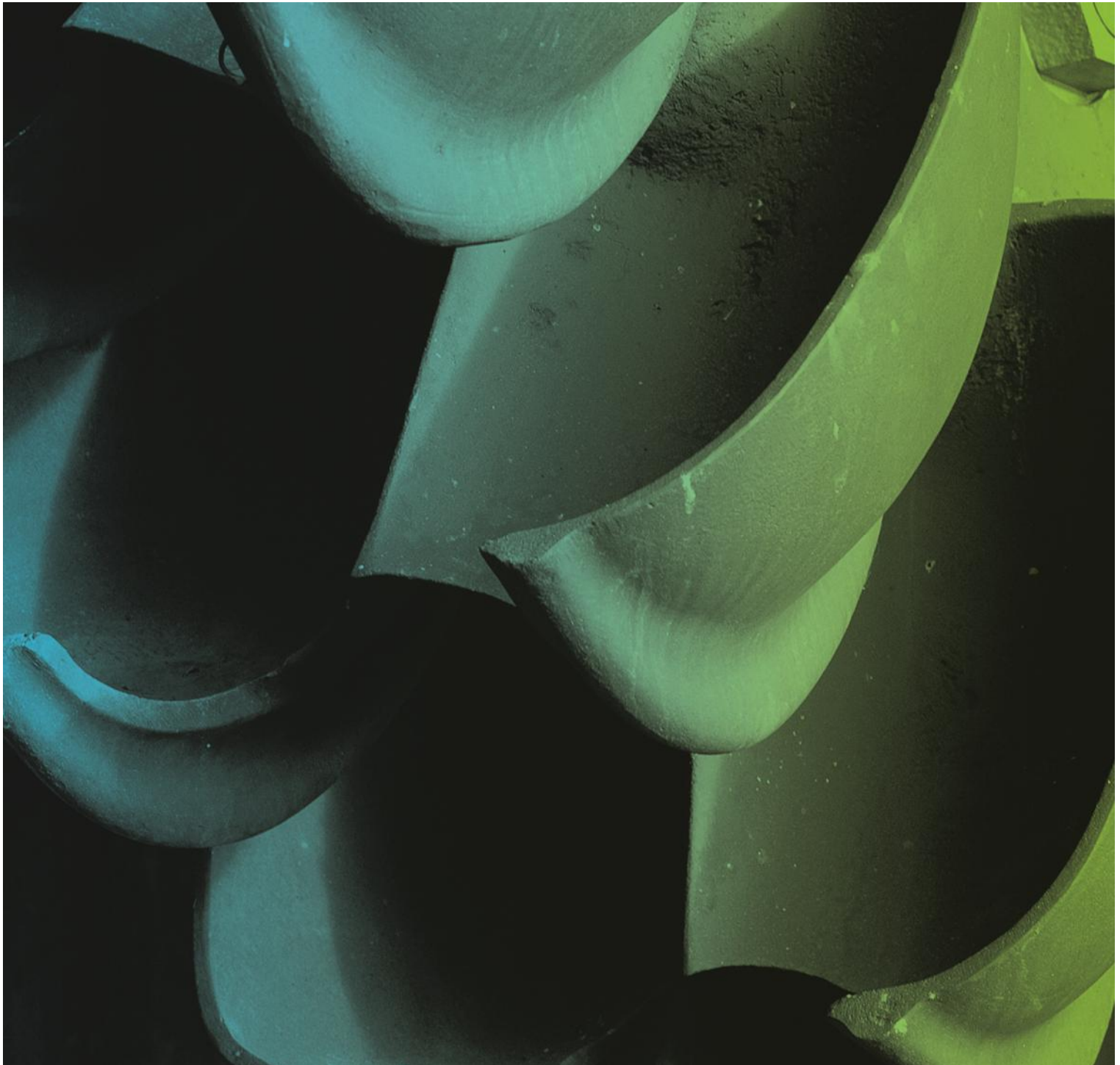


Air Quality Impact Assessment

One Sydney Harbour - Stage 1B Basement - State Significant
Development Application



Air Quality Impact Assessment

One Sydney Harbour - Stage 1B Basement - State Significant Development Application

Client: Lend Lease (Millers Point) Pty Limited

ABN: 15 127 727 502

Prepared by

AECOM Australia Pty Ltd

17 Warabrook Boulevard, Warabrook NSW 2304, PO Box 73, Hunter Region MC NSW 2310, Australia

T +61 2 4911 4900 F +61 2 4911 4999 www.aecom.com

ABN 20 093 846 925

06-Sep-2016

Job No.: 60336060

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Glossary of Terms

Term	Description
BTEX	Benzene, toluene, ethylbenzene and xylenes
DEC	Department of Environment and Conservation
EPA	Environment Protection Authority
EPL	Environment Protection Licence
Lend Lease	Lend Lease (Millers Point) Pty Ltd
NO ₂	Nitrogen dioxide
NO _x	Oxides of nitrogen
OCS	Odour Control Structure
OEH	Office of Environment and Heritage
PM ₁₀	Particulate matter with an average diameter less than 10 micrometres
Site	Area associated with the Stage 1B Development Application. The Site is located on land generally known and identified in the approved Concept Plan MP06_0162 (as modified) as Blocks 4A and 4B and part of the public domain area between those blocks and Block 5.
SSD	State Significant Development
TSP	Total suspended particulates
USEPA	United States Environmental Protection Agency
VOCs	Volatile organic compounds

1.0 Introduction

This Air Quality Impact Assessment (AQIA) report supports a State Significant Development Application (SSD) (SSD 15_6960) which has been submitted by Lend Lease (Millers Point) Pty Limited (Lend Lease) to the Minister for Planning pursuant to Part 4 of the *Environmental Planning and Assessment Act 1979* (EP&A Act). The Development Application (DA) seeks approval for construction of the Stage 1B Basement and associated works at Barangaroo South as described below.

This AQIA has been updated to respond to submissions made by the NSW EPA during public exhibition of the Application.

1.1 Overview of Proposed Development

The Stage 1B Basement DA seeks approval for the construction of a four level basement to accommodate parking and services for the Stage 1B Residential Buildings (subject to separate SSD applications). The works include the construction of common plant and services, loading docks, waste rooms and storage areas, as well as structural cores and associated building services for the Stage 1B Residential Buildings. The proposed development also includes above ground elements such as roads, car park ramps and risers, and temporary public domain and landscaping works.

It is noted that site preparation works, including demolition and remediation, are covered under SSD 5897 (formerly MP10_0026). As such, those works are not addressed in this report.

1.2 Scope of Works

The Secretary's Environmental Assessment Requirements (SEARs) were issued for the project on 2 April 2015. Requirement 6 of the SEARs specified that an AQIA was required which:

- Was prepared in accordance with the Environment Protection Authority's (EPA's) *Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales 2005*;
- Makes appropriate reference to the EPA's *Assessment and Management of Odour from Stationary Sources in New South Wales: Technical Framework 2006* and *Management of Odour from Stationary Sources in New South Wales: Technical Notes 2006*;
- Identifies the pollutants of potential concern (referred to in this assessment as chemicals of potential concern), including individual toxic air pollutants, dust and odours;
- Identifies and assesses all relevant fugitive and point source emissions, including cumulative impacts of the operation of the plant in relation to other construction activities;
- Provides appropriate coverage of all aspects of the development, including construction, excavation, storage and transport;
- Includes proposed air quality management and monitoring procedures during construction; and
- Considers the requirements of the *Protection of the Environment Operations (Clean Air) Regulation 2001*.

This AQIA was prepared to meet the above requirements.

As the basement excavation works will be undertaken over a long period, and will occur concurrently with other aspects of the Stage 1B development, assessment of the highest expected pollutant-generating activity on the site for the entire Stage 1B development was undertaken. Dispersion modelling of the proposed activities was undertaken using the CALPUFF model. The assessment was undertaken in accordance with and/or in reference to the *Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales* (EPA, 2005).

The potential impacts of the proposed works were assessed through the analysis of two scenarios, which represented the expected highest activity levels of all on-site activities that may occur during the Stage 1B Development. Based on staging information provided by Lend Lease, the following concurrent activities are expected to represent the worst-case emissions during the Stage 1B Development works, and were included in the modelling:

- Excavation and handling of spoil for the excavation of the basement for the R5 building;
- Truck movements transporting spoil;

- Excavation and construction of the Stage 1C area;
- Remediation of the Hickson Road area;
- Remediation of the Block 5 area; and
- Operation of the on-site water treatment plant.

Meteorological and terrain files and receptor locations used in the dispersion modelling were the same as those used for the assessment of the Hickson Road remediation works (AECOM, 2016), with a number of additional receptors in the vicinity added to represent:

- potential receptors associated with completed sections of the Stage 1A Barangaroo Development i.e. residential and commercial receptors along the northern edge of the Stage 1A buildings. This included the podium of building T1 and the residential buildings R9 to the southwest of the Stage 1B excavation area;
- An existing childcare centre at the ground floor of the AON building at 201 Kent Street, facing west towards the subject site. This childcare centre has indoor and outdoor areas, with openable windows and doors, and air conditioning.
- A proposed childcare centre at podium level of the commercial building T1 immediately to the south of Basement 1B. This childcare centre is proposed to have indoor and outdoor areas, with openable windows and doors, and air conditioning. It is proposed that during remediation and Basement 1B construction, the outdoor play area will not be used, and windows and doors facing north and east will be kept closed.

Relevant source characteristics used in previous assessments undertaken by AECOM for the Barangaroo South development were used in this assessment for consistency.

While the Stage 1B site is located within a currently contaminated area, remediation works in Block 5, and Stage 1B excavation works. will be undertaken concurrently. Emissions of contaminants, including odour, were not considered likely to occur during the majority of the Stage 1B works (particularly the stage considered in this assessment); as such, emissions of toxic pollutants and odour associated with contaminated soil were not assessed.

This report relates to the development as described in the following drawings:

BB2_PA2_A000	Rev B	Title Sheet
BB2_PA2_A001	Rev B	Aerial Location Plan
BB2_PA2_A002	Rev B	Survey Plan
BB2_PA2_A003	Rev B	Demolition Plan
BB2_PA2_A105	Rev B	BASEMENT PLAN LEVEL B5
BB2_PA2_A100	Rev B	BASEMENT PLAN LEVEL B0
BB2_PA2_A101	Rev B	BASEMENT PLAN LEVEL B1
BB2_PA2_A102	Rev B	BASEMENT PLAN LEVEL B2
BB2_PA2_A103	Rev B	BASEMENT PLAN LEVEL B3
BB2_PA2_A104	Rev B	BASEMENT PLAN LEVEL B4
BB2_PA2_A501	Rev B	BUILDING ELEMENTS - ELEVATIONS
BB2_PA2_A402	Rev B	BUILDING ELEMENTS - PODIUM 2
BB2_PA2_A401	Rev B	BUILDING ELEMENTS - PODIUM 1
BB2_PA2_A400	Rev B	BUILDING ELEMENTS - GROUND FLOOR
BB2_PA2_A303	Rev B	SECTION 04
BB2_PA2_A302	Rev B	SECTION 03
BB2_PA2_A301	Rev B	SECTION 02
BB2_PA2_A300	Rev B	SECTION 01

2.0 Site Description

2.1 Site Location

Barangaroo is located on the north western edge of the Sydney Central Business District (CBD), bounded by Sydney Harbour to the west and north, the historic precinct of Millers Point (for the northern half), The Rocks and the Sydney Harbour Bridge approach to the east, and bounded to the south by a range of new development dominated by large CBD commercial tenants.

The Barangaroo site has been divided into three distinct redevelopment areas (from north to south) – the Barangaroo Reserve, Central Barangaroo and Barangaroo South.

The Stage 1B Basement DA Site area is located within Barangaroo South as shown in **Figure 1** (drawing BB2_PA2_A001). The DA Site is located on land generally known and identified in the approved Concept Plan MP06_0162 (as modified) as Blocks 4A and 4B and part of the public domain area between those blocks and Block 5.

2.2 Role of Lend Lease

Lend Lease was contracted by the Barangaroo Delivery Authority to undertake remediation of portions of the Barangaroo site, and was appointed by the Barangaroo Delivery Authority as the Proponent to undertake the development for Barangaroo South.

2.3 Surrounding Land Use and Receptors

The Site is bordered by Sydney Harbour on the western side and by Hickson Road to the east. The closest off-site receptors are located approximately 25 m to the east of the site boundary, on Hickson Road, and consist of residential and commercial properties. A number of finger wharves containing a mixture of residential and commercial developments are located directly opposite the Site, the closest being approximately 250 m west of the site, while the residential suburb of Balmain East is located approximately 400 m to the west of the northern end of the site.

At the time the Stage 1B basement works are expected to commence, the Stage 1A works are expected to be completed; as such, receptors will also be expected to be located within that area of the Barangaroo site, which is adjacent to the Stage 1B Site. Details of the sensitive receptors considered in this assessment are provided in **Section 5.6**.

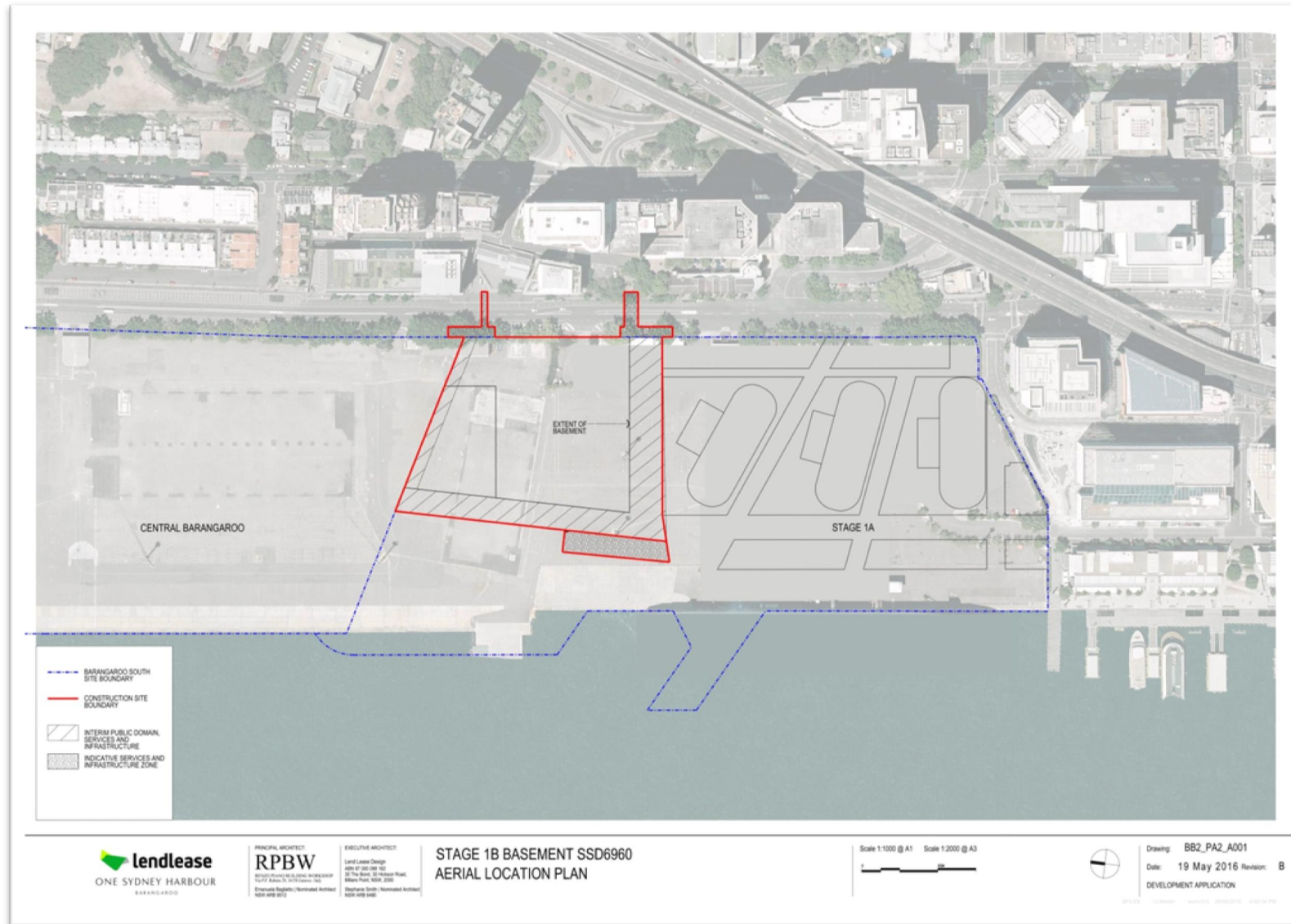


Figure 1 Stage 1B Basement SSD6960 Aerial Location Plan

3.0 Project Description

3.1 Environmental Controls

Due to the scale of the works and proximity to sensitive receptors, the effectiveness of environmental controls and environmental management is critical to the overall success of the project. The EPA recommended that environmental management at Barangaroo should focus on source controls rather than end of pipe controls. Primary management was, therefore, the focus of proposed mitigation strategies; a number of secondary (end of pipe) controls are also recommended where necessary.

3.1.1 Sediment Controls

Sediment can lead to dust generation; as such, management measures for sediment are management measures for air emissions. In accordance with the EPA recommendations, the most effective sediment management measures will be based on source controls. As a contingency for the failure of source controls, a number of secondary controls should be implemented. Relevant primary (source) controls and secondary controls recommended in the *City of Sydney Guidelines to Erosion and Sediment Control on Building Sites* are provided in **Table 1**.

Table 1 Sediment Control Options

Category	Control Device	Location
Source controls	Sediment sumps	Perimeter of excavation area
	Runoff diversion	Perimeter of excavation area and stockpile areas
	Tarping/mulching/gravel armouring	External stockpiles and exposed soils, haulage trucks
Secondary controls	Wheel wash	Site exit
	Shaker grids	Site exit
	Sediment fence	Stormwater inlets, stockpile perimeters
	Sediment sock	Stormwater inlets, stockpile perimeters
	Straw bales	Stormwater inlets, stockpile perimeters

3.1.2 Management of Dust

Excavation and materials handling works generate dust emissions. Such emissions are traditionally managed through standard construction measures, such as watering of material when visible dust is present, and suspending activities during high wind conditions.

3.2 Chemicals of Potential Concern

The proposed works will generate particulate (PM₁₀ and TSP) emissions associated with excavation works, materials handling, and wind erosion of exposed areas and stockpiles. The works will primarily use electrical and diesel-powered plant and equipment. The combustion of diesel fuel generates a range of pollutant emissions, primarily oxides of nitrogen (NO_x) and PM₁₀, as well as volatile organic compounds (VOCs) (particularly benzene, toluene, ethylbenzene, and xylenes, which are known collectively as BTEX). These pollutants were considered in this assessment. The potential health effects of the chemicals of potential interest are summarised in **Appendix A**.

Other emissions, such as carbon monoxide and sulfur dioxide, are also emitted from combustion engines, but were not assessed as they were considered to be lower risk than particulate and NO_x emissions due to their generally higher assessment criteria. While the Stage 1B site is located within a currently contaminated area, the remediation works will be completed before the Stage 1B works commence. Emissions of contaminants other than those listed above, including odour, were not considered likely to occur during the majority of the Stage 1B works (particularly the stage considered in this assessment); as such, emissions of toxic pollutants and odour associated with contaminated soil were not assessed.

3.3 Impact Assessment Criteria

The EPA has specified ground level concentration criteria that are intended to minimise the adverse effects of airborne pollutants on sensitive receptors (DEC, 2005). The ambient air quality criteria for the pollutants considered in this assessment are shown in **Table 2** (combustion products, particulates and air toxics). The EPA does not have a criterion for VOCs; the criteria for the most relevant individual VOC species are presented in the table.

Table 2 EPA Impact Assessment Criteria – Combustion Products, Dust and Soil Contaminants

Pollutant	Averaging Period	Criteria (mg/m ³)
Combustion Products and Dust		
Nitrogen dioxide (NO ₂)	1 hour	246
	Annual	62
Total suspended particulates (TSP)	Annual	90
Fine particulate matter (PM ₁₀)	24 hours	50
	Annual	30
Air Toxics		
Benzene	1 hour	29
Ethylbenzene	1 hour	8,000
Toluene	1 hour	360
Xylenes	1 hour	190

3.4 Potential Emission Sources

Emissions associated with the works assessed in this AQIA can be grouped into four categories: particulate emissions from materials handling/excavation works; particulate emissions from wind erosion; combustion emissions from plant and equipment; and emissions from the water treatment plant. It should be noted that the water treatment plant is part of a separate, already approved, phase of the Barangaroo development. Particulate emissions would be expected to be generated from excavation, truck loading, stockpile loading, crushing and screening works, wheel-generated dust from truck movements, and wind erosion. Combustion emissions would be generated by all fuel-driven equipment, including excavators, front end loaders, bulldozers, bobcats, trucks and generators.

The off-site transport of the excavated material also has the potential to result in air emissions. These emissions were not considered in this assessment. Emissions associated with transport operations will be minimised through the management practices outlined in **Section 7.1**.

Details of plant and equipment expected to be used during the excavation and construction works considered in this assessment were provided by Lend Lease. Further emission source details are provided in **Section 5.4**.

3.5 Indicative Staging

The indicative staging of the Barangaroo works, provided by Lend Lease, is summarised in **Table 3**.

Table 3 Barangaroo Development Staging Summary

Project	Proposed Dates	Overlap with Stage 1B Basement Excavation
Barangaroo Reserve Main Works	Apr 2013 – Jul 2015	No
T2 Commercial Building	May 2013 – Oct 2015	No
Concrete Batch Plant Operation	Sep 2013 – Sep 2015	No
T3 Commercial Building	Oct 2013 – Jun 2016	No
R8/R9 Residential Buildings Construction	Jan 2014 – Nov 2015	No

Project	Proposed Dates	Overlap with Stage 1B Basement Excavation
T1 Commercial Building	Mar 2014 – Sep 2016	No
Central Barangaroo – Waterfront Promenade	Mar 2014 – Jul 2015	No
Stage 1A Public Domain works	Jul 2014 – Mar 2016	No
City Walk Link Bridge	Oct 2014 – Jun 2015	No
R1 Construction	Jul 2016 – Mar 2017	No
Crown Hotel Construction	Jun 2016 – Sept 2020	Yes
Block 5 Remediation Works	Sep 2016 – Mar 2019	Yes
R7 Construction	Dec 2015 – Oct 2016	No
C2/C6 Above GF Only (GF + 6 floors)	Feb 2016 – Apr 2017	No
C1/H2 Above GF Only (GF + 6 floors)	Sep 2017 – Dec 2018	Yes – not significant
Block 4 Remediation Works	May 2016 – Mar 2019	No
Hickson Road Remediation Works	Nov 2016 – Aug 2018	Yes – not significant
Stage 1B Basement (excavation and construction)	Jun 2017 – Mar 2021	-
Wynyard Walk Bridge	Apr 2013 – Sep 2015	No
Barangaroo Ferry Wharf	Feb 2016 – Nov 2016	No
R4A	Dec 2019 – Apr 2022	No
R4B	Jan 2021 – Jan 2023	No
R5	Aug 2021 – Jul 2023	No

This assessment considered the worst-case emissions associated with the Stage 1B Basement Excavation and Construction works, which, based on staging information provided by Lend Lease, were considered to occur between June 2017 and March 2021.

During this period, the concurrently occurring Stage 1B activity would consist of the late stages of the Blocks 4 and 5 remediation activities, rock excavation for the R5 building, construction of the Crown tower (also known as Stage 1C), operation of the water treatment plant; Hickson Road remediation; no other construction activities at the Barangaroo site as a whole were expected to overlap these works.

It is anticipated that Hickson Road remediation would be largely complete when the highest level of emissions from the Stage 1B Development are expected to occur, and hence have not been assessed in this report.

Based on the staging information provided by Lend Lease, the worst-case concurrent activities associated with the Stage 1B Development, which were the activities included in the dispersion modelling, are as follows:

- Excavation and handling of spoil for the excavation of the basement for the R5 building;
- Truck movements transporting spoil;
- Excavation and construction of the Stage 1C area;
- Remediation of the Hickson Road area;
- Remediation of the Block 5 area; and
- Operation of the on-site water treatment plant.

4.0 Existing Environment

4.1 Regional Air Quality

The EPA operates a network of air quality monitoring stations around the state. The closest station to the site is located at Rozelle (approximately 3.5 km to the west). Ambient pollutant concentrations recorded at this station in 2013 were adopted for this assessment for consistency with the meteorological data.

Three exceedances of the EPA's 24 hour PM₁₀ assessment criterion were recorded at Rozelle in 2013, relating to concentrations of 58.5 µg/m³ (the maximum recorded 24 hour PM₁₀ concentration as shown in **Table 4**), 57.0 µg/m³, and 50.7 µg/m³. As such, the cumulative concentrations predicted for this assessment will contain three exceedances due to elevated background concentrations.

Ambient TSP concentrations have not been monitored at Rozelle since 2004. The ratio of PM₁₀ to TSP from Rozelle for 2004 (the last recorded year of TSP monitoring at Rozelle) was used with the ambient annual PM₁₀ concentration from Rozelle in 2008 to estimate the annual TSP concentration. The ratio of PM₁₀ to TSP for 2004 was calculated to be 49 % at Rozelle (i.e. 49 % of TSP in the region monitored by Rozelle was PM₁₀), which, when applied to the 2013 ambient annual PM₁₀ concentration of 18.3 µg/m³, equates to an annual TSP concentration of 37.4 µg/m³. The background concentrations used in the AQIA are summarised in **Table 4**.

Table 4 Ambient Pollutant Concentrations, Rozelle Monitoring Station

Pollutant	Averaging Period	Maximum Background Concentration (µg/m ³)	Assessment Criteria (µg/m ³)
NO ₂ ¹	1 hour maximum	131.6	246
	Annual	21.4	62
PM ₁₀	24 hour maximum	58.5	50
	Annual	18.3	30
TSP ²	Annual	37.4	90
Ozone ³	1 hour maximum	143.1	214
	Annual	33.6	-

¹ NO₂ contemporaneous background data used to predict background concentrations using the OLM detailed in **Section 5.8**.
² Calculated from annual PM₁₀ concentration as described in text.
³ Ozone concentrations used for NO₂ contemporaneous assessment calculations. Ozone was not modelled as a pollutant.

4.2 Climate

The Bureau of Meteorology (BOM) collects meteorological data from various sites in the Sydney Basin. The station at Observatory Hill is less than 200 m from the eastern boundary of the Barangaroo Site, while Fort Denison is approximately 2 km to the east of the site. The meteorological data collected from these two stations is complementary and, together, provides an indication of the climate in the immediate area around Barangaroo. Long term data averages recorded between 1859 and June 2014 are summarised in **Appendix B**.

Average maximum temperatures in summer range from 25.2 °C to 25.9 °C, while minimum temperatures range from 17.5 °C to 18.8 °C. In winter, the average maximum temperature ranges from 16.3 °C to 17.8 °C and the average minimum temperature ranges from 8.0 °C to 9.3 °C. The annual average humidity reading collected at 9 am from the site is 69 %, and at 3 pm the annual average is 57 %. Rainfall data collected at Observatory Hill shows, on average, that the wettest months are January to June, with average rainfall of greater than 100 mm for each of the intervening months.

4.3 Terrain

The Barangaroo Site is located on Sydney Harbour. The ground surface of the entire Barangaroo Site is at an elevation of approximately 2 - 5 m (AHD). The surrounding landform (outside the bounds of the site) rises rapidly to the east, with a 10 m high sandstone cliff situated east of Hickson Road and Sussex Street. This is the most substantial natural terrain feature in the area; high rise buildings may potentially also affect wind patterns in the Site.

5.0 Dispersion Modelling Methodology

5.1 Overview

Dispersion modelling was undertaken to predict the potential effects of the excavation and construction activities associated with the Stage 1B Development occurring during the expected highest period of air emissions. The following sections outline details of the dispersion model used and its inputs (specifically meteorology, terrain, modelling scenarios, source characteristics and emission rates), sensitive receptor locations, and the methodology used in the estimation of pollutant concentrations.

The modelling was conducted in accordance with and/or in consideration of the Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (DEC, 2005).

5.2 Dispersion Model

The CALPUFF dispersion model was used in accordance with the EPA Approved Methods (DEC, 2005). CALPUFF is a non steady-state, three-dimensional Gaussian puff model developed for the US Environmental Protection Agency (USEPA) for use in situations where basic Gaussian plume models are not effective, such as areas with complex meteorological or topographical conditions, including coastal areas with re-circulating sea breezes. Input parameters used in the CALPUFF dispersion modelling are summarised in **Table 5**.

Table 5 CALPUFF Input Parameters

Parameter	Input
CALPUFF version	6.42
Modelling domain	40 km x 40 km with 0.3 km spacing
Terrain data	Included in CALMET
Building wake data	Not included
Dispersion algorithm	Dispersion coeff. Used turbulence computer from micrometeorology. Used PDF Method for sigma-z in the convective BL.
Hours modelled	8760 hours (365 days)
Meteorological data period	1 January 2013 – 31 December 2013

Inputs to CALPUFF are discussed in the following sections.

5.2.1 Meteorology

The CALMET meteorological model uses meteorological observations to generate three dimensional wind fields on an hourly time step at a grid of points covering the area under investigation. Topographical features and land use factors are then used to further refine the wind fields, which are subsequently used in the CALPUFF dispersion model.

Local meteorological and topographical data were used to develop the CALMET wind fields to ensure the data used in the dispersion modelling were representative of local conditions. Prognostic meteorological data generated by the WRF model and the following local meteorological data recorded by the BOM were used as inputs to CALMET:

- Observatory Hill - rainfall and temperature;
- Fort Denison - wind speed and direction; and
- Sydney Airport - wind speed, wind direction, temperature, relative humidity and solar radiation.

The WRF data, which were prepared by Lakes Environmental, were used to define the upper air meteorology for the area surrounding Barangaroo, and were entered into CALMET for the site meteorological conditions together with the surface meteorological data recorded at Sydney Airport, Observatory Hill and Fort Denison. Analyses of the data are provided in **Appendix B**. The WRF data were prepared for a 50 x 50 km grid with a spacing of 4 km for the period 1 January 2013 – 31 December 2013, centred on latitude: 33.8675 S and longitude: 151.13 E with a

WGS datum. The WRF file was prepared with 35 vertical levels; the lowest level was approximately 20 metres above ground level.

5.2.2 Terrain

The NASA Shuttle Radar Topographic Mission (SRTM) provides digital elevation data (DEM) for over 80 % of the globe. The SRTM data are available as 3 arc second DEMs, which provide a resolution of approximately 90 m.

Digital terrain data required by CALMET were obtained from the global SRTM database through the CALPUFF View user interface for the modelling domain.

5.3 Modelling Scenarios

To assess the potential impacts associated with the Stage 1B Basement excavation works, two scenarios were modelled to examine the potential effect of the Stage 1B Basement excavation activities and the various different cumulative activities occurring on the site. The scenarios considered were as follows:

- **Scenario 1** – Stage 1B Excavation in isolation from other Barangaroo developments and background air quality
- **Scenario 2** – All concurrent Barangaroo construction activities and background air quality.

All other activities on the Barangaroo site, including works associated with Barangaroo South and the remediation of Hickson Road (which were addressed in previous assessments), are expected to be completed when the highest level of emissions from the Stage 1B Development are expected to occur and hence have not been assessed in this report.

In addition to the construction activities directly associated with the Basement Excavation and other remediation activities being undertaken by Lend Lease (Block 5 remediation), the Stage 1C Remediation and Bulk Earthworks is expected to occur concurrently for the cumulative modelling scenario. These impacts have been assessed in the report *South Barangaroo Stage 1C Remediation and Earthworks Air Quality Impact Assessment* (Wilkinson Murray 2015). Predicted impacts have been modelled based on the Wilkinson Murray 2015 report have been added to the predicted impacts from Scenario 2 to determine the cumulative impacts from all concurrent activities and are described in **Section 6.1**.

5.3.1 Assumptions

The location and emissions associated with the water treatment plant were assumed to be the same as those used in AECOM (2011) for a water flow rate of 25 L/s.

Emissions from activities such as materials handling were estimated using emission factors and equations in the following National Pollutant Inventory Emission Estimation Technique manuals:

- Australian Government. (2012). National Pollutant Inventory Emission Estimation Technique Manual for Mining, Version 3.1. Commonwealth of Australia: Canberra.
- Australian Government. (2008). National Pollutant Inventory Emission Estimation Technique Manual for Combustion Engines, Version 3.0. Commonwealth of Australia: Canberra.

Emission factors for wheel-generated dust were obtained from US EPA (2011). Additional emission factors for specific construction plant and equipment were sourced from a report on a large construction project (Pacific Institute, 2001), which was accepted by the US EPA and references the South Coast Air Quality Management District (California Environmental Quality Act) Air Quality Handbook. Stack parameters for trucks, which were used in previous assessments (SKM, 2005), were also used for the point sources. Further assumptions are provided in the following sections.

5.4 Source Characteristics

The source characteristics used in the dispersion modelling are described in the following sections. Information regarding the type and number of plant and equipment that would be used in the works, as well as excavation volumes and other operational parameters, was provided by Lend Lease. Except for wind erosion of the soil stockpile and the excavation area, emissions of all sources were assumed to occur between the hours of 7 am and 6 pm; wind erosion was assumed to occur constantly.

Emissions can be grouped into four categories: materials handling/excavation emissions; combustion emissions from plant and equipment; wind erosion emissions; and emissions from the water treatment plant.

5.4.1 Materials Handling/Excavation Sources

The Basement rock excavation works were assumed to be undertaken between 7 am and 6 pm at a rate of 250 m³ of excavation per day. Details of the plant and equipment associated with the works are provided in **Table 6**.

Table 6 Rock Excavation Equipment

Plant/equipment	Number
Excavators/FELs	3 (2 excavators, 1 FELs)
Bulldozer	1
Trucks	27 trips per day

Material excavated from the basement area would be taken by truck directly off-site with no on-site spoil storage or handling.

The source characteristics of trucks assumed for the modelling are shown in **Table 7**.

Table 7 Trucks - Source Information

Activity	On-site Haul Distance (m)	Number of Trucks/Day	Number of Volume Sources Modelled
Basement excavation	250	17	6

5.4.2 Combustion Emissions

At the time the rock excavation for the Basement works will be undertaken, construction of the R4A and R4B buildings will not be underway. On this basis, no forklift or concrete pumping emissions have been assumed.

One generator is expected to be on site as part of these works. The utilisation of this generator is unclear at this point in time but is expected to be used as needed during the day when excavation works are occurring i.e. not used at night. The assumed emission characteristics of this plant are shown in **Table 8**.

Table 8 Generator Source Characteristics (assumed)

Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/s)	Exit Temperature (K)
3	0.5	15	473.15

Trucks would move material directly from the excavation area to offsite disposal areas. The parameters in **Table 9** were used for the truck sources. In the absence of other information, these parameters were also used for the excavator sources at the excavation and soil stockpile areas.

Table 9 Truck and Excavator Emission Characteristics

Parameters	Value	Units
Effective stack height	4	m
Stack diameter	0.1	m
Exhaust gas temperature	349.15	K
Exhaust gas velocity	10	m/s

5.4.3 Wind Erosion

Wind erosion is not expected from the basement excavation due to the depth of the excavation and the blocking effects of the buildings and construction hoarding around the excavation itself.

5.4.4 Block 5

The Block 5 excavations were assumed to be undertaken for 10 hours per day at a rate of 350 tonnes per day. Details of the equipment and stack characteristics are provided in **Table 10** and **Table 11** respectively. The Odour Control Structure (OCS) stack was assumed to be located on the western side of the OCS structure.

Table 10 Block 5 Excavation Equipment

Plant/equipment	Number	Notes
Excavator	3	2 x 30 t; 1 x 20 t
Bulldozer	1	
Front end loader	1	
Skid screen bobcat	1	loader
Powerscreen	1	screen
Trucks	50	trips per day (off site)

Table 11 Block 5 Excavation OCS Stack Characteristics

Details	Value	Units
Tent height	14	m
Stack height	4	m
Velocity	25	m/s
Diameter	0.76	m
Volumetric flow rate	11.2	m ³ /s
Temperature	25	°C

5.4.5 Hickson Road

The Hickson road excavation activities were assumed to be undertaken for 10 hours per day at a rate of 350 tonnes per day. Details of the equipment and stack characteristics are provided in **Table 10** and **Table 11** respectively. The Odour Control Structure (OCS) stack was assumed to be located on the western side of the OCS structure.

Table 12 Hickson Road Excavation Equipment

Plant/equipment	Number	Notes
Excavator	1	
Skid screen bobcat	1	loader
Trucks	33	trips per day (off site)

Table 13 Hickson Road Excavation OCS Stack Characteristics

Details	Value	Units
Tent height	11	m
Stack height	4	m
Velocity	25	m/s
Exit area	0.3	m ²
Diameter	0.64	m
Volumetric flow rate	7.94	m ³ /s
Temperature	25	°C

5.4.6 Water Treatment Plant

The on-site water treatment plant will be operational during the Stage 1B development works. The plant will have two point emission sources: the inlet tank displacement valve and the air strippers discharge stack. Details of these sources are provided in **Table 14**. It should be noted that the modelled emissions are expected to represent emissions during remediation works; at the time the Stage 1B works are undertaken, the contaminant levels in the water fed to the treatment plant are expected to be lower.

Table 14 Water Treatment Plant Stack Characteristics

Source	Stack Height (m)	Diameter (m)	Stack Velocity (m/s)	Exit Temperature (K)
Inlet tank displacement valve	2.77	0.10	3.2	288.75
Air strippers discharge stack	2.77	0.42	8.2	288.75

5.4.7 Stage 1C Remediation and Earthworks

As previously described, dispersion modelling for the remediation, earthworks and construction activities for Stage 1C were previously undertaken (Murray Wilkinson 2015); for information on source characteristics refer to the referenced report.

Predicted impacts modelled in the Stage 1C report have been added to the predicted impacts from Scenario 2 to determine the cumulative impacts from all concurrent activities and are described in **Section 3.5**.

5.5 Emissions

Emissions from the plant and equipment to be used on site were estimated using factors published by the Australian Government for use in the National Pollutant Inventory, measured vehicle emissions from the M5 Freeway Project (SKM, 2002) and emission factors published for a large construction project (Pacific Institute, 2001).

Expected operational times for the construction works are 7 am – 6 pm Monday to Friday and 7 am – 5 pm Saturdays. No works are expected on Sundays. For modelling purposes, emission rates were entered into the model for all activities for the hours 7 am to 6 pm except for wind erosion and the water treatment plant, which were modelled with constant emissions.

5.5.1 Materials Handling/Excavation Sources

The rock excavation works were assumed to be undertaken between 7 am and 6 pm at a rate of 250 m³ of excavation per day. Materials handling emissions from all the plant/equipment within the excavation area were summed and entered into the model as a single area source. This consisted of the crusher and screen emissions, as well as emissions from the excavators and dozers. The same was done for the soil stockpile area, where the sources consisted of the stockpile and excavators. Emissions are shown in the following tables.

Table 15 Emissions – Rock Excavation Materials Handling

Pollutant	Emissions (g/s)
TSP	0.20
PM ₁₀	0.12

For this assessment, trucks were assumed to move excavated material from the rock excavation area directly off-site. Emissions associated with each area were summed and modelled as volume sources. Emission rates associated with wheel-generated dust were calculated using the AP-42 emission factors for paved roads for concrete batching plant published by the US EPA (2011). Haul roads were assumed to be watered, with a 75 % reduction in emissions. Emission factors associated with truck movements are provided in **Table 16**.

Table 16 Wheel-generated Dust Emission Factors

Equipment	Pollutant		Units
	TSP	PM ₁₀	
Emission factor (unsealed road)	2.817	0.776	kg/VKT
Uncontrolled emission rate · Basement to Off-Site Disposal	4.7	1.3	kg/day
Controlled emission rate* · Basement to Off-Site Disposal	0.12	0.03	g/s
*75 % reduction due to watering			

It should be noted that the modelling only assessed truck emissions within the site boundary.

5.5.2 Combustion Emissions

The generator associated with the excavation and soil stockpile areas was assumed to have an engine power of 450 kW and a load factor of 0.5. The emission factors were taken from the National Pollutant Inventory, and represent factors for diesel industrial engines greater than 450 kW.

Table 17 Emissions - Generator

Pollutant	Emission Factor (kg/kWh)	Emissions (g/s)
NO _x	0.0040	0.500
PM ₁₀	0.0002	0.025
VOCs	0.0013	0.163

The *Protection of the Environment (Clean Air) Regulation 2010* general standards of concentration for scheduled premises: general activities and plant would apply to these plant, which are stationary reciprocating internal combustion engines. The relevant Group 6 limits are 50 mg/m³ for solid particles; 450 mg/m³ for NO₂, nitric oxide or both as NO₂ equivalent; and 1140 mg/m³ for VOCs. Using the generator source characteristics from **Table 8**, the modelled emission rates are all well below the allowable Group 6 levels.

Emission factors used for the calculation of emissions from trucks are shown in the following table. These emission rates were applied to all trucks assessed.

Table 18 Emission Factors – Combustion - Trucks

Pollutant	Emissions (g/km)
NO _x *	7.84
PM ₁₀ *	0.52
VOCs **	0.72
*Source: SKM. (2002). M5 East Freeway Sub-Regional Air Quality Management Plan - rigid truck (diesel) emissions	
** Source: NPI for Combustion Engines V3 2008, Table 21; diesel vehicle exhaust emissions (HGV), applying an assumed fuel usage value of 40L/100km	

5.5.3 Block 5

Details of the emission rates for the Block 5 excavation OCS are provided in **Table 19**.

Table 19 Treatment Tent Stack Emission Rates

Pollutant	Total Emission Rates	
	Before filtration	After filtration
NO _x (g/s)	2.74	0.69
PM ₁₀ (g/s)	0.49	0.010
TSP (g/s)	1.54	0.031
VOCs combustion emissions (g/s)	0.27	0.00054
Benzene	0.0490	0.00010
Ethylbenzene	0.038	0.00008
Toluene	0.0700	0.00014
Total xylenes	0.16	0.00031

Truck emissions were apportioned to four volume sources. The emission rates per volume source associated with the Block 5 are provided in Table 20.

Table 20 Block 5 Truck Emissions

Pollutant	Emissions Rates (g/s/source)
NO _x	0.00022
PM ₁₀	0.000015
TSP	0.000015
VOC	0.00002

5.5.4 Hickson Road

Details of the emission rates for the Hickson Road excavation OCS are provided in **Table 19**.

Table 21 Treatment Tent Stack Emission Rates

Pollutant	Total Emission Rates	
	Before filtration	After filtration
NO _x (g/s)	1.16	0.29
PM ₁₀ (g/s)	0.16	0.03
TSP (g/s)	0.51	0.01
Odour (OU/s)	17,220	34.4
VOCs combustion emissions (g/s)	3.26	0.0007
Benzene (g/s)	0.05	0.00010
Ethylbenzene (g/s)	0.04	0.00008
Toluene (g/s)	0.07	0.00014
Total xylenes (g/s)	0.16	0.0003
Naphthalene (g/s)	3.28	0.007
Phenol (g/s)	0.18	0.0004
* Peak to mean ratio of 2.3 applied to odour emissions		

5.5.5 Water Treatment Plant

Emission rates as provided in AECOM (2011) for the two associated WTP point sources are provided in **Table 22**.

Table 22 Water Treatment Plant Emission Rates

Pollutant	Emission Rate (g/s)	
	Inlet tank displacement valve	Air strippers discharge stack
Benzene	0.0010	0.009
Toluene	0.0004	0.004
Ethylbenzene	0.0001	0.001
Xylenes	0.0002	0.001

The emission rates correspond to a stripping efficiency of 99 % and a water flow rate of 25 L/s.

The water treatment plant will emit volatile organic compounds; as there will be no combustion associated with those emissions, however, the emissions are not addressed in the *Protection of the Environment (Clean Air) Regulation 2010*. Naphthalene, another pollutant that may be emitted from the water treatment plant, is similarly not addressed in that regulation.

5.6 Reactive Mitigation

The environmental management of the Barangaroo construction site includes the operation of a real-time air quality management system. This system monitors real-time particulate levels and provides alerts and alarms for site environmental personnel when particulate levels reach levels that are of concern.

This type of system is not typically included in dispersion modelling calculations (which is considered to be another layer of conservatism of the modelling), however it also results in predictions that may unrealistically conservative. As the Barangaroo monitoring system is well established and has been operating successfully throughout excavation and construction activities since 2011, the inclusion of the reactive plan and its influence on the modelling results is considered reasonable.

The methodology adopted for the use of a reactive mitigation scheme is as follows:

- Dispersion modelling was undertaken as previously described in **Section 5.5**.
- The results for the top ten receptors were extracted on an hourly basis from the dispersion model for each receptor for PM₁₀ concentrations.
- For each day of the modelling year the following methodology was applied:
 - No changes in concentration were applied for hours outside of the project operating hours i.e. predictions were unchanged between 5pm in the afternoon and 7am the following morning.
 - Hourly concentrations between 7am and 5pm were analysed to examine the change in concentration between the modelled hours (this approach was adopted as the aim is to prevent the accumulation of dust concentrations during the day leading to a potential exceedance by tracking the change in dust concentration between hours). The change in dust concentration (not the absolute hourly dust concentration) was assessed in accordance with the following trigger values:
 - § **Tier 1 Mitigation Trigger:** If the change in concentration (DC) from hour to hour is greater than 50ng/m³ but less than 100 ng/m³, then mitigation measures will be implemented to halve the emission rates¹.
 - § **Tier 2 Mitigation Trigger:** If the change in concentration (DC) is greater than 100ng/m³, then excavation operations will be assumed to have been shut down, reducing the site emissions for the following hour to zero). The operation on site will resume provided the next hourly concentration does not trigger the above change in concentration levels again and when

¹ The halving of the emission rates will occur as will be defined as part of the site environmental management plan.

concentrations fall below the "Investigate" site concentration trigger limits previously adopted for the site (refer Section 7.2) mitigation measures will be implemented to halve the emission rates².

- § **Tier 3 Mitigation Trigger:** If the Tier 2 mitigation trigger is triggered twice in a single day, then it is highly likely that there are conditions conducive to poor dispersion and high dust loads and as such, full production is not recommended. Under these conditions, the site will only re-start at half of the operational capacity (equivalent to Tier 1 mitigation).

An example calculation has been provided below:

Day 207 (26 Jul 2013) modelling predictions and mitigated concentrations based on the trigger levels and the associated emissions reductions are shown in **Table 2**. The critical points to note from the example data are as follows:

- For hours 0 – 6 (midnight till 6am) and hours 17 – 23 (5pm until midnight) predictions were low, corresponding to site shutdown period with zero emissions (refer **column e**).
- For hour 7, the change in the dust concentration between those hours and the previous hours' concentrations was greater than $100\mu\text{g}/\text{m}^3$ (**Tier 2 Mitigation trigger**) hence the site would need to cease for hour 8 to allow concentrations to fall to acceptable levels (as per for those periods to allow the dust concentration to reduce to levels less likely to result in 24 hour exceedance of criteria).
- For hour 9, the change in the dust concentration between those hours and the previous hours' concentrations was greater than $100\mu\text{g}/\text{m}^3$ (**Tier 2 Mitigation trigger**) hence the site would need to cease for hour 10 to allow concentrations to fall to acceptable levels (as per for those periods to allow the dust concentration to reduce to levels less likely to result in 24 hour exceedance of criteria).
- For this particular day, there are two or more exceedances of the Tier 2 trigger and as such the site will only re-start at half capacity after the second shut-down period.
- Hours 11, 13 and 15 all exceeded the concentration increase trigger resulting in shutdowns for hours 12, 14, and 16.
- In summary, for the example day provided below, the data showed the following:
 - Hours 7, 9, 11, 13 and 15 all had predicted concentrations at this particular receptor that triggered the Tier 2 mitigation response for the subsequent hour (100% reduction in emissions through reduction in on-site activities);
 - Hours 11, 13 and 15 require 50% reduction in emissions through reduction in throughput and on-site activities;
 - Operational Hour 17 required no reduction in emissions and operations could proceed at full capacity.
 - Cumulative 24 Hour Concentration reduced from the predicted $137.0\text{mg}/\text{m}^3$ (**column g**) to $50.3\text{mg}/\text{m}^3$ (**column i**) following the application of the reactive measures. This corresponds to a cumulative concentration of $73.5\text{mg}/\text{m}^3$.

² How the halving of the emission rates will occur will be defined as part of the site environmental management plan.

Table 23 Worked Example of Application of Modelling Use of Reactive Mitigation

Year	Hour of Day	Background Conc.	Predicted Conc.	Mitigated Conc.	Cumulative Predicted Conc.	Cumulative Mitigated Conc.	Hourly Mitigated Cumulative Conc.
a	b	c	e	f	g	h	i
2013	0	23.4	0	0	0	0	23.4
2013	1	30.8	0	0	0	0	30.8
2013	2	24.8	0	0	0	0	24.8
2013	3	19.7	0	0	0	0	19.7
2013	4	19.3	0	0	0	0	19.3
2013	5	17.8	0	0	0	0	17.8
2013	6	18.1	0	0	0	0	18.1
2013	7	15.9	321	321.0	321	321	336.9
2013	8	13.9	354.2	0.0	675.2	321	13.9
2013	9	16.5	102.9	102.9	778.1	423.9	119.4
2013	10	17.5	366.9	0.0	1145	423.9	17.5
2013	11	17.2	165	82.5	1310	506.4	99.7
2013	12	10	20.5	10.3	1330.5	516.65	20.25
2013	13	17.8	35	17.5	1365.5	534.15	35.3
2013	14	16.5	76	38.0	1441.5	572.15	54.5
2013	15	16.7	41	20.5	1482.5	592.65	37.2
2013	16	19.7	87	43.5	1569.5	636.15	63.2
2013	17	37.4	1.2	0.6	1570.7	636.75	38
2013	18	39.2	0.2	0.2	1570.9	636.95	39.4
2013	19	27.9	0	0	1570.9	636.95	27.9
2013	20	41	0	0	1570.9	636.95	41
2013	21	38.6	0	0	1570.9	636.95	38.6
2013	22	29.6	0	0	1570.9	636.95	29.6
2013	23	27.8	0	0	1570.9	636.95	27.8
Cumulative 24 hour Average (mg/m3)					65.5	26.5	49.8
	Yellow Shading denotes the hours for which Tier 1 Mitigation need to be applied						
	Yellow Shading denotes the hours for which Tier 2 Mitigation need to be applied						

5.7 Sensitive Receptors

The EPA considers sensitive receptors to be areas where people are likely to either live or work, or engage in recreational activities (DEC, 2005a). The receptors assessed in this report were selected to be the most representative sensitive receptors in proximity to the proposed works. A total of 111 receptors were assessed, which were primarily located along the eastern side of Hickson Road at various heights, with some located specifically on the site boundary. The receptor locations are shown in **Figure 2** and are detailed in **Appendix C**.

It should be noted that some of the buildings in Stage 1A of the Barangaroo project will be occupied at the time the Stage 1B works commence; these receptors were modelled in this assessment including:

- Sensitive receptors within the T1 commercial tower, with receptors included at ground level and open balconies located on levels 18 and 32;
- Proposed childcare centre to be located within the T1 podium;
- Sensitive receptors at ground level and various heights within the R8 and R9 residential towers; and
- New operational childcare centre located within the AON podium.

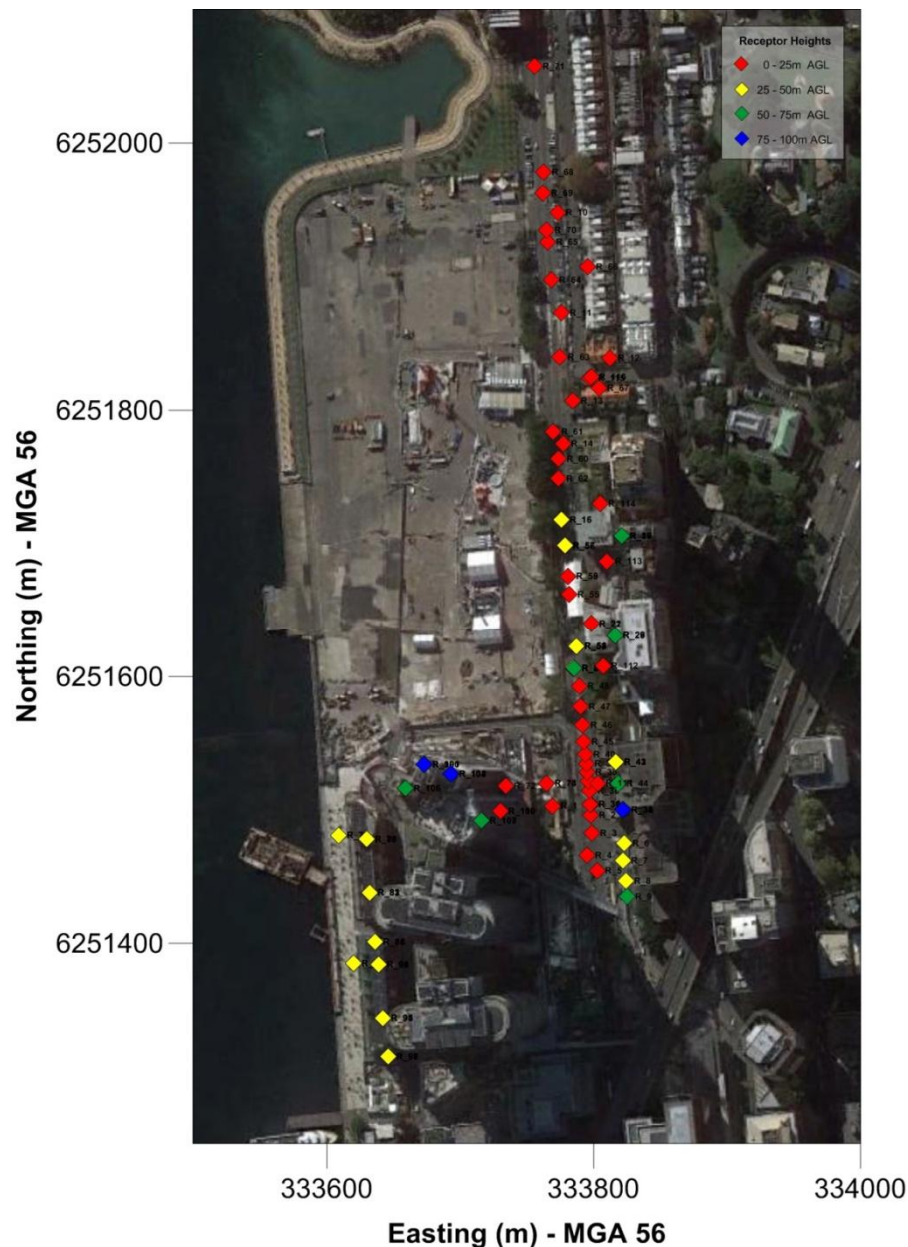


Figure 2 Sensitive Receptor Locations – Site Boundary

5.8 Prediction of Cumulative Impacts

For NO₂, PM₁₀ and TSP, DEC (2005) specifies that AQIAs are to assess the cumulative impacts of a proposal against their impact assessment criteria. This involves adding existing background pollutant levels and expected pollutant levels from other concurrent developments to maximum pollutant concentrations of these pollutants predicted by dispersion modelling.

The cumulative assessment comprised the addition of the maximum measured data described in **Section 4.1** (assumed ambient pollutant concentrations) for TSP to predicted pollutant concentrations, and comparison of the results to the relevant criteria. For this assessment, all the Barangaroo works expected to occur concurrently during the period of greatest expected air emissions were included in the dispersion modelling.

Pollutant concentrations associated with the concurrent Stage 1B development works, including the operation of the water treatment plant, were included in the dispersion model. No other works associated with the Barangaroo development are expected to occur at the same time as these works. No other potential development in the area that might occur at the same time was known at the time of preparation of this assessment.

5.9 Conversion of NO_x to NO₂

Nitrogen oxides are produced in most combustion processes and are formed during the oxidation of nitrogen in fuel and nitrogen in the air. During high-temperature processes, a variety of oxides are formed including nitric oxide (NO) and NO₂. NO will generally comprise 95 % of the NO_x by volume at the point of emission. The remaining NO_x will consist of NO₂. Ultimately, however, all nitric oxides emitted into the atmosphere are oxidised to NO₂ and then further to other higher oxides of nitrogen.

The USEPA's Ozone Limiting Method (OLM) was used to predict ground-level concentrations of 1 hour NO₂. The OLM is based on the assumption that approximately 10 % of the initial NO_x emissions are emitted as NO₂. If the ozone (O₃) concentration is greater than 90 % of the predicted NO_x concentrations, all the NO_x is assumed to be converted to NO₂, otherwise NO₂ concentrations are predicted using the equation $NO_2 = 46/48 * O_3 + 0.1 * NO_x$. This method assumes instant conversion of NO to NO₂ in the plume, which overestimates concentrations close to the source since conversion usually occurs over periods of hours. This method is described in detail in DEC (2005a). Background O₃ data from the Rozelle monitoring station (refer to **Section 4.1**) were used to convert the modelled NO₂ concentrations in accordance with the EPA approved OLM (Method 2, Level 2 Assessment; DEC, 2005a).

6.0 Results

The results of the dispersion modelling are shown in **Table 24**. The results show:

- The maximum project contribution from the Stage 1b Basement Excavation works (Scenario 1);
- The cumulative pollutant concentrations from Scenario 2 which include:
 - Block 5 remediation works; and
 - Operation of the water treatment plant.
- The cumulative pollutant concentrations from Scenario 2 and background concentrations; and
- The cumulative pollutant concentrations from Scenario 2, background concentrations, and maximum predicted project contributions from remediation, excavation and construction of Stage 1C.

6.1 Modelling Predictions

The results of the dispersion modelling are shown in **Table 24**.

The results show the total cumulative pollutant concentrations of the excavation of the Stage 1B basement area, operation of the Block 5 and Hickson Road remediation activities and operation of the on-site water treatment plant. In addition, the emissions from the Stage 1C excavation and earthworks activities have been added to the predictions.

The highest project contributions (pollutant concentrations associated with the Stage 1B project only) predicted at any sensitive receptor assessed are shown as Scenario 1 results. These contributions represent the 100th percentile for NO₂, PM₁₀ and TSP and the 99.9th percentile for benzene, ethylbenzene, toluene and xylenes. Overall site concentrations, representing the Stage 1B excavation along with the other excavation and remediation based activities operating at the same time as Stage 1B have been presented as Scenario 2. Cumulative pollutant concentrations, which represent the project contribution, other Barangaroo excavation and remediation activities plus the background pollutant concentrations, are provided for NO₂, PM₁₀ and TSP as required by the EPA. For TSP, the ambient concentration was estimated from the PM₁₀ concentration as described in **Section 4.1**.

The EPA criteria for air toxics apply at and beyond the boundary of the facility. The concentrations reported below represent the highest 99.9th percentile concentrations for any sensitive receptor assessed, which include receptors located on the boundary and the Barangaroo Stage 1A receptors.

As shown, exceedances of the EPA criteria were predicted to occur for 1 hour NO₂, 24 hour and annual PM₁₀, and annual TSP. These exceedances are at the closest sensitive receptors situated to the south and east of the Stage 1B area.

A number of conservative assumptions were implemented in the modelling, including the location of the sources in the south-eastern corner of the excavation area (which will produce worst case results, assumption that the plant would be operating for at least 80% of the time between the hours of 7 am to 6 pm, every day of the year. This assumption is likely to lead to overestimates of annual predictions, particularly as this level of concurrent work is only expected to occur for a three month period.

In addition to the conservative assumptions made for the modelling, the degree to which restrictions would occur on emission flow from a pit surrounded by hoarding and wind limiting structures cannot be adequately accounted for. As a result, it is expected that the actual emissions from the site would be much lower than the concentrations predicted by the model.

Monitoring at the construction boundary is expected to be able to be used to minimise any adverse impacts through the reactive management of those emissions.

Table 24 Dispersion Modelling Results

Pollutant	Averaging Period	Units	Maximum Predicted Contribution	Cumulative Concentration (Stage 1b Basement Excavation plus additional activities)		Criteria
			Stage 1B Basement Excavation [#]	Block 5, Hickson Rd & WTP (Scenario 2)	Scenario 2 & Background	
NO ₂	Max 1 hour average	ng/m ³	296	326	365	246
	Annual average	ng/m ³	20.3	27.3	47.5	62
PM ₁₀	Max 24 hour average	ng/m ³	57.8	64.3	79.6	50
	Additional Exceedances ¹	-	1	5	48	-
	Annual average	ng/m ³	15.8	19.0	34.8	30
TSP	Annual average	ng/m ³	56.0	64.0	102	90
Benzene	99.9 th 1 hour	ng/m ³	0.0	6.96	N/A	29
Toluene	99.9 th 1 hour	ng/m ³	0.0	0.90	N/A	8,000
Ethylbenzene	99.9 th 1 hour	ng/m ³	0.0	3.62	N/A	360
Xylenes	99.9 th 1 hour	ng/m ³	0.0	0.99	N/A	190
* Maximum cumulative concentration calculated contemporaneously [#] Does not include background concentration. Exceedances denoted in bold type. ¹ Additional 24 hour average exceedances are counted at each discrete receptor location i.e. no receptor has more additional exceedances than those outlined in the table above for the relevant scenario.						

Results of the assessment indicate that the Stage 1b operations may result in limited exceedances of the PM₁₀ and NO₂ criteria at sensitive receptors. Despite these potential exceedances, adverse impacts are not expected to occur due to the following reasons:

- Conservatism of the modelling (as discussed above).
- Air quality management plan implementation is expected to be more effective than can be accounted for in the dispersion modelling e.g. visual observations of dust generation leading to additional mitigation activities are one of the most effective means of dust minimisation, but cannot be readily included in the dispersion modelling calculations.
- The assessment assumes the operation over a full year. It would be expected that the project would not operate on this basis i.e. there would be days when excavation levels are low, weekends, and periods of down time for maintenances etc. All of these factors would be expected to decrease the annual average concentration predicted and may reduce the number of short term impacts.

Despite these mitigating factors, there are predicted exceedances and additional analysis should be undertaken to further understand the concentration predicted. The following section further analyses the PM₁₀ and NO₂ concentrations as these are the pollutants of primary concern due to their potential concentrations.

Further reduction of the emissions can occur through the application of mitigation measures and work reductions. Further mitigation measures associated with the reduction in work practices have been outlined in **Section 7.0**.

PM₁₀ Exceedance Analysis

As outlined in **Table 24**, there are the potential for exceedances of the PM₁₀ criteria as a result of the Stage 1B excavation activities. The exceedances are expected to be due to a combination of proximity of the receptors to the boundary of the facility and the conservatism inherent to the emission factors used in the assessment. Additional analysis has been undertaken to further examine the predicted number of days in the year that exceedances are predicted and when those exceedances may occur.

The receptor with the highest predicted 24 hour PM₁₀ concentration was extracted from the model (Receptor 72, located immediately to south of the Stage 1B SE corner, on the newly constructed Stage 1A area) and the daily cumulative PM₁₀ predictions (including all concurrent construction and remediation activities) ranked based on concentration. A plot showing the maximum concentration down to the lowest concentrations predicted are shown in **Figure 3**.

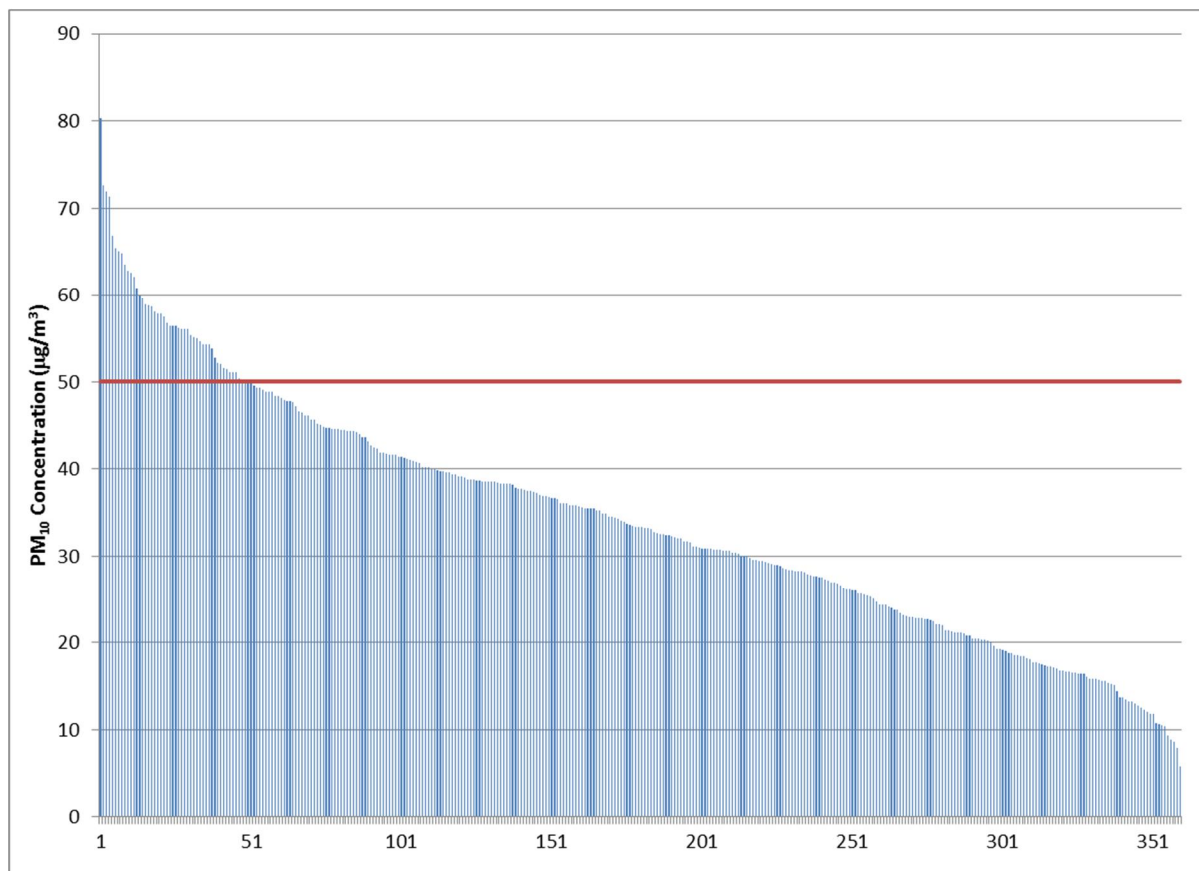


Figure 3 PM₁₀ cumulative concentrations ranked and plotted over the full modelling period

Results show that although there are predicted exceedances during the year, the overall number of exceedances and the overall concentrations predicted are low with the large majority of the cumulative PM₁₀ concentrations falling well below the assessment criteria.

As part of the dispersion modelling process, predictions for the hourly PM₁₀ concentration were made. Although these concentrations cannot be directly compared with the assessment criteria, they can be analysed to see whether any particular time of day produces worse concentrations than others. On this basis, an analysis of the predicted concentrations for time of day was undertaken to examine whether there were any trends that could be used to further refine the mitigation measures. A box and whisker plot for the hour PM₁₀ concentration is shown in **Figure 4**. Results show that the highest concentrations occur typically during the morning period and drop throughout the day with the lowest concentrations typically occurring during the late afternoon. This trend suggests that mitigation measures targeted at preventing generation of particulates in the morning hours would enable the most effective minimisation of particulate emissions.

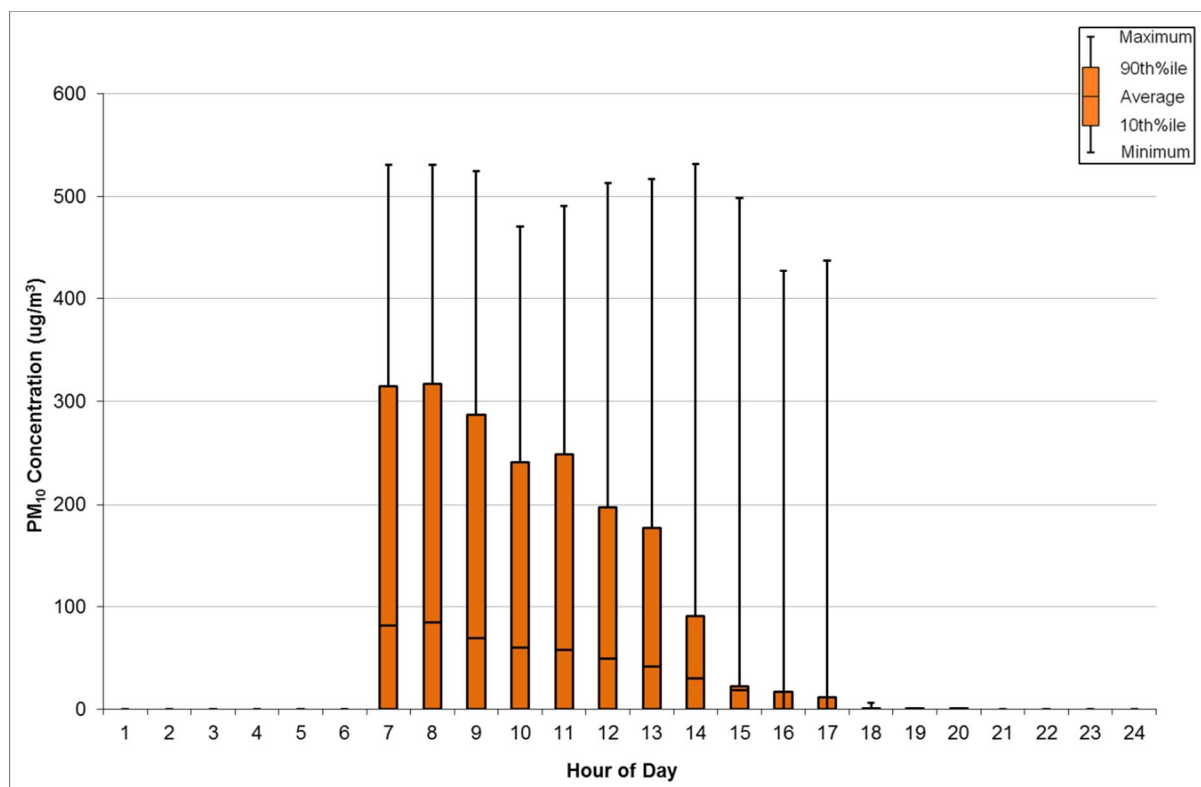


Figure 4 PM₁₀ concentrations examined for time of day

NO₂ Concentrations

As outlined in **Table 24**, there are the potential for exceedances of the NO₂ criteria. Although it is expected that these exceedances are due more to conservatism than the expectation that exceedances will occur, additional analysis has been undertaken to examine the predicted number of hours in the year that exceedances are predicted and when those exceedances may occur.

The receptor with the highest predicted NO₂ concentration was extracted from the model (Receptor 46, located immediately to west of the Stage 1B SE corner) and the hourly cumulative NO₂ predictions ranked based on concentration. A plot showing the maximum concentration down to the lowest concentrations predicted are shown in **Figure 5**.

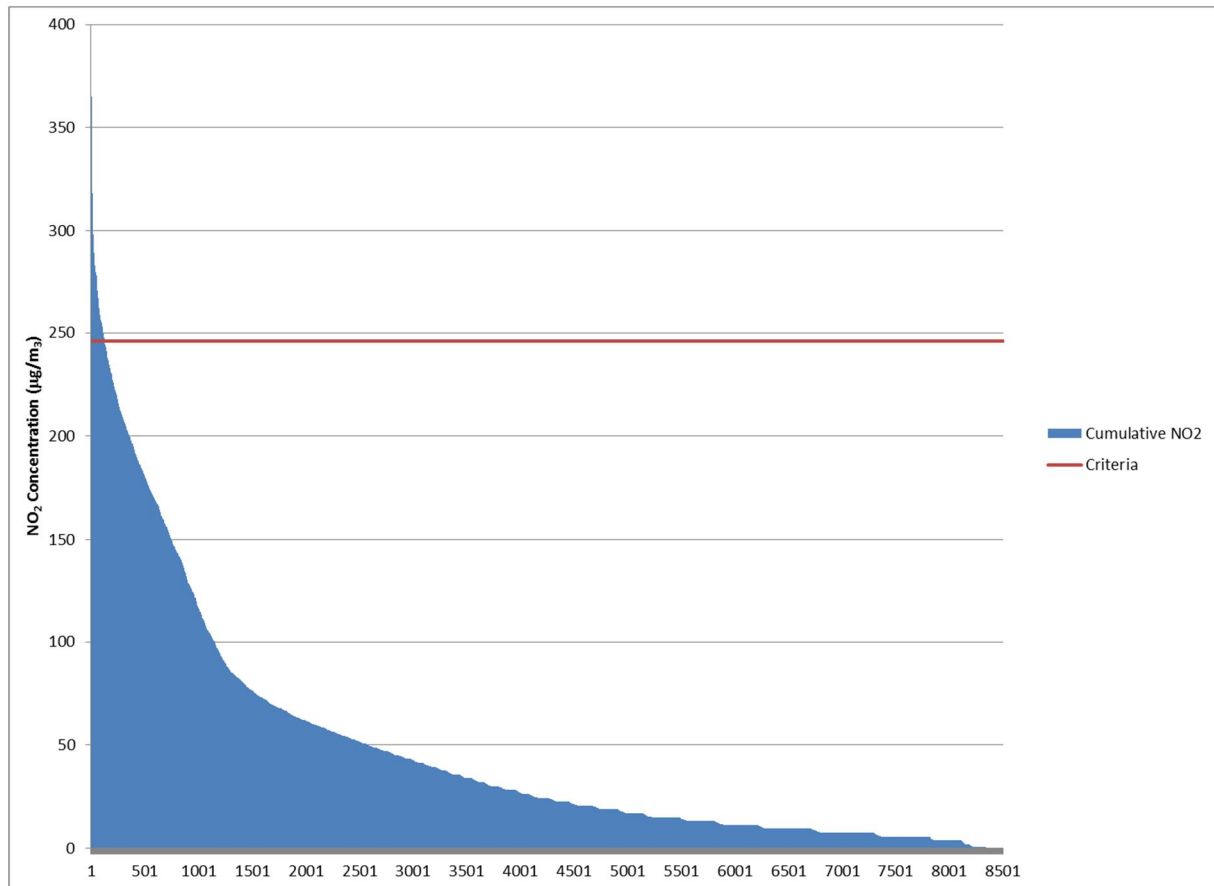


Figure 5 NO₂ concentrations ranked and plotted over the full modelling period

Results show that although there are predicted exceedances during the year, the overall number of exceedances and the overall concentrations predicted are low with the vast majority of the cumulative NO₂ concentrations falling well below the assessment criteria.

In addition to the absolute number of exceedances predicted, additional analysis was undertaken to examine the time of day of the exceedances occurring due to the Stage 1B modelling. Results of the analysis have been presented in terms of a Box and Whisker Plot (refer **Figure 6**). This plot shows that the majority of the NO₂ concentrations are low with elevated concentrations spread throughout the day.

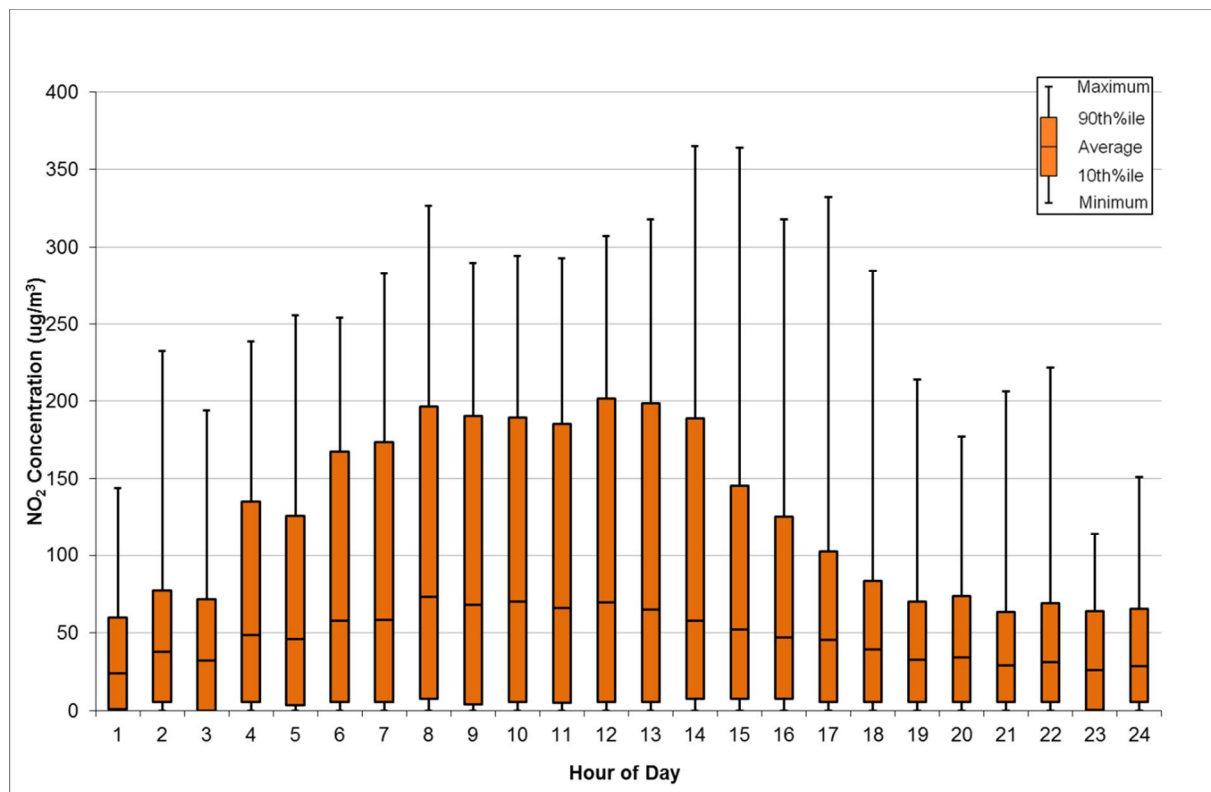


Figure 6 NO₂ cumulative concentrations examined for time of day

The results of the NO₂ modelling expressed as a time of day are shown in **Figure 6**. These results represent the cumulative full site operations and show that there is a definite trend of NO₂ concentration increases during the early hours of the day followed by a reduction late in the day after the site closes. No clear trend enabling additional NO₂ mitigation was able to be extracted from this plot. Given the expected lower than full utilisation of the on-site equipment, additional limitation on equipment use is not considered to be a useful mitigation measure.

An additional consideration is the reactive dust mitigation activities and the expected variable use of the onsite equipment that would also be generating NO_x emissions on top of the dust emissions. The reactive mitigation used to control the dust emissions and potential impacts of the particulates would also be expected to decrease the NO_x emissions through the reduction in the activities on the site. These reductions have not been included but would serve to reduce the emissions on the site.

6.2 Limitations

Best efforts were made to estimate the likely numbers, operational parameters (including operational hours and handling volumes) and emissions of plant and equipment in the AQIA. The numbers used were based on information available from Lend Lease at the time of preparation of this report, and may change to reflect the detailed design of the remediation activities.

If major changes are proposed to pollutant emitting activities during the excavation works, further modelling may be required to assess the effects of those changes on local air quality.

7.0 Recommended Air Quality Management and Mitigation

7.1 Mitigation Measures

Mitigation measures will be implemented proactively, based on the reactive management program, and taking into account the nature of the works being undertaken on site at any time. The proposed mitigation measures are listed below.

- Mains power will be used where available and suitable.
- The dust and meteorological monitoring program will be continued as per Stage 1B remediation works.
- Vehicle engines will be turned off while parked on site.
- Vehicular access will be confined to designated access roads. Haul road lengths will be minimised, and site speed limits will be implemented.
- Construction and ongoing maintenance of a wheel wash facility for vehicles exiting site
- Equipment, plant and machinery will be appropriately tuned, modified or maintained to minimise visible smoke and emissions.
- If odorous material is encountered, control measures, such as covering exposed soil or using odour suppressants, would be used. Exposed areas will be minimised as much as practical.
- Loads will not be overfilled and will be covered during transport.
- Good housekeeping practices will be implemented to minimise dust on hardstand areas.
- Spills will be immediately cleaned up.
- The complaints management system will be maintained.
- Work practices will be adjusted (as required) based on wind observations and real time monitoring results.
- Water sprays at a frequency of at least once per hour during operational periods, including:
 - directional water sprays and mist units will be used at bulk excavation and spoil handing points to minimise particulate generation.
 - water sprays will be used on stockpile areas, disturbed areas and haul routes (at a rate that exceeds 2 L/m²/hr).
 - water sprays on dry excavations where particulate generation is excessive.
- Windbreak barriers will be erected at the site boundary / around exposed sides of stockpiles.
- Exposed surfaces and roads will be watered as required.
- Visual surveillance of site work activities to address point source dust generating activities in real time. Monitor and adjust work activities depending of key metrological (wind conditions).
- Close coordination with other Barangaroo construction projects to address cumulative air quality issues and implement best practice and consistent mitigation measures across the Barangaroo South precinct.

These measures are intended to reduce risks to human health and nuisance impacts.

The proposed monitoring works should be undertaken for the duration of the Stage 1B basement excavation works.

The mitigation measures, contingency measures and monitoring works will be consistent with the requirements of Environment Protection Licence 13336, which would be varied following the granting of project approval for the proposed development works.

7.2 Contingency Measures

When monitoring systems continuously measure pollutant concentrations, an early warning system based on trigger levels can be used to minimise adverse impacts on the environment. The trigger levels are generally set below a relevant assessment criterion.

A reactive management plan was developed for the site, based on a three-stage approach:

- *Investigate*: Identification of likely reasons for elevated pollutant concentrations and formulation of a response;
- *Action*: Implementation of the measures formulated in the investigative stage and review of their effectiveness; and
- *Stop Work*: Air polluting works should stop at this stage until the measured pollutant levels are below the action level to avoid an exceedance of the pollutant criterion.

The reactive management procedure for PM₁₀ is provided in Table 23.

The two trigger levels are based on:

- Modelled hourly PM₁₀ concentrations, and applying reactive measures to hourly change in concentrations, to minimise the emissions in an effort to reduce ground level concentration to below the 24 hour and annual EPA criteria.
- Hourly PM₁₀ concentrations likely to cause an exceedance of the 24 hour EPA criteria.

Table 25 Reactive Management Procedure – PM₁₀

Reactive Management Procedure (PM ₁₀)				
Trigger Stage	Change in conc. trigger (hourly)	Actual value trigger (hourly)	Other trigger	Action Required
1 Investigate	-	85 ng/m ³	-	- Environmental Manager to undertake review of possible dust sources operating during the hourly period. - Identify possible measures to reduce dust emissions based on Section 7.1; action if deemed necessary.
2 Action	50 ng/m ³	470 ng/m ³	Visual dust at site perimeter	- Targeted shut down or additional mitigation of dust-generating activities to achieve a 50% reduction in emissions, until the measured pollutant levels are below the relevant trigger value. - Increase in frequency of water application. - Effectiveness of control actions in Section 7.1 to be reviewed and escalate where appropriate. Identify long-term solutions to dust issues. - Complete Lend Lease Environmental Response Form.
3 Stop Work	100 ng/m ³	940 ng/m ³	Visual dust at site perimeter	- Targeted shut down of all dust-generating activities until the measured pollutant levels are below the relevant trigger value, or until favourable meteorological conditions. - Complete Lend Lease Environmental Response Form.

Notwithstanding the requirements of the Reactive Management Procedure, any exceedance of the air quality criteria as identified by other air quality monitoring would require a review of mitigation measures provided in the AQMP and associated work methods. The findings of the review shall be incorporated into the appropriate notification to the EPA and/or the Monthly Report.

Calculation of the above trigger level values is based around the objective of remaining below the $50\text{ng}/\text{m}^3$, 24 hour average PM_{10} concentration at the monitoring location.

1 Hour Average Trigger Values

For the 1 hour average trigger levels, the total of all 1 hour average concentrations throughout the day i.e. sum of individual 1 hour concentrations, needs to fall below $1200\text{ng}/\text{m}^3$ ($50\text{ng}/\text{m}^3 \times 24$ hourly results = $1200\text{ng}/\text{m}^3$). On this basis the trigger levels have been set based around the daily summing of individual hourly concentrations to ensure that they do not exceed $1200\text{ng}/\text{m}^3$. The process for calculating the 1 hour trigger levels is discussed below.

The non-operational PM_{10} concentration is equal to approximately $20\text{ng}/\text{m}^3$ (based on results from existing monitoring location). Assuming an 11 hour operational day, and therefore 13 non-operational hours, the maximum daily sum of 1 hour average concentrations is calculated as follows:

- Daily 1 hour average maximum total = $1200\text{ng}/\text{m}^3 - 13 \times 20\text{ng}/\text{m}^3 = 940\text{ng}/\text{m}^3$

Over the working day, therefore, the 1 hour average concentration should stay below the following value:

- Alert Value = $940\text{ng}/\text{m}^3 / 11 \text{ hours} = 85\text{ng}/\text{m}^3$

In regards to the Action trigger value, the objective is to have a value which aims to prevent exceedance of the criteria due to two 1 hour averaging periods. As calculated above, the daily value which the sum of the hourly concentration need to fall below is $940\text{ng}/\text{m}^3$. To ensure this value is not exceeded in a two hour period, the Action trigger value is as follows:

- Action Trigger Value = $940\text{ng}/\text{m}^3 / 2 \text{ hours} = 470\text{ng}/\text{m}^3$

The shutdown criterion represents a concentration whereby the daily assessment criteria would likely be exceeded if this value is exceeded. On this basis, the shutdown value is simply equal to the daily allowed total. On this basis, the Shutdown trigger value is as follows:

- Shutdown Trigger Value = $940\text{ng}/\text{m}^3$

7.3 Air Quality Monitoring Program

Ambient air quality monitoring around the Barangaroo site has been undertaken since October 2011 in accordance with the Air Quality Management Plan and EPL for the site. The monitoring has the following objectives:

- Allow a real time assessment of the various activities on the site, which can then be related back to operational changes to reduce off-site impacts;
- Allow reactive dust mitigation measures to be implemented based on real time monitoring data;
- If required, review of the reactive trigger levels and management strategies to reduce exceedances that may occur during the stage 1B excavation activities.

The monitoring is undertaken generally in accordance with the following guidelines and Australian Standards:

- The EPA's *Approved Methods for Sampling and Analysis of Air Pollutants in New South Wales* (DEC, 2005a);
- AS/NZS 3580.9.3:2015 *Methods for sampling and analysis of ambient air - Determination of suspended particulate matter - Total suspended particulate matter (TSP) - High volume sampler gravimetric method*;
- AS 3580.9.8:2008 *Methods for sampling and analysis of ambient air - Determination of suspended particulate matter - PM_{10} continuous direct mass method using a tapered element oscillating microbalance analyser*;
- AS3580.14: 2014 *Methods for sampling and analysis of ambient air - Guide to siting air monitoring equipment*; and

- AS 2923-1987 *Ambient air - Guide for measurement of horizontal wind for air quality applications*.

Details of the relevant monitoring equipment and locations are provided in **Table 26** and **Figure 7**. These monitoring plans vary depending on the types of work undertaken. The works are always carried out in accordance with the site's EPL.

The Air Quality Management Plan for the works would include the following information:

- the implementation of best available control technology and best environmental practice to ensure emissions are being reduced to the maximum extent achievable for all air pollutant generating activities;
- an ambient air monitoring program and reactive management strategy, including real-time meteorological monitoring and particulate monitoring for management purposes, fit for purpose odour monitoring, and the implementation of appropriate triggers to further develop the reactive management strategy for air pollution mitigation;
- details of all air quality emission control measures including:
 - timeframe for implementation of all identified emission controls;
 - monitoring method(s), including location, frequency and duration;
 - response mechanisms;
 - responsibilities for demonstrating and reporting achievement of EPA guidelines and EPL requirements;
 - record keeping and complaints response register; and
 - compliance reporting.

Table 26 Ambient Monitoring Agenda

Parameter	Equipment	Frequency	Locations	EPA Criteria	Sampling Method	Timing
TSP	HVAS	24 hours every 6 days	EPL points 4, 6	90 µg/m ³ as an annual average	AM-15 AS 3580.9.3:2015	Throughout basement excavation*
PM ₁₀	TEOM Aeroqual Dust Sentry	Continuous	EPL point 4 EPL points 5, 6	50 µg/m ³ as a 24 hour average** 30 µg/m ³ as an annual average	AM-22, AS 3580.9.8-2008 Aeroqual method	Throughout basement excavation*
VOC (speciated)	Summa	As needed	As needed	***	USEPA TO-15	Throughout basement excavation*
Met station	-	Continuous	EPL point 4	Site complies with <i>Approved Methods</i>	AM-4 AS3580.14 - 2014	Throughout basement excavation*
* Or as agreed with the EPA ** 24 hour average of a calendar day defined as midnight to midnight. *** Too many criteria to list; criteria based on DEC (2005a)						



Figure 7 Approximate Barangaroo South Monitoring Locations

8.0 Conclusion

AECOM undertook an air quality impact assessment of the proposed Stage 1B Basement works. As the basement excavation works will be undertaken over a long period, and will occur concurrently with other aspects of the Stage 1B development, assessment of the highest expected pollutant-generating activity on the site for the entire Stage 1B development was undertaken.

The potential impacts of the proposed works were assessed through the analysis of a single scenario, which represented the expected highest activity levels of all on-site activities that may occur during the Stage 1B Development. Based on staging information provided by Lend Lease, the following concurrent activities are expected to represent the worst-case emissions during the Stage 1B Development works, and were included in the modelling:

- Rock excavation of the basement for the R5 building;
- Remediation of the Block 5 area;
- Remediation of the Hickson Road area;
- Excavation and construction at the Stage 1C area; and
- Operation of the on-site water treatment plant;

Exceedances of the criteria for NO₂, PM₁₀ and TSP were predicted to occur. The exceedances are primarily a result of the proposed excavation activities close to the site boundary and, subsequently, close to receptors. The closest receptor where concentrations are predicted to exceed the criteria were situated to the south of 38 Hickson Road and to the south of the Stage 1B area in the newly constructed Stage1A area (receptors were approximately 30m from the construction site boundary). Emissions from these activities may require mitigation above that incorporated into typical dispersion modelling, which are included in **Section 7.0**. The additional mitigation that is recommended is included in the Reactive Management Procedure described in **Section 5.6**.

Lend Lease operates a reactive dust mitigation system at the Barangaroo South site, which is directly linked to real-time warnings and incorporates work procedures to ensure that action is taken to reduce dust levels when they are elevated and at risk of exceeding acceptable air pollution levels. The system has been operational on the Barangaroo South site since 2011, and will operate throughout the duration of the Stage 1B remediation and excavation works.

Lend Lease uses its air quality monitoring network and its operational procedures to ensure site emissions are mitigated to an appropriate level and that adverse impacts (i.e. exceedances of ambient air quality criteria) are minimised at sensitive receptor locations as a result of site operations.

Lend Lease has demonstrated that it can undertake significant materials handling activities with substantial plant and equipment numbers on site while minimising emissions through this reactive management and monitoring system.

9.0 References

- AECOM. (2011). Air Quality Impact Assessment – Water Treatment Plant, Barangaroo South.
- AECOM. (2010). Air Quality Impact Assessment – Barangaroo Site Excavation and Preparation Works.
- Australian Government. (2012). National Pollutant Inventory Emission Estimation Technique Manual for Mining, Version 3.1. Commonwealth of Australia: Canberra.
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, 41(1), pp 298 – 301.
- Pacific Institute (2001) The Cadiz Valley Groundwater Storage Project;
http://www.pacinst.org/reports/cadiz/feir/volumes/vol1/appendix/v1a_c1.pdf
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- US EPA. (2011). Emission factor Documentation for AP-42, Section 13.2.1 – Paved Roads.

Appendix A

Chemicals of Potential Interest

Appendix A Chemicals of Potential Interest

For the purposes of this AQIA, pollutants of interest were defined as pollutants most likely to be generated by the proposed excavation and construction works, which were:

- Nitrogen dioxide (NO₂);
- Particulate matter (PM₁₀ and TSP); and
- VOCs.

The potential health effects of the pollutants of interest are summarised below. Details were obtained from the National Pollutant Inventory (NPI, 2010) unless otherwise specified.

Nitrogen Dioxide

Nitrogen dioxide (NO₂) is a brownish gas with a pungent odour. It exists in the atmosphere in equilibrium with nitric oxide. The mixture of these two gases is commonly referred to as NO_x. NO_x is a product of combustion processes. In urban areas, motor vehicles and industrial combustion processes are the major sources of ambient NO_x. NO₂ can cause damage to the human respiratory tract, increasing a person's susceptibility to respiratory infections and asthma. NO₂ can also cause damage to plants, especially in the presence of other pollutants such as ozone and sulfur dioxide. NO_x are also primary ingredients in the reactions that lead to photochemical smog formation.

Particulate Matter

Suspended particulate matter may be emitted from site via combustion activities (i.e. vehicle and plant operations) and site preparation, excavation and remediation works.

Airborne particles are commonly differentiated according to size based on their equivalent aerodynamic diameter. Particles with a diameter of less than or equal to 50 micrometres (µm) are collectively referred to as total suspended particulates (TSP). TSP primarily causes aesthetic impacts associated with settling on surfaces, which also causes soiling and discolouration. Uncontrolled emissions of these large particles, however, can cause some irritation of mucosal membranes and can increase health risks from ingestion if contaminated. Particles with diameters less than or equal to 10 µm (known as PM₁₀ or fine particles) tend to remain suspended in the air for longer periods than larger particles, and can penetrate into human lungs.

Exposure to particulate matter has been linked to a variety of health effects, including respiratory problems (such as coughing, aggravated asthma and chronic bronchitis) and non-fatal heart attacks.

VOCs

Organic compounds with a vapour pressure at 20 °C exceeding 0.13 kPa are referred to as VOCs. VOCs have been implicated as a major precursor in the production of photochemical smog, which causes atmospheric haze, eye irritation and respiratory problems. VOC emissions are typical for oil processing, petrochemical and chemical plants and include emissions from point sources (storage tanks and filling stations vents) and fugitive emissions from pipelines and process equipment leaks. A variety of VOCs were detected at the site, which may be released during the proposed activities.

BTEX

BTEX are a category of volatile organic compounds (VOCs). VOCs are organic compounds with a vapour pressure at 20 °C exceeding 0.13 kPa. These compounds have been implicated as a precursor in the production of photochemical smog, which may cause atmospheric haze, eye irritation and respiratory effects. VOC emissions are typical for oil processing, petrochemical and chemical plants and include emissions from point sources (storage tanks and filling stations vents) and fugitive emissions from pipelines and process equipment leaks.

Benzene

Benzene is an airborne substance that can be washed out of the air by rain, and evaporated into the air. It will decompose in soil or water when oxygen is present. Benzene exposure commonly occurs through inhalation of air containing the substance. It can also enter the body through the skin, although it is poorly absorbed this way. Low levels of benzene exposure may result from tobacco smoke and car exhaust.

Benzene is considered to be a toxic health hazard and a carcinogen. Human exposure to very high levels for even brief periods of time can potentially result in death. Lower level exposure can cause skin and eye irritation,

drowsiness, dizziness, headaches and vomiting, and over longer periods damage to the immune system, leukaemia and birth defects.

Toluene

Toluene (methylbenzene) is a highly volatile chemical that quickly evaporates to a gas if released as a liquid. After a few days, the substance breaks down in air into chemicals that are harmful to human health. Bacteria in soil and water also break down toluene. Due to relatively fast degradation, toluene emissions are typically confined to the local area in which it is emitted. Toluene is a component of petrol and paints, and is also found in tobacco smoke. Human exposure typically occurs through breathing contaminated air, but toluene can also be ingested or absorbed through the skin (in liquid form). Toluene usually leaves the body within twelve hours.

Short-term exposure to high levels of toluene can cause dizziness, sleepiness, unconsciousness and sometimes death. Long-term exposure can cause kidney damage and permanent brain damage that can lead to speech, vision and hearing problems, as well as loss of muscle and memory functions.

Ethylbenzene

Ethylbenzene is a highly volatile substance, so is typically present in air. Ethylbenzene rapidly enters the body through the lungs and digestive tract. The substance has both acute and chronic toxic effects on animals and plants, including shortened lifespan, reproductive problems and behaviour changes. Exposure to high concentrations can cause dizziness, paralysis, breathing difficulties and death. Chronic health effects in humans can last for months or years. Ethylbenzene is present in petroleum, pesticides, cleaning products and solvents.

Xylenes

Xylenes are flammable liquids that are moderately soluble in water. They are quickly degraded by sunlight when released to air, and rapidly evaporate when released to soil or water. They are used as solvents and in petrol and chemical manufacturing.

Xylenes can enter the body through inhalation or skin absorption (liquid form), and can cause irritation of the eyes and nose, stomach problems, memory and concentration problems, nausea and dizziness. Excessively high-level exposure can cause death.

Appendix B

Climate Averages and Meteorological Analyses

Appendix B Climate Averages and Meteorological Analyses

Average climate data recorded at the Observatory Hill meteorological station between 1859 and 2014 are shown in the following table. These data are summarised in **Section 4.2**.

Average Climate Data – Observatory Hill, 1859 – 2014 (June)

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average temperature													
Maximum (°C)	25.9	26	24.7	22.4	19.4	16.9	16	18	20	22	24	25	21.7
Minimum (°C)	18.7	19	17.6	14.7	11.5	9.3	8	9	11	14	16	18	13.8
Rainfall													
Mean rainfall (mm)	101	118	130	127	120	132	98	80	68	77	84	77	1213
Average 9 am conditions													
Temperature (°C)	22.5	22	21.1	18.2	14.6	11.9	11	13	16	19	20	22	17.5
Relative humidity (%)	71	74	74	72	74	74	71	66	62	61	66	67	69
Wind speed (km/h)	8.6	8.2	7.9	8.8	10.5	11.9	13	13	12	12	11	9.8	10.6
3 pm conditions													
Temperature (°C)	24.8	25	24	22	19.4	16.9	16	18	19	21	22	24	21
Relative humidity (%)	62	64	62	59	57	57	51	49	51	56	58	59	57
Wind speed (km/h)	17.9	17	15.2	13.8	12.7	13.6	15	18	18	19	19	20	16.6

The following discusses the meteorological data from the CALMET data file for the year 2013 in terms of wind speed and wind direction.

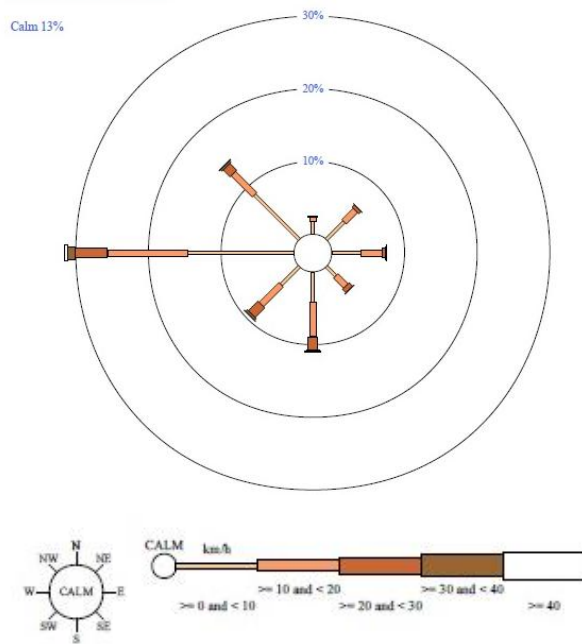
The Bureau of Meteorology (BoM) operates a network of meteorological monitoring stations around the country. The closest station to the site that measures long-term parameters is located at Observatory Hill, Sydney, approximately 200 m northeast of the Site and is considered a good representation of the regional climate.

Wind Rose

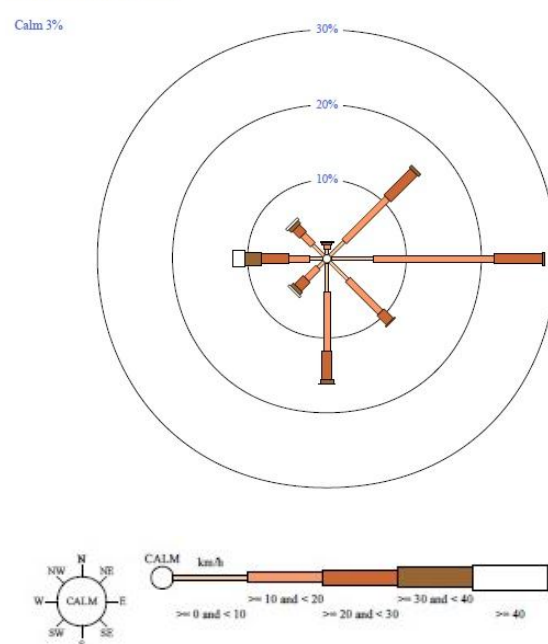
Wind speed and direction are important variables in dispersion modelling, as they dictate the direction and distance pollutant plumes travel. A comparison of wind roses from the meteorological data used in the dispersion modelling and the data from Observatory Hill was conducted. The 9 am and 3 pm wind roses for each data source are shown in the table below. The 9 am data sets were comparable in wind direction, although the prognostic data, as expected, predicted fewer calm periods than the historical measured data (1.4% vs 13 %). The prognostic wind speeds were lower than the measured wind speeds. At 3 pm, again, the wind directions were similar, with a high proportion of winds from the northeast. The proportion of calm periods (0.82% vs 3%) and wind speeds were again higher in the measured data set.

9 am
13502 Total Observations

Calm 13%

3 pm
13347 Total Observations

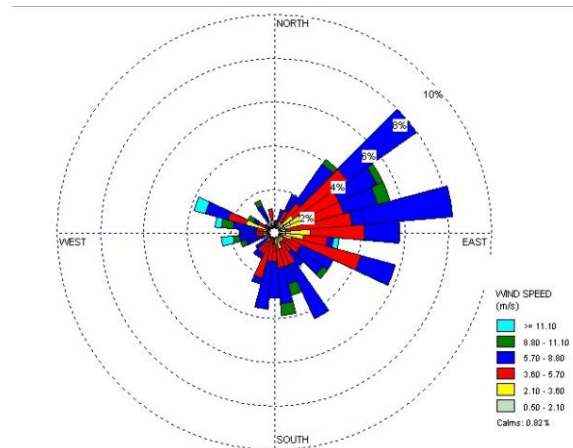
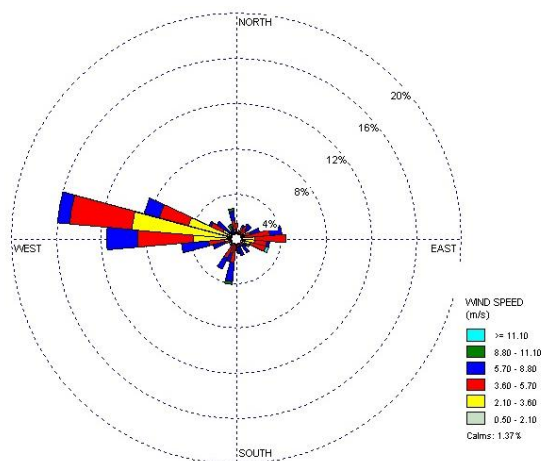
Calm 3%



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Prepared by National Climate Centre of the Bureau of Meteorology.
Contact us by phone on (03) 0050 4082, by fax on (03) 0050 4515, or by email on climate.data@bom.gov.au
We have taken all due care but cannot provide any warranty nor accept any liability for this information.

9 am wind rose – Observatory Hill (1955 – 1992)

3 pm wind rose – Observatory Hill (1955 – 1992)



9 am wind rose – CALMET, 2013

3 pm wind rose – CALMET, 2013

Wind Speed

The frequency distribution of hourly averaged wind speed values from the 2013 CALMET data generated for the assessment is shown in **Figure B1**. As shown, wind speeds in the area are medium strength, with speeds between 2 and 9 m/s occurring for around 80% of the time. The average wind speed is 4.2 m/s and the maximum wind speed is 15 m/s. Given the relative coastal location of the station, the high percentage of strong winds is expected.

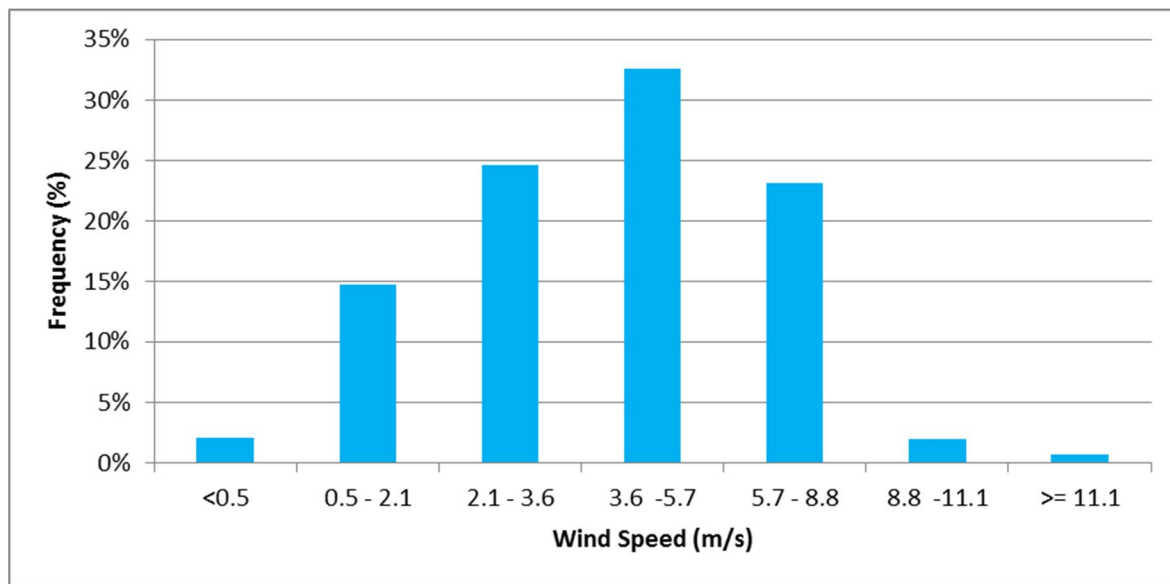


Figure B1 Frequency Distribution of Wind Speed – Barangaroo CALMET 2013

Figure B2 shows the distribution of average wind speeds by hour of day. Higher wind speeds tend to occur during the daytime between 10 am and 7 pm, with a peak around 2 pm. This is a typical diurnal pattern.

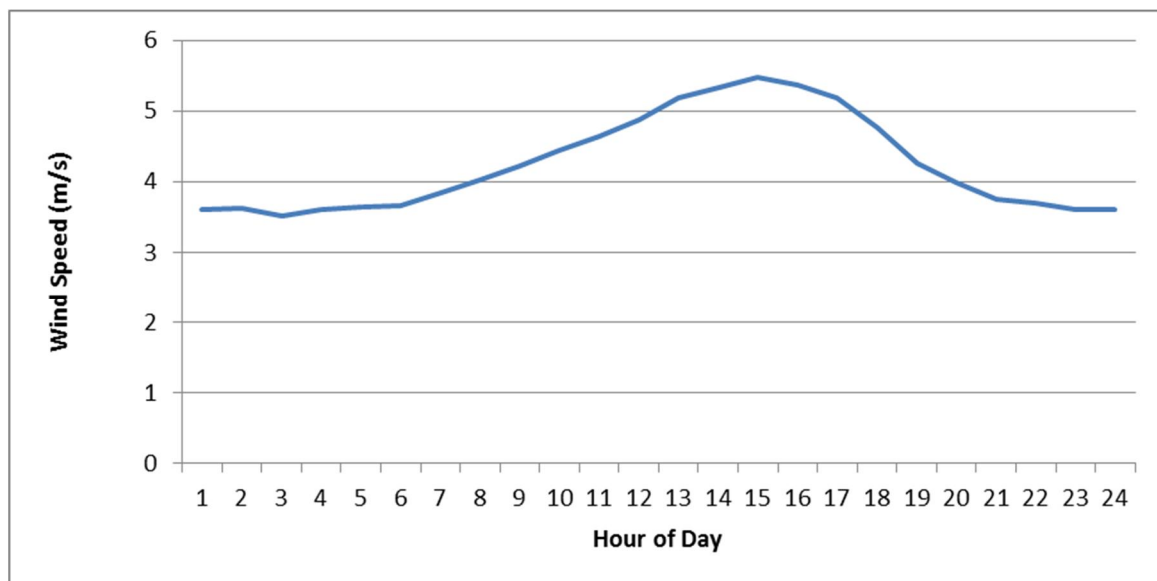


Figure B2 Wind Speed by Hour of Day – Barangaroo CALMET 2013

Appendix C

Sensitive Receptor Locations

Appendix C Sensitive Receptor Locations

The coordinates and heights of the sensitive receptors included in the dispersion modelling are provided below.

Sensitive Receptors

Receptor ID	Coordinates		Base Elevation (m)	Flagpole Height (m)	Description
	X (m)	Y (m)			
ID_Receptor	X (m)	Y (m)	Base_Elevation (m)	Flagpole_Height (m)	Description
R_1	333769	6251503	25	0	
R_2	333798	6251496	28	18	
R_3	333799	6251483	28	0	
R_4	333795	6251466	27	0	
R_5	333802	6251454	28	0	
R_6	333823	6251475	32	25	
R_7	333822	6251462	33	25	
R_8	333824	6251447	33	48	
R_9	333825	6251435	33	50	
R_10	333773	6251948	14	0	Preschool
R_11	333776	6251873	12	0	
R_12	333812	6251839	19	0	
R_13	333784	6251807	17	0	
R_14	333777	6251775	19	0	
R_15	333776	6251718	20	0	
R_16	333776	6251718	20	30	
R_17	333821	6251706	25	0	
R_18	333821	6251706	25	20	
R_19	333821	6251706	25	40	
R_20	333821	6251706	25	60	
R_21	333798	6251640	10	0	
R_22	333798	6251640	10	20	
R_23	333785	6251606	8	0	
R_24	333785	6251606	8	20	
R_25	333785	6251606	8	30	
R_26	333816	6251631	24	0	
R_27	333816	6251631	24	20	
R_28	333816	6251631	24	40	
R_29	333816	6251631	24	60	
R_30	333798	6251504	28	0	
R_31	333797	6251504	28	20	

Receptor ID	Coordinates		Base Elevation (m)	Flagpole Height (m)	Description
	X (m)	Y (m)			
R_32	333822	6251500	32	20	
R_33	333822	6251500	32	40	
R_34	333822	6251500	32	60	
R_35	333822	6251500	32	80	
R_36	333797	6251514	27	0	
R_37	333796	6251521	27	0	
R_38	333795	6251528	26	0	
R_39	333795	6251535	26	0	
R_40	333794	6251542	25	0	
R_41	333817	6251536	30	0	Stamford on kent
R_42	333817	6251536	30	20	Stamford on Kent
R_43	333817	6251536	30	40	Stamford on Kent
R_44	333819	6251520	30	60	Stamford on Kent
R_45	333792	6251551	25	0	
R_46	333792	6251564	24	0	
R_47	333790	6251577	23	0	
R_48	333789	6251593	21	0	
R_49	333785	6251606	20	10	38 Hickson Rd
R_50	333785	6251606	20	30	38 Hickson Rd
R_51	333785	6251606	20	50	38 Hickson Rd
R_52	333787	6251623	20	0	38 Hickson Rd
R_53	333787	6251623	20	20	38 Hickson Rd
R_54	333787	6251623	20	40	38 Hickson Rd
R_55	333782	6251662	19	0	
R_56	333778	6251698	20	20	30 The Bond
R_57	333778	6251699	20	40	30 The Bond
R_58	333781	6251676	20	30	30 The Bond
R_59	333781	6251676	20	10	30 The Bond
R_60	333774	6251764	19	0	
R_61	333770	6251784	18	0	
R_62	333773	6251749	20	0	
R_63	333775	6251840	15	0	
R_64	333768	6251897	12	0	
R_65	333766	6251926	13	0	
R_66	333796	6251907	15	10	Observatory Hotel
R_67	333804	6251817	20	20	Observatory Hotel

Receptor ID	Coordinates		Base Elevation (m)	Flagpole Height (m)	Description
	X (m)	Y (m)			
R_68	333763	6251978	14	0	
R_69	333762	6251963	14	10	Preschool
R_70	333765	6251935	13	0	Preschool
R_71	333756	6252057	13	0	
R_72	333734	6251518	22	0	Stage 1A receptor
R_73	333765	6251520	24	0	Stage 1A receptor
R_74	333765	6251520	24	10	Stage 1A receptor
R_75	333609	6251481	3	0	R8/R9 Ground Level
R_76	333609	6251481	3	18	R8/R9 Level 6
R_77	333609	6251481	3	32	R8/R9 Level 12
R_78	333630	6251478	4	0	RA/R9 Ground Level
R_79	333630	6251478	4	16	R8/R9 Level 6
R_80	333630	6251478	4	32	R8/R9 Level 12
R_81	333632	6251438	4	0	R8/R9 Ground Level
R_82	333632	6251438	4	18	R8/R9 Level 6
R_83	333632	6251438	4	32	R8/R9 Level 12
R_84	333636	6251401	5	0	R8/R9 Ground level
R_85	333636	6251401	5	18	R8/R9 Level 6
R_86	333636	6251401	5	32	R8/R9 Level 12
R_87	333620	6251385	4	0	R8/R9 Ground Level
R_88	333620	6251385	4	18	R8/R9 Level 6
R_89	333620	6251385	4	32	R8/R9 Level 12
R_90	333639	6251384	5	0	R8/R9 Ground level
R_91	333639	6251384	5	18	R8/R9 Level 6
R_92	333639	6251384	5	32	R8/R9 Level 12
R_93	333642	6251344	4	0	R8/R9 Ground Level
R_94	333642	6251344	4	18	R8/R9 Level 6
R_95	333642	6251344	4	32	R8/R9 Level 12
R_96	333646	6251315	4	0	R8/R9 Ground Level
R_97	333646	6251315	4	18	R8/R9 Level 6
R_98	333646	6251315	4	32	R8/R9 Level 12
R_99	333673	6251534	9	0	T1 Ground level
R_100	333673	6251534	9	54	T1 Level 18
R_101	333673	6251534	9	96	T1 Level 32
R_102	333693	6251527	12	0	T1 Ground level
R_103	333693	6251527	12	54	T1 Level 18

Receptor ID	Coordinates		Base Elevation (m)	Flagpole Height (m)	Description
	X (m)	Y (m)			
R_104	333693	6251527	12	96	T1 Level 32
R_105	333659	6251516	7	0	T1 Ground Level
R_106	333659	6251516	7	69	T1 Level23
R_107	333716	6251492	15	0	T1 Ground level
R_108	333716	6251492	15	69	T1 Level 23
R_109	333730	6251499	17	0	T1 Podium Ground level
R_110	333730	6251499	17	12	T1 Podium Childcare Centre Level 4
R_111	333803	6251520	42	0	AON Podium Childcare centre
R_112	333807	6251608	46	0	Jenkins St
R_113	333810	6251687	39	0	Jenkins Street
R_114	333805	6251730	30	0	Jenkins Street
R_115	333797	6251824	23	0	High Ln
R_116	333798	6251825	23	0	High Ln

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