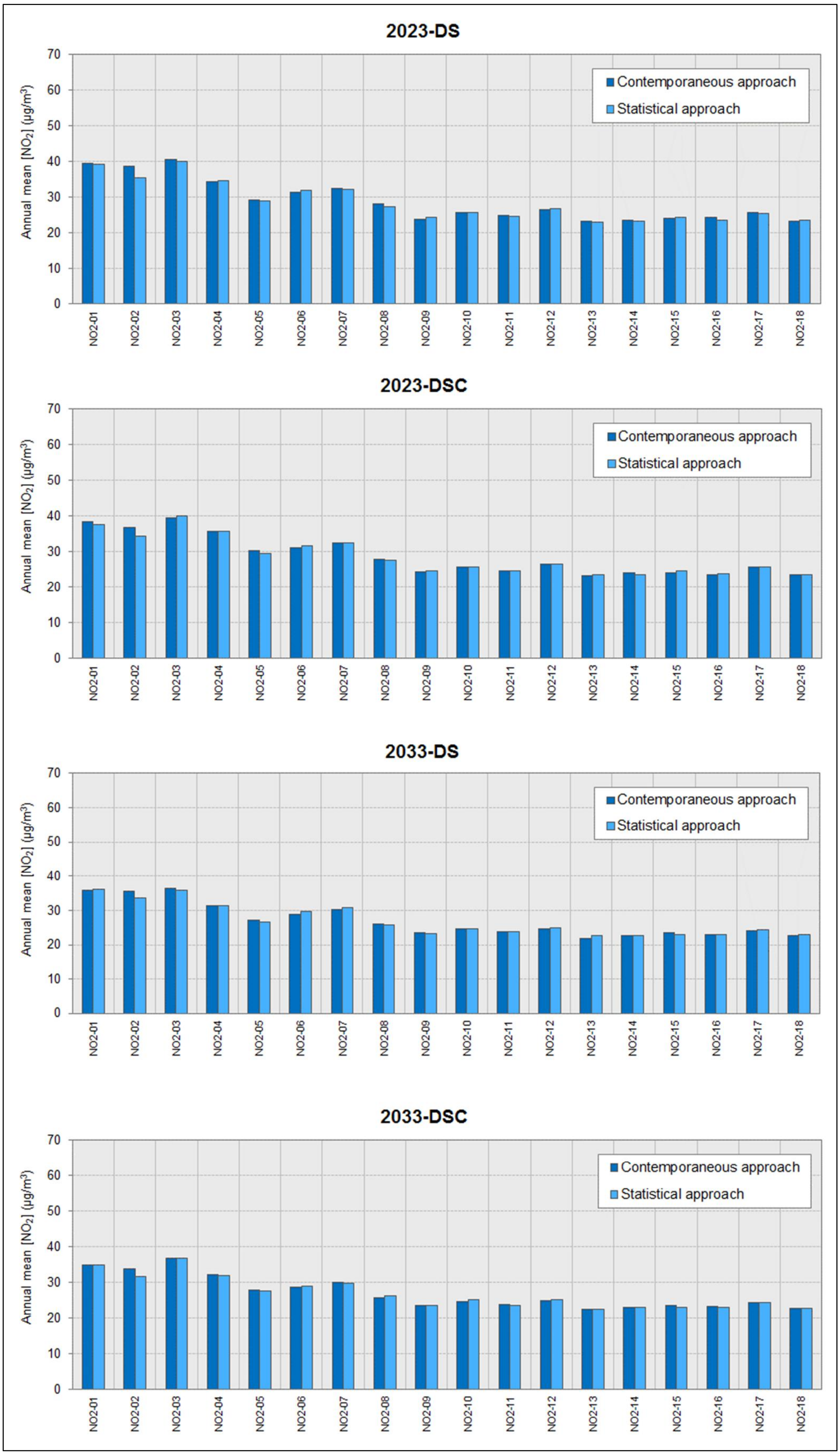

Figure 8-110 Contemporaneous approach vs statistical approach for annual mean NO_2 at selected receptors (with-project and cumulative scenarios)

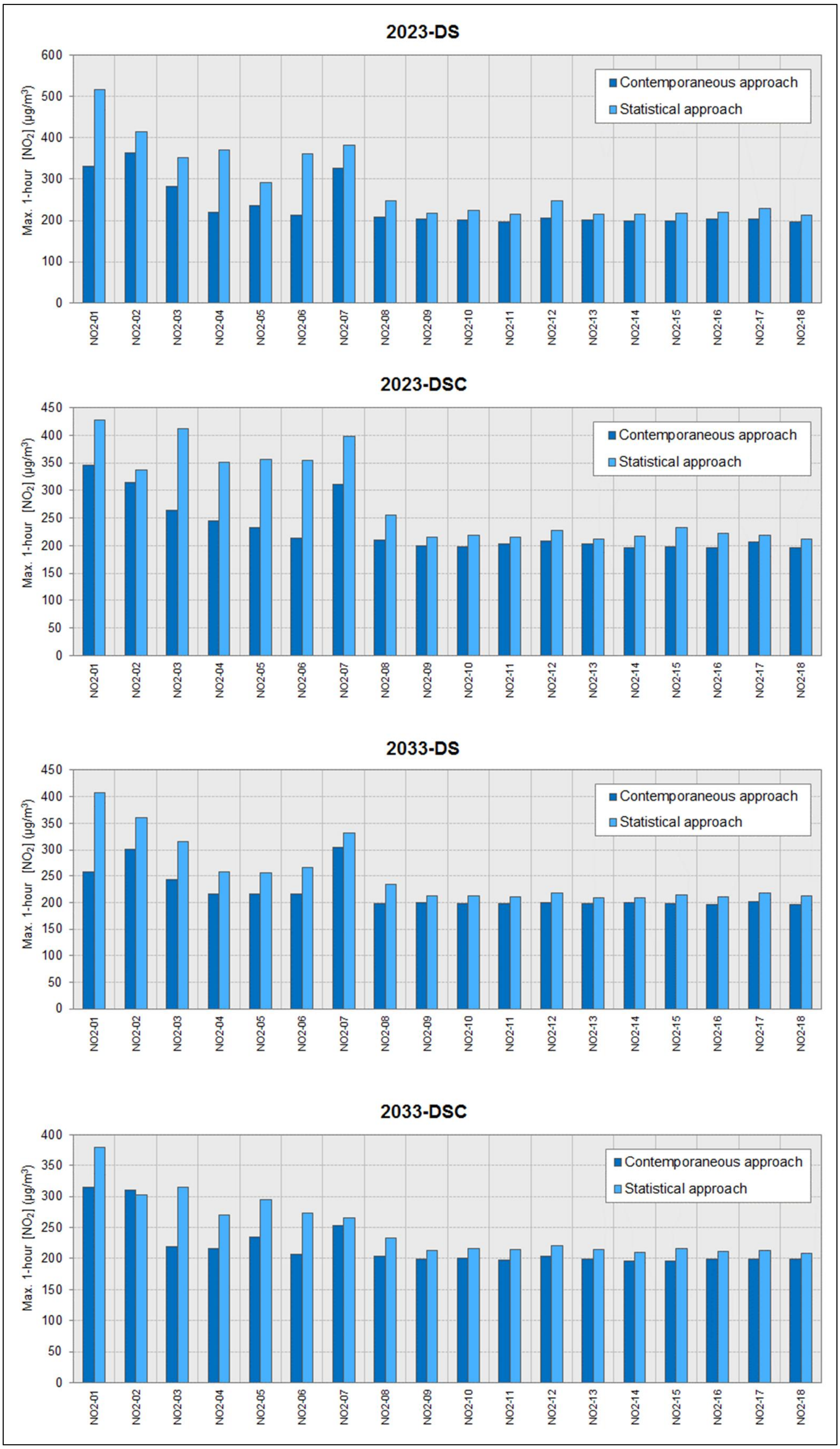

Figure 8-111 Contemporaneous approach vs statistical approach for maximum one hour NO_2 at selected receptors (with-project and cumulative scenarios)

Change in annual mean $PM_{2.5}$

In total, 38 receptors had an increase in annual mean $PM_{2.5}$ of more than 0.8 µg/m^3 (10 per cent of the air quality criterion) in any scenario. The affected receptors were in two areas: one near Anzac Bridge, as in the case of one hour NO_2, and one in St Peters, as shown in **Figure 8-112**. The one (commercial) receptor that had an increase of more than 1.8 µg/m^3 (the health risk criterion) is highlighted in yellow. These affected receptors in the St Peters area all appeared to be associated with Sydney Gateway, and therefore in an area of the domain where the road layout was provisional and indicative, and where the positions of receptors relative to new roads could not be known accurately. Sydney Gateway would be subject to a separate planning approvals process. In this area, some of the affected RWR receptors would either not exist in the future because they would be within a construction footprint for Sydney Gateway, or if they do still exist then the provisional alignment of roads would have to change.

