



Ecological Risk Assessment

DRAFT

Barangaroo Delivery Authority

Barangaroo Headland Park
Hickson Road, Sydney, NSW

February 2011
JBS41181-16421 Rev C
JBS Environmental Pty Ltd

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List of Abbreviations

A list of the common abbreviations used throughout this report is provided below.

- ACL added contaminant level
- As Arsenic
- Cd Cadmium
- Cr Chromium
- Cu Copper
- BDA Barangaroo Delivery Authority
- BTEX Benzene, Toluene, Ethylbenzene and Xylenes
- B(a)P Benzo (a) pyrene
- COPCs Constituents of Potential Concerns
- DECCW NSW Department of Environment Climate Change and Water
- DQO Data Quality Objectives
- DP Deposited Plan
- EPA NSW Environment Protection Authority
- HHERA Human Health and Ecological Risk Assessment
- Hg Mercury
- HI Hazard Index
- HIL Health Based Investigation Level
- LOR Limit of Reporting
- LTEMP Long Term Environmental Management Plan
- MAH Monocyclic Aromatic Hydrocarbon
- Ni Nickel
- OCP Organochlorine Pesticide
- OoW NSW Office of Water
- SAR Site Audit Report
- SAS Site Audit Statement
- PAH Polycyclic Aromatic Hydrocarbons
- Pb Lead
- PIL Phytotoxicity Based Investigation Level
- PCB Polychlorinated Biphenyls
- PQL Practical Quantitation Limit
- PSH Phase Separated Hydrocarbons
- QA/QC Quality Assurance/Quality Control
- REMP Remediation Environmental Management Plan

- RME Reasonably Maximum Exposed
- ROHSMP Remediation Occupational Health and Safety Management Plan
- RPD Relative Percentage Difference
- SWC Sydney Water Corporation
- TPH Total Petroleum Hydrocarbons (C₆-C₉ and C₁₀-C₃₆)
- Zn Zinc

Executive Summary

JBS Environmental Pty Ltd (JBS) was engaged by the Barangaroo Delivery Authority (BDA) to complete an ecological risk assessment for the portion of the Barangaroo development site known as the Barangaroo Headland Park. It is proposed that surplus materials from the Barangaroo development site will be used within the development of the northern portion of the development (consisting of the proposed Headland Park), consistent with the zero waste and ecological sustainability objectives of the proposed development. It is estimated that up to 500 000 m³ of materials will be required to develop the proposed final landform of the Park.

A number of environmental assessments have identified environmentally impacted material across the Barangaroo Site. Ecological risk assessment (ERA) is required to determine the suitability of environmentally impacted material from the Barangaroo Site for the development of Headland Park based on the range of potential ecological receptors expected to be present within the Park landform, and currently and potentially present within Darling Harbour in proximity to the site, and Northern Cove proposed adjoining the site.

The ecological risk assessment has been undertaken substantially in accordance with the methodology outlined in Heemsbergen D, Warne M, McLaughlin M and Kookana R CSIRO (October 2009) 'The Australian Methodology to Derive Ecological Investigation Levels in Contaminated Soils' (CSIRO, 2009) as supplemented with site specific data where possible. The findings of the risk assessment shall be used to determine future site management requirements for soils and groundwater within the current area of the Headland Park site and to assess suitability of surplus materials proposed to be used on the Headland Park as fill materials (including growing medium).

The risk assessment has considered a range of ecological exposure scenarios for the proposed development of the Headland Park. The key facets of the proposed Headland Park development that have been considered in the risk assessment include:

- Provision of growing medium to areas of site plantings designated as grasses, shrubs, or large tree plantings;
- Control of sub-surface water on the site by engineered controls to prevent uncontrolled discharge to adjoining surface waters in some areas of the Headland Park; and
- Harvesting of surface and sub-surface water flows and re-use on the Park as irrigation water.

On the basis of these land-use parameters and the conceptual plans for the Headland Park and the limitations provided in **Section 12**, the following risk based ecological criteria have been derived for use on the site as summarised in **Table ES1**. It is intended that each of the criteria are to be applied as follows:

- Ecological Investigation Level (EIL) Protective of Potential Phytotoxicity Effects – to be applied to soils classified as growing medium;
- EIL Protective of Surface Water – Headland Park Soils, Saturated Zone – to be applied to soils sourced from / located within the Headland Park that are present below the depth of groundwater (assumed to be 1.9m AHD based on 2100 high water mark) and not subject to sub-surface drainage controls;

- EIL Protective of Surface Water – Fill Material from Barangaroo Central and South, Saturated Zone – to be applied to soils sourced from the Barangaroo South / Central site and used as fill within the Headland Park in a location below the depth of groundwater (assumed to be 1.9m AHD based on 2100 high water mark) and not subject to sub-surface drainage controls;
- EIL Protective of Surface Water – Headland Park Soils, Unsaturated Zone – to be applied to soils sourced from / located within the Headland Park that are present above the depth of groundwater (assumed to be 1.9m AHD based on 2100 high water mark) and not subject to sub-surface drainage controls;
- EIL Protective of Surface Water – Fill Material from Barangaroo Central and South, Unsaturated Zone – to be applied to soils sourced from the Barangaroo South / Central site and used as fill within the Headland Park in a location above the depth of groundwater (assumed to be 1.9m AHD based on 2100 high water mark) and not subject to sub-surface drainage controls; and
- Protection of Phytotoxicity Irrigation Water Criteria – to be applied to irrigation water used within the Headland Park in vegetated areas.

It is noted that soil criteria have been provided specific to the current location of the soils consequent of site specific estimates of leachability (i.e. estimates specific to the footprint of the Headland Park or Barangaroo Central and South).

In addition to these risk based criteria for soils, all discharges from the site are required to meet ecological criteria as defined by DECCW guidelines and standards.

Table ES1: Summary of Ecological Risk Based Criteria for Headland Park

Constituent	Ecological Criteria					
	Ecological Investigation Level Protective of Potential Phytotoxicity Effects	EIL Protective of Surface Water – Headland Park Soils, Saturated Zone	EIL Protective of Surface Water – Fill Material from Barangaroo Central and South, Saturated Zone	EIL Protective of Surface Water – Headland Park Soils, Unsaturated Zone	EIL Protective of Surface Water – Fill Material from Barangaroo Central and South, Unsaturated Zone	Protection of Phytotoxicity Irrigation Water Criteria
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/L
Arsenic	27	23	26	92	102	0.93
Chromium	415	-	-	-	-	0.053
Copper	152	31	22	124	87	4.3
Lead	979	157	129	629	518	1.1
Mercury	2.9	0.2	7	0.8	27	0.056
Nickel	67	1061	700	4242	2800	1.0
Zinc	430	99	45	395	180	6.9
Cyanide	0.5	<LOR	<LOR	<LOR	<LOR	0.051
Benzene	1	1.3	1.3	5.4	5.4	0.023
Toluene	1.4	0.7	0.7	2.9	2.9	0.020
Ethylbenzene	3.1	<LOR	<LOR	<LOR	<LOR	0.023
Xylene	14	<LOR	<LOR	1.9	1.9	0.12
Acenaphthene	10	70	222	279	888	0.0066
Acenaphthylene	-	5.0	2.9	20	12	-
Anthracene	-	42	58	167	233	-
Fluoranthene	-	35	23	140	90	-
Fluorene	30	2.4	3.2	10	13	0.011
Naphthalene	-	208	26	833	104	-
Phenanthrene	-	17	6	67	24	-
Pyrene	14	12	4.8	48	19	-
Phenol	-	1.2	1.2	4.9	4.9	0.25
Cresols	-	1.0	1.0	3.9	3.9	-
2,4-dimethylphenol	-	<LOR	<LOR	<LOR	<LOR	-
TPH C ₆ -C ₉ (aliphatic)	-	65	65	261	261	-
TPH C ₁₀ -C ₁₄ (aliphatic)	-	2308	2308	9231	9231	-
TPH C _{>16} (aliphatic)	-	>MAX	>MAX	>MAX	>MAX	-
TPH C ₁₀ -C ₁₄ (aromatic)	-	23	23	92	92	-
TPH C _{>16} (aromatic)	-	1429	1429	5714	5714	-
TPH C ₆ -C ₉	65	-	-	-	-	-
TPH C ₁₀ -C ₃₆	1000	-	-	-	-	-

1 Introduction

1.1 Introduction and Background

JBS Environmental Pty Ltd (JBS) was engaged by the Barangaroo Delivery Authority (BDA) to complete an ecological risk assessment for the portion of the Barangaroo development site known as the Barangaroo Headland Park. It is proposed that surplus materials from the Barangaroo development site will be used within the development of the northern portion of the Barangaroo development site in the formation of a Headland Park, consistent with the zero waste and ecological sustainability objectives of the proposed development. It is estimated that up to 500 000 m³ of materials will be required to develop the proposed final landform of the park and cove.

A number of environmental assessments have identified environmentally impacted material across the Barangaroo Site. Ecological risk assessment (ERA) is required to determine the suitability of environmentally impacted material from the Barangaroo Site for the development of Headland Park based on the range of potential ecological receptors expected to be present within the Park landform, and currently and potentially present within Darling Harbour in proximity to the site, and Northern Cove to be constructed adjoining the site.

The ecological risk assessment has been undertaken substantially in accordance with the methodology outlined in Heemsbergen D, Warne M, McLaughlin M and Kookana R CSIRO (October 2009) 'The Australian Methodology to Derive Ecological Investigation Levels in Contaminated Soils' (CSIRO, 2009). The findings of the risk assessment shall be used to determine future site management requirements for soils and groundwater within the current area of the Headland Park site and to assess suitability of surplus materials proposed to be used on the Headland Park as fill materials (including growing medium).

1.2 Objectives

The objective of the ERA is:

- To determine the suitability of levels of a range of environmental constituents identified as being present in soils and groundwater across the Barangaroo Site for future use in the area of the proposed Headland Park; and
- To establish environmental standards to assess the ecological suitability of surplus materials proposed to be used as fill materials to form the Headland Park.

2 Summary Site Condition/Surrounding Environment

2.1 Site Identification

The Barangaroo Project Site is located at Hickson Road, Sydney, NSW and is legally referred to as Lots 1, 3, 5 and 6 Deposited Plan (DP) 876514 and includes the adjacent parts of Sussex Street, Hickson Road and Towns Place, as shown in **Figure 1**. The Barangaroo Project Site details are summarised in **Table 2.1** and described in more detail in the following sections.

Table 2.1 Summary Details for the Barangaroo Project Site

Lot/DP	Lots 1, 3, 5 and 6 of Deposited Plan 876514, including adjacent parts of Sussex Street, Hickson Road and Towns Place
Address	Hickson Road Millers Point NSW
Local Government Authority	City of Sydney
Site Zoning	Zone B4 Mixed Use and RE1 Pubic Recreation
Current Use	Vacant/Roadway
Geographical Co-ordinates, Elevation	Easting – 333643m E, Northing – 6251851m S, 2-3m AHD
Site Area	Approximately 22 ha

The Headland Park Site is located at the northern part of the Barangaroo Project Site and the details are summarised in **Table 2.2** and described in more detail in the following sections.

Table 2.2 Summary Details for the Headland Park Site

Lot/DP	Lot 1 and Part Lot 5 of Deposited Plan 876514, including adjacent parts of Hickson Road and Towns Place
Address	Hickson Rd Millers Point NSW
Local Government Authority	City of Sydney
Site Zoning	Zone B4 Mixed Use and RE1 Pubic Recreation
Current Use	Vacant
Geographical Co-ordinates, Elevation	Easting – 333547m E, Northing – 6252278m, 2-3m AHD
Site Area	Approximately 8 ha

For the purposes of the environmental assessment and the ensuing Site Audit, the final site as intended to be described in the Site Auditor sign off consists of the site as defined by the high water mark boundary. A plan view of the proposed site is shown as **Figure 2**. Proposed sections are shown as **Figures 3A to 3F** and **4**.

It is noted that a substantial area of the current Lots 1, 3, 5 and 6 are proposed to be inundated with the proposed site development. These inundated areas are understood to be excluded from the area of the final site audit (and excluded from consideration in this ERA). Approximate dimensions and locations of the future site boundary can be identified as the 1m AHD contour as shown on **Figure 2**.

Soils contained within the proposed inundated area will be excavated to a maximum likely depth of approximately -4m AHD. The majority of these soils are proposed to be used as fill material in the creation of the headland landform on the Headland Park Site.

With the proposed finished landform of the Headland Park it is noted that two portions have been excluded from the Barangaroo Project Site for the purposes of environmental assessment and remediation planning, consisting of:

- Moore’s Wharf (in the far north eastern section of the Headland Park Site); and
- The area immediately surrounding the Port Control Tower.

The location of these areas relative to the Barangaroo Project Site is shown on **Figure 5**, which also shows the location of former structures that were present during the former commercial/industrial site use.

2.2 Current Site Condition

The Headland Park Site has an approximate rectangular shape, with the longest boundary in a north-south direction. The far north-eastern portion of the Headland Park Site, known as Moores Wharf (Ports Services), was reported to contain a large heritage listed sandstone building and this section of the Headland Park Site was recently utilised as a base for marine operations by Sydney Ports Marine Services.

The remainder of the Headland Park Site was previously used for wharfage and storage of materials and was last occupied by Patrick Stevedoring. The large warehouse buildings associated with this former use have been demolished. The surface of the Headland Park Site is generally covered with areas of concrete and asphaltic pavement. The pavement surfaces have been reported as being in generally reasonable condition (ERM 2008a). The Sewage Pumping Station at the north of the Headland Park Site is still present.

The main vehicular access to the Headland Park Site is from a number of gates on Hickson Road on the eastern boundary of the Barangaroo Site, in addition to gates off Towns Place.

2.3 Proposed Site Condition

The Headland Park Site is proposed to be developed into a naturalistic headland that will simulate the shoreline as it was in 1836. Establishment of the naturalistic headland will involve shaping of the shoreline through the extraction of approximately 150,000 m³ of fill materials within or behind the existing caissons and seawall that form the current western and northern boundaries of the site.

The proposed Headland Park Site development can be observed on **Figure 2**, and cross sections as shown on **Figures 3A to 3F** and **4**. The Headland Park Site is proposed to include the following elements:

- A substantial open area of sloped parkland over the majority of the site provided with a network of pathways and plantings formed by a substantial filling program;
- A submerged area at the south known as Northern Cove and a modified shoreline throughout the perimeter of the site resulting in the excavation of approximately 150,000m³ of fill based soils;
- A void to a depth of -7.6m AHD as created by a proposed sandstone extraction program located within the central portion of the site, comprise dimensions of 85m (east-west) and 70m (north-south) resulting in the excavation of approximately 60,000m³ of sandstone and approximately 5,000m³ of overlying fill materials;
- A multi-level Car Park as constructed within the void, partially contained within the area of proposed sandstone extraction and extending within an excavation placed to a depth of -2m AHD within the central to southern portion of the site. The proposed dimensions of the car park are 40m (east-west) and 165m (north-south). In addition to the surplus soils as generated by the sandstone excavation, an additional 5,000m³ of fill based and natural soils (alluvium and potential sandstone) will be generated by this proposed excavation outside the designated area of sandstone extraction;

- A 'Cultural Facility' as constructed above the Car Park and substantially contained within a void created within the fill forming the Headland Park Site; and
- A system to control seepage water movement, collection and re-use, as constructed with the filling and formation of the headland profile of the Park.

Geological and hydrological characteristics of the proposed Headland Park and Northern Cove are described further in **Sections 2.5 to 2.8** and within the conceptual site model as **Section 4**.

2.4 Surrounding Land use

The surrounding uses of land adjacent to the Headland Park Site have been previously reported as follows (ERM 2008b¹):

- North: Immediately to the north is Sydney Harbour;
- East: Immediately to the east is the residential and commercial area of Millers Point (NE), in addition to Hickson Road (SE);
- South: Immediately to the south is the temporary overseas passenger terminal, beyond which lies the Stage 1 Development; and
- West: Immediately to the west is Darling Harbour.

A former gasworks is known to have operated until the 1920s over part of the Stage 1 Development, as shown on **Figure 5**. The former gasworks location is known to continue to the east beneath Hickson Road, and the contaminated gasworks waste material in this area has been identified to contaminate soils and groundwater on the south-eastern portion of the Barangaroo Project Site. This part of the Stage 1 Development, referred to as the Declaration Area in this RAP, has been declared a Remediation Site by NSW DECCW (Declaration No. 21122, Area No. 3221) under the CLM Act 1997. It is understood that environmental assessment programs are being undertaken on the Stage 1 Development in preparation for remediation.

2.5 Topography

The topography of the current area of the Headland Park Site is relatively flat, having been cut and filled for its previous use as a stevedoring facility (ERM 2008b). The Headland Park Site abuts a man-made cliff face on the north-eastern boundary.

The proposed topography will be heavily modified as can be observed from **Figures 2, 3A to 3F and 4**. This will be achieved by the importation of fill material to create a mound over the central portion of the site, and excavation at the north-western and southern areas of the site to form inundated areas. The site elevation will range from the level of surface water in Darling Harbour to a height of 20m in the central eastern portion of the site. Several steep slopes will occur across the site, consistent with a 'headland' topography.

¹ Draft Stage 2 Remedial Action Plan for Barangaroo, Hickson Road, Sydney, ERM, September 2008 (ERM 2008b)

2.6 Hydrology

The closest surface water body to the Headland Park Site is Darling Harbour, located immediately adjacent to the west and north of the Headland Park Site (ERM 2008b). Surface water from the Headland Park Site is currently collected via a sub-surface drainage network, which generally flows toward the Harbour. The current drainage network is shown on **Figure 5**.

Hydrology on the proposed Headland Park will be substantially modified with the amended topography. Sub-surface drainage will be controlled on the proposed Park. This is shown on a proposed Park section as provided as **Figure 6** and the sketch provided to **Appendix A**. As can be partially observed from **Figure 6** and the sketch to **Appendix A** two drainage systems are proposed over the majority of the proposed Park area with the site redevelopment:

- A shallow drainage system comprising a series of bioswales will be used to collect shallow seepage water in surface soils, used as a growing medium (not shown on the figure but shown in the sketch in **Appendix A**); and
- A deep drainage system with a clay bottom liner which will be placed under the majority of the proposed area of filling over the Park. The drain will be located below the depth of the current site surface. The clay liner will rise from the location of the drain at a reported slope of 1°. The most recent advice provided to JBS is that the clay liner will commence at a depth of approximately 2.5m AHD at the boundary of the Headland Park. The indicative lateral extent of the clay liner, consistent with the pathway proposed at the boundary of the Headland Park Site is shown on **Figure 9**.

The movement of water within the Proposed Park development has been described in AgEnviro Solutions (29th September 2010) 'Barangaroo Water Balance', included as **Appendix A**. The hydrological regime of the proposed Park has been described as follows:

- 64.46 ML of rainfall falling over the area of the Park annually;
- 9.4 ML of run-on water entering the Headland Park site from surface water flows from adjoining sites;
- 24.46 ML of water lost by evapotranspiration from Plants on the Park;
- 10.8 ML of water lost as surface water run-off and discharged into the Harbour;
- 40.91 ML of water placed on the surface of the Park collected in a near surface drainage system consisting of bioswales;
- 12.05 ML seeping into deeper soils (below the depth of influence of the bioswale drainage system) of which 7.3 ML is captured by a deep drain, 1.6ML seeping through the clay bottom liner provided to the deep drain into underlying groundwater, and 3.15ML seeping into deeper soils at the northern, western and southern extremities of the site outside of the area of the proposed deep drainage system and discharge into Darling Harbour as seepage water / groundwater outflows;
- 19.56 ML of collected water from the near surface drains (bioswales) and deep drain system is re-used as irrigation water on the Park;
- 3.72 ML of water as placed on the surface in areas concentrated to the northern, western and southern extremities of the site outside of the area of the proposed bioswale system, infiltrating into near surface soils only and discharging into Darling Harbour by shallow seepage water discharge;
- 2.91 ML per year of water re-used as irrigation is lost by evaporation; and

- The remaining 23.64 ML of surplus water (collected water in the sub-surface drainage systems that is in excess of the Parks irrigation / waters re-use requirements) requires to be discharged from the site.

By observation of **Figure 6**, the deep drain system will be present underlying all soils imported onto the Headland Park site, apart from a thin layer of materials to be placed underlying the clay liner to achieve the drain slope (immediately above the current site surface). By correlation to the water balance, the seepage water discharges as reported to occur from the deeper fill materials and near surface soils will occur from soils below the current depth of Headland Park site (2.5-3m AHD) and located at the boundaries of the Park. No drainage controls are known to be proposed for soils to the south of Northern Cove. No significant filling works are proposed in this area of the site.

2.7 Geology

According to the 1:100 000 Geological Survey of NSW (Sydney) Sheet 9130 (Ed 1) 1983, the Headland Park Site is generally underlain by man-made fill that has been placed over marine sands and Hawkesbury Sandstone, which is described as follows (ERM 2008b):

- Man-made fill may consist of “dredged estuarine sand and mud, demolition rubble, industrial and household waste”; and
- Hawkesbury Sandstone is characterised as “medium to coarse-grained quartz sandstone with very minor shale and laminite lenses”.

A substantial network of soil sample locations has been previously placed across the Barangaroo Project Site. The general geological profile observed at the Headland Park Site, as reported by previous investigations, is summarised in **Table 2.3**.

Table 2.3 Summary of Observed Site Geology

Lithological Unit	Description	Depth (mbgl)
Hardstanding	Asphalt, bitumen or concrete, generally in good condition with no staining.	0 – 0.46
Road base fill	Very dark grey, dry, loose, medium grained sand to fine gravel, poorly sorted, sub angular, no odours or staining noted.	0 – 0.5
Fill	Silty, gravelly sand, olive brown, grey brown, light yellowish brown, dry to wet, fine to coarse sand, sandstone floaters. Fill material including building rubble, bricks, concrete. Black staining and a hydrocarbon odour and significant contamination have been identified in some boreholes, particularly within and around the former gasworks area.	0 – 18.0
Marine Clay/Sand	Interbedded clayey sand and sandy clay, dark greyish brown, saturated, some shell fragments and organic matter. Sandy clay – soft, high plasticity. Clayey Sandy – loose to dense, fine to coarse sand, low to no plasticity. Contamination has been identified within and around the former gasworks area.	3.0 – 18.4
Marine Clay/Sand	Interbedded clayey sand, sandy clay and sand, light yellowish brown, white, reddish brown or dark greyish brown, saturated. Sandy clay – stiff to hard, medium to high plasticity. Clayey Sandy and sand – loose to dense, fine to coarse sand, low to no plasticity.	4.9 – 32.75
Bedrock	Weathered sandstone, white, light yellowish brown, olive brown and reddish brown, wet, fine to coarse grained, some fracturing noted. Contamination has been identified within and around the former gasworks area.	1.3 – 32.75

It was further reported that some areas along the western foreshore and building footprints were covered by concrete with a thickness up to 0.5 m. A layer of fill was observed in all boreholes and ranged in thickness from 1.3 m on the eastern portion of the Barangaroo Project Site to 18 m on the western portion of the Barangaroo Project Site.

The current site geology is described in more detail in the site conceptual model provided as **Section 4**. The most significant changes proposed to the site geology of the final Headland Park site (excluding areas to the north-west and south below the high water mark) include:

- Excavation of soils at the proposed boundaries of the Headland Park to form the proposed grades along the length of the site boundary to the edge of Darling Harbour;
- Placement of substantial quantities of imported fill over the majority of the proposed Park area so as to form the proposed Headland; and
- Excavation of 60,000m³ of sandstone and overlying fill based soils from the central portion of the eastern site. Backfilling of the subsequent void by imported soils.

Sydney Environmental & Soil Laboratory (undated) 'Soil Requirements for Barangaroo A Preliminary Scoping Paper' and conceptual plans have been provided to JBS as the basis of the soil design of the Headland Park. Four soil horizons are nominated in this correspondence as listed following:

- A Horizon – topsoil, with the highest fertility, organic matter and biological activity of the layers. It is always sandy and is not anticipated to have a silt / clay content in excess of 5%;
- B Horizon – a subsoil layer that is typically yellow clayey sand containing little if any organic matter. It is of low fertility. In the oldest profile type, the Podsollic, it contains the maximum clay content in the profile (15-30% silt plus clay). Clay content is also reported to increase with depth;
- C Horizon – decomposed rock with little structure, but allows some root penetration as it is not solid rock. Reported as being typically a clayey sand to sandy clay in texture; and
- R Horizon – Described as solid rock, highly compacted engineered material or concrete.

Upper soils on the parkland site, to be used as growing medium, are reported to most likely consist of A and B horizons soils and are proposed to be manufactured with soils available from the development and selected imported materials (i.e. compost). The most recent advice received as to intended depths of soils to be used as growing medium on the Park has been provided in an email from BDA (23/11/2010) and includes:

- Grassed areas – 500mm;
- Areas planted with shrubs – 800mm; and
- Tree plantings – 1.5m.

The surface soils will be drained by the bioswale system as described in the water balance in **Section 2.6**.

Further advice from Sydney Environmental & Soil Laboratory (SESL) as emailed to JBS (9/7/2010), advised that below the depths of the growing medium would be compacted to "prevent root penetration virtually completely". A further email from SESL to JBS (14/7/2010) advised that surface soils used as growing medium will contain organic content consequent of blending. It was advised that a total organic carbon content of at least 3% should be anticipated for the surface soils / growing medium.

The majority of the in-situ geology, within the boundaries of the Headland Park will remain undisturbed.

2.8 Hydrogeology

As previously reported (ERM 2008b), information obtained from the Department of Natural Resources (DNR) indicated that 32 registered groundwater bores were situated within a 4 kilometre (km) radius of the Headland Park Site. Review of the groundwater bore information indicated that the bores were used for the following purposes: recreation (8), irrigation (3), and monitoring (22). None of the listed bores were reported to be registered for drinking water purposes. No registered groundwater bores have been reported to be present on or adjacent to the Headland Park Site.

The quality of groundwater has been reported to have been assessed via a network of monitoring wells installed across the Headland Park Site (ERM 2008b). Locations of groundwater monitoring wells within the area of the Headland Park are shown on **Figure 8**. Hydrogeological data indicated that groundwater on the Headland Park Site was strongly influenced by tidal fluctuations, suggesting that the substantial hydraulic connection with the Harbour potentially associated with conduits in the fill material.

The hydrogeological data suggest that much of the Headland Park Site is likely to be subject to significant seawater flushing. Under typical conditions there is reported to be a likely net groundwater flux towards the Harbour, at a velocity of between 0 and 7.6 m/day (ERM 2008b).

It is not anticipated that the current hydrogeological regime would change substantially with the proposed Park development. The current rate of surface water recharge over the area of the site is unknown as it is controlled by cracks / penetrations in site pavement. Based on the water balance modelling, it has been estimated that 4.75 ML of seepage per year will infiltrate to groundwater from the Headland Park. It is reported that 1.6ML of this vertical seepage recharge will be derived from contained soils as placed above the current site surface forming the Headland profile.

2.9 Meteorology

The Sydney area has a humid to temperate climate with a seasonal rainfall maximum during the summer and autumn months. Annual mean rainfall recorded at Sydney (Observatory Hill) is 1212 mm².

The area has a history of droughts, which are broken by periods of heavy rainfall resulting in significant recharges to groundwater resources. The 1940s and 1980s and the current decade are observed to be dry periods, while the early 1970s and 1990s were wet periods.

Summer winds are predominantly northeasterly with southerly thunderstorms common. Winter winds are predominantly westerly.

² http://www.bom.gov.au/climate/averages/tables/cw_066062.shtml visited 7th May 2010

3 Summary Site History/Previous Assessments

3.1 Barangaroo Project Site

The Barangaroo Project Site was a large precinct occupied by shipping and related merchants over the 1900s. A gasworks operated by The Australian Gas Light Company (AGL) over the period of 1840 to 1925 was located on part of the Barangaroo Project Site, within the Stage 1 Development, and extended across what is now Hickson Road. During the use of the Barangaroo Project Site for these purposes, the original shoreline was altered to enable the constitution of a number of finger wharves and associated activities, with these reclaimed over the period spanning the 1950s to 1970s. Over the past 20 years, the Barangaroo Project Site was used for principally stevedoring purposes until the majority of buildings were demolished and the land prepared for redevelopment in the past 5 years.

3.2 Headland Park Site

A summary of the Headland Park Site history has been provided in the previous reports (ERM 2008b). A chronological list of activities at the Headland Park Site is summarised below:

- 1840 to 1910: The Headland Park Site was owned by merchants, composers, manufacturers and various shipping companies and was also used for ship berthing and associated activities. Ownership was largely transferred to Sydney Harbour Trust Commissioners (SHTC) in approximately 1910.
- 1910 to 1936: The majority of the Headland Park Site continued to be owned by the SHTC and was used for ship berthing and associated activities such as workshops and stores.
- 1936 to 1998: Ownership was transferred to the Maritime Services Board of NSW and subject to various commercial leases. Part of the Headland Park Site initially consisted of finger wharves, which were removed over time with a significant portion of land reclaimed from the Harbour with unclassified fill between 1951 and 1972.
- 1998: Marine Ministerial Holding Corporation was the proprietor of Lot 1. Sydney Ports Corporation was proprietor of Lots 2, 4 and 5.
- 1996-2007: A number of environmental investigations were conducted on the Headland Park Site; and
- 2007 - 2008: The Headland Park Site was vacated by Patrick Stevedores Operations. The warehouses were demolished and the land was cleared and leveled in preparation for future redevelopment.

3.3 Previous Site Assessments

A number of previous site investigations have been undertaken which provide relevant environmental data for remediation planning. Environmental Assessments that have been made available to JBS include:

- ERM (June 2007) 'Environmental Site Assessment, East Darling Harbour, Sydney, NSW' (ERM 2007);
- ERM, (July 2008) 'Additional Investigation Works at Barangaroo, Hickson Road, Millers Point, NSW' (ERM 2008a);
- ERM (September 2008) 'Draft Stage 2 Remedial Action Plan for Barangaroo, Hickson Road, Sydney' (ERM 2008b);
- Douglas Partners (14 May 2010) 'Barangaroo Draft Factual Environmental Site Investigation Report' (DP 2010a);
- AECOM Australia (27 May 2010) 'Data Gap Investigation, Other Remediation Works (South) Area Hickson Road, Millers Point NSW' (AECOM 2010a);
- AECOM (23 September 2010) 'Data Gap Investigation EPA Declaration Area (Parts of Barangaroo Site and Hickson Road), Millers Point, NSW' (AECOM 2010b); and
- AECOM (20 October 2010) 'Data Gap Investigation Other Remediation Works North, Hickson Road, Millers Point, NSW' (AECOM 2010c).
- AECOM (3 November 2010) 'Groundwater Discharge Study Stage 1 Barangaroo Development' (AECOM 2010d); and
- Douglas Partners (17 December 2010) 'Factual Report – Pre Early Works Additional Environmental Assessment – Soils Barangaroo Headland Park' (DP 2010b).

The works and findings of each of these assessments is summarised following.

3.3.1 Environmental Site Assessment (ERM 2007)

This investigation (ERM 2007³) comprised a desktop study of existing and previous land uses, the placement of 161 soil sample locations across the site and the assessment of groundwater from 25 groundwater monitoring wells. Soil sample locations are shown as BH001 to BH161 on **Figure 7**. Groundwater monitoring well locations are shown as MW01 to MW25 on **Figure 8**.

The investigations reported encountering a layer of silty / gravelly sand fill in all boreholes, ranging in thickness from 0.5 to 21m. Boreholes drilled in the northern and eastern portion of the Barangaroo Project Site were reported as being generally devoid of a layer of natural sediment, with fill underlain by the sandstone bedrock. In the central portion of the Barangaroo Project Site the fill layer was found to be underlain by natural marine sediments generally comprising silty clays underlain by sandstone. An underground storage tank (UST) was identified at the north-eastern corner of the Barangaroo Project Site.

Soils were reported to be sampled and analysed for a wide range of contaminants commonly associated with former gasworks and industrial sites including heavy metals (As, Cd, Cr, Cu, Pb, Hg, Ni and Zn), cyanides, sulphates, total petroleum hydrocarbons

³ *Environmental Site Assessment, East Darling Harbour, Sydney, NSW, ERM, June 2007 (ERM 2007)*

(TPH), monocyclic aromatic hydrocarbons (including benzene, toluene, ethylbenzene and xylene – collectively referred to as BTEX), polycyclic aromatic hydrocarbons (PAHs), phenols, polychlorinated biphenyls (PCBs), organochlorine pesticides (OCPs) and organophosphorus pesticides (OPPs).

Two primary areas were identified which had levels of contaminants above the adopted investigation criteria. These areas were described as being located in the proximity of the former gasworks (see **Figure 5**) and in the north-western portion of the site adjacent to Warehouse 3. The primary COPCs were identified as copper, lead, PAHs, TPH, BTEX and sulphates.

Isolated areas of soil impact were also identified including the western portion of Wharf 8, the eastern boundary of north of Warehouse 5 and the western edge of Warehouse 4. Impact at these locations was found to consist of PAHs including benzo(a)pyrene and lead. Impact was found to occur within a fill layer present to a maximum reported depth of 3.5m bgl.

Widespread elevated levels of heavy metals were also reported across the Barangaroo Project Site. The potential for asbestos containing materials (ACM) to be present was also identified across the Barangaroo Project Site. However, the consultant (ERM 2007) noted that the sampling methods employed as part of the assessment were not considered appropriate to identify ACM.

Groundwater underlying the Barangaroo Project Site was found to be subject to strong tidal influence. Groundwater impact was identified as consistent with the constituents identified as soil impact. The majority of groundwater impact was identified in the proximity of the former gasworks, with localised impact in other areas of the Barangaroo Project Site, such as in the proximity of the UST. Groundwater constituents identified at elevated levels included PAHs, TPH, BTEX cadmium, copper, lead, zinc and free cyanide.

3.3.2 Additional Investigation Works (ERM 2008a)

This additional investigation (ERM 2008a) consisted of additional soil and groundwater assessment to address perceived data gaps in the initial site assessment (ERM 2007).

A total of 55 soil sample locations were placed across the Barangaroo Project Site, consisting of 34 grid based locations and 21 targeted locations. Sandstone bedrock was additionally cored at 13 locations. Sample locations are shown as BH162 to BH215 on **Figure 7**.

A total of 23 existing wells and 13 newly installed wells were assessed across the site. The additional wells are referred to as sample locations MW179, MW198, MW200, MW204S, MW204D, MW205, MW206, MW209, MW210 and MW212 to MW215 on **Figure 8**.

Soil and groundwater were analysed for the COPCs identified in the initial site assessment (ERM 2007). The following results were reported (ERM 2008a):

- Localised levels of lead, TPH, BTEX, PAHs and sulphate exceeded the adopted assessment criteria. The highest levels were located within the area of the former gasworks;
- The highest levels of groundwater impact, occurring as TPH, BTEX and PAHs were located within the area of the former gasworks. Groundwater impact was identified in this area as occurring in fill materials, natural clayey sands and sandstone;

- Groundwater was found to be substantially influenced by tidal movements with very high hydraulic conductivities recorded for the fill material. It was considered that substantial tidal flushing of the aquifer had occurred which had resulted in a relatively small migration of impact from the area of the former gasworks; and
- Phase separated hydrocarbon (PSH) impact was identified at monitoring well MW204D in the area of the former gasworks.

The same limitations with the sampling methodology to identify ACM were present in both ERM 2007 and ERM 2008a investigations.

3.3.3 Stage 2 Remedial Action Plan (ERM 2008b)

A remedial strategy for the whole of the Barangaroo Project Site was prepared in ERM (2008b). The preferred remedial approach for the former gasworks portion of the site, currently subject to the DECCW regulation and proposed for future mixed use, was determined to be source removal via either excavation and off-site treatment and disposal (for the most heavily impacted materials) or excavation and on-site stabilisation / reuse (for less heavily impacted materials). Re-use of materials was proposed to occur in any appropriate area of the site, including the proposed Headland Park.

The remaining areas of the Barangaroo Project Site (including the area of the Headland Park) were proposed to be made suitable for the proposed developments by on-site management involving capping of impacted materials and hotspot removal of materials exceeding risk based clean-up levels.

3.3.4 AECOM Data Gap Investigation Remediation Works (South) Area (AECOM 2010a)

Targeted sampling and analysis was completed by AECOM in the area of Blocks 1, 2 and 3 within Stage 1 of the Barangaroo Project Site. The investigations were undertaken to obtain additional contaminant data in these areas. The works comprised the placement of 35 soil sample locations, seven groundwater monitoring wells, four soil vapour wells and additional sampling and analysis of selected existing groundwater monitoring wells. Sample locations are shown on **Figure 10**.

Hot-spots of environmental impact were recorded throughout the fill materials and in the proximity of the former gasworks on the site. Constituents identified included lead, total petroleum hydrocarbons, benzene, xylenes, polycyclic aromatic hydrocarbons and sulphate.

Of the limited number of soils analysis for acid sulphate soils, potential acid sulphate soils were generally recorded in the natural soils.

3.3.5 AECOM Data Gap Investigation EPA Declaration Area (AECOM 2010b)

Targeted sampling and analysis was undertaken by AECOM in the area of Blocks 3, 4 and 5 of the Barangaroo Project Site, part of the proposed Southern Cove and part of Hickson Rd adjacent to the Barangaroo Site. The investigations were undertaken to obtain additional contaminant data in these areas. The works comprised the placement of 25 soil sample locations, nine groundwater monitoring wells, seven soil vapour wells and additional sampling and analysis of selected existing groundwater monitoring wells. Sample locations are shown on **Figure 11**.

The additional sampling and analysis confirmed the findings of previous assessments that substantial environmental impact is present in the proximity of the former gasworks infrastructure. Soil vapour, principally consisting of naphthalene, was identified in the proximity of the former gasworks.

Of two samples analysed for acid sulphate soils, one sample consisting of clayey sand from a depth of 7.3-7.5m recorded potential acid sulphate soils. The other sample consisting of sandy gravelly clay fill did not report acid sulphate soils

Samples submitted for 'neutral water leach' (by ASLP leaching) reported some potentially leachable levels of lighter PAHs and heavy metals.

3.3.6 AECOM Data Gap Investigation Remediation Works (North) Area (AECOM 2010c)

Targeted sampling and analysis was undertaken by AECOM in the area of the proposed Blocks 4, 5, Southern Cove and the Public Domain of the Barangaroo Project Site. The investigations were undertaken to obtain additional contaminant data in these areas. The works comprised the placement of 13 soil sample locations, five groundwater monitoring wells, one soil vapour well and additional sampling and analysis of selected existing groundwater monitoring wells. Sample locations are shown on **Figure 11**.

Elevated levels of hydrocarbon constituents were identified at some sample locations, including monocyclic aromatic hydrocarbons and polycyclic aromatic hydrocarbons. The highest levels of soil impact were identified in Blocks 4 and 5 in close proximity of the former gasworks. Naphthalene was identified in soil vapour. Some elevated levels of heavy metals were identified in groundwater, with the highest levels being recorded in wells screened at deeper depths.

Samples submitted for 'neutral water leach' (by ASLP leaching) reported some potentially leachable levels of lighter PAHs and heavy metals.

3.3.7 AECOM Additional Analysis

Limited additional analysis of AECOM samples was undertaken by JBS to assist with the interpretation of the leachability data. Analytical data has been provided in JBS Environmental (10 January 2011) 'Summary of Results of Soil Analysis of Chemical Constituent Leachability Barangaroo'.

3.3.8 AECOM Intertidal Study (AECOM 2010d)

AECOM undertook a study of groundwater discharge from the Barangaroo Central and South Sites. It was found that an attenuation factor of five could be applied to groundwater constituents as present in groundwater underlying the site as discharging to Darling Harbour. This factor is intended to be applied to predict the dilution of leachate in saturated soil to the receiving environment (i.e. Darling Harbour). AECOM have advised JBS that the results of the study are applicable to groundwater discharge on the Headland Park site.

3.3.9 Douglas Partners Sampling and Analysis

Targeted sampling and analysis works were completed by Douglas Partners (DP2010a & 2010b) across the majority of the Barangaroo Project Site in April, May, November and December 2010. Sample locations undertaken in May, November and December 2010 are shown on **Figure 12**. Soil analyses included analysis of total and ASLP leachable concentrations.

A comparison of total and leachable levels of constituents as generated by the completion of the DP (2010a & 2010b) works has been provided in JBS Environmental (10 January 2011) 'Summary of Results of Soil Analysis of Chemical Constituent Leachability Barangaroo'.

Two additional groundwater monitoring wells were also installed within the Headland Park site during the November and December 2010 works and all monitoring wells (new and existing) within the Headland Park site were sampled and analysed.

3.3.10 Data Quality

Each of the respective assessments identified in **Section 3.3.1** to **3.3.9** have concluded that the data presented is adequately reliable to be used in decision making on the Barangaroo site. JBS has undertaken no further assessment of the data and it is assumed that all data is reliable for use in the ERA.

4 Conceptual Site Model

A conceptual site model (CSM) has been prepared to document the constituents of potential concern (COPCs), sources of COPCs, pathways, and potential receptors. The CSM is considered to be an essential pre-requisite prior to the consideration of the scope of the ERA.

It is noted that the CSM has not focussed extensively on existing pathways or contaminant distribution. Substantial earthworks are proposed for the Headland Park Site which will result in the movement of soils about the site. The CSM has instead focussed on potential interactions with soils with the future development of the site, focussed to the Headland Park.

4.1 Geology

As described in detail in **Section 2.7** the proposed Headland Park geology can be described as:

- Soils in accessible parts of the site to a maximum depth of 1.5m consisting of top-soils. These are characterised as being well aerated and having high levels of organic carbon;
- Fill based soils as sourced from shoreline reclamation, Northern Cove excavation and surplus soils from Barangaroo Central and South used to form the Headland profile of the park. Limited descriptions provided for these materials indicate that they will be well compared and have low levels of oxygen;
- Clay liner placed at an approximate elevation of 3m AHD underlying the majority of the site as associated with the retention of seepage water formed in the filled portion of the site;
- Existing in-situ soils, as consisting of a shallow depth of fill materials overlying naturally occurring clayey sand soils or sandstone, as present at the Park boundaries and underlying the clay liner in the remaining Park area. These soils are not anticipated to be substantially modified from the current condition.

Further details on the composition of sub-surface soils on the proposed Headland Park can be determined from review of **Figures 13 to 15**.

Figures 13 and 15 show a wedge of cement stabilised sandstone that is proposed to be placed adjoining the walls of the proposed Car Park structure and the majority of the lower walls of the overlying 'Future Cultural Facility' Building Space. This has been advised by BDA to consist of crushed sandstone blended with cement. The cement is generally used to fill the voids in the crushed sandstone and is hydrated so to achieve the strength characteristics required. The voids between the hydrated cement would be anticipated to minimise vapour and seepage water movement through this material, in a similar manner to a low permeability soil.

It is understood that the remainder of the backfill in the vicinity of the Car Park, including a potential void underlying the Car Park, as shown in **Figures 13 to 15** will consist of general fill materials. No engineering specification has been provided for these materials.

Limited analysis of geological parameters of existing soils on the Barangaroo Site has been undertaken in AECOM (2010a and 2010b), DP (2010a) and/or the additional analysis of AECOM (2010) samples. Levels of organic carbon in site soils have been found to range from 0.15% to 2.8%.

On this basis, for the purposes of risk assessment and fate and transport modelling, there are considered to be four distinct soil types that will be present in the majority of the Park:

- Soils present at near surface depths (depths of 0.5-1.5m dependent on the nature of the associated planting) to be used as growing medium;
- Soils to be present in the sandstone retaining wall as shown on **Figure 15**;
- Soils to be present as general fill material throughout the bulk of the Park; and
- In-situ soils as will be present below the capping layer as provided to the Park.

4.2 Hydrogeology and Water Balance

As described in **Sections 2.6** and **2.8**, surface and sub-surface water movement on the proposed Headland Park can be broadly described as:

- Surface water flows over the majority of the park surface will be collected and controlled by a system of shallow 'bioswale' drains;
- Deeper surface water which infiltrates into the Headland profile of the Park is anticipated to infiltrate to the depth of an underlying clay liner as part of a deep seepage water collection system;
- Existing groundwater present underlying the site (within in-situ soils) which is substantially tidally influenced;
- Minor leakage of seepage water out of the Headland portion of the site into the underlying in-situ soils; and
- Substantial re-use of collected seepage waters as irrigation water on the Park subsequent to treatment, otherwise disposal off-site.

There is anticipated to be very limited interaction between seepage water occurring within the headland portion of the site, and the existing and continuing tidally influenced groundwater underlying the site.

No information is available on a likely depth of a seepage water table that may occur within the Headland portion of the site. Noting the extent of compaction proposed with soils below a depth of 0.5-0.8m bgs (the typical depth of 'growing medium soils' to be placed over the majority of the Park area) there is a potential that a seepage water horizon (as associated with a significant area of connected saturated soils) may occur above this depth, however the Park is being designed to ensure the rapid drainage of this seepage water. Depending on the effectiveness of the deep drain to be installed above the clay liner, there is also a potential that a seepage water horizon may also establish at depth underlying the headland.

Advice on groundwater flows in the current sub-surface underlying the area of the Park has been provided in emails from John Braybrooke of Douglas Partners (28/7/2010). It has been advised:

- Groundwater inflow /outflow into the proposed excavation underlying the Car Park is anticipated to be very low and less than 1 litre/minute; and
- The majority of groundwater movement underlying the site consists of water movement through the high permeability fill materials that are currently present overlying the natural sandstone at the boundaries of the Park site. It has been estimated that groundwater fluxes of 100-150 ML/day may move in and out of the highly permeable sub-surface zone.

4.3 Constituents of Potential Concern

COPCs identified as adversely impacting soils and/or groundwater have been found to include:

- Heavy metals including copper, lead, and zinc;
- Total petroleum hydrocarbons (TPH);
- Monocyclic aromatic hydrocarbons including benzene, toluene, ethylbenzene and xylenes;
- Polycyclic aromatic hydrocarbons;
- Phenols;
- Cyanides;
- Ammonia;
- Sulphates; and
- Asbestos.

Other COPCs that may also be present that have not been previously tested for include:

- Other volatile organic compounds, particularly including other monocyclic aromatic hydrocarbons (e.g. trimethylbenzenes).

4.4 Known On-Site Occurrences of COPCs

The principal area of impact in the proximity of the proposed Headland Park and Northern Cove is located at the footprint of the former gasworks (ERM 2008b). COPCs including PAHs, BTEX, TPH, phenols, cyanide, lead and zinc have been identified in this area of the Barangaroo Project Site. Highest levels of hydrocarbon constituents are co-incident with former gasworks infrastructure, with the depth of impact below the site surface generally increasing with further distance away from the former infrastructure.

Elevated levels of lead have also been identified throughout the area of the former gasworks, generally associated with near surface fill material generally described as consisting of sand and silty sand soils. These fill materials are present throughout the site and the lead impact does not appear co-incident with this or any particular type of fill.

Hydrocarbon impacts have been identified in fill based soils, underlying natural soils and within deeper sandstone occurring within rock fractures within the area of the former gasworks. There is evidence of the lateral and downward migration of hydrocarbon impact.

Several hot-spots are located over the remainder of the Barangaroo Project Site including the proposed location of the Headland Park and Northern Cove. These hot-spots generally consist of lead impacted fill materials, or PAH impacted fill materials. These specifically include:

- Lead hot-spots at the south-west of the Barangaroo Project Site and the centre of the eastern boundary; and
- Several hot-spots of PAH impact generally present in fill materials across the Barangaroo Project Site including hot-spots at the perimeter of the former gasworks, extensive impact in fill materials at the north-western portion of the Barangaroo Project Site and localised hot-spots over the central and southern portions of the Barangaroo Project Site.

Common fill types are identified by the review of borelogs across the site. It is noted that for the extent of fill material across the Barangaroo Project Site, that a broad program of sampling and analysis has been undertaken. It is likely that localised lead, and particularly PAH/TPH impacts, may be present in other areas of the site due to the heterogeneous nature of the fill materials.

It is also noted that the highest levels of hydrocarbon impacts (PAHs, TPH and BTEX) have been coincident with aesthetic impacts including odours and observations of tar. This indicates that where areas of gross impacts have not been identified by the sampling and analysis works completed to date, they will be identified by aesthetic indicators during the proposed future earthworks.

Groundwater at the northern portion of the site in the proximity of the proposed Headland Park and Northern Cove is currently found to be free of substantial environmental impact.

4.5 Potential Off-Site Sources of COPCs

The remnant gasworks infrastructure beneath Hickson Rd has been identified as a potential off-site source of COPCs. This is hydrogeologically upgradient of the central and southern portion of the Barangaroo Site. No potential off-site sources of COPCs have been identified at the north of the Barangaroo Site in the proximity of the Headland Park and Northern Cove.

4.6 Preferential Pathways

For the purpose of this assessment, preferential pathways have been identified as natural and/or manmade pathways that result in the preferential migration of COPCs as either liquids or gasses.

Man-made preferential pathways are present at the north of the Barangaroo Project Site, generally associated with extensive sand and gravel based fill materials. As indicated by estimates of hydraulic conductivity and extent of tidal influence observed in groundwater monitoring wells, these fill materials are found to have a high permeability.

Fill materials sourced from on-site and comprising sand based soils potentially with crushed sandstone, will form the basis of the geology of the Headland Park. The geological profile of the area of the Headland Park, in particular, will be substantially altered by these proposed filling works. As such, the geology of the Headland Park formed by the filling and raising of the site profile, is also likely to be very permeable. There is potential that a perched / localised aquifer, recharged by surface infiltration and potential shallow sub-surface flows from the east of the site, will occur within the fill materials.

4.7 Potential Leaching of Environmental Impact

Impacted soils are present across the area of the proposed Headland Park and Northern Cove. These are generally present within fill materials as hot-spots. Low levels of environmental impact have been identified in groundwater underlying the proposed area of the Park and Cove. The low levels of impact in groundwater, compared to the potential leaching potential of the impacted fill materials, have been indicated in previous assessments to be consequent of extensive tidal flushing of marine water occurring in the high permeability sub-surface soils.

The excavation and handling of soils during the development of the Headland Park may expose areas of environmental impact to future leaching processes. Fill materials from

the Barangaroo Project Site used to raise the surface of the Park may be subject to environmental impact. The hydrogeological regime of the redeveloped park has been defined in AgEnviro (2010) and summarised in **Section 4.2**. Seepage water flows will occur in upper depth permeable soils and through deeper less permeable fill based soils. Constituents present in each of the soils will potentially be impacted by leaching from fill materials used to form the soils.

4.8 Exposure Pathways

The ecological exposure pathways considered to be potentially complete include:

- Contaminant uptake by vegetation proposed to be established in the Headland Park. Root zones of plantings are proposed to be contained within soils defined as 'growing medium' and will not exceed 1.5m in depth. Contaminant intake will occur through soils and leachate / seepage water as present in soils; and
- Exposure of ecological receptors within Darling Harbour to leachate from fill materials, as located outside the extent of the clay lined sub-surface drainage system, migrating through seepage water / groundwater flows to the extent of the Harbour.

It is anticipated that groundwater extraction will not occur over the area of the Headland Park site. Therefore, this has not been considered as a complete exposure pathway.

4.9 Receptors

Potential ecological receptors of COPCs include:

- Flora species to be established on the Headland Park including large fig plantings; and
- The marine water ecosystem of Darling Harbour and Port Jackson.

5 Issue Identification

Issue identification is the first step of the risk assessment process.

5.1 Issue Identification

Issue identification determines whether risk assessment is useful, and establishes a context for the risk assessment by a process of identifying the concerns the risk assessment needs to address. Issue identification draws on all relevant lines of information.

Issue identification comprises several phases:

1. Identification of environmental health issues (or an individual issue) and determining whether there are hazards amenable to risk assessment. This will involve demarcating 'hazards' from 'issues' and may require environmental sampling;
2. Putting the hazards into their environmental health context (clarification and prioritising of problems and hazards);
3. Identification of potential interactions between agents; and
4. Stating clearly why risk assessment is needed and the scope and objectives of the risk assessment. This will involve identifying problems for which information is, or can be, available to undertake adequate risk assessments and problems which risk assessment cannot assist.

5.2 Identification of Environmental Hazards

Environmental health hazards may be caused by physical, chemical, biological or social factors in the environment. Physical factors include heat, cold, noise, mechanical hazards etc. Chemical factors include synthetic and naturally occurring substances. Biological factors include viruses, prions, bacteria, parasites and vermin.

The proposed Headland Park Site is the subject of this assessment. Environmental impact is currently present in isolated areas of the Barangaroo Project Site, reported to be consequent of historical placement of fill materials associated with the former industrial use of the Headland Park Site and surrounding area.

The fill materials currently present in the portion of the Barangaroo Project Site to be developed as the Headland Park and Northern Cove are impacted with elevated levels of heavy metals, petroleum hydrocarbons and monocyclic and polycyclic aromatic hydrocarbons (MAHs and PAHs).

Surplus materials from the remainder of the Barangaroo Project Site will potentially be used as fill materials in the construction of the Headland Park. A range of industrial uses and associated filling activities have occurred across the Barangaroo Project Site. Most significantly a former gasworks operated within the southern portion. A range of environmental contaminants have been identified within soil and groundwater in the proximity of the former gasworks including heavy metals, petroleum hydrocarbons, MAHs, PAHs, cyanides and phenols. The highest levels of these constituents have generally been associated with observations of tar within soils and groundwater.

5.3 Environmental Sampling and Analysis

Environmental sampling and analysis are a key factor in identifying the agents that may be present, their concentrations and distributions. Environmental sampling and analysis require to be targeted to address the identified potential environmental hazards.

Environmental sampling and analysis have been detailed in the previous investigations listed in **Section 3**. Within the area of the proposed Headland Park a range of environmental constituents including heavy metals, petroleum hydrocarbons, MAHs, and PAHs have been identified in soils at levels exceeding NSW DECCW published and/or endorsed investigation criteria. Across the broader area of the Barangaroo Project Site, where fill materials may potentially be sourced from to create the proposed landform of the Park, significantly elevated levels of heavy metals, petroleum hydrocarbons, MAHs, PAHs, cyanides and phenols have been reported in soils and/or groundwater, in particular, associated with tar impacted materials identified in the proximity of the former gasworks.

5.4 Putting Hazards into their Environmental Health Context

Putting the hazards into their environmental context entails a consideration of:

- Whether the hazard has single or multiple sources;
- Whether the type of environmental impact affects multiple environmental media;
- How stakeholders perceive the problem including the consideration of different groups; and
- How do the hazards compare to other environmental hazards affecting the community.

The environmental hazards across the Barangaroo Project Site may have multiple sources arising from the former commercial / industrial processes undertaken (including operation of a gasworks) and the anticipated significant generation and potential on-site placement of waste materials / by-products. These materials may also pose potential ecological impacts, particularly in locations where leaching of impact may enter waterways, or in soils used as growing media.

The risk assessment requires consideration of the redevelopment of the northern portion of the Barangaroo Project Site as the Headland Park. Potential ecological receptors within the open waters of Darling Harbour and potential flora to be used in the park (including large tree plantings) may be exposed to this impact.

As the environmental hazards present on the Barangaroo Project Site are related to commonly occurring commercial / industrial contaminants, including heavy metals, petroleum hydrocarbons, monocyclic hydrocarbons and polycyclic hydrocarbons, that previously had widespread use throughout Australia, it can be assumed that the environmental hazard does not pose a unique hazard to the community. However, the presence of these contaminants in uncontrolled locations, potentially accessed by sensitive populations, may serve to increase the exposure of the community and/or the environment to the environmental hazard.

5.5 Identification of Potential Interactions between Agents

There may be interactions between the physical, chemical, biological and social hazards that require identification and consideration as part of a risk assessment. There are several potential types of interactions between hazardous agents which include: additive effects; synergistic effects; potentiation effects and antagonistic effects.

It is widely acknowledged that activities such as smoking can increase the susceptibility of a person to the potential effects of some carcinogens. To this effect, it will be required to be ensured that conservatively derived data and reasonably maximum exposed receptors are used as the basis for any risk assessment.

5.6 Why is Risk Assessment Needed?

The occurrence of environmental hazards in a site sub-surface is unique for every site and location. Further, the particular populations exposed to an environmental hazard are unique for every occurrence of the environmental hazard. Regulatory authorities within NSW do not provide comprehensive guidance for the assessment as an environmental hazard of the range of contaminants identified within the proposed Headland Park or present within the wider Barangaroo Project Site, where fill materials to construct the Park may be sourced. The limited guidance available is considered unsuitable to be solely applied to the development of the proposed Headland Park and Northern Cove.

The requirement, and method, for remediation/management for an environmental hazard needs to be determined. The extent of this potential requirement must be determined by the assessment of the presence of an environmental hazard; the degree of potential harm posed by the environmental hazard (in an isolated environment); and the likely exposure of the environment to the environmental hazard. Only through the assessment of all these factors can the true impact of the environmental hazard be assessed. The risk assessment process is designed to include all of these factors to determine a site specific requirement and associated acceptance criteria for a range of environmental constituents, which may be present in soils and/or and/or seepage water and/or groundwater which will occur on the Site.

5.7 Limitations and Uncertainties

Potential limitations and uncertainties that may occur in the risk assessment process include:

- Information gaps, e.g. effects of mixtures, low level and variable exposures over time, relative contribution of 'lifestyle' factors;
- Poor exposure information, e.g. complex mixtures of hazards with complex behaviours in the environment; limited knowledge about the actual or potential sub-population;
- Limitations of toxicological or epidemiological research, e.g. small populations and limited exposure information, multifactorial causes of many diseases on health impacts; 'background noise' affecting research into common diseases or symptoms; population heterogeneity;
- Complexity, e.g. large numbers of combinations of hazards, exposures and health states;
- Confidentiality of health and commercial information;
- Charged atmosphere of fear, antagonism and distrust; and

- Value conflicts.

The risk assessment requires a thorough sensitivity analysis subsequent to the provision of the risk outcomes. The sensitivity analysis will be required to take these matters into account, testing the outcome of the risk assessment of reasonable upper and lower bounds of each. Sensitivity analysis of all assumptions has been undertaken throughout the risk assessment. Risk assessment outcomes may require to be modified where sensitive parameters are observed to have large reasonable potential deviations.

6 Selection of Constituents of Potential Concern

Extensive soil and groundwater data have been collected from underlying the Barangaroo Project Site. Surplus soils may potentially be received from the Barangaroo Project Site and used in the development of the Headland Park (subject to environmental suitability). Such soils may further leach contaminants and impact sub-surface seepage water, which may potentially occur at shallow depths within the area of the Headland Park. Sub-surface seepage water collection, proposed as part of remedial planning for the Park, may facilitate re-use of seepage water on the Headland Park site. Consequently, the proposed Headland Park Site development will potentially alter the exposure patterns to current site groundwater.

A screening assessment is required to select constituents of potential concern (COPCs) so as to distinguish between chemical constituents which pose little or no risk to the environment and those constituents which may pose a risk. The screening assessment has been undertaken by a comparison of measured constituent concentrations with adopted screening criteria. Constituent concentrations across the whole of the Barangaroo Project Site have been considered.

Where constituent concentrations in the soil at the Barangaroo Project Site do not exceed the screening criteria, it may be concluded with a high degree of confidence that those constituents do not pose a significant risk to the environment. Constituents exceeding screening criteria are set as COPCs for further risk assessment.

Similarly, constituent concentrations in groundwater are compared against the adopted screening criteria. Groundwater contaminants exceeding the screening criteria are also termed COPC and are nominated for risk assessment

6.1 Selection of Screening Criteria

Assessment criteria for sensitive land-uses are provided by regulatory authorities in Australia and internationally. Though these assessment criteria are not strictly applicable to the exposure scenarios and occurrence of site impact within the study area, they can be used to select constituents of potential concern (COPC's) requiring further assessment. The published assessment criteria used include:

- Soil criteria published in NSW DEC (2006) 'Contaminated Sites: Guidelines for the NSW Site Auditor Scheme 2nd Edition'. Provisional phytotoxicity-based investigation levels (PPBILs) have been selected to assess potential ecological impacts;
- Soil criteria published in NSW EPA (1994) 'Contaminated Sites: Guidelines for Assessing Service Station Sites'. Criteria provided in this document have been used to assess potential ecological impacts;
- Water quality trigger levels published in ANZECC/ARMCANZ (2000) 'Australian and New Zealand Guidelines for Fresh and Marine Water Quality'. Marine Water 95% protection values have been used for the assessment of ecological impacts of groundwater.
- The Dutch Intervention Level for soils, sediments and groundwater provided to Ministry of Housing, Spatial Planning and the Environment (2000) 'Circular on target and intervention values for soil remediation'. Soil / sediment target values have been used as screening criteria for ecological impacts to soils. Groundwater

criteria have been considered as ecological criteria, as they are derived by a consideration of human health and ecological effects; and

- US EPA Region III (1995) BTAG Screening Levels. These criteria have been used as screening criteria for ecological impacts in soils. These criteria are reported to be very conservative.

The criteria selected from the above sources are summarised in **Table 6.1**, following, for soils and **Table 6.2** for groundwater, for each constituent recorded above detection limits in the analytical data sets.

Table 6.1: Summary of Soil Screening Criteria (mg/kg)

Constituent	Ecological Criteria
<i>Heavy metals</i>	
Arsenic	20 ²
Cadmium	3 ²
Chromium	1 ^{1, 2}
Copper	100 ²
Lead	600 ²
Mercury	1 ²
Nickel	60 ²
Zinc	200 ²
<i>Other Inorganics</i>	
Sulphate	NC
Cyanide (total)	1 ^{3, 7}
<i>Total Petroleum Hydrocarbons</i>	
TPH C ₆ -C ₉	65 ⁴
TPH C ₁₀ -C ₁₄	1,000 ⁴
TPH C ₁₅ -C ₂₈	
TPH C ₂₉ -C ₃₆	
<i>Monocyclic Aromatic Hydrocarbons</i>	
Benzene	1 ⁴
Toluene	1.4 ⁴
Ethylbenzene	3.1 ⁴
Xylene (total)	14 ⁴
<i>Polycyclic Aromatic Hydrocarbons</i>	
Total PAHs	20 ⁴
Acenaphthene	0.1 ⁵
Acenaphthylene	0.1 ⁵
Anthracene	0.1 ⁵
Benz(a)anthracene	0.1 ⁵
Benzo(a)pyrene	0.1 ⁵
Benzo(b)fluoranthene	0.1 ⁵
Benzo(g,h,i)perylene	0.1 ⁵
Benzo(k)fluoranthene	0.1 ⁵
Chrysene	0.1 ⁵
Dibenz(a,h)anthracene	0.1 ⁵
Fluoranthene	0.1 ⁵
Fluorene	0.1 ⁵
Indeno(1,2,3-c,d)pyrene	0.1 ⁵
Naphthalene	0.1 ⁵
Phenanthrene	0.1 ⁵
Pyrene	0.1 ⁵
<i>Phenols</i>	
Phenol	0.05 ⁷
2,4-dimethylphenol	0.1 ⁵
2-methylphenol	0.05 ^{6, 7}
3- & 4-methylphenol	

- Notes: 1. Value for Cr(VI)
 2. DEC (2006) 'Provisional phytotoxicity based investigation levels
 3. Based on cyanides (free)
 4. NSW EPA (1994)
 5. US EPA Region III (1995) BTAG Screening Level, soil, flora and fauna
 6. Criteria for sum of cresols
 7. Netherlands Ministry for Housing, Spatial Planning and the Environment (2000) target value
 NC no criteria

Table 6.2: Summary of Groundwater Screening Criteria (µg/l)

Constituent	Ecological Criteria
<i>Heavy metals</i>	
Arsenic	2.3 ^{1, 2}
Cadmium	0.7 ^{1, 13}
Chromium (total)	4.4 ^{1, 3, 4}
Copper	1.3 ^{1, 3}
Lead	4.4 ^{1, 3}
Mercury	0.1 ^{1, 13}
Nickel	7 ^{1, 13}
Zinc	15 ^{1, 3}
<i>Other Inorganics</i>	
Ammonia	910 ^{1, 5}
Cyanide (total)	4 ^{1, 6}
<i>Total Petroleum Hydrocarbons</i>	
TPH C ₁₅ -C ₂₈	600 ⁷
TPH C ₂₉ -C ₃₆	
<i>Monocyclic Aromatic Hydrocarbons</i>	
Benzene	500 ^{1, 8}
Xylenes	75 ^{1, 9}
1,2,4-trimethylbenzene	150 ¹⁵
<i>Polycyclic Aromatic Hydrocarbons</i>	
Benz(a)anthracene	0.5 ⁷
Benzo(a)pyrene	0.2 ^{1, 10}
Benzo(b)fluoranthene	0.05 ^{7, 11}
Benzo(g,h,i)perylene	0.05 ⁷
Benzo(k)fluoranthene	0.05 ⁷
Chrysene	0.2 ⁷
Fluoranthene	1.4 ^{1, 10}
Indeno(1,2,3-c,d)pyrene	0.05 ⁷
Naphthalene	50 ^{1, 8, 14}
Phenanthrene	2 ^{1, 10}
Pyrene	0.24 ¹²

- Notes: 1. ANZECC / ARCANZ (2000)
2. Low reliability value derived for As(III)
3. High reliability value, 95% protection
4. Value for Cr(VI)
5. Moderate reliability with 95% protection for pH 8.0 and ammonia (as N)
6. Moderate reliability with 95% protection for 36ionized HCN
7. Netherlands Ministry for Housing, Spatial Planning and the Environment (2000) intervention value for mineral oil. Mineral oil adopted for assessment of total petroleum hydrocarbons.
8. Moderate reliability
9. Based on freshwater value
10. Low reliability with 95% protection
11. As per value for benzo(k)fluoranthene
12. TNRCC (Texas Natural Resource Conservation Commission), Toxicology and Risk Assessment Section. December 2001. Guidance for Conducting Ecological Risk Assessments at Remediation Sites in Texas
13. High reliability value, 99% protection level. Used on basis of potential bioaccumulation.
14. 99% protection level. Used on basis of potential bioaccumulation.
15. Netherlands Ministry for Housing, Spatial Planning and the Environment (2000) criteria for aromatic solvents in groundwater, based on 40.5% of 1,2,4-trimethylbenzene.
NC no criteria

It is noted that analysis has been undertaken for additional monocyclic aromatic hydrocarbons (MAHs) and polycyclic aromatic hydrocarbons (PAHs) and other semi-volatile organic compounds to those listed in **Tables 6.1** and **6.2**. In undertaking these assessments it is noted that ecotoxicological data to assess these constituents is very limited. Observing the extent of available ecotoxicological data for these constituents, and their general co-occurrence with the other MAHs and PAHs, it is considered that assessment of the selected hydrocarbon constituents will be adequately protective of the constituents omitted from the assessment.

It is also noted that an expanded list of metals to the eight priority metals assessed here have been detected in soils on the Barangaroo South and Central sites. Where the highest levels of these other heavy metals occur, it is generally coincident with elevated levels of some of the eight selected heavy metals. It is considered that restriction of the

ecological assessment to the eight priority metals will be protective of the potential impacts of the other heavy metals.

6.2 Selection of COPCs in Soils

Environmental data for the Barangaroo Project Site have been reviewed and the maximum concentration of each constituent determined.

It is noted that on the basis of the total PAH criteria as published by Australian jurisdictions that all PAH constituents require to be selected as COPCs in soils and potential sediments. Where speciated criteria are available from international agencies these have also been referred to in the refinement of the selection of PAH constituents for detailed risk assessment. These speciated criteria were also included in **Table 6.1**. This has resulted in the reduction of the number of PAH constituents for detailed consideration for human health assessment.

Maximum concentrations have been compared to the screening criteria and selected as a COPC where the screening criteria are exceeded, as summarised in **Table 6.3**, following.

Table 6.3: Summary of Selection of COPCs for Soils

Constituent	Maximum Concentration (mg/kg)	COPC Selection
		Ecological (soils)
<i>Heavy Metals</i>		
Arsenic	94	X
Cadmium	5	
Chromium	1600	X
Copper	1480	X
Lead	13,600	X
Mercury	14.7	X
Nickel	470	X
Zinc	4770	X
<i>Other Inorganics</i>		
Sulphate	31,500	
Cyanide (total)	6900	X
<i>Total Petroleum Hydrocarbons</i>		
TPH C ₆ -C ₉	10,282	X
TPH C ₁₀ -C ₁₄	89,207	X
TPH C ₁₅ -C ₂₈	166,423	X
TPH C ₂₉ -C ₃₆	25,800	X
<i>Monocyclic Aromatic Hydrocarbons</i>		
Benzene	1510	X
Toluene	2650	X
Ethylbenzene	261	X
Xylene (total)	2629	X
<i>Polycyclic Aromatic Hydrocarbons</i>		
Acenaphthene	511	X
Acenaphthylene	2569	X
Anthracene	2150	X
Benz(a)anthracene	1870	X
Benzo(a)pyrene	908	X
Benzo(b)fluoranthene	975	X
Benzo(g,h,i)perylene	305	X
Benzo(k)fluoranthene	975	X
Chrysene	1009	X
Dibenz(a,h)anthracene	110	X
Fluoranthene	2569	X
Fluorene	2100	X
Indeno(1,2,3-c,d)pyrene	404	X
Naphthalene	17,064	X
Phenanthrene	5186	X
Pyrene	2640	X
<i>Phenols</i>		
Phenol	1720	X
2,4-dimethylphenol	754	X
2-methylphenol	1160	X

Constituent	Maximum Concentration (mg/kg)	COPC Selection
		Ecological (soils)
3- & 4-methylphenol	2290	X

6.3 Selection of COPCs in Groundwater

Environmental data for the Headland Park and Northern Cove only have been reviewed and the maximum concentration of each constituent determined. This has restricted the assessment of groundwater to results from monitoring wells MW01 to MW07, MW19, MW25 and MW215 as reported in ERM (2007 and 2008) and BH322A and BH328 as reported in DP (2010b). Maximum concentrations have been compared to the screening criteria and selected as a COPC where the screening criteria are exceeded, as summarised in **Table 6.4**, following.

Table 6.4: Summary of Selection of COPCs for Groundwater

Constituent	Maximum Concentration (µg/l)	COPC Selection
		Ecological
<i>Heavy metals</i>		
Arsenic	13	X
Cadmium	43.2	X
Chromium (total)	1.9	
Copper	153	X
Lead	65	X
Manganese	410	X
Mercury	0.1	
Nickel	303	X
Zinc	392	X
<i>Other Inorganics</i>		
Ammonia	4,320	X
Cyanide (total)	11.8	X
<i>Total Petroleum Hydrocarbons</i>		
TPH C ₁₅ -C ₂₈	400	X
TPH C ₂₉ -C ₃₆	200	X
<i>Monocyclic Aromatic Hydrocarbons</i>		
Benzene	3	
Xylenes	3	
1,2,4-trimethylbenzene	1.2	
<i>Polycyclic Aromatic Hydrocarbons</i>		
Benz(a)anthracene	2.2	X
Benzo(a)pyrene	2.7	X
Benzo(b)fluoranthene	2.8	X
Benzo(g,h,i)perylene	2	X
Benzo(k)fluoranthene	1.6	X
Chrysene	2.4	X
Fluoranthene	5.5	X
Indeno(1,2,3-c,d)pyrene	1.8	X
Naphthalene	7.7	
Phenanthrene	2.5	X
Pyrene	6.5	X

On the basis of **Tables 6.3** and **6.4** the COPCs to be considered for each media requiring risk assessment are summarised in **Table 6.5** to **6.7**, following.

Table 6.5: Summary of COPCs for Soils

Soils (used as growing medium)
Arsenic
Chromium
Copper
Lead
Mercury
Nickel
Zinc
Cyanide
TPH
Benzene
Toluene
Ethylbenzene
Xylene
Acenaphthene
Acenaphthylene
Anthracene
Benz(a)anthracene
Benzo(a)pyrene
Benzo(b)fluoranthene
Benzo(g,h,i)perylene
Benzo(k)fluoranthene
Chrysene
Dibenz(a,h)anthracene
Fluorene
Fluoranthene
Indeno(1,2,3-c,d)pyrene
Naphthalene
Phenanthrene
Pyrene
Phenol
2,4-dimethylphenol
2-methylphenol
3-&4-methylphenol

- Note:
1. Not selected as a COPC for human health effects as comparison to conservative NSW DEC (2006) soil screening did not identify exceedances. NSW DEC (2006) criteria are considered to be suitably protective of human exposures to sediments in Northern Cove.
 2. Not selected as a COPC for human health effects as assessment of more toxic PAH constituents, as identified by selection of COPCs for human health assessment considered to be adequately protective of these COPCs.
 3. Included as toxicological data readily available. To ensure that the potential extent of PAHs is adequately assessed based on DEC (2006) total PAH criteria being exceeded in toxicological review.

Table 6.6: Summary of COPCs for Groundwater

Groundwater (existing – ecological)
Arsenic
Cadmium
Copper
Lead
Manganese
Nickel
Zinc
Ammonia (as N)
Cyanide
TPH (C ₁₅ -C ₂₈)
TPH (C ₂₉ -C ₃₆)
Benz(a)anthracene
Benzo(a)pyrene
Benzo(b)fluoranthene
Benzo(g,h,i)perylene
Benzo(k)fluoranthene
Chrysene
Fluoranthene
Indeno(1,2,3-c,d)pyrene
Phenanthrene
Pyrene

Seepage water horizons will potentially be formed at the site at shallow depths, and at deeper depths. It is proposed to re-use seepage water as irrigation water on the Park. Seepage water may be subject to chemical impact by leaching of soils. COPCs for seepage / irrigation water are summarised in **Table 6.7**.

Table 6.7: Summary of COPCs for Potential Future Seepage Water Re-Used as Irrigation Water

Seepage Water (future – ecological)
Arsenic
Chromium
Copper
Lead
Mercury
Nickel
Zinc
Cyanide
TPH
Benzene
Toluene
Ethylbenzene
Xylene
Acenaphthene
Acenaphthylene
Anthracene
Benz(a)anthracene
Benzo(a)pyrene
Benzo(b)fluoranthene
Benzo(g,h,i)perylene
Benzo(k)fluoranthene
Chrysene
Dibenz(a,h)anthracene
Fluorene
Fluoranthene
Indeno(1,2,3-c,d)pyrene
Naphthalene
Phenanthrene
Pyrene
Phenol
2,4-dimethylphenol
2-methylphenol
3-&4-methylphenol

The selection of COPC’s for seepage water have included the COPC’s selected by comparison to soil and groundwater screening criteria, as these are indicative of the constituents that may leach from site soils and cause potential human health impacts in seepage water.

The selection of COPCs for seepage water that may have potential ecological impacts has included each of the constituents selected in soils as potentially posing an ecological risk. These are considered to be the constituents that may leach from soils and pose potential ecological impacts.

Ecological risk assessment of soils, for use as growing medium, is undertaken in **Section 7** by a phytotoxicity assessment. Ecological risk assessment of potential future seepage water and groundwater is undertaken in **Section 8**.

7 Phytotoxicity Assessment

Substantial vegetation plantings are proposed with the development of the Headland Park. This includes a number of garden areas with a range of shrubs, and importantly a number of mature Fig tree plantings. Soils which are defined as growing medium, which are accessible to the root network of the proposed plantings, are required to be suitable from a phytotoxicity perspective to be used as growing medium. It has been identified that soils classified as a growing medium will be present:

- To a depth of 0.5m in areas of grass plantings;
- To a depth of 0.8m in areas of shrub plantings; and
- To a depth of 1.5m in proximity of tree plantings.

The phytotoxicity assessment for soils applies to soils proposed to be used as growing medium within the area of the Park.

A screening assessment has been undertaken in **Section 6** to identify COPCs in soils for potential phytotoxicity / ecological impacts.

Specific ecological criteria for the protection of potential plantings / vegetation have been derived for the site in substantial accordance with the methodology presented in Heemsbergen D, Warne M, McLaughlin M and Kookana R CSIRO (October 2009) 'The Australian Methodology to Derive Ecological Investigation Levels in Contaminated Soils' (CSIRO, 2009). It is reported in CSIRO (2009) that the methodology presented in the document is the basis of the revised ecological criteria proposed in the revision of the National Environment Protection (Assessment of Site Contamination) Measure. This is described in the following sections.

7.1 Level of Protection

The proposed Headland Park is classified as 'Urban residential and public open space' as per the definitions provided to CSIRO (2009). These are described as "*not pristine, rather extensively modified, but retaining important functions and species. These land-uses are expected to maintain plant growth of both introduced and native species*".

Microorganisms and soil invertebrates are nominated as requiring to be protected for these land-uses.

It is recommended in CSIRO (2009) that 80% of species and soil microbial processes are protected for this land-use, increasing to 85% for constituents that have a potential for biomagnification.

7.2 Exposure Pathways

The following exposure pathways require to be addressed for the site soils, as per CSIRO (2009):

- Soil – organism (via ingestion, organisms include herbivores and soil dwellers);
- Soil – soil organism (passive absorption);
- Soil – soil organisms – soil predators including the potential for biomagnification for contaminants having biomagnification potential;
- Soil – plants;
- Soil – plant – herbivores – carnivores for contaminants having biomagnification potential;

- Soil – soil organisms and/or soil predators – terrestrial predators for contaminants having biomagnification potential;
- Soil – groundwater – surface water – aquatic organisms – aquatic predators for contaminants having biomagnification potential; and
- Soil – surface water – aquatic organisms as the site of the Headland Park is proposed to slope significantly to Darling Harbour.

7.3 Constituent Data

A range of constituent data is identified in CSIRO (2009) as requiring to be assessed for the COPCs. This includes constituent half life in the environment, Henry's Law constant, octanol-water partition co-efficients and organic carbon-water coefficients.

This data are summarised in **Table 7.1** for each of the COPCs.

On the basis of these chemical properties the exposure routes requiring to be considered for each of the COPCs are summarised in **Table 7.2**.

7.4 Background Concentrations

It is advised in CSIRO (2009) that naturally occurring concentrations must be considered when deriving ecological investigation levels (EILs) for soils. This is based on the 'added risk approach'. This approach assumes that the availability of the ambient background concentration (ABC) of a contaminant is zero or sufficiently close that it makes no practical difference. It assumes that the background has resulted in the biodiversity of ecosystems or serves to fulfil the needs for micronutrients for the organisms in the environment. This approach views only the effect of added contaminants to the environment as adverse.

Though the Headland Park is proposed to consist of new plantings, these plantings are consistent with plant species that are present throughout similar parks in the Sydney region (e.g. Mrs Macquarie's Chair). Though the specific plants may not have been exposed to specific background concentrations on the actual Headland Park site, it is reasonable to assume that actual species are present in other areas of Sydney at least partially consequent of background levels of environmental constituents in soils. The added risk approach has been adopted for the proposed Headland Park.

Background concentrations of COPCs in soils have been determined by review of soils concentrations as reported in Olszowy H, Torr P, Imray P (1995) 'Trace Element Concentrations in Soils from Rural and Urban Areas of Australia'. These are summarised in **Table 7.3** following as based on the values reported for 'old suburbs high traffic' in NSW.

Limited data are available on background levels of organic COPCs in Sydney soils. It is likely that these are very low, and for the purposes of this assessment will be assumed to be equal to zero.

Table 7.1: Summary of Data for COPCs

COPC	Half-life	K _H	K _{ow}	K _{oc}	Comments / Source
Arsenic	1 * 10 ⁸	-	-	-	Half life from California Office of Environmental Health Hazard Assessment (2000) 'Air Toxics Hotspots Program Risk Assessment Guidelines Part IV: Exposure Assessment and Stochastