David Radford
Design Director
Grocon Group

12 August 2016

Dear David,

Ribbon Development – Refined Assessment of Level 29 Pool Area

Further to your request, please find detailed below our review of air quality and meteorological data for the proposed Level 29 pool area.

1 Background

Pacific Environment has previously assessed potential air quality impacts of the Cross City Tunnel Vent (CCTV) on the proposed Ribbon Sydney development (the Development), (PE, 2013, 2015, 2016a, 2016b), due to commence operations in late 2019 – early 2020.

These studies have involved the assessment of potential nitrogen dioxide (NO_2) impacts using conventional regulatory environmental atmospheric dispersion models (PE, 2013, 2015), with subsequent refinement using Computational Fluid Dynamic (CFD) modelling (PE, 2016a). This work has followed a specific protocol (the Protocol) established for the Cross City Tunnel, which applies an incremental NO_2 criterion of 150 µg/m^3 for assessment in accordance with pre-defined emission scenarios.

More recently, Grocon has sought to understand the nature of potential air quality impacts for an open roof design. This design would feature an open-top deck and pool area within Level 29 and Level 30 of the development (the L29 pool area). Attachment A1 and A2 provide an outline of the area in which the Level 29 pool area is proposed. This area is proposed to be open to the ambient environment, and spans between Finished Floor Level (FFL) extents of 80.66 mFFL and 88.36 mFFL.

Accordingly, Pacific Environment was then commissioned to undertake a review of previous dispersion modelling and CFD analyses to understand potential air quality impacts in the vicinity of the L29 pool area (PE, 2016b). This study recommended a refined, quantitative assessment approach which is the subject of this letter report.

2 Scope of Work

Pacific Environment has been commissioned to undertake an assessment of risk that includes a probabilistic analysis of potential air quality impacts including:

- Frequency of worst case meteorological conditions;
- Frequency and magnitude of worst case CCTV emissions;
- Nature of CCTV stack emission parameters;
- Hours of occupation for the L29 rooftop area.

This involves the following scope of work:

- Compilation of operational CCTV emissions parameters;
- Review of Protocol emission estimates in reference to future vehicle fleets;
- Revised near-field atmospheric dispersion modelling (undertaken using the GRAL micro-scale model);
- Assessment of rooftop NO_2 levels.

Details of this work are provided in the following sections.

3 GRAL Dispersion Modelling

The GRAL micro-scale dispersion model has been used for the assessment of all major traffic air quality assessments in NSW for the past four years, including the evaluation of all road tunnel ventilation outlets associated with the WestConnex network. As such, it is considered an appropriate tool for the current application.

The following sections describe the configuration of GRAL. Further information on the GRAL modelling system is provided within **Appendix B**.

3.1 Assessment scenarios

PE (2016) provided a detailed CFD analysis of potential air quality impacts on the Development for three separate modelling scenarios. These scenarios were identified as representing worst case dispersion conditions within the air quality assessment (PE, 2015). These three scenarios all used a wind speed of 1.0 m/s. In order to test the influence of higher wind speeds, the three scenarios have been repeated for wind speeds of 2.0 m/s and 3.0 m/s within this analysis, with an additional 10 m/s wind speed included on Scenario 3.

A summary of these modelling scenarios is provided in **Table 1**.

Table 1: CCT modelling parameters by scenario

Parameter	Scenario		
	1 / 1a / 1b	2 / 2a / 2b	3 / 3a / 3b / 3c
CCT Emission Type	High	Medium	Medium
Time of Day	6am – 10am, 3pm – 7pm	10am – 3pm	10am – 3pm
NO2 Emission Rate (g/s)	1.8	1.0	1.0
Exit Velocity (m/s)	21	11	11
In-Stack Temperature	Ambient + 5 °C (20°C)	Ambient + 5 °C (25 °C)	Ambient - 7 °C (13°C)
Wind Direction (°)	225	225	225
Wind Speeds (m/s)	1.0 / 2.0 / 3.0	1.0 / 2.0 / 3.0	1.0 / 2.0 / 3.0 / 10.0
Ambient Temperature (°C)	15	20	20
Season	Winter	Spring	Summer
Stability Class	F / E / D	B / B / C	B / B / C / D
Mixing Height (m)	600	1000	500

As shown in **Table 1**, Scenario 3 comprises a "negative buoyancy" scenario, where the CCTV exhaust air is cooler (and denser) than the ambient air into which it is released, thus restricting plume rise. It is noted that the adoption of a negative buoyancy assumption for a peak emission scenario is considered highly conservative given the buoyancy effects of vehicle waste heat that would be present when peak vehicle emissions occur.

3.2 GRAL domain and main parameters

Table 2 presents the main parameters selected in GRAL for the model runs.

GRAL was configured to provide predictions for a Cartesian grid of points with an equal spacing of 2 metres in both the x and y directions. As GRAMM was not used in this study, the terrain was set to 'flat' in GRAL. This was deemed representative of the terrain at the Project site.

Figure 1 presents a map of the study area, the Ribbon building and the discrete receptors selected for assessment (discussed further below).

Table 2: GRAL configuration

Parameter	Value(s)
General	
Domain in UTM (WestConnex GRAL)	N = 6250640, S = 6250140, E = 333400, W = 333900
Dispersion time (s)	3600
Number of particles per second[(a)]	500
Surface roughness[(b)]	0.5
Latitude (˚)[(c)]	-33
Buildings	Included using prognostic approach
Concentration grid	
Vertical thickness of concentration layers (m)	2
Horizontal grid resolution (m)	2
Number of horizontal slices	1
Height above ground level (m)	95

(a) Defines the total number of particles released in each dispersion situation.

(b) Defines the roughness length in the whole model domain. The roughness length alters the shape of the velocity profile near the surface.

(c) Average latitude of the model domain.

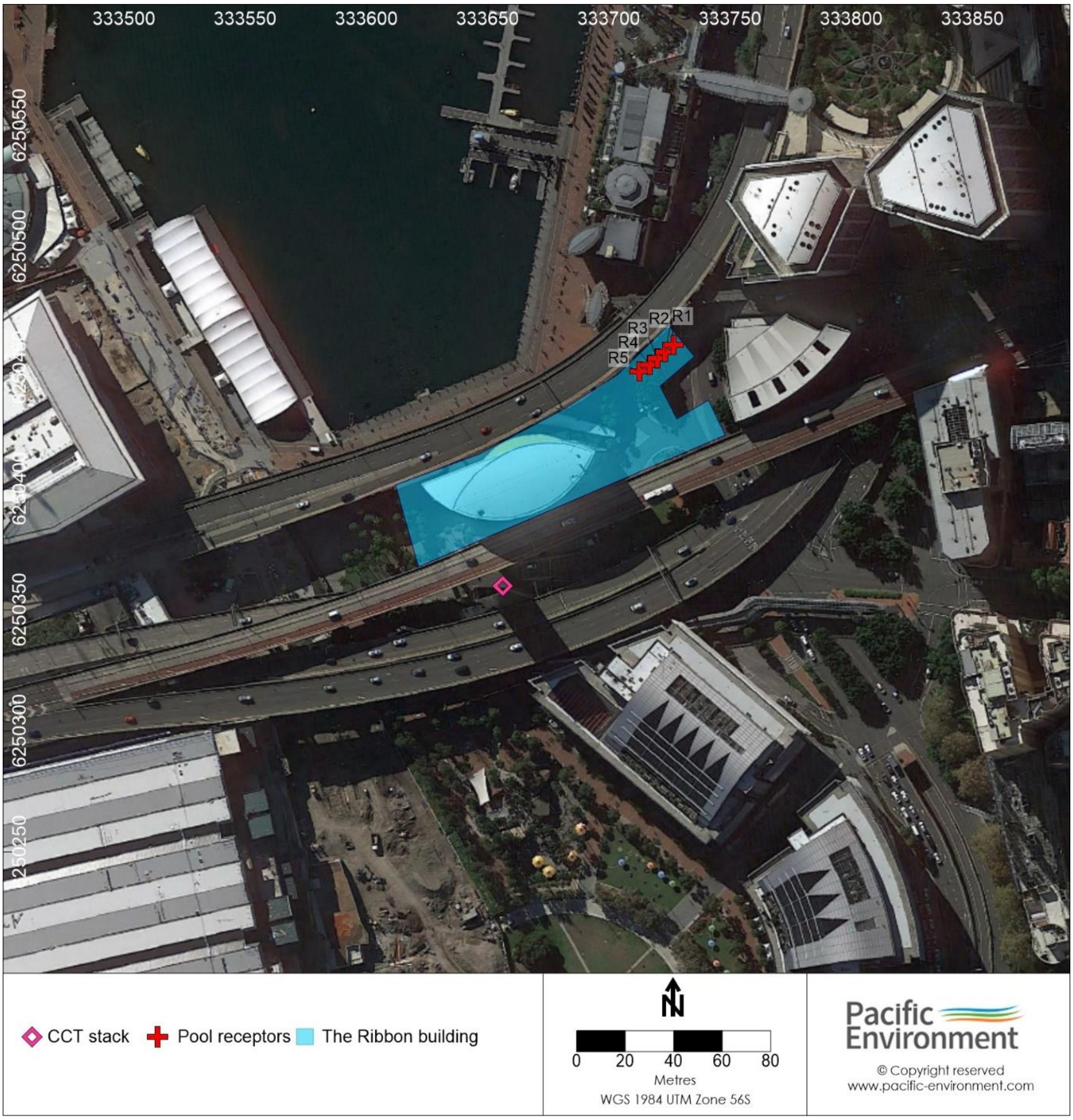

Figure 1: Study area and location of discrete receptors

3.3 Representation of buildings

The Ribbon building was represented by a series of individual vertical buildings at different heights. The stack was also represented as a 'building' in GRAL to ensure that any wake effects were captured.

GRAL provides two modelling options for assessing buildings; using a simple diagnostic approach or a more complex prognostic approach. The buildings in this study were modelled using the prognostic approach to enable a full, mesoscale model approach.

3.4 Discrete receptors

Five discrete receptors were included in the model and these are shown on **Figure 1**. These were selected to represent the L29 pool area at the top of the Ribbon building. These receptors were placed at a height of 95 m which is just above the building height at the L29 pool area location. This was completed to ensure that the receptors were not within the building in the model.

3.5 Modelling Results

Table 2 presents a summary of GRAL modelling results at discrete receptor locations. Contour isopleths for these results are presented in **Attachment C**. As shown in **Table 2**, all results are within the Protocol assessment criterion of 150 µg/m³.

Table 2: Summary of GRAL modelling results at discrete receptor locations.

Receptors	Maximum predicted 1-hour NO_2 concentration (µg/m³) at 95 m				
	R1	R2	R3	R4	R5
Scenario 1	0.0	0.0	0.0	0.0	0.0
Scenario 1a	0.0	0.0	0.0	0.0	0.0
Scenario 1b	0.0	0.0	0.0	0.0	0.0
Scenario 2	0.0	0.0	0.0	0.0	0.0
Scenario 2a	0.0	0.0	0.2	0.3	0.3
Scenario 2b	0.8	0.3	0.4	0.7	0.1
Scenario 3	0.0	0.0	0.0	0.0	0.0
Scenario 3a	0.6	0.7	0.2	0.1	0.2
Scenario 3b	1.8	1.7	2.1	2.5	1.4
Scenario 3c	22.6	26.0	27.5	61.8	53.4

4 Review CCT Emission Estimates

The Protocol emission estimates were based on 1996 PIARC emission factors, with correction to a 2006 reference fleet year (RTA, 2002). Since this time, vehicle emission performance has improved significantly, with the implementation of improved vehicle emission standards, and progressive modernisation of the vehicle fleet. Whilst the numerical analysis within this assessment has ultimately applied the emission rates contained within the Protocol, estimates of current operational emissions have been performed to provide additional context around the Protocol analysis.

Pacific Environment and Grocon requested information on tunnel operations with the CCT operator Transurban. This information was not available hence independent estimates have been undertaken using publically available data for the CCT (Transurban, 2017a, 2017b) in conjunction with current emission estimation techniques for motorway networks within NSW.

Peak-hour NO_X emissions from the traffic in the CCT (and hence the tunnel ventilation outlet) have been estimated using average-speed emission factors supplied by the New South Wales Environment Protection Authority (NSW EPA). These emission factors are specifically designed for use in NSW, and take into account the characteristics of the state's vehicle fleet. Correction factors have been applied to allow for the effects of road gradient on emissions. NSW EPA has not developed gradient correction factors, and therefore these have been estimated using the emission rates for speed-gradient combinations in PIARC (2012). The fuel splits for cars and light vehicles were taken from a recent RMS fleet model (O'Kelly, 2016), and heavy-duty vehicles (HDVs) were apportioned based on information provided by NSW EPA.

The assumptions adopted within the modelling are summarised in **Table 3**.

Table 3: Assumptions for CCT emission estimation

Parameter	Selection/value
Fleet Year	2017
Tunnel length	2.1 km in each direction
Traffic volume	20,000 vehicles per day in each direction[(a)]
Peak hour volume	2 x average hourly traffic volume
%HDV	10%[(b)]
Gradient	Half of tunnel at -6%, half at +6%
Speed	80 km/h
Road type	Motorway (with associated traffic mix)

(a) The tunnel currently has around 38,000 cars per day (https://www.transurban.com/content/dam/investor-centre/03/FY17-ResultsPresentation.pdf)
(b) Cars currently make up around 98% of the traffic in the tunnel (http://www.asx.com.au/asxpdf/20170504/pdf/43j0lkzqqgtgby.pdf).

Using the assumptions in **Table 1**, the NO_X emission rate from the tunnel ventilation outlet is estimated to be 9.7 kg/h, which based on the Protocol assumption that 20% of NO_x emissions exist in the form of NO_2, equates to an NO_2 emission rate of 0.54 g/s. **Table 4** provides a comparison of NO_2 emission estimates for the Protocol and current operations.

Table 4: Comparison between Protocol and calculated operational NO_2 emission estimates

Parameter	Protocol Estimate	Current Operational Estimate
Fleet Year	2006	2017
NO_2 Emission Rate (g/s)	1.8	0.54
Fraction of Protocol Estimate	-	30%

Further to the above, emission estimates are anticipated to be lower for future years, as consistent with modernisation of vehicle fleets. For example, based on the estimation methodology outlined above, in conjunction with PIARC (2012), the 2030 NO_x emission rate would be 5.2 kg/h (i.e. 46% lower again than the 2017 estimate), as associated with improvements in vehicle fleet emissions performance. It is noted that reductions in average emissions per vehicle may be offset by a growth in traffic.

Noting that specific information on CCT road grade was not publically available, the emission estimation has adopted an average grade of 6%, as representing a conservative estimate. For a tunnel gradient of 4%, the corresponding emission rate would be 7.4 kg/h, approximately 76% of the emission rate estimated for a 6% grade. Emission rates during the inter-peak period were estimated to be approximately 25% lower than those during the peak period.

It is likely that these assumptions would result in a conservative estimate of NO_X emissions from the future traffic in the tunnel for a number of reasons. For example:

- The calculations were undertaken for the year 2017. Emission estimates will be lower for future years following operational start of the Development in 2019 - 2020. For example, based on the estimation methodology outlined above, in conjunction with PIARC (2012), the 2030 NO_x emission rate would be 5.2 kg/h (i.e. 46% lower than in 2017), as associated with improvements in vehicle fleet emissions performance. It is noted that reductions in average emissions per vehicle may be offset by a growth in traffic.
- It was assumed that all HDVs would make up 10% of the traffic. This is known to be higher than the actual percentage of HDVs in the CCT, and is likely to be considerably higher than the percentage during peak traffic periods when traffic tends to be dominated by light-duty vehicles.
- The accuracy of the NSW EPA model (using the PIARC gradient factors) has been investigated using measurements from the ventilation outlets of the Lane Cove Tunnel (Boulter and Manansala, 2014). On average, the model overestimated NO_X emissions in the tunnel by a factor of between 2.2 and 3.3, depending on the direction of travel. This overestimation is likely to be due, at least in part, to an inherent over-prediction in the PIARC gradient factors, as well as the tunnel environment itself reducing emissions. In other words, the piston effect and any forced ventilation in the direction of the traffic flow can combine to produce an effective tail wind that reduces aerodynamic drag on the vehicles in the tunnel, and hence emissions (John et al., 1999).

5 Meteorological Analysis

In order to understand the frequency of winds from south westerly directions, a review of local meteorological data records has been undertaken. A full year of monitoring records from 70 mAGL on the Millennium Towers, located on Day Street, approximately 150 m south-east of the Development. The monitoring data was collected between September 2005 and August 2006 and is presented in **Table 5**.

Wind directions of interest to potential advection of CCTV emissions to the L29 Pool Area include SSW, SW and WSW. As shown in **Table 5**, these directions are present for approximately 13% of the time.

Further to this analysis, a review of congested scenario diurnal emission profiles (RTA, 2002) indicates that these wind directions are present for approximately 7% of the time in which CCTV emissions are equal to or greater than 50% of peak emission rates.

Table 5: Wind speed frequency distribution – Millennium Tower (70 m AGL).

Direction	Wind Speed (m/s)								Total
	0.5 - 1.5	1.5 - 3	3 - 4.5	4.5 - 6	6 - 7.5	7.5 - 9	9 - 10.5	>10	
NNE	1.14%	0.02%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1%
NE	1.91%	0.26%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	2%
ENE	7.40%	12.05%	2.00%	0.00%	0.00%	0.00%	0.00%	0.00%	21%
E	1.70%	0.13%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	2%
ESE	3.50%	0.35%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	4%
SE	2.76%	0.34%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	3%
SSE	1.84%	2.07%	0.41%	0.08%	0.00%	0.00%	0.00%	0.00%	4%
S	2.18%	4.67%	2.25%	0.16%	0.01%	0.00%	0.00%	0.00%	9%
SSW	***1.19%***	***2.21%***	***1.37%***	***0.29%***	***0.01%***	***0.00%***	***0.00%***	***0.00%***	***5%***
SW	***0.99%***	***1.53%***	***0.70%***	***0.09%***	***0.00%***	***0.00%***	***0.00%***	***0.00%***	***3%***
WSW	***1.22%***	***2.85%***	***1.16%***	***0.08%***	***0.00%***	***0.00%***	***0.00%***	***0.00%***	***5%***
W	2.29%	2.71%	0.80%	0.22%	0.00%	0.00%	0.00%	0.00%	6%
WNW	2.90%	2.24%	0.57%	0.19%	0.00%	0.00%	0.00%	0.00%	6%
NW	4.27%	2.40%	0.57%	0.18%	0.01%	0.00%	0.00%	0.00%	7%
NNW	7.09%	1.06%	0.25%	0.01%	0.00%	0.00%	0.00%	0.00%	8%
N	4.92%	0.08%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	5%

Annual and season wind roses for these data are provided in **Figure 2**.

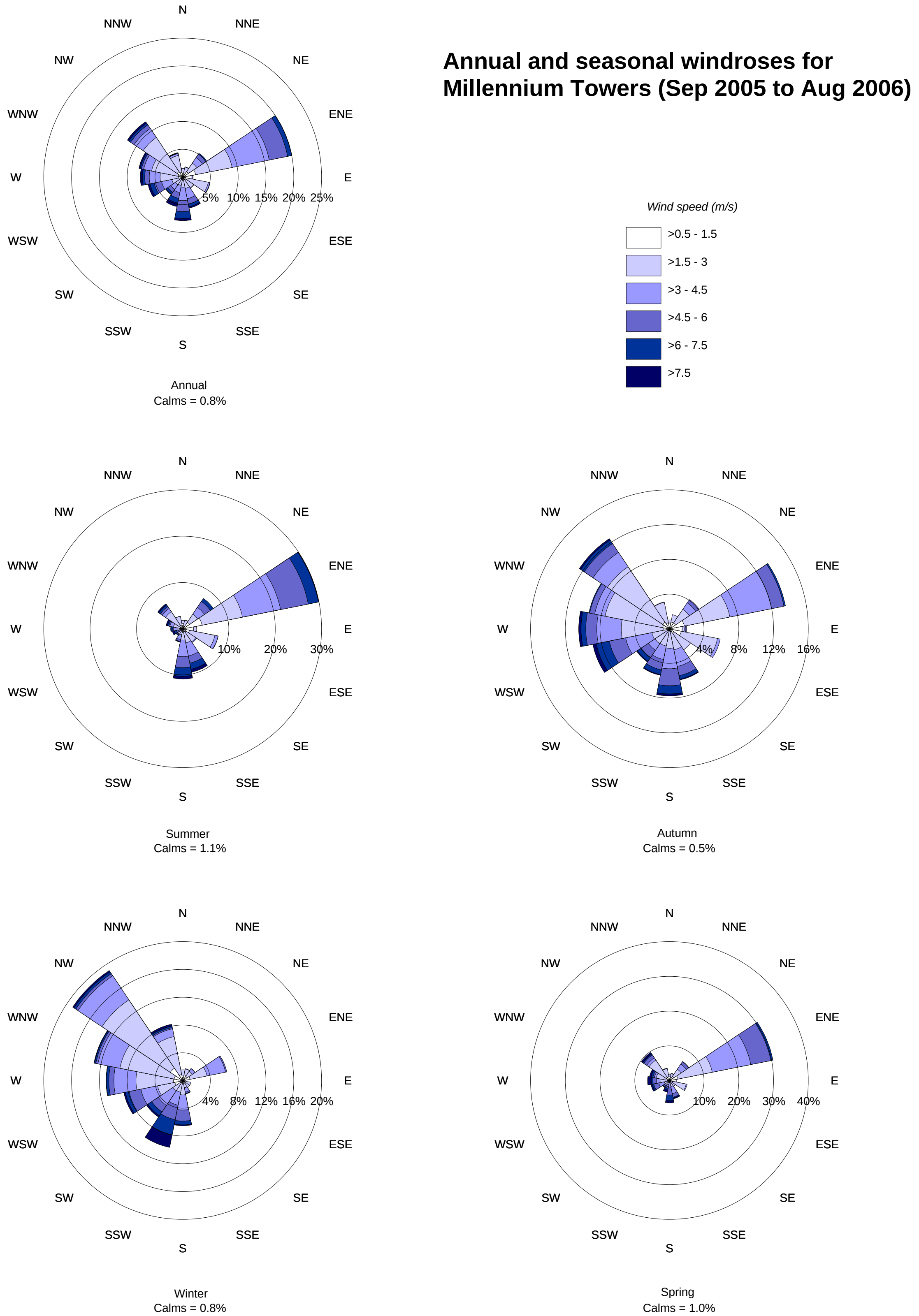

Figure 2 Annual and seasonal wind roses for Millenium Towers monitoring data (70 mAGL)

6 Conclusions

The GRAL modelling has predicted that concentrations at the L29 Pool Area will be below the impact assessment criteria detailed within the Protocol for all critical meteorological conditions identified.

A review of the CCT emission estimates has indicated that current and future operational NO_2 emission are likely to be significantly lower than those applied within the Protocol (and thus the current quantitative assessment).

Accordingly, refined, quantitative assessment approach indicates that the risk of exceedances of the NSW EPA ambient air quality criteria (using NO_2 as a marker) associated with operation of the L29 pool area is minor.

Further, an evaluation of the frequency of worst-case meteorological conditions and peak CCTV emissions indicates that constraints upon the hours of occupation of the L29 pool area are not necessary to protect occupant exposure.

We hope that this meets your current requirements. Please feel free to contact me should you have any additional queries.

Yours sincerely,

D.A.Roddis

Damon Roddis
Principal Consultant – Air Quality
Pacific Environment

7 References

Boulter P and Manansala F (2014). Lane Cove Tunnel ventilation investigation. Report AQU-NW-010-08788. Pacific Environment, North Sydney, NSW.

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Transurban (2017b) *Results for FY17*, Transurban, 8 August 2017 https://www.transurban.com/content/dam/investor-centre/03/FY17-ResultsPresentation.pdf (accessed 14 August 2017)

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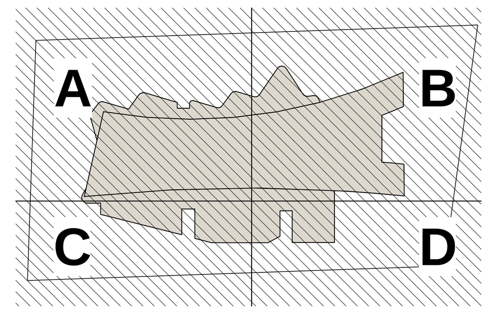
Attachment A General Layout Drawings

D SECTION D
1 : 200

REFERENCE MAP



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REV	DESCRIPTION	DATE
2	ISSUED FOR INFORMATION	31/10/2016
1	ISSUED FOR SCHEMATIC DESIGN	30/06/2016
0	ISSUED FOR INFORMATION	03/06/2016

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CLIENT

Grocon

PROJECT

THE RIBBON HOTEL, SERVICED APARTMENTS AND RETAIL
31 WHEAT ROAD, SYDNEY

DRAWING TITLE

SECTION D

STATUS

FOR INFORMATION

SCALE @ B1	DRAWN	CO-ORD	REVIEWED	APPROVED
1 : 200	HSL	ARC-HSL	RB	JO

PROJECT NUMBER	DRAWING NUMBER	REV
A004409	ARC-HSL- 3002	2

Original Sheet Size B1-1000 x 707mm

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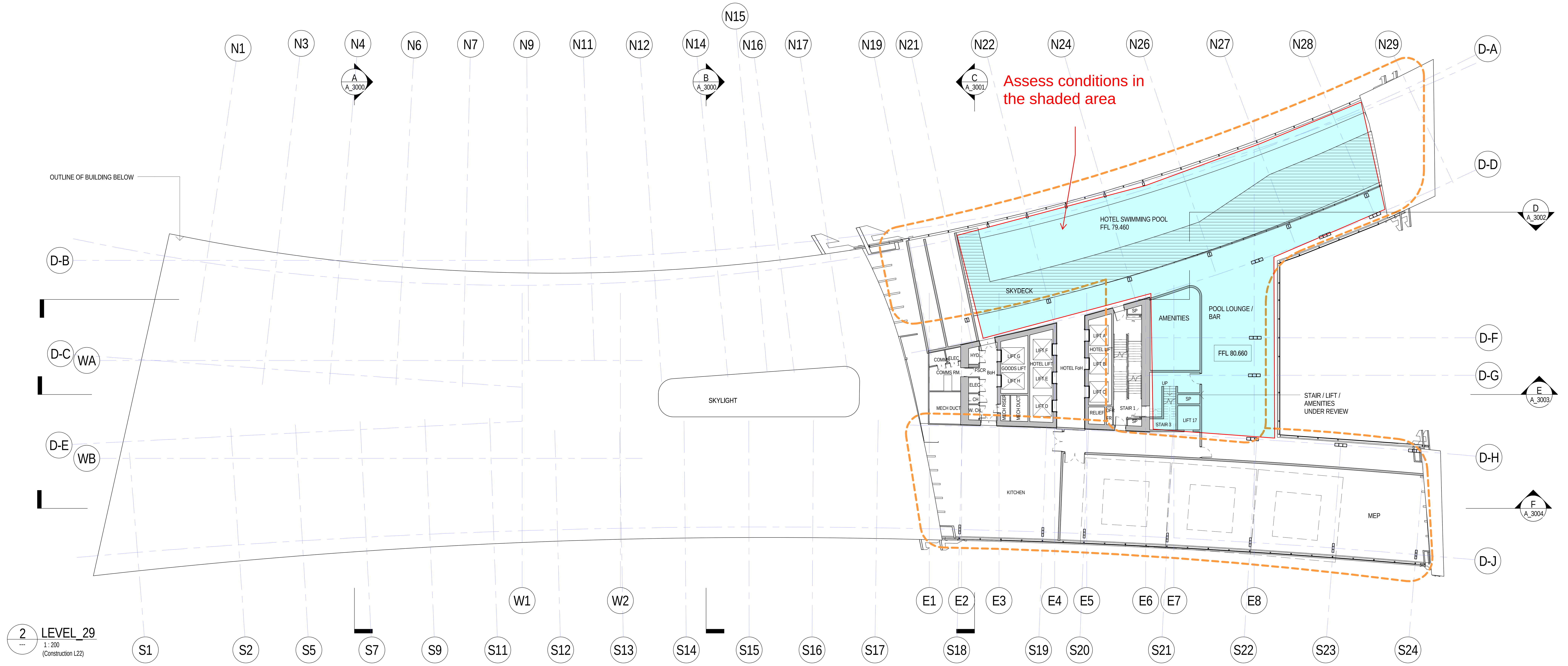

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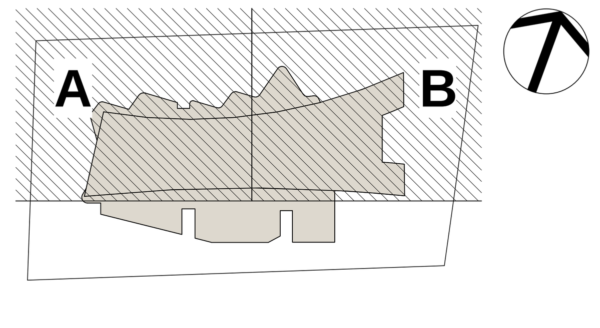

NORTH

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LEVEL 22 NOTES

MEP	UPDATE PENDING
DUMB WAITERS	TWO ARE TO BE ALLOWED FOR FROM LEVEL 22 TO 23
POOL	POOL EQUIPMENT ZONE PENDING

REV	DESCRIPTION	DATE
5	ISSUED FOR INFORMATION	31/10/2016
4	PRELIMINARY SERVICES COORDINATION	13/09/2016
3	INITIAL INFORMATION - DESIGN DEVELOPMENT	02/09/2016
2	ISSUED FOR SCHEMATIC DESIGN	30/06/2016
1	ISSUED FOR INFORMATION	17/06/2016
0	ISSUED FOR INFORMATION	03/06/2016

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PROJECT

THE RIBBON HOTEL, SERVICED APARTMENTS AND RETAIL
31 WHEAT ROAD, SYDNEY

DRAWING TITLE

GA PLANS - L28 AND L29

(Construction L21 & L22)

STATUS

FOR INFORMATION

SCALE @ B1	DRAWN	CO-ORD	REVIEWED	APPROVED
1 : 200	HSL	ARC-HSL	MH	EL

PROJECT NUMBER	DRAWING NUMBER	REV
A004409	ARC-HSL- 1113	5

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Attachment B GRAL Model Overview

The model system consists of two main modules: a prognostic wind field model (Graz Mesoscale Model – GRAMM) and a dispersion model (GRAL itself). An overview of the GRAMM/GRAL modelling system is presented in Figure B-1. The system has in-built algorithms for calculating emission rates (the grey area of the Figure), but these were replaced by the project-specific emission rates.

GRAMM is the meteorological driver for the GRAL system. Its main features include the use of prognostic wind fields, a terrain-following grid, and the computation of surface energy balance. Given the small study area and the dominant flat terrain surrounding the Project, the GRAMM component was not used for this study.

GRAL is a Lagrangian model, whereby ground-level pollutant concentrations are predicted by simulating the movement of individual 'particles' of a pollutant emitted from an emission source in a three-dimensional wind field. The trajectory of each of the particles is determined by a mean velocity component and a fluctuating (random) velocity component.

GRAL stores concentration fields for user-defined source groups. Up to 99 source groups can be defined (eg traffic, domestic heating, industry), and each source group can have specific monthly and hourly emission variations. In this way annual mean, maximum daily mean, or maximum concentrations for defined periods can be computed. Usually, about 500–600 different meteorological situations are sufficient to characterise the dispersion conditions in an area during all 8,760 hours of the year.

Other general parameters required by the program include surface roughness length, dispersion time, the number of traced particles (influences the statistical accuracy of results), counting grids (variable in all three directions), as well as the size of the model domain.

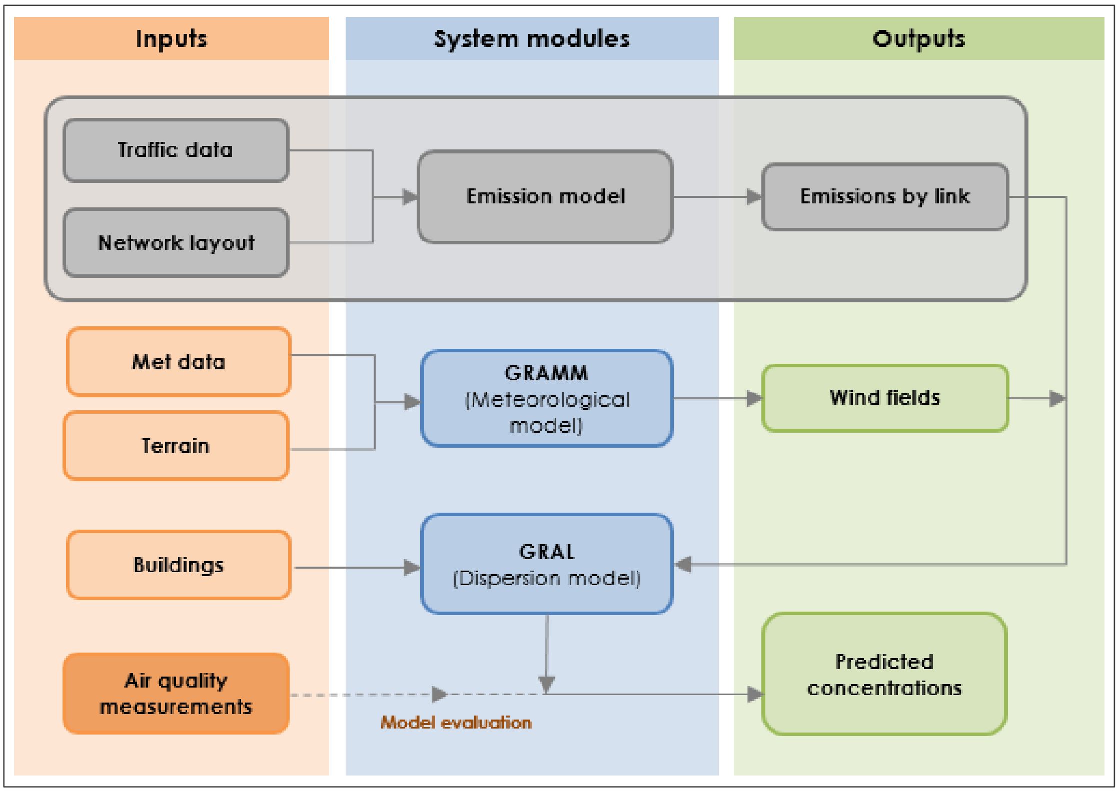

Figure B-1: Overview of the GRAMM/GRAL modelling system

Attachment C GRAL Modelling Contour Isopleths

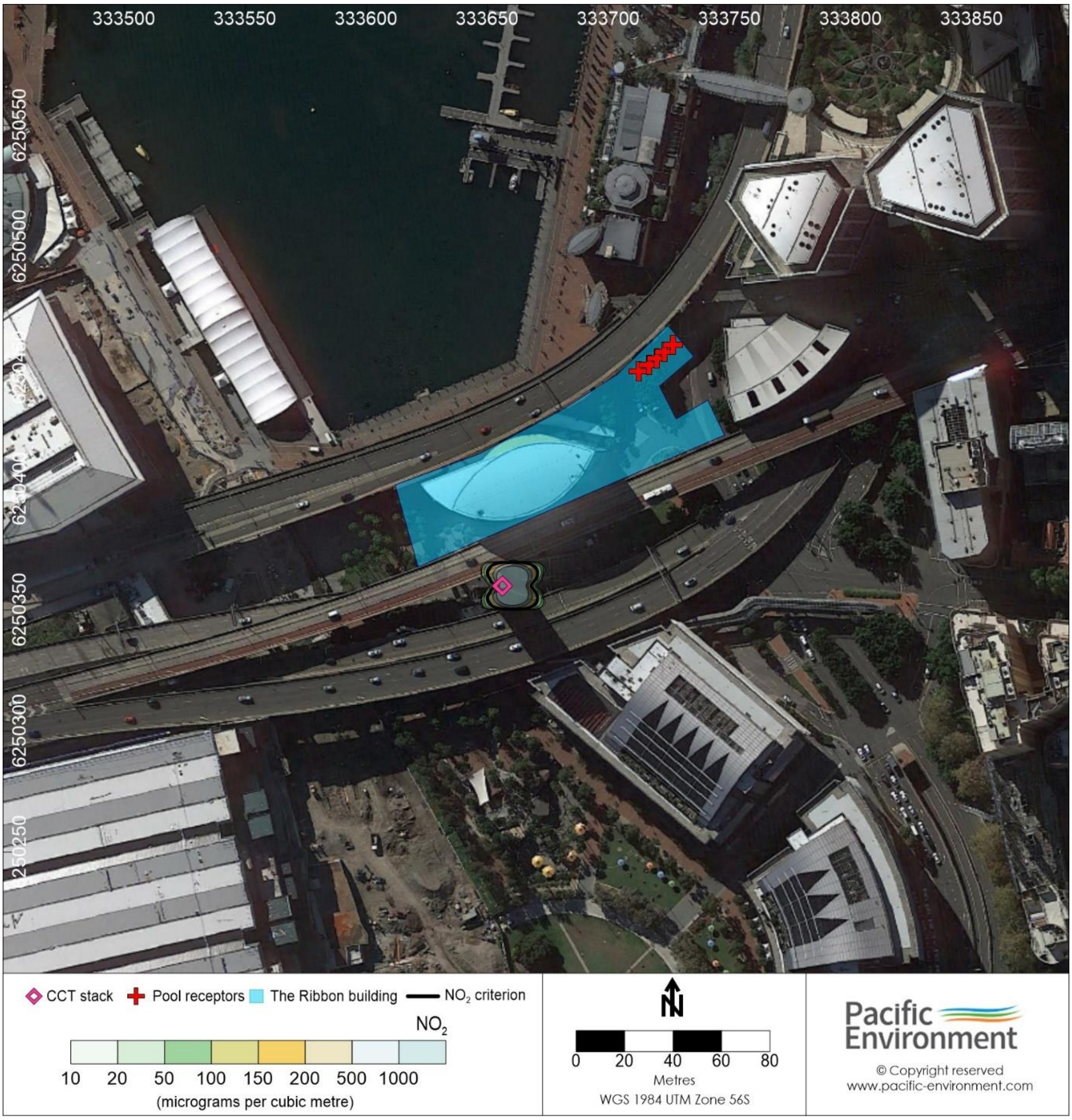

Figure B.1 GRAL NO_2 Predictions at 95 mAHD: Scenario 1

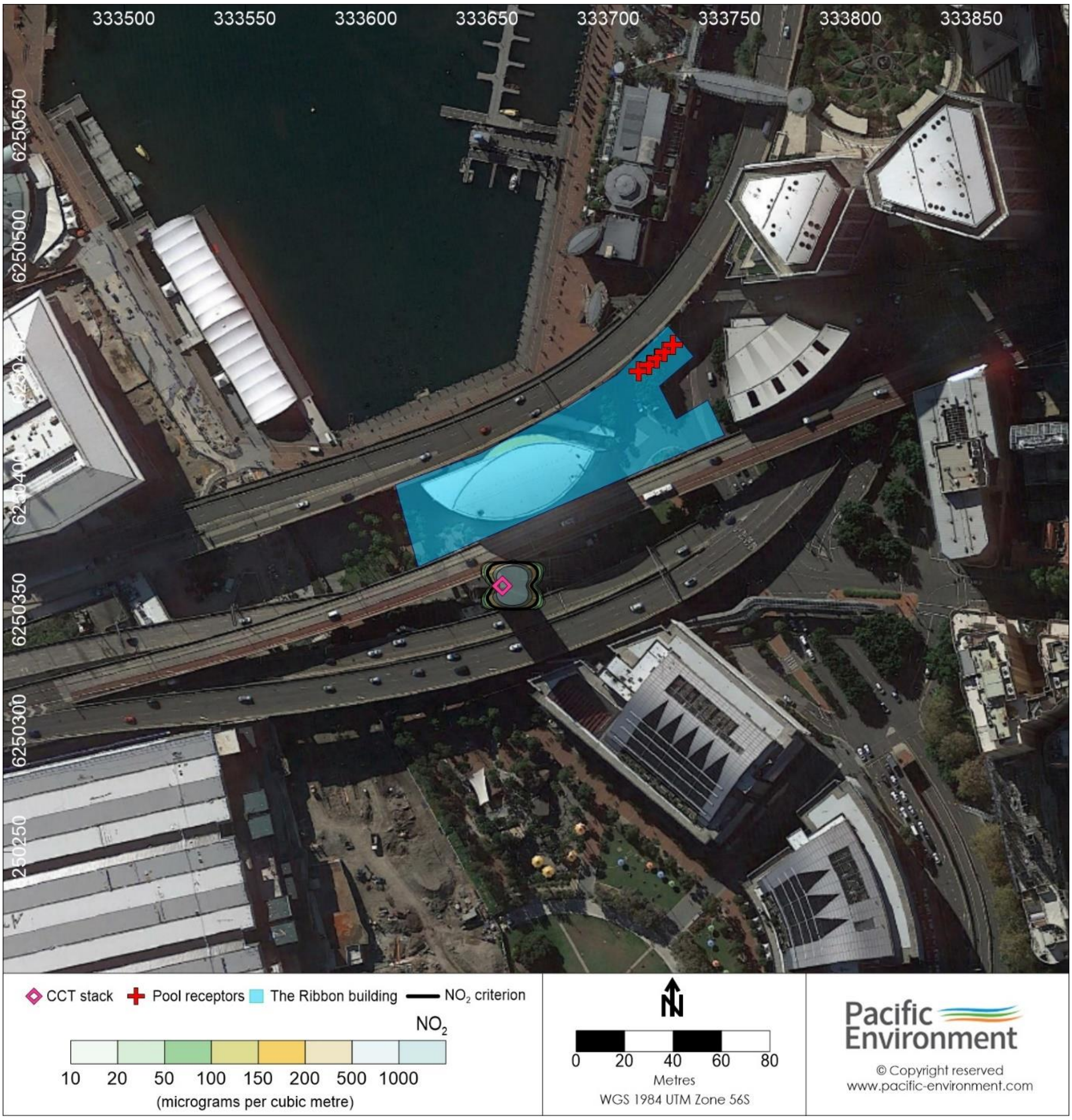

Figure B.2 GRAL NO_2 Predictions at 95 mAHD: Scenario 1a

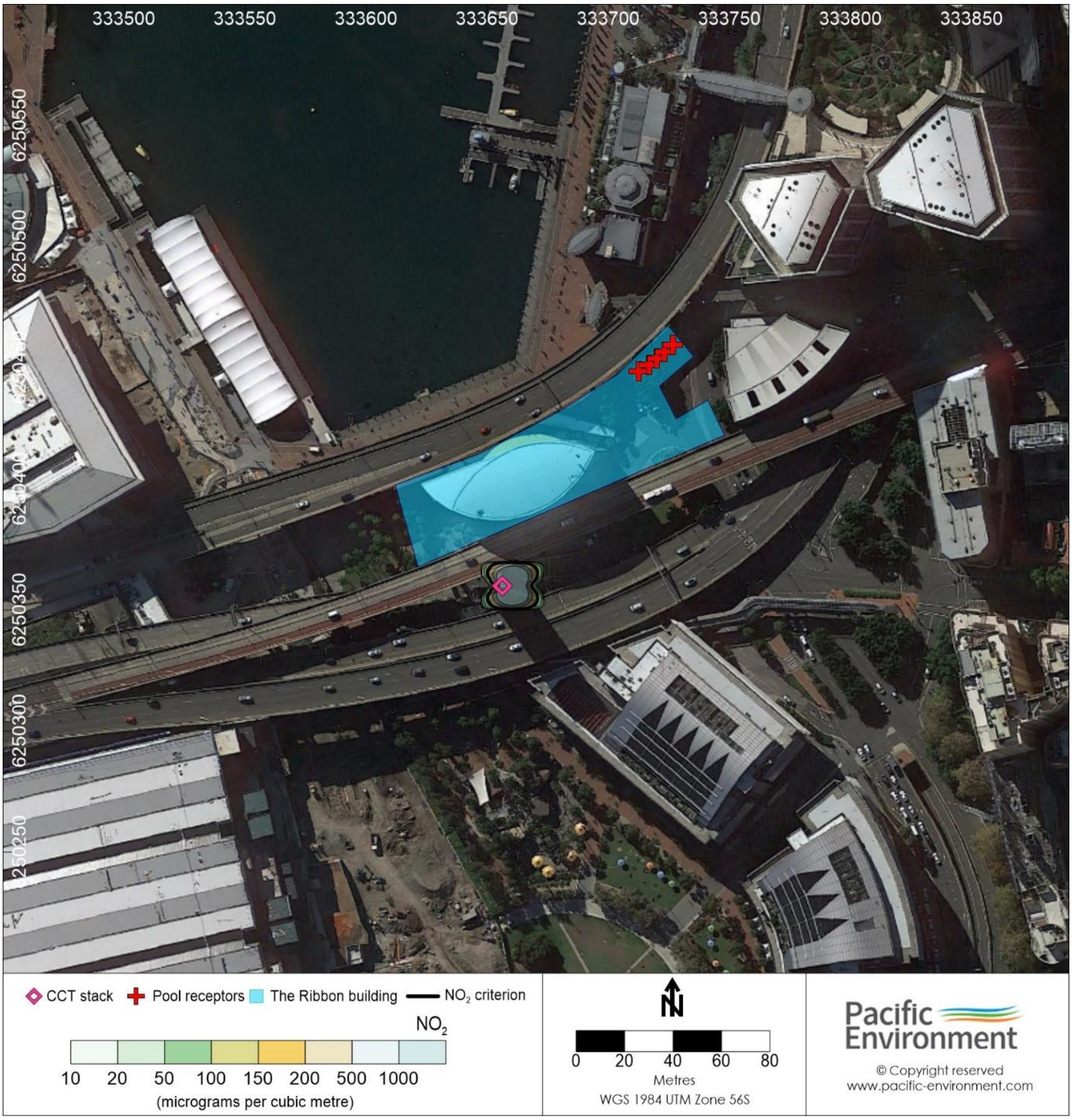

Figure B.3 GRAL NO_2 Predictions at 95 mAHD: Scenario 1b

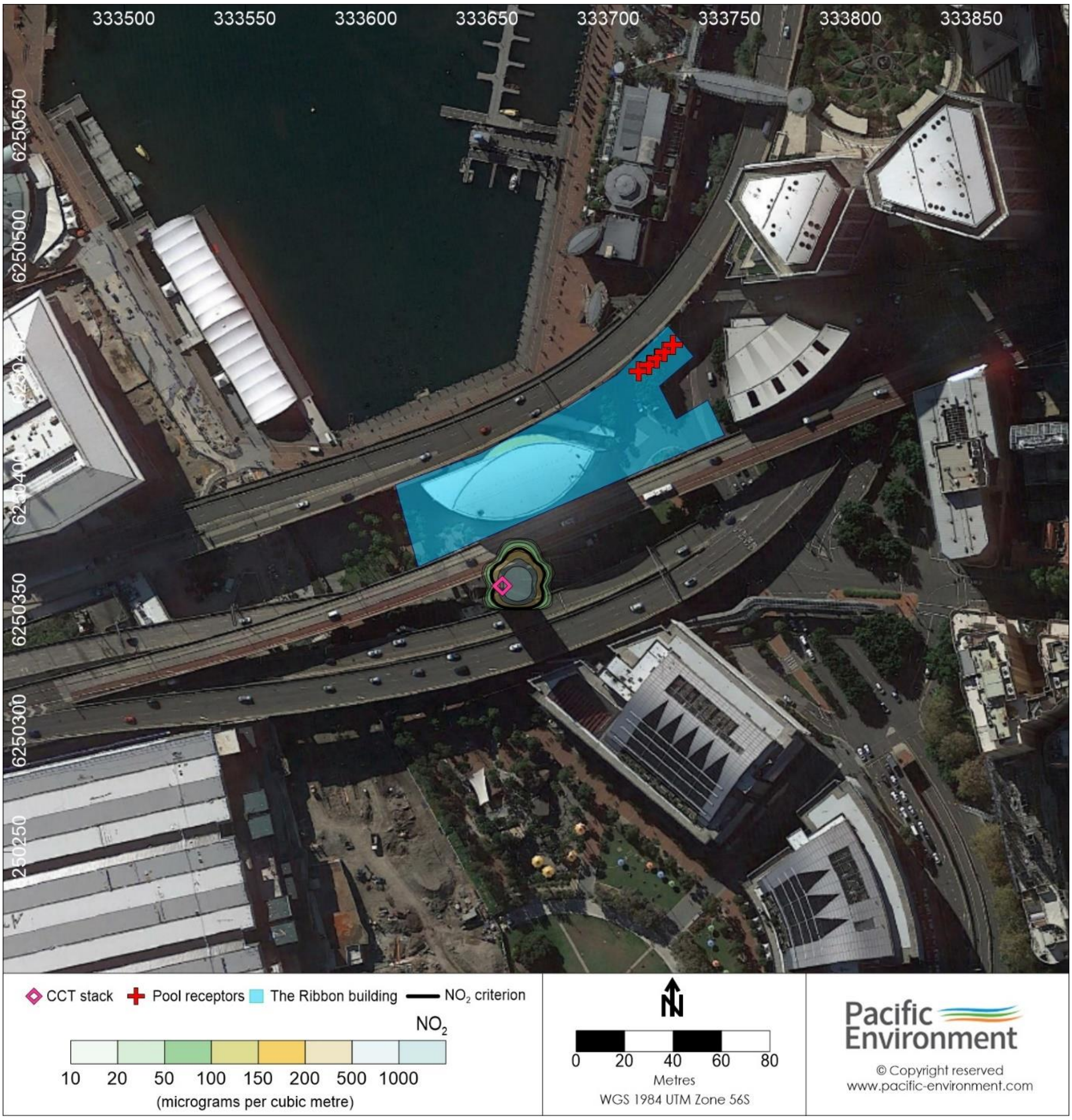

Figure B.4 GRAL NO_2 Predictions at 95 mAHD: Scenario 2

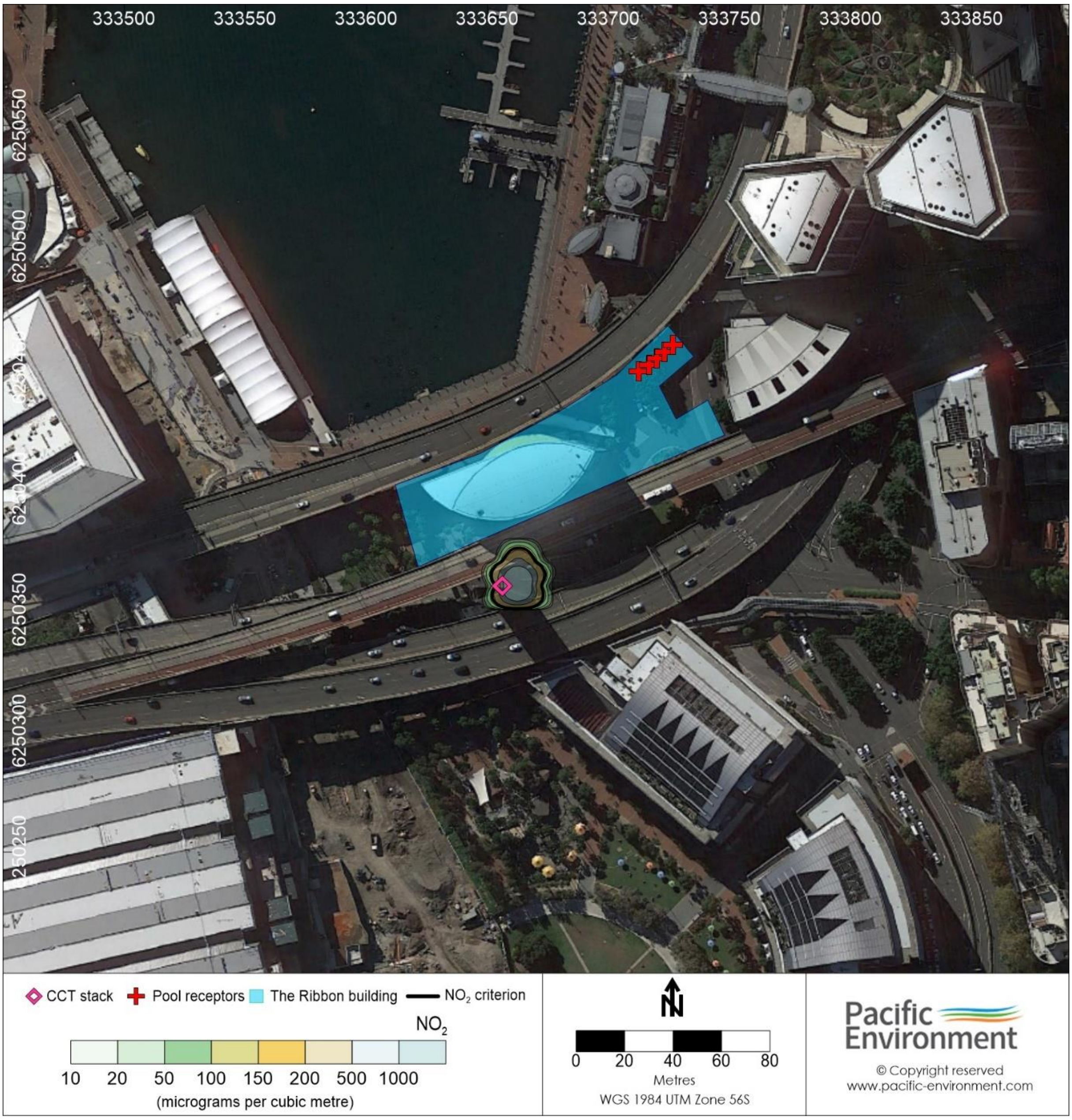

Figure B.5 GRAL NO_2 Predictions at 95 mAHD: Scenario 2a

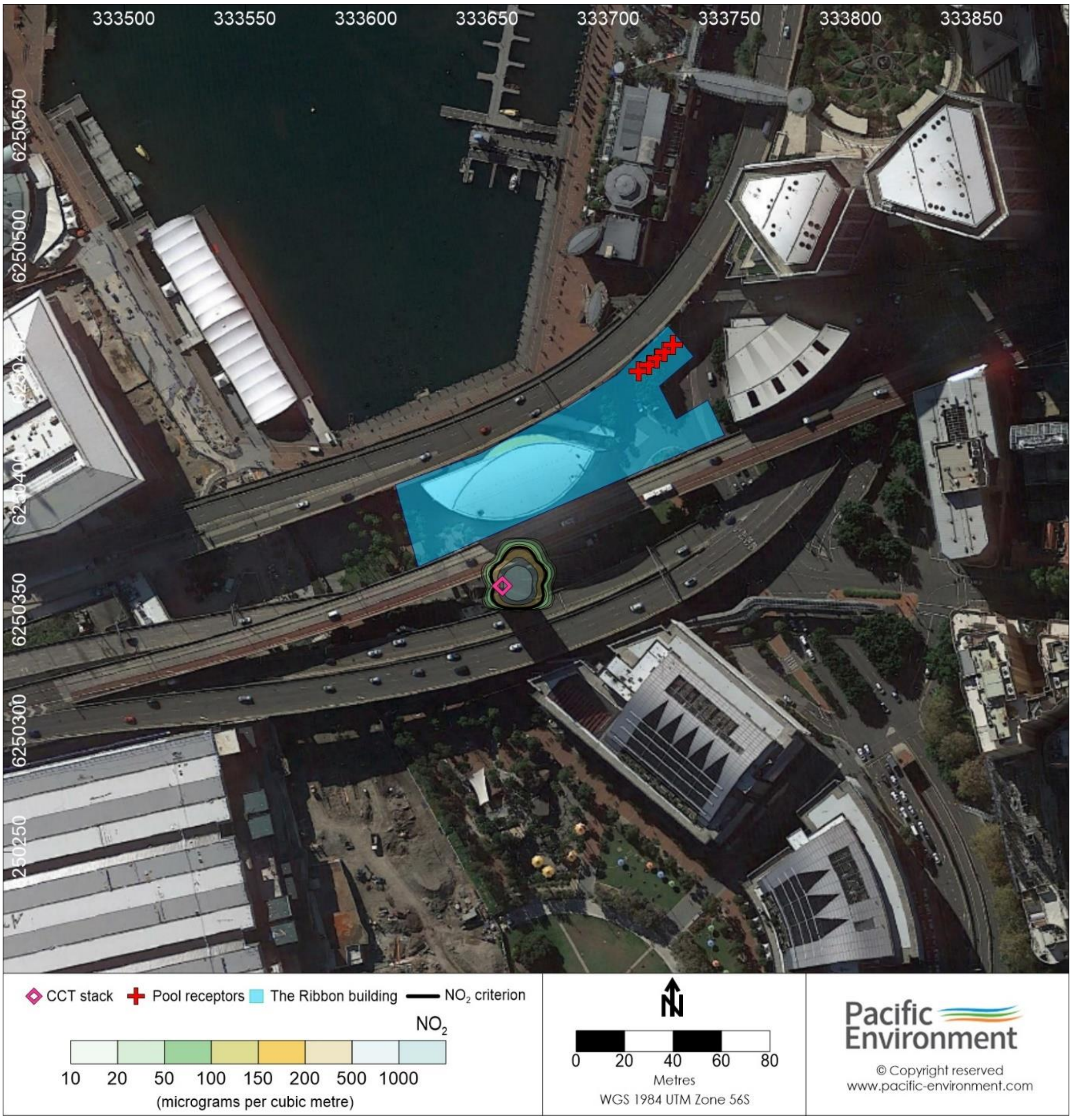

Figure B.6 GRAL NO_2 Predictions at 95 mAHD: Scenario 2b

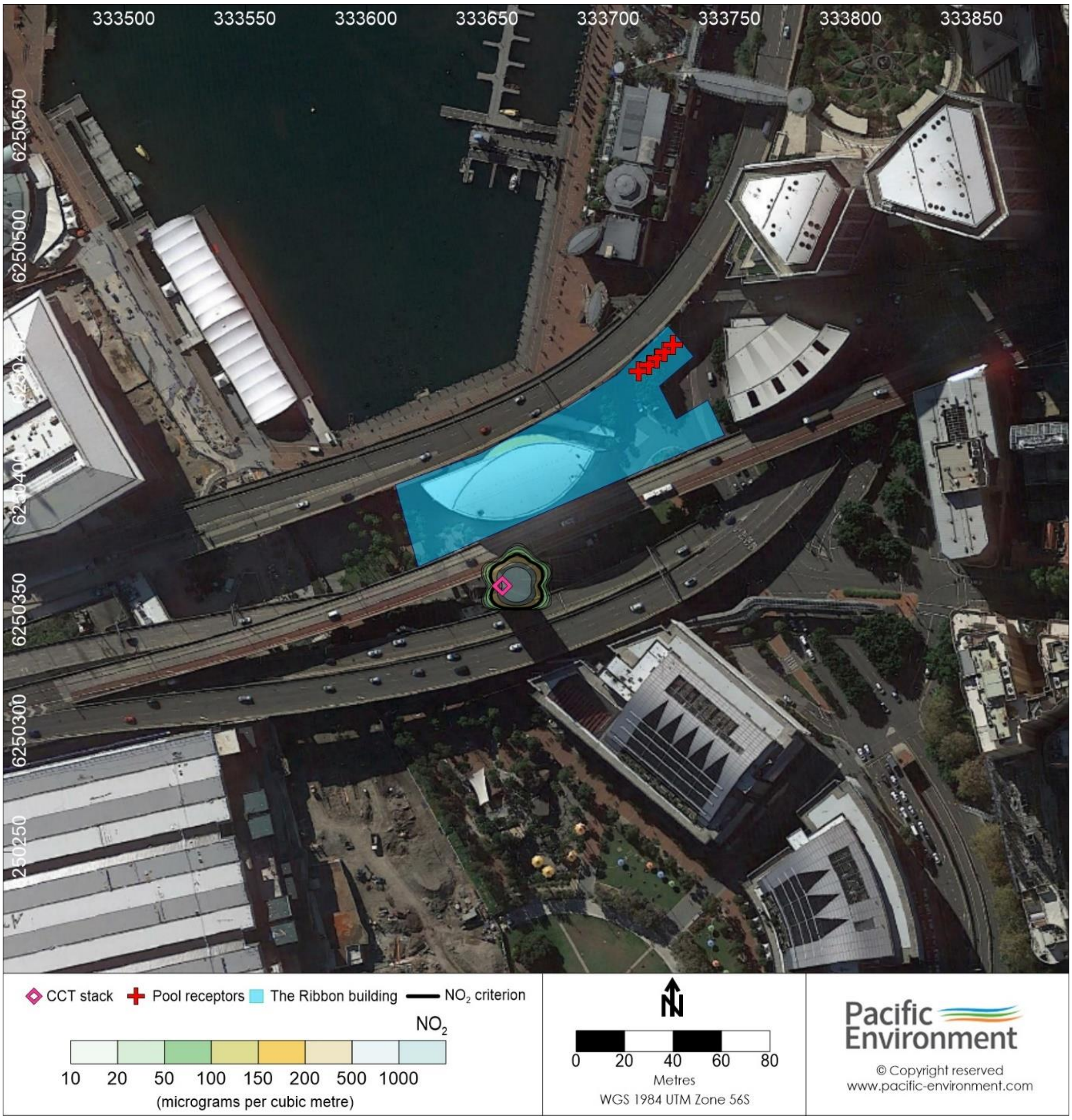

Figure B.7 GRAL NO_2 Predictions at 95 mAHD: Scenario 3

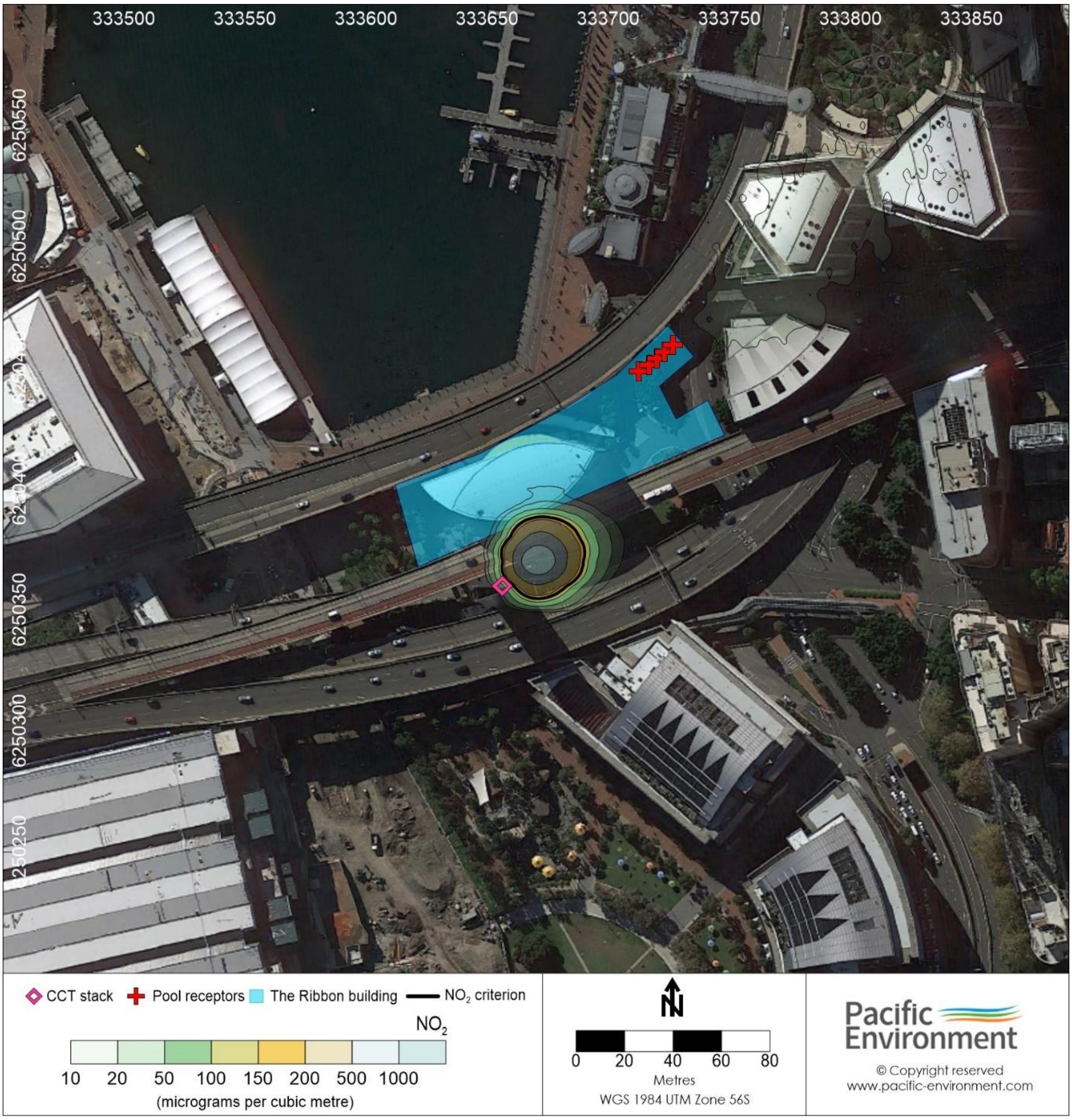

Figure B.8 GRAL NO_2 Predictions at 95 mAHD: Scenario 3a

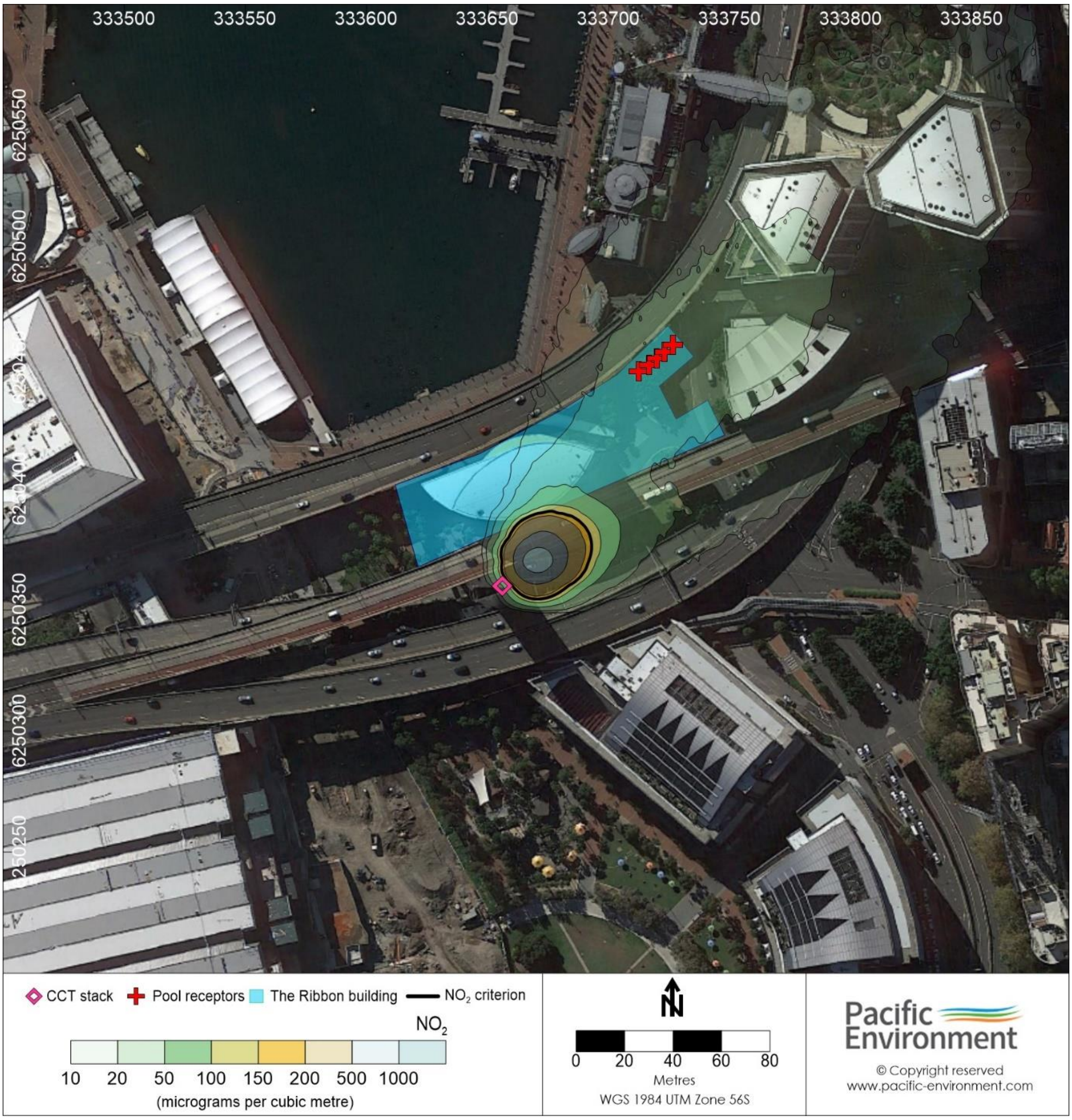

Figure B.9 GRAL NO_2 Predictions at 95 mAHD: Scenario 3b

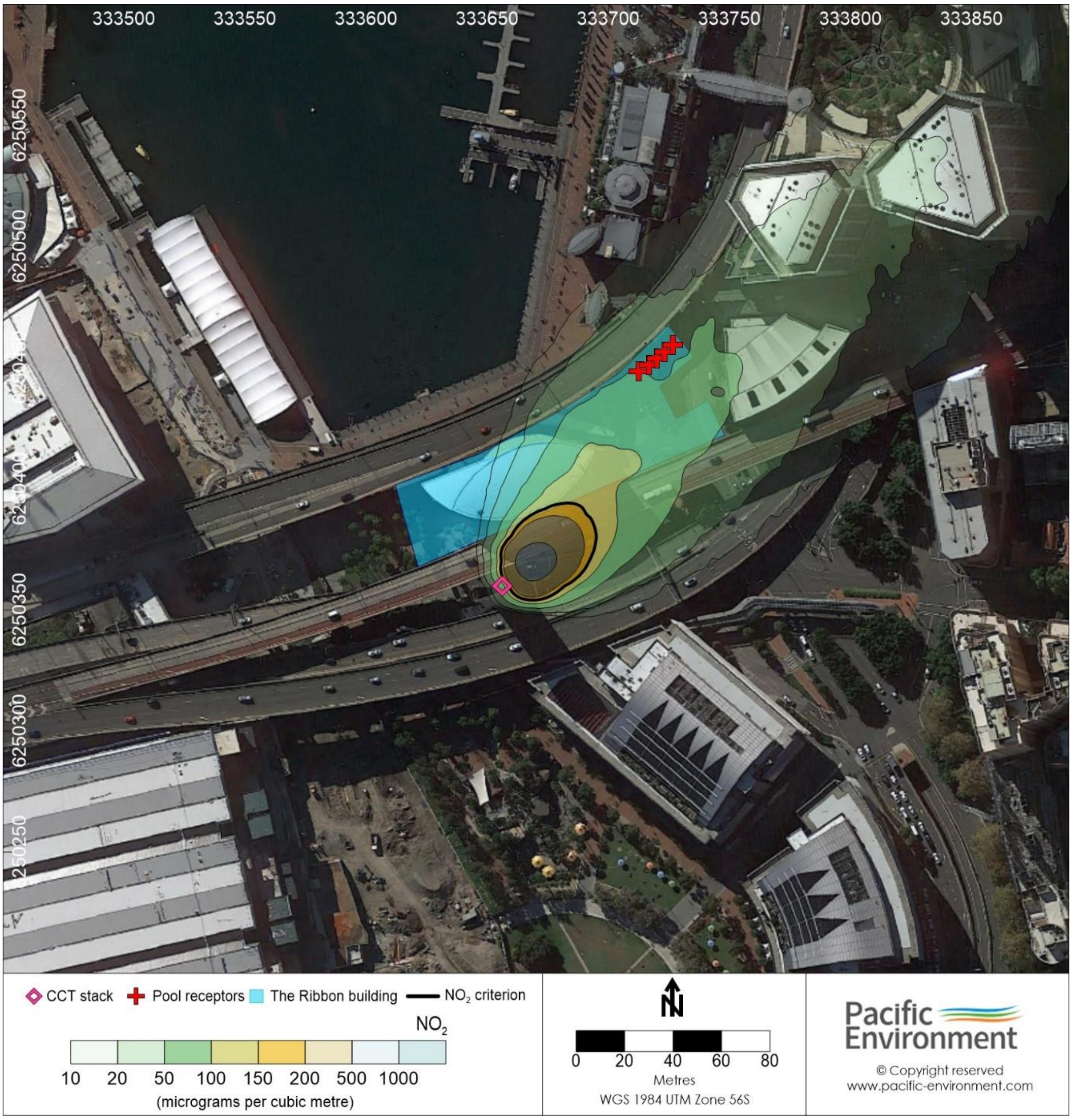

Figure B.10 GRAL NO_2 Predictions at 95 mAHD: Scenario 3c