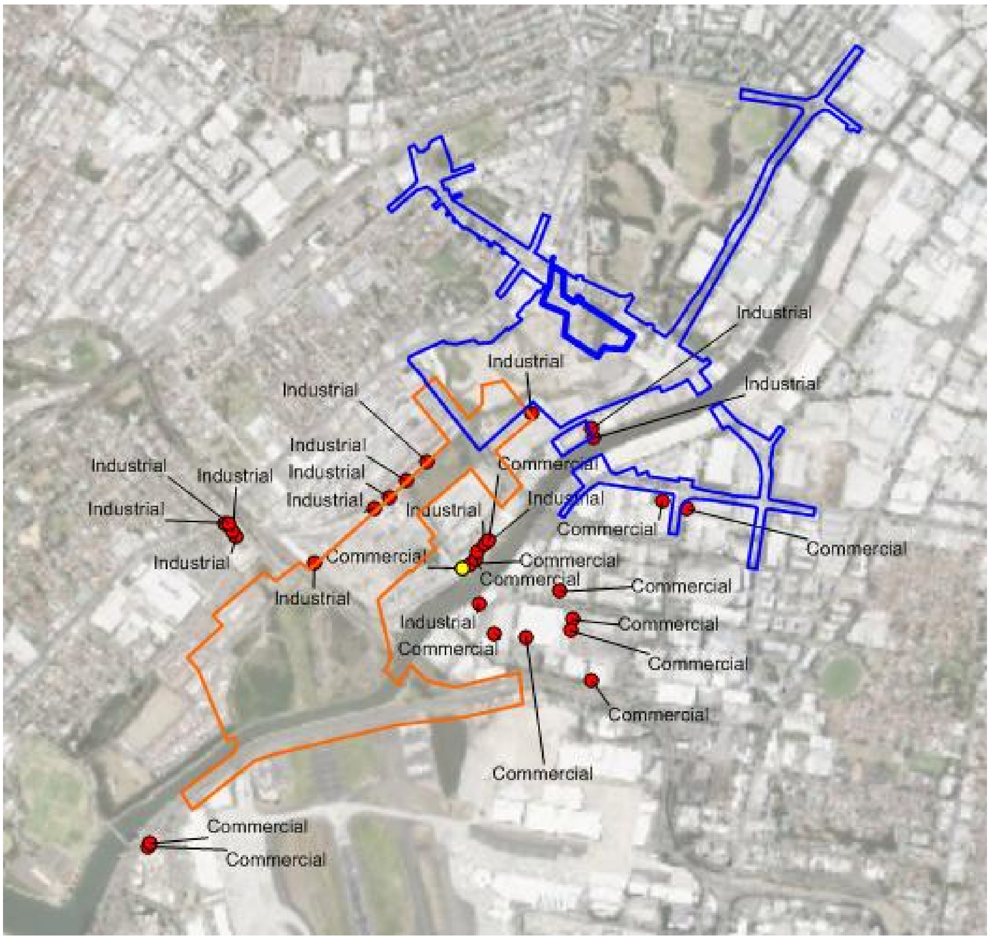

Figure 8-112 Receptors in the St Peters area with a change in annual mean $PM_{2.5}$ concentration above 0.8 µg/m^3 in any scenario. The blue boundary represents the construction footprint for the New M5 project. The orange line represents an indicative construction footprint for the Sydney Gateway project.

8.4.15 Sensitivity tests

In the EISs for the M4 East and New M5 projects, several sensitivity tests were conducted for various model inputs (Boulter et al., 2015; Manansala et al., 2015). These included:

- The influence of ventilation outlet temperature
- The influence of ventilation outlet height

- The inclusion of buildings near tunnel ventilation outlets.

These tests were based upon a sub-area of the M4 East and New M5 GRAL domains of two to three kilometres around the project ventilation outlets. Only the ventilation outlet contribution, and only annual mean $PM_{2.5}$ and maximum 24 hour $PM_{2.5}$, were included in the tests. A sub-set of sensitive receptors was evaluated. The predicted concentrations were indicative, as the aim of the sensitivity tests was to assess the proportional sensitivity of the model to specific input parameters.

As the outcomes of the tests from both the M4 East and New M5 projects were very similar, the tests were therefore not repeated for this project, and it was assumed that the previous outcomes would apply to the M4-M5 Link project.

The following sections present a summary of the tests.

Ventilation outlet temperature

The ventilation outlet temperatures for the M4 East and New M5 projects were around 25ºC. For this test, the effects of using outlet temperatures 10˚C below and above this value were modelled.

The results of the tests showed that the predicted concentrations for the ventilation outlets were higher for the lower temperature (by a factor of, on average, around 1.5). The predicted concentrations for both projects remained well below the standards for $PM_{2.5}$, and made up a very small proportion of the total combined results (for surface roads and ventilation outlets). Even with a significant change in ventilation outlet temperature, the total predicted concentration (roads and ventilation outlets) is unlikely to be affected significantly.

Ventilation outlet height

The height of the ventilation outlets for the M4 East and New M5 projects was around 30 metres. For this test, the effects of using outlet heights 10 metres below and above this value were modelled.

The results for both projects were similar to those for the temperature sensitivity tests, with the lower outlet resulting in concentrations that were around 1.3 times greater, on average, than the higher outlet. Again, ventilation outlet height is unlikely to represent a large source of uncertainty in the overall predictions.

Buildings

The sensitivity of the inclusion of buildings to predicted concentrations was assessed in the M4 East and New M5 projects. The closest commercial buildings to the ventilation outlets were included in one model run, and excluded in the other.

The results showed that, when buildings were included, there was an average increase in concentrations associated with the ventilation outlet by a factor of around 1.3 to 1.5. Whilst these tests were not comprehensive, they indicated that the inclusion or exclusion of buildings is unlikely to represent a large source of uncertainty in the overall predictions. The total predicted concentrations, and the conclusions of the assessment, would not change significantly with the inclusion of buildings.

8.5 Regional air quality

The changes in the total emissions resulting from the project were given in **Table 8-9** and **Table 8-10**. These changes can be viewed as a proxy for the project's regional air quality impacts which, on the basis of the results, are likely to be negligible. For example:

- The increases in NO_X emissions for the assessed road network in a given year ranged from 71 to 174 tonnes per year. These values equate to a very small proportion (around 0.3 per cent) of anthropogenic NO_X emissions in the Sydney airshed in 2016 (around 53,700 tonnes)
- The increases in NOx in a given year are much smaller than the projected reductions in emissions between 2015 and 2033 (around 2,340 tonnes per year).

The regional air quality impacts of a project can also be framed in terms of its capacity to influence ozone production. NSW EPA has developed a Tiered Procedure for Estimating Ground Level Ozone

Impacts from Stationary Sources (ENVIRON, 2011). Although this procedure does not relate specifically to road projects, it was applied here to give an indication of the likely significance of the project's effect on ozone concentrations in the broader Sydney region.

The first step in the procedure involved the classification of the region within which the project is to be located as either an ozone 'attainment' or 'non-attainment' area, based on measurements from OEH monitoring stations over the past five years and criteria specified in the procedure. Following this approach, the project was identified as being in an ozone non-attainment area.

The second step involved the evaluation of the change in emissions due to the project against thresholds for NO_X and VOCs. For both attainment and non-attainment areas the procedure gives an emission threshold for NO_X and VOCs (separately) of 90 tonnes/year for new sources, above which a detailed modelling assessment for ozone may be required. Some lower thresholds are also specified for modified sources and for the scale of ozone non-attainment.

The results in **Table 8-9** show that – for the 2023-DSC and 2033-DSC scenarios – the increases in NO_X emissions (127 and 174 tonnes per year respectively) were above the 90 tonnes/year threshold. In cases such as this, the procedure specifies that a 'Level 1' assessment is to be undertaken using a screening tool provided by NSW EPA[28]. The tool estimates the increases in one hour and 4 hour ground-level ozone concentrations, based on an input of emissions of CO, NOx and VOC (THC) in tonnes per day. For sources located within ozone non-attainment areas, the incremental increases in ozone concentration predicted by the tool are compared against a screening impact level (SIL) of 0.5 ppb, and against a maximum allowable increment of one ppb. In cases where the maximum ozone increment is below the SIL and/or below the relevant maximum allowable increment, further ozone impact assessment is not required, but a best management practice (BMP) determination should be undertaken for the source. The results from the tool, shown in **Table 8-29**, show that the project falls into this category.

Table 8-29 Results from ozone screening tool

Scenario	Change in emissions with the project (tonnes per day)			Incremental O_3 concentration (ppb)		SIL (ppb)
	CO	NOx	THC	Max. 1 hour	Max. 4 hour	
2023-DSC	+0.483	+0.349	-0.026	0.13	0.11	0.50
2033-DSC	+0.784	+0.478	-0.002	0.17	0.15	

Overall, it is concluded that the regional impacts of the project would be negligible, and undetectable in ambient air quality measurements at background locations.

8.6 Odour

For each of the RWR receptors, the change in the maximum one hour THC concentration as a result of the project was calculated. The largest change in the maximum one hour THC concentration across all receptors was then determined, and this was converted into an equivalent change for three of the odorous pollutants identified in the Approved Methods (toluene, xylenes, and acetaldehyde). These pollutants were taken to be representative of other odorous pollutants from motor vehicles.

The changes in the levels of three odorous pollutants as a result of the project, and the corresponding odour assessment criteria from the Approved Methods, are given in **Table 8-30**. It can be seen that the change in the maximum one hour concentration of each pollutant was an order of magnitude below the corresponding odour assessment criterion in the Approved Methods.

[28] http://www.epa.nsw.gov.au/air/appmethods.htm.

Table 8-30 Comparison of changes in odorous pollutant concentrations with criteria in Approved Methods (RWR receptors)

Scenario	Largest increase in maximum 1 hour THC concentration relative to Do Minimum scenario (µg/m^3)	Largest increase in maximum 1 hour concentration for specific compounds		
		Toluene (µg/m^3)	Xylenes (µg/m^3)	Acetaldehyde (µg/m^3)
2023-DS	141.0	10.8	8.9	2.0
2023-DSC	137.1	10.5	8.6	1.9
2033-DS	110.8	7.0	5.8	2.0
2033-DSC	98.9	6.3	5.2	1.8
Odour criterion (µg/m^3)		360	190	42

9 Management of impacts

9.1 Management of construction impacts

Step 3 of the construction assessment involved determining mitigation measures for each of the four potential activities in Step 2. This was based on the risk of dust impacts identified in Step 2C. For each activity, the highest risk category was used. The results are shown in **Table 9-1** to **Table 9-6**, and are all highly recommended. Most of the recommended measures are routinely employed as 'good practice' on construction sites.

A Construction Air Quality Management Plan will be produced to cover all construction phases of the M4-M5 Link project. This should contain details of the site-specific mitigation measures to be applied. Additional guidance on the control of dust at construction sites in NSW is provided as part of the NSW EPA Local Government Air Quality Toolkit[29]. Detailed guidance is also available from the UK (GLA, 2006) and the United States (Countess Environmental, 2006). For precise requirements, reference should be made to the Baseline Conditions of Approval for the project.

Table 9-1 Mitigation for all sites: communication

	Mitigation measure	All scenarios 1 – 7
1	Communication, notification and complaints handling requirements regarding air quality matters will be managed through the Community Communication Strategy (CCS).	Highly recommended

Table 9-2 Mitigation for all sites: dust management

	Mitigation measure	All scenarios 1 – 7
2	A Construction Air Quality Management Plan will be developed and implemented to monitor and manage potential air quality impacts associated with the construction for the project. The Plan will be implemented for the duration of construction.	Highly recommended
Site management		
3	Regular communication to be carried out with sites in close proximity to ensure that measures are in place to manage cumulative dust impacts.	Highly recommended
Monitoring		
4	Regular site inspections will be conducted to monitor for potential dust issues. The site inspection, and issues arising, will be recorded.	Highly recommended
Preparing and maintaining the site		
5	Construction activities with the potential to generate dust will be modified or ceased during unfavourable weather conditions to reduce the potential for dust generation.	Highly recommended
6	Measures to reduce potential dust generation, such as the use of water carts, sprinklers, dust screens and surface treatments, will be implemented within project sites as required.	Highly recommended
7	Unsealed access roads within project sites will be maintained and managed to	Highly recommended

[29] http://www.epa.nsw.gov.au/air/lgaqt.htm

	Mitigation measure	All scenarios 1 – 7
	reduce dust generation.	
8	Where reasonable and feasible, appropriate control methods will be implemented to minimise dust emissions from the project site.	Highly recommended
9	Storage of materials that have the potential to result in dust generation will be minimised within project sites at all times.	Highly recommended
Operating vehicle/machinery and sustainable travel		
10	All construction vehicles and plant will be inspected regularly and maintained to ensure that they comply with relevant emission standards.	Highly recommended
11	Engine idling will be minimised when plant is stationary, and plant will be switched off when not in use to reduce emissions.	Highly recommended
12	The use of mains electricity will be favoured over diesel or petrol-powered generators where practicable to reduce site emissions.	Highly recommended
13	Haul roads will be treated with water carts and monitored during earthworks operations, ceasing works if necessary during high winds where dust controls are not effective.	Highly recommended
Construction		
14	Suitable dust suppression and/or collection techniques will be used during cutting, grinding or sawing activities likely to generate dust in close proximity to sensitive receivers.	Highly recommended
15	The potential for dust generation will be considered during the handling of loose materials. Equipment will be selected and handling protocols developed to minimise the potential for dust generation.	Highly recommended
16	All vehicles loads will be covered to prevent escape of loose materials during transport.	Highly recommended

Table 9-3 Mitigation specific to demolition

<table>
<tr><th></th><th>Mitigation measure</th><th>Scenario 1</th><th>Scenario 2</th><th>Scenario 3</th><th>Scenario 4</th><th>Scenario 5</th><th>Scenario 6</th><th>Scenario 7</th></tr>
<tr><td>17</td><td>Demolition activities will be planned and carried out to minimise the potential for dust generation.</td><td>Desirable</td><td colspan="3">Highly recommended</td><td>Desirable</td><td>Highly recomm-ended</td><td>Desirable</td></tr>
<tr><td>18</td><td>Adequate dust suppression will be applied during all demolition works required to facilitate the project.</td><td>Desirable</td><td colspan="6">Highly recommended</td></tr>
<tr><td>19</td><td>All potentially hazardous material will be identified and removed from buildings in an appropriate manner prior to the commencement of demolition.</td><td>Desirable</td><td colspan="6">Highly recommended</td></tr>
</table>

Table 9-4 Mitigation specific to earthworks

	Mitigation measure	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
20	Areas of soil exposed during construction will be minimised at all times to reduce the potential for dust generation.	Not required	Desirable		Highly recommended			
21	Exposed soils will be temporarily stabilised during weather conditions conducive to dust generation and prior to extended periods of inactivity to prevent dust generation.	Not required	Desirable		Highly recommended			
22	Exposed soils will be permanently stabilised as soon as practicable following disturbance to minimise the potential for ongoing dust generation.	Not required	Desirable		Highly recommended			

Table 9-5 Mitigation specific to construction

	Mitigation measure	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
23	Ensure sand and other aggregates are stored in bunded areas and are not allowed to dry out, unless this is required for a particular process, in which case ensure that appropriate additional control measures are in place.	Highly recommended						
24	Ensure fine materials are stored and handled to minimise dust.	Desirable			Highly recommended			

Table 9-6 Mitigation specific to track-out of loose material onto roads

	Mitigation measure	All scenarios 1 – 7
25	Deposits of loose materials will be regularly removed from sealed surfaces within and adjacent to project sites to reduce dust generation.	Highly recommended
26	During establishment of project ancillary facilities, controls such as wheel washing systems and rumble grids will be installed at site exits to prevent deposition of loose material on sealed surfaces outside project sites to reduce potential dust generation.	Highly recommended

9.2 Management of operational impacts

9.2.1 Overview

The SEARs for the project require details of, and justification for, the air quality management measures that have been considered. This Section of the report firstly reviews the measures that are available for improving tunnel-related air quality, and then describes their potential application in the context of the project. The measures have been categorised as follows:

- Tunnel design
- Ventilation design and control
- Air treatment systems

- Emission controls and other measures.

9.2.2 Review of approaches

Tunnel design

Tunnel infrastructure is designed in such a way that the generation of pollutant emissions by the traffic using the tunnel is minimised. The main considerations are minimising gradients and ensuring that lane capacity remains constant or increases from entry to exit point. Traffic management can also be used to improve traffic flows, which results in reduced overall emissions.

Ventilation design and control

There are several reasons why a tunnel needs to be ventilated. The main reasons are:

- Control of the internal environment. It must be safe and comfortable to drive through the tunnel. Vehicle emissions must be sufficiently diluted so as not to be hazardous during normal operation, or when traffic is moving slowly or stationary
- Protection of the external environment. It is unacceptable for polluted air from tunnel portals, or ventilation outlets to present a health or nuisance hazard to the community. Ventilation, and the dispersion of pollutants, is overwhelmingly the most popular method for minimising the impacts of tunnels on ambient air quality. Collecting emissions and venting them via ventilation outlets is a very efficient way of dispersing pollutants. Studies show that the process of removing surface traffic from heavily trafficked roads and releasing the same amount of pollution from an elevated location results in substantially lower concentrations at sensitive receptors (PIARC, 2008). Ventilation outlets need to be designed and sited accordingly, and high vertical discharge velocities from outlets may be required to assist dispersion
- Emergency situations. When a fire occurs in a tunnel, it is desirable to be able to control the heat and other combustion products in the tunnel so as to permit safe evacuation of occupants, and to provide the emergency services with a safe route to deal with the fire and to rescue any trapped or injured persons.

A two-fold approach to ventilation design is generally adopted:

- The amount of fresh air required to dilute pollutants to acceptable levels is calculated based on the likely emissions from vehicles in the tunnel, and the ventilation system is designed accordingly. The choice and design of a suitable ventilation system depends on the following factors:
  - Tunnel length and geometry
  - Traffic flow and composition
  - Fresh air requirement under normal and specific traffic conditions
  - Admissible air pollution levels around tunnel portals
  - Fire safety considerations
- Sensors are installed in the tunnel to initiate the operation of the ventilation system in order to maintain the levels of pollutants below limit values. In rare cases, traffic entry may need to be restricted by closing lanes, reducing speeds or completely closing the tunnel if air quality limits are being approached or exceeded.

Short tunnels can be adequately and safely ventilated by the piston effect. The external wind may also generate a flow of air within a tunnel due to the static air pressure difference between the portals.

There are three basic concepts for mechanical tunnel ventilation:

- Longitudinal ventilation, whereby air is introduced to, or removed from, the tunnel at a limited number of points. The main movement of air is along the tunnel from the entrance to the exit

- Transverse ventilation, whereby air may be introduced into a tunnel at various points along its length, and may also be extracted at other points along its length. The main movement of air inside the tunnel is perpendicular to the longitudinal axis of the tunnel
- Semi-transverse ventilation. Semi-transverse ventilation involves a combination of longitudinal and transverse ventilation. For example, fresh air can be delivered longitudinally through the tunnel portals, and exhaust air is removed uniformly (and transversely) over the length of the tunnel.

Jet fans may also be mounted within the tunnel space, usually at fixed intervals along the tunnel and near to the tunnel ceiling. They function by producing a relatively narrow jet of air moving at high speed (typically 30 metres per second), and rely on turbulent friction and jet entrainment effects to transfer momentum from the jet into the main body of air in the tunnel.

Ventilation control is achieved by adjusting the number of fans in operation at any one time, with the individual units being operated at full power or not running. A further refinement is available in installations where fan speed is controllable. The required level of ventilation at any particular time tends to be determined in response to visibility levels and the concentrations of airborne pollutants. Normally, the CO concentration or the visibility inside the tunnel are the only parameters measured for this purpose.

Air treatment

There are several air treatment options for mitigating the effects of tunnel operation on both in-tunnel and ambient air quality. Where in-tunnel treatment technologies have been applied to road tunnels, these technologies have focused on the management and treatment of PM. The most common of these is the electrostatic precipitator (ESP), and this is discussed in detail below. Information is provided on the method of operation, the international experience with ESPs in tunnels, and the effectiveness of systems. Other techniques include filtering, denitrification and biofiltration, agglomeration and scrubbing. These are also described below.

In Australia, the issue of air treatment frequently arises during the development of new tunnel projects. All tunnel projects have, however, gravitated towards a decision not to install an air treatment system, and to rely instead on the primary approach of dilution of air pollution (through ventilation systems) (PIARC, 2008; CETU, 2010).

Electrostatic precipitators

<u>Description of method</u>

For a number of years, work has progressed on the application of electrostatic precipitators (ESPs) to road tunnel air. In a typical ESP, the air flow is initially passed through an ionising chamber containing wires or plates maintained at several thousand volts. These produce a corona that releases electrons into the air-stream. The electrons attach to particles in the air flow, and give them a net negative charge. The particles then pass through a collector chamber or passageway which contains multiple parallel collecting plates. The collecting plates are grounded and attract the charged dust particles.

The cleaning of an ESP is vital to ensure that it remains in proper working order (CETU, 2010). In a conventional ‘dry’ electrostatic precipitator the collecting plates are periodically shaken to dislodge the collected dust, which then falls into hoppers for collection and disposal. Most electrostatic precipitation systems also involve a regular manual washing and cleaning of the collecting plates to remove collected particles, and to maintain operational efficiency.

Dry ESPs are effective in removing particles between one and 10 microns in diameter. Varying efficiency results have been claimed and reported in relation the removal of sub-micron particles. Some ESPs can be retro-fitted to tunnels. Child and Associates (2004) described a relatively low-cost Norwegian system which can be bolted directly to the tunnel roof and fixed to the jet fans. Removal efficiencies of between 66 per cent (PM_1) and 98 per cent (PM_{10}) are claimed.

The ionisation phase prior to the filtration of dust particles produces nitrogen dioxide (NO_2). Specifically, the ionisation produces ozone which reacts with nitrogen monoxide (NO) to form NO_2 (CETU, 2010).

ESPs are generally configured in one of two ways:

- Bypass-type installations. These are typically used to improve visibility in long tunnels, with the air being extracted, filtered and reinjected into the tunnel
- Extraction-type installation. Where major environmental requirements are involved, ESPs can be installed at the level of the polluted air outlets.

Installations by country

Around the world, there are relatively few road tunnels with installed filtration systems. The international experience with ESPs and filtration systems has been reviewed in a number of documents (eg Child & Associates, 2004; Willoughby et al., 2004; NHMRC, 2008; PIARC, 2008; CETU, 2010; AECOM, 2014b). A review of the use of the international electrostatic precipitators by country is provided below. Norway and Japan are two countries involved in the development of ESPs.

Japan

The application of ESPs to remove particles from tunnel air began in Japan, which has about 8,000 road tunnels comprising a total length of 2,500 kilometres. More ESPs have been installed in road tunnels in Japan than in any other country. CETU (2010) listed 46 road tunnels in which ESPs are installed, or was being installed at the time of its report. Most of the Japanese tunnels with particulate matter filtration are less than five kilometres long. ESPs were installed for the first time anywhere in the world in the Tsuruga tunnel (2.1 kilometres) in 1979. The development of ESPs has extended the range of longitudinal ventilation. The first long tunnel combining longitudinal ventilation and ESPs was the Kan'etsu tunnel (11 kilometres) in 1985.

According to Willoughby et al. (2004), there is no fixed policy in Japan on the installation and use of ESPs, but that tunnels are considered on a case by case basis. CETU state that the ESPs have been installed either to improve in-tunnel visibility, to manage the discharge air pollution from tunnel ventilation outlets or portals, or both. No Japanese road authority gave health concerns as a reason for installation of ESPs. Willoughby et al. (2004) also note that the policy in Japan is to consider ESPs for tunnels longer than two kilometres, although ESPs have been installed in shorter tunnels on an experimental basis. Where particulate matter filtration technology is installed to manage in-tunnel visibility (the main reason in Japan), this is typically as a result of a high percentage of diesel powered vehicles and a very high percentage of heavy goods vehicles using the road tunnel (AECOM, 2014b).

For most Japanese road tunnels with ESPs, the ESPs are located in bypass passages (to improve visibility). However, potential environmental impacts have led to the installation of electrostatic precipitators in around ten tunnels. For example, ESPs have been installed at the base of the extraction outlets in the Tennozan (two kilometres), Kanmon (3.5 kilometres), Asukayama (0.6 kilometres), Midoribashi (3.4 kilometres) and Hanazonobashi tunnels (2.6 kilometres). The Tokyo Bay tunnel (9.6 km) is mainly equipped with ceiling-based ESPs (CETU, 2010). The location the tunnel under Tokyo Bay makes the use of an intermediate ventilation outlet to manage in-tunnel air quality impractical, and a particulate matter filtration system has been installed as an alternative means to manage in-tunnel visibility.

In each case where ESPs have been installed in ventilation outlets, the reason given was that they were installed to limit particulate emissions in response to community concerns, but without support by technical assessment, dispersion modelling or any air quality monitoring at nearby receptors (Willoughby et al., 2004).

Norway

Norway has around 1,000 road tunnels. Norwegian tunnels have specific challenges in terms of visibility. In-tunnel visibility deteriorates significantly in winter when studded tyres are used. These increase abrasion of the road surface and, consequently, the suspension of PM (CETU, 2010). In warmer climates, where studded tyres are not required (such as in Sydney), road abrasion is much less of an issue (AECOM, 2014b).

Only eight of the tunnels in Norway have a PM filtration system installed. Two of these tunnels, the Festning Tunnel and the Bragernes Tunnel, have filtration systems that are designed principally to improve emissions to the environment (CETU, 2010). The Festning Tunnel passes beneath central Oslo. It is 1.8 kilometres long and carries 60,000 vehicles per day. The Laerdal Tunnel, which is the longest road tunnel in the world at 24.5 kilometres, also features a PM treatment system. The tunnel only carries 1,000 vehicles per day, and the principal purpose of the filtration system is to improve visibility within the tunnel, as the tunnel is deep underground with no opportunity to introduce additional fresh air along its length.

According to CETU (2010), the precipitators located upstream of extraction systems in Norwegian tunnels are no longer used for a variety of reasons, in particular, the need to replace electrical cables. There are also doubts concerning the benefits of putting the systems back into service given that they have proved less effective than predicted.

Spain

The M-30 Orbital Motorway circles the central districts of Madrid. It is the innermost ring road, with a length is 32.5 kilometres. It has at least three lanes in each direction, supplemented in some parts by two or three lane auxiliary roads. It connects to the main Spanish radial national roads that start in Madrid. From 2005 to 2008, major upgrading works took place, and now a significant portion of the southern part runs underground. The M-30 Orbital Motorway is essentially a number of independent tunnels and surface roads. They are the longest urban motorway tunnels in Europe, with sections of more than six kilometres in length and three to six lanes in each direction (AECOM, 2014b). Overall there are 22 particulate matter filtration systems and four denitrification systems installed by four different manufacturers (CETU, 2010).

France

The Mont Blanc Tunnel was retrofitted with an ESP system around 2010. The tunnel is a two lane bi-directional tunnel 11.6 kilometres long and originally constructed in 1965. It has a relatively small cross sectional area. The objective of the particulate matter filtration system is to contribute to various local initiatives aimed at improving air quality in the Chamonix Valley (CETU, 2010).

Italy

Only one tunnel in Italy – the Le Vigne tunnel in Cesene – has a particulate matter filter system installed. This tunnel is 1.6 kilometres in length and is located in a heavily populated area which is particularly sensitive to air emission from the tunnel portals. The objective of the particulate matter filtration system for this tunnel is to reduce the emission levels from the tunnel portals.

Germany

One tunnel in Germany (under the Elbe in Hamburg) has a small-scale particulate matter filtration systems installed. This has been installed by filtration system manufacturers for trial and development purposes (CETU, 2010).

South Korea and Vietnam

Five tunnels in South Korea and one tunnel in Vietnam (Hai Van Pass tunnel) are equipped with ESPs. The 2010 CETU study identifies that in these two countries, the systems are mainly used to provide adequate in-tunnel visibility where there are constraints on the intake of fresh air into the tunnels (as an alternative means of managing in-tunnel visibility).

Hong Kong

Design and construction contracts have been awarded for the Central Wan Chai Bypass in Hong Kong. It is understood that both denitrification and particulate matter filtration systems are to be installed in this tunnel. This is a 3.7 kilometre twin tunnel with three lanes of traffic in each direction. It is due to open in 2017.

Australia

An in-tunnel air treatment system – including ESP and denitrification technologies – was trialled in the Sydney M5 East tunnel, although measurement campaigns have indicated that emissions from the tunnel outlet do not have any significant impact on external air quality. The filtration system was installed 500 metres from the western portal in the westbound tunnel. A structure was built to host the

ESP and NO_2 treatment systems, fans, offices and ancillary equipment. A 300 metre ventilation duct to connect the plant to the tunnel was also built. The filtered air from the tunnel, rather than being discharged directly to outside, the air is reinjected into the tunnel and then eventually discharged by the existing outlet. The end-to-end cost of this treatment project was $65 million. The high cost reflects the fact that the tunnel was not originally designed to accommodate such systems (CETU, 2010).

<u>Effectiveness</u>

Japan

The two major manufacturers of ESPs in Japan are Matsushita Electric Co Ltd and Mitsubishi Heavy Industries. Both companies claim efficiency of at least 80 per cent removal of particles for their ESPs (Willoughby et al., 2004). While this is guaranteed by the companies, it is based on laboratory data and the performance has not been measured in an operating tunnel. Research by both companies has targeted improvement of particle collection efficiency and an increase in air speed through the ESPs. The companies report that testing has shown that for air speeds of up to nine metres per second an efficiency of 90 per cent can be achieved. ESPs have been developed and installed (Asukayama tunnel) that can operate at speeds of up to 13 metres per second. At this speed, however, the efficiency drops to just over 80 per cent (Willoughby et al., 2004).

As confirmed in the CETU report, ESPs have been installed at the Central Circular Route (Chuo-Kanjo-Shinjuku) in Tokyo since 2007. Data published on the website of the Tokyo Metropolitan Expressway Company claims a minimum 80 per cent PM reduction.

Austria

Child and Associates (2004) report the findings of a study by the Technical University of Graz of an Austrian ESP system in the Plabutsch tunnel. The removal efficiency ranged from more than 99 per cent for particles larger than 10 µm to 67 per cent for particles smaller than 1 µm.

South Korea

For an ESP installed in the Chinbu tunnel in South Korea, Drangsholt (2000) reports an average removal efficiency for particles between 0.3 µm and 10 µm of 83 per cent to 97 per cent.

Australia

The ESP trial in the Sydney M5 East westbound tunnel commenced in March 2010 and lasted 18 months. Roads and Maritime (then the Roads and Traffic Authority) engaged CSIRO to undertake a six-month monitoring and analysis program of the ESP to review the system's performance.

In a review of the trial, AMOG (2012) concluded the following:

- The PM removal efficiency (for the air passing through the ESP) was around 65 per cent, compared with a target efficiency of 80 per cent. There was a corresponding improvement in in-tunnel visibility. After mixing the filtered air with the tunnel air, the net improvement was reduced to 29 per cent. This was reduced to a much lower overall improvement in visibility at the western end of the tunnel of six per cent, which may not have been perceptible to tunnel users
- The ESP was unable to effectively or, given the cost of the system, cost-effectively, remove PM
- Around 200 m^3/s of air was drawn through the ESP. It is possible that the ESP was operating at or beyond its air flow velocity limit. The efficiency of the ESP could be improved by significantly reducing the throughput of air or increasing the path length of the system. Both of these options would add to the capital cost of the system, and the space required
- The ESP was unreliable and was only available for 84 per cent of the trial period
- The operation of the ESP should cease.

<u>Operational periods</u>

The operating periods of ESPs in tunnels are highly variable. ESPs are not automatically operated continuously, and a number of systems appear to have been rarely (or never) used. Child and

Associates (2004) cited the reasons given including low traffic flows, variable efficiency, the complexity of operation, and particle levels being well within limit values. In both Norway and Japan, the operation of air cleaning technologies is on a needs basis, as the net effect of the technology (coupled with its effectiveness) dictates that the technology is best used when air quality is at its worst and hence the benefit is greatest (Dix, 2006).

The ESPs in Japanese tunnels operate based on actual pollution measurements. In the case of the Kan'etsu tunnel, this results in an average operating time of 143 hours per month (20 per cent of the time) at the north portal and 40 hours per month (three per cent of the time) at the south portal. The Tokyo Bay tunnel only records 12 to 13 hours of operation per year (ie around 0.15 per cent of the time) (Dix, 2006)

In Norway the need for ESP operation it is usually on a time clock which corresponds with peak hour traffic (Dix, 2006).

According to CETU (2010), the ESPs on the Madrid M-30 network were initially operated for 20 hours per day, but now only operate for a few hours each week.

Material filters

Some dust filtration systems remove airborne particulate matter using physical filters. For example, Matsushita manufacture a system in which sheet filters are attached to filter units, which are incorporated into the dust collector. The dust collector is equipped with an automatic carrying mechanism to transfer the filter units to the regeneration part. When a filter is polluted and clogged with dust and soot, the filter is automatically regenerated by air blow to exfoliate dust and soot. Physical filters may be used in conjunction with ESPs.

According to Willoughby et al. (2004), fabric ('bag') filters are in use in 14 tunnels in Japan, including installation as recently as the Tokyo Bay tunnel. However, as this equipment has been found to only filter about 20 per cent of total PM it is understood that its use is being discontinued. A significant issue is the inability of filter materials to remove the very fine particles that are present in vehicle exhaust.

Denitrification systems

Description of method

Denitrification refers to systems or processes that are designed to remove NO_2, and other oxides of nitrogen, from tunnel air. A number of alternative systems are available. NO_X removal by catalytic and biological processes has been tested in Austria, Germany and Japan in the early 1990s. Due to their weak performance in NO removal efficiency, these tests were stopped. Subsequent developments have concentrated on pilot systems for NO_2 removal. No significant progress in robust NO treatment has been reported.

Installations and effectiveness by country

Norway

As of 2004, the operational use of denitrification technology in road tunnels had been limited to the installation of a system supplied by Alstom in the Laerdal tunnel in Norway (Child & Associates, 2004).

However, the performance and efficiency of this installation is difficult to assess, because traffic volumes in the Laerdal tunnel are relatively low. The resulting pollution levels within the tunnel are lower than those required to trigger the use of the electrostatic precipitation and denitrification systems that have been installed. Based on tests in the Festnings tunnel, the Alstom system removes 85–90 per cent of NO_2 and 60–75 per cent of hydrocarbons (Child & Associates, 2004).

Japan

In Japan two types of NO_X-reduction system were developed in 2004. In one of the systems – called 'adsorption' system – NO_2 molecules are removed by the physical adsorption effects of removing agents. In the other system – called 'absorption' – NO_2 molecules are chemically changed to neutral salts by removing agents soaked in alkaline water solutions, and are removed by the absorption of the neutral salts. Both systems have shown NO_2 removal efficiency of 90 per cent. Both technologies are being trialled in the ventilation outlets of the Central Circular Shinjyuka Tunnel. The tunnel is located in a crowded city area where it is difficult to comply with the local environmental standards for NO_2 (PIARC, 2008; CETU, 2010).

Germany

FILTRONtec in Germany has also developed a denitrification system. This system has been successfully demonstrated in German road tunnels, although no commercial applications of this technology have taken place (Child & Associates, 2004).

Spain

The M30 project in Madrid has major denitrification systems which are in occasionally in operation (PIARC, 2008).

Australia

The ESP trial in the Sydney M5 East westbound tunnel also included an assessment of a denitrification system consisting of an array of modules containing activated carbon as the filter medium. Around 50 m^3/s of air was drawn through this system.

In a review of the trial, AMOG (2012) concluded the following:

- The system removed 55 per cent of the NO_2 in the processed air, which was much less than expected
- The system only processed 14 per cent of the air in the westbound tunnel, so could not have a large impact on in-tunnel NO_2 levels. Enlargement of the system to process all tunnel air was considered to be impractical
- The system was not cost-effective at reducing NO_2, but there may be potential to develop an effective system.

Other technologies

Consideration also needs to be given to the potential use of other novel techniques for reducing in-tunnel pollutant concentrations which are distinctly different from those discussed earlier. A number of these techniques are reviewed below.

<u>Wet electrostatic precipitation</u>

'Wet' ESP differs from dry ESP primarily in the mechanism by which the collecting electrodes are cleaned, and the collected particles removed. In a typical wet ESP, a continuous washing process is used to clean the collecting electrodes, rather than the mechanical shaking process employed in dry ESPs. The wet environment also creates a potential for the removal, or part removal, of soluble pollutant gases, and assists in retaining and removing ultrafine particles. Some conventional electrostatic precipitation systems already involve an automatic wash process to periodically clean the collection plates, and remove the particles that have been collected. The distinction between this approach and the wet system is that the latter involves a continuously wet environment. One of the advantages argued for wet electrostatic precipitation, compared with the conventional process, is that the presence of a continuously wet environment increases the level of efficiency in removing particles smaller than 1 µm and soluble gaseous contaminants. Wet electrostatic precipitation has been used in a number of industrial applications, but does not appear to have been used in road tunnel applications (Child & Associates, 2004).

<u>Bio-filtration</u>

Bio-filtration is a general term used to describe processes in which contaminated air is passed over or through some medium containing micro-organisms capable of consuming, converting or otherwise removing some or all of the harmful pollutants present. Child and Associates (2004) describe bio-filtration systems manufactured by Fijita. Polluted air is passed through an aeration layer into one or two soil beds, each 50 centimetres thick. Removal efficiencies are stated as 95 per cent for TSP 91 per cent for NO_2, 88 per cent for NO, 95 per cent for CO and 94 per cent for SO_2. The authors note, however, that the application of bio-filtration processes to emission treatment in road tunnels involves a conflict between the need to move large volumes of air relatively quickly and the need for air to have relatively long exposures or residence times for the biological processes to be effective. Bio-filtration remains an emission treatment option of potential interest, but still an emerging or developing option in respect of road tunnel applications.

Agglomeration

Agglomeration is an electrostatic process whereby opposite electrical charges are applied to very fine airborne particles, causing them to combine or agglomerate into larger particles, which can then be more easily and effectively removed by other processes, or by gravity. Some electrostatic precipitation technologies include the principle of agglomeration in their basic designs. From a road tunnel viewpoint, agglomeration remains an emerging or developing technology, but would appear to have the potential to enhance the effectiveness of other PM removal systems (Child and Associates, 2004).

Scrubbing

Scrubbing describes a range of processes in which contaminated air is passed through a wash liquid, and pollutants are either entrained or dissolved in the liquid. Scrubbing is a well-established treatment technology in a number of industrial process applications, but generally in applications involving more heavily contaminated or polluted air streams than are experienced in road tunnels. Scrubbing has a potential application in the treatment of road tunnel emissions, but at this stage remains an emerging or developing technology in such applications (Child and Associates, 2004).

Photo-catalytic coatings

Considerable efforts have been made by researchers to develop and refine construction materials and coatings which have the potential for reducing levels of air pollution. The de-polluting properties of these materials are normally reliant upon photo-catalysis, whereby a photo-catalytic substance is used to increase the rate of chemical reactions. One of the most commonly used photo-catalysts is the compound titanium dioxide (TiO_2).

The potential of photo-catalytic coatings to reduce air pollution in tunnels is limited on account of the absence of sunlight, although application to portal walls and street furniture may be beneficial (though not necessarily cost-effective). Italy has experimented with photocatalytic denitrification at the relatively short (350 metres) bidirectional Umberto Tunnel in Rome. However, health concerns relating to TiO_2 appear to have limited its use (CETU, 2010).

Emission controls and other measures

Various operational measures are available to manage in-tunnel emissions and ambient air quality. These include the following:

- Traffic management. Traffic management may be employed by tunnel operators to control exposure to vehicle-derived air pollution. Measures might include (PIARC, 2008):
  - Allowing only certain types of vehicle
  - Regulating time of use
  - Tolling (including differential tolling by vehicle type, emission standard, time of day, occupancy)
  - Reducing capacity
  - Lowering the allowed traffic speed
- Incident detection. Early detection of incidents and queues is essential to enable tunnel operators and the highway authority to put effective traffic management in place. Monitoring via CCTV cameras is normally a vital part of the procedure for minimising congestion within tunnels
- Preventing abnormal loads

- Public information and advice. Traffic lights, barriers, variable message signs, radio broadcasts, loudspeakers and other measures can help to provide driver information and hence influence driver behaviour in tunnels
- Cleaning the tunnel regularly avoiding high concentrations of small particles (PIARC, 2008).

9.2.3 Summary and implications for the M4-M5 Link project

Tunnel design

The project design provisions to reduce pollutant emissions and concentrations within the tunnel will include:

- Minimal gradients. The main alignment tunnels would have gradients of less than four per cent. By comparison, the M5 East tunnel has a grade of up to eight per cent on the long western exit, which causes trucks to slow down and increase emissions. Isolated locations connecting to the existing surface road network may require short lengths of steeper grades of up to eight per cent. These grades generally match with existing conditions on local surface roads or are required to ensure appropriate ground conditions. Excessively long entry and exit ramps would be avoided
- The tunnels would have a large cross-sectional area to reduce the pollutant concentration for a given emission into the tunnel volume, and to permit greater volumetric air throughput. The mainline tunnels would have widths varying between 10.5 to 16.0 metres and be higher than most previous tunnels
- Increased height. The height of the M4-M5 Link tunnels will be 5.3 metres which will reduce the risk of incidents involving high vehicles blocking the tunnel and leading to disruption of traffic. This would reduce the risk of higher pollutant concentrations associated with flow breakdown.

Ventilation design and control

The project ventilation system has been designed and would be operated so that it will achieve some of the most stringent standards in the world for in-tunnel air quality, and will be effective at maintaining local air quality. The design of the ventilation system will ensure no portal emissions.

The ventilation system would be automatically controlled using real-time air flows and air quality sensor readings, to ensure in-tunnel conditions are managed effectively in accordance with the agreed criteria. Furthermore, specific ventilation modes will be developed to manage breakdown, congested and emergency situations.

Air treatment

The effectiveness of the treatment of tunnel emissions has been evaluated as part of the environmental assessment phase of a number of existing Sydney road tunnels, including the M5 East, Cross City Tunnel and Lane Cove Tunnel. It has also been subject of numerous NSW Legislative Council (Upper House) inquiries and independent scientific reviews including by the CSIRO. In general, these evaluations have indicated that it is more cost-effective to reduce pollutants at the source, using improved fuel standards and engine technology, which will result in greater benefits to air quality, both in-tunnel and in the ambient air, at the local and regional scales (WDA, 2013).

Electrostatic precipitators

The EIS for NorthConnex included an analysis of the potential costs and benefits of tunnel filtration systems, and argues why such systems are not warranted (AECOM, 2014a,b). These same arguments are also relevant to the M4-M5 Link project, and are summarised below:

- M4-M5 Link in-tunnel air pollutant levels, which are comparable to best practice and accepted elsewhere in Australia and throughout the world, would be achieved without filtration. As the conventional ventilation system is effective, there would be little benefit in providing an in-tunnel filtration system
- This Air Quality Assessment Report has demonstrated that the emissions from the ventilation outlets of the M4-M5 Link tunnels have a negligible impact on existing ambient pollutant

concentrations. These would meet ambient air quality criteria and would pose a very low risk to human health. In this context, there is no basis to justify installation of filtration systems

- Of the systems that have been installed, the majority have subsequently been switched off or are currently being operated infrequently (in some cases only a few hours per year in response to unusual or infrequent conditions, and/ or ongoing maintenance requirements). Where the operation of in-tunnel air treatment systems have been discontinued or reduced, the reasons have been that:
  - The technology has proved to be less effective than predicted
  - The forecast traffic volumes have not eventuated
  - Reductions in vehicle emissions.

As a result of these reasons, the high ongoing operational costs of the technology have not been justified. Most tunnels achieve acceptable air quality criteria without filtration. Less than 0.1 per cent of tunnels in the world use filtration to reduce particulate matter or nitrogen dioxide levels to maintain acceptable in-tunnel or external air quality.

If in-tunnel air quality levels could not be achieved with the proposed ventilation system, the most effective solution would be the introduction of additional ventilation outlets and additional air supply locations. This is a proven solution and more sustainable and reliable than tunnel filtration systems.

Incorporating filtration to the ventilation outlets would have negligible benefit and require a significant increase in the size of the tunnel facilities to accommodate the equipment. It would result in increased project size, community footprint, and capital cost. The energy usage would be substantial and does not represent a sustainable approach. Further, the air leaving the outlet is not highly concentrated with pollutants (as demonstrated by the air quality assessment) since it must be of a quality to be acceptable for tunnel users. Any predicted impact on local air quality is very small even without a filtration system.

In summary, the provision of a tunnel filtration system does not represent a feasible and reasonable mitigation measure and is not being proposed.

Denitrification

The technology around tunnel air filtering systems for nitrogen dioxide is relatively new, and any benefit has yet to be sufficiently measured.

Emission controls

Smoky vehicle cameras would be installed to automatically detect vehicles with excessive exhaust smoke, with penalties applying to offenders. A similar initiative is in place for the M5 East tunnel and has resulted in a reduction of smoky vehicles using the tunnel.

10 Summary and conclusions

This report has presented an assessment of the construction and operational activities for the M4-M5 Link project that have the potential to affect in-tunnel, local and regional air quality. The main conclusions of the air quality assessment for the project are summarised below.

10.1 Construction impacts

In the absence of specific direction for road and tunnel projects in NSW, the potential impacts of the construction phase of the project were assessed using guidance published by the UK Institute of Air Quality Management. The UK guidance was adapted for use in NSW, taking into account factors such as the assessment criteria for ambient PM_{10} concentrations.

The risks associated with construction dust emissions were assessed for four types of activity: demolition, earthworks, construction, and track-out. The assessment methodology considered three separate dust impacts: annoyance due to dust soiling, the risk of health effects due to an increase in exposure to PM_{10}, and harm to ecological receptors.

For the M4-M4 Link, above-ground construction activities would take place at a number of separate locations, and these were grouped into 11 distinct compounds for the purpose of the assessment.

For dust soiling impacts, the sensitivity for all areas and all activities was determined to be ‘high’. For human health impacts, the sensitivity for all areas and all activities was determined to be ‘medium’. For ecological impacts, the sensitivity of activities and areas was either ‘medium’ or ‘low’.

Several locations and activities were determined to be of high risk. Consequently, a wide range of management measures has been recommended to mitigate the effects of construction works on local air quality at the nearest receptors. Most of the recommended measures are routinely employed as ‘good practice’ on construction sites.

10.2 Operational impacts

10.2.1 In-tunnel air quality

In-tunnel air quality for the project was modelled using the IDA Tunnel software and Australia-specific emission factors from PIARC. Consideration was given to peak in-tunnel concentrations of CO and NO_2, as well as the peak extinction coefficient (for visibility). The work covered expected traffic, regulatory demand, and worst case operations scenarios.

In addition, all possible travel routes through the M4-M5 Link and the adjoining tunnels were identified for each direction of travel, and these were assessed against the in-tunnel criterion for NO_2 assessed as an average along any route through the tunnel network.

The information presented in the report has confirmed that the tunnel ventilation system would be designed to maintain in-tunnel air quality well within operational limits for all scenarios.

10.2.2 Ambient air quality (expected traffic, ground-level concentrations)

General conclusions

The following general conclusions have been drawn from this assessment:

- The predicted total concentrations of all criteria pollutants at receptors were usually dominated by the existing background contribution
- For some pollutants and metrics (such as annual mean NO_2) there was also predicted to be a significant contribution from the modelled surface road traffic
- Under expected traffic conditions, the predicted contribution of tunnel ventilation outlets to pollutant concentrations was negligible for all receptors

- Any predicted changes in concentration were driven by changes in the traffic volumes on the modelled surface road network, not by the tunnel ventilation outlets
- For air quality some metrics (one hour NO_2 and 24 hour PM_{10}), exceedances of the criteria were predicted to occur both with and without the project. However, where this was the case the total numbers of receptors with exceedances decreased slightly with the project and in the cumulative scenarios
- Where increases in pollutant concentrations at receptors were predicted, these were mostly small. A very small proportion of receptors were predicted to have larger increases. However, it is likely that the predictions at these locations were overly conservative
- The spatial changes in air quality as a result of the project were quite complex, reflecting the complex changes in traffic on the network. For example:
  - There were predicted to be marked reductions in concentration along Dobroyd Parade / and Parramatta Road to the south-east of the Parramatta Road ventilation station. In the 2023-DM scenario, the traffic to and from the M4 East tunnel would access the tunnel using these roads. In the with-project scenarios, the M4-M5 Link tunnel connects to the M4 East tunnel, thus relieving these roads
  - There was predicted to be a substantial reduction in concentrations along the Victoria Road corridor south of Iron Cove at Rozelle, due to traffic being diverted through the Iron Cove Link tunnel
  - There would also be reductions in concentration along General Holmes Drive, Princes Highway and the M5 East
  - However, there would be additional traffic (and an increase in pollutant concentrations) to the north of Iron Cove Link and near Anzac Bridge as a result of the general increase in traffic due to the project
  - Concentrations were also predicted to increase along Canal Road, which would be used to access St Peters interchange, and other roads associated with the Sydney Gateway project.

Pollutant-specific conclusions

Carbon monoxide (maximum one hour mean)

- For all receptors and scenarios, the predicted maximum one hour CO concentration was well below the NSW impact assessment criterion of 30 $\mu g/m^3$, as well as the lowest international air quality standard identified in the literature (22 $\mu g/m^3$)
- There was an increase in CO at between 32 and 38 per cent of receptors, although even the largest increases were an order of magnitude below the criterion
- The largest contribution from ventilation outlets at any receptor was less than 0.1 mg/m^3.

Carbon monoxide (maximum rolling eight hour mean)

- As with the one hour mean, at all receptors the concentration was well below the NSW impact assessment criterion, which in this case is 10 $\mu g/m^3$. No lower criteria appear to be in force internationally
- The largest increase at any community receptor with the project or in the cumulative scenarios was around 0.6 mg/m^3 (equating to 6 per cent of the criterion).

Nitrogen dioxide (annual mean)

- At all receptors, the NO_2 concentration was well below the NSW impact assessment criterion of 62 $\mu g/m^3$. At almost all receptors the NO_2 concentration was also below the EU limit value of 40 $\mu g/m^3$. Concentrations at the vast majority (more than 98 per cent) of receptors were between around 20 $\mu g/m^3$ and 30 $\mu g/m^3$
- The maximum contribution of tunnel ventilation outlets for any scenario and receptor was 0.6 $\mu g/m^3$, whereas the maximum surface road contribution was 21.6 $\mu g/m^3$. Given that NO_2

concentrations at the majority of receptors were well below the NSW criterion, the contribution of the ventilation outlets was not a material concern

- There was predicted to be an increase in the annual mean NO_2 concentration at between 15 per cent and 20 per cent of receptors, depending on the scenario. Conversely, there was a reduction in annual mean NO_2 at between around 80 per cent and 85 per cent of receptors. The increase in was greater than 2 µg/m^3 for less than 0.1 per cent of receptors.

Nitrogen dioxide (maximum one hour mean)

- At all community receptor locations investigated in detail, the maximum on-hour NO_2 concentration was below the NSW impact assessment criterion of 246 µg/m^3
- At the RWR receptors, there were some predicted exceedances of the NSW one hour NO_2 criterion (246 µg/m^3), both with and without the project. The number of receptors with exceedances decreased with the project and in the cumulative scenarios
- There was predicted to be an increase in the maximum one hour NO_2 concentration at between 26 per cent and 33 per cent of RWR receptors, depending on the scenario. Conversely, there was a reduction in the maximum concentration at between around 67 per cent and 74 per cent of receptors
- At the majority of receptors the change was relatively small; at around 93 per cent of receptors in 2023, the change in concentration (either an increase or a decrease) was less than 20 µg/m^3. Some of the changes at receptors were much larger (up to 234 µg/m^3), but the predictions at these locations were considered to be unrealistic
- The maximum contribution of tunnel outlets to NO_X at any receptor in the with-project or cumulative scenarios was 57 µg/m^3 in 2023-DSC. This would equate to a very small NO_2 contribution relative to the air quality assessment criterion.

PM_{10} (annual mean)

- The annual mean PM_{10} concentration at the majority of receptors was below the NSW impact assessment criterion of 25 µg/m^3
- The surface road contribution was less than 10 µg/m^3, with an average of 1.1–1.2 µg/m^3. The largest contribution from tunnel ventilation outlets at any receptor was 0.37 µg/m^3
- There was an increase in concentration at 32–36 per cent of the receptors with the project and in the cumulative scenarios, depending on the scenario. At the majority of receptors the change was relatively small, and where there was an increase, this was greater than 2.5 µg/m^3 at only one receptor.

PM_{10} (maximum 24 hour mean)

- At all community receptor locations, the maximum concentration was close to the NSW impact assessment criterion of 50 µg/m^3, which is also the most stringent standard in force internationally
- The results for the RWR receptors were highly dependent on the assumption for the background concentration. Because this was quite high (46.2 µg/m^3), the total concentration at the majority of receptors in the with-project and cumulative scenarios was above the NSW impact assessment criterion of 50 µg/m^3. However, the proportion of receptors with a concentration above the criterion decreased slightly as a result of the project
- The maximum contribution of tunnel ventilation outlets at any receptor was 1.2 µg/m^3 to 1.9 µg/m^3, depending on the scenario
- There was an increase in concentration at just below 40 per cent of receptors with the project and in the cumulative scenarios, depending on the scenario. Where there was an increase, this was greater than 5 µg/m^3 (10 per cent of the criterion) at just 0.1 per cent of receptors.

$PM_{2.5}$ (annual mean)

- The predictions for annual mean $PM_{2.5}$ were based on an assumed background concentration of 8 µg/m^3 (ie the same as the NSW criterion), and therefore exceedances were predicted for all receptors. Internationally, there are no standards lower than 8 µg/m^3 for annual mean $PM_{2.5}$

- The highest concentration at any receptor was 14.2 µg/m^3. In the with-project and cumulative scenarios, the surface road contribution was between 0.2 µg/m^3 and 5.4 µg/m^3. The largest contribution from tunnel ventilation outlets in these scenarios was 0.25 µg/m^3
- There was an increase in concentration at between 29 per cent and 37 per cent of receptors, depending on the scenario. The largest predicted increase in concentration at any receptor as a result of the project was 2.3 µg/m^3. Where there was an increase, this was greater than 0.1 µg/m^3 at around 2-3 per cent of receptors
- Only one RWR receptor had a value for $\Delta PM_{2.5}$ that was above the acceptable value 1.8 µg/m^3. However, this receptor was a commercial building that was very close to the indicative alignment of Sydney Gateway
- Annual mean $PM_{2.5}$ was taken as the indicator for the operational effects of Option B for project construction. The effects of Option B were not significantly different from those for Option A.

$PM_{2.5}$ (maximum 24 hour mean)

- The maximum concentrations at receptors with the project and in the cumulative scenarios were above the NSW impact criterion of 25 µg/m^3, although exceedances were already predicted without the project. Internationally, there are no standards lower than 25 µg/m^3 for 24 hour $PM_{2.5}$. However, the AAQ NEPM includes a long-term goal of 20 µg/m^3, and the results suggest that this would be difficult to achieve in the study area at present
- The maximum contribution of tunnel outlets at receptors with the project and in the cumulative scenarios was 1.2 µg/m^3
- The largest predicted increase in concentration at any receptor as a result of the project was 8.7 µg/m^3 (2023-DSC scenario). For most of the receptors the change in concentration was small; where there was an increase in concentration, this was greater than 2.5 µg/m^3 (10 per cent of the criterion) at only 0.2–0.3 per cent of receptors.

Air toxics

- Four air toxics – benzene, PAHs (as BaP), formaldehyde and 1,3-butadiene – were considered in the assessment. These compounds were taken to be representative of the much wider range of air toxics associated with motor vehicles, and they have commonly been assessed for road projects
- The changes in the maximum one hour concentrations were compared with the relevant NSW impact assessment criteria. For each compound, where there was an increase in the concentration, this was well below the NSW impact assessment criterion.

10.2.3 Ambient air quality (expected traffic, elevated receptors)

Concentrations at two elevated receptor heights (10 metres and 30 metres) were considered for annual mean and 24 hour $PM_{2.5}$. It should be noted that, for the 10 metre and 30 metre outputs, it was not necessarily the case that there were existing buildings at these heights at the RWR receptor locations.

The influence of surface roads was clearly reduced at 10 metres compared with at ground level, and was negligible at 30 metres. At the height of 30 metres, the increases in concentration were larger than at 10 metres, but they were much more localised around the ventilation outlets. This was due to some of the grid points at 30 metres being very close to the ventilation outlets.

The implications of the results can be summarised as follows:

- For all existing receptor locations, the changes in $PM_{2.5}$ concentration at 10 metres are likely to be acceptable. This assumes that the changes in $PM_{2.5}$ concentration for heights between ground level and 10 metres are also acceptable
- Future developments to the height of 10 metres should be possible at all locations in the GRAL domain

- The predicted concentrations do not indicate the need for any restrictions on future developments to 30 metres height, except in the vicinity of ventilation outlets at Campbell Road ventilation facility. The ventilation outlets would not adversely impact any existing receptors, as there are no existing buildings 30 metres or higher located close to the proposed ventilation facilities. Planning controls should be developed in the vicinity of St Peters to ensure future developments at heights about 10 metres are not adversely impacted by the ventilation outlets, A building height of 10 metres was selected because the screening analysis was only done at 10 and 30 metres and predictions for concentrations between these heights was not undertaken. Development of planning controls would need to be supported by detailed modelling addressing all relevant pollutants and averaging periods.

10.2.4 Ambient air quality (regulatory worst case)

The concentrations in the regulatory worst case scenario were, of course, higher than those for the expected traffic scenarios in all cases, and the following points are noted for the former:

- The maximum one hour CO concentration was negligible, especially taking into account the fact that CO concentrations are well below the NSW impact assessment criterion. For example, the maximum one hour outlet contribution in the regulatory worst case scenario (0.50 mg/m^3) was a very small fraction of the criterion (30 mg/m^3). The maximum background one hour CO concentration (3.27 mg/m^3) was also well below the criterion. Exceedances of the criterion due to the ventilation outlets are therefore highly unlikely
- For PM_{10} the maximum contribution of the ventilation outlets would have been small. For both the annual mean and maximum 24 hour metrics the outlet contributions were less than 10 per cent of the respective criteria. This would be significant for some receptors, but exceedances of the criteria due to the ventilation outlets alone would still be unlikely
- The ventilation outlet contribution would be most important for $PM_{2.5}$, with the maximum contributions equating to 13 per cent and 18 per cent of the annual mean and 24 hour criteria respectively. However, exceedances of the criteria due to the ventilation outlets alone would again be unlikely.

A detailed analysis was conducted for one hour NO_2. Although in some cases the ventilation outlet contributions appeared to be substantial, this is deceptive. As the background and surface road contributions (and hence total NOx) increase, there is a pronounced reduction in the contribution of the outlets to NO_2. The analysis showed that maximum outlet contribution occurred when other contributions were low, such that overall NO_2 concentrations were well below the criterion or even the predicted maximum.

Moreover, whilst the contributions to maximum one hour concentrations of NO_2 and 24 hour concentrations of $PM_{2.5}$ could have been significant, the contributions would be theoretical worst cases, and there are several reasons why they would not represent a cause for concern in reality. For example:

- The probability of a ‘worst case event’ occurring that would lead to these concentrations in the ventilation outlets is very low
- Were a worst case event to occur, the probability of it lasting up to one hour would be very low. It is extremely unlikely that such an event would last for 24 hours
- The probability of a worst case event coinciding with the worst 24 hour period for dispersion would be very unlikely
- The probability of a worst case event coinciding with a high background concentration would also be very low. In the case of NO_2, even if this were to occur the NO_2/NO_X ratio would be low.

Peak in-tunnel concentrations for all traffic scenarios, including the capacity traffic at different speeds, were well within the in-tunnel concentrations associated with the regulatory worst case scenarios. It therefore follows that the predicted ventilation outlet contributions to ambient concentrations for any in-tunnel traffic scenario would be lower than those used in the regulatory worst case assessment.

It can be concluded that emissions from the project ventilation outlets, even in the regulatory worst case scenarios, would be unlikely to result in adverse impacts on local air quality. SMC would conduct ambient air quality monitoring to demonstrate that emissions from the ventilation outlets would have no detectable impact on local air quality.

10.3 Management of impacts

10.3.1 Construction impacts

A range of measures for the management of construction impacts has been provided in the report. Most of the recommended measures are routinely employed as ‘good practice’ on construction sites. A Construction Air Quality Management Plan will be produced to cover all construction phases of the project. This should contain details of the site-specific mitigation measures to be applied.

10.3.2 Operational impacts

The report has provided a review of the measures that are available for improving tunnel-related air quality, and then describes their potential application in the context of the project. The measures that will be adopted for the project are summarised below.

Tunnel design

The project design provisions to reduce pollutant emissions and concentrations within the tunnel will include:

- Minimal gradients. The main alignment tunnels would generally have a maximum gradient of less than four per cent
- Large main line tunnel cross-sectional area. The mainline tunnels would have widths varying between 10.5 to 16.0 metres and be higher than most previous tunnels
- Increased height to reduce the risk of incidents involving high vehicles blocking the tunnel and disrupting traffic.

Ventilation design and control

The project ventilation system has been designed and would be operated so that it will achieve some of the most stringent standards in the world for in-tunnel air quality, and will be effective at maintaining local air quality. The design of the ventilation system will ensure zero portal emissions.

The ventilation system would be automatically controlled using real-time air velocity and air quality sensor data to ensure that in-tunnel conditions are managed effectively in accordance with the agreed criteria. Furthermore, specific ventilation modes will be developed to manage breakdown, congested and emergency situations.

Air treatment

The provision of a tunnel filtration system does not represent a feasible and reasonable mitigation measure and is not being proposed. The reasons for this are as follows:

- In-tunnel air pollutant levels, which are comparable to best practice and accepted elsewhere in Australia and throughout the world, would be achieved without filtration
- Emissions from the ventilation outlets of the M4-M5 Link tunnel will have a negligible impact on existing ambient pollutant concentrations
- Of the systems that have been installed, the majority have subsequently been switched off or are currently being operated infrequently
- Incorporating filtration to the ventilation outlets would require a significant increase in the size of the tunnel facilities to accommodate the equipment. It would result in increased project size, community footprint, and capital cost. The energy usage would be substantial and does not represent a sustainable approach.

If in-tunnel air quality levels could not be achieved with the proposed ventilation system, the most effective solution would be the introduction of additional ventilation outlets and additional air supply locations. This is a proven solution and more sustainable and reliable than tunnel filtration systems.

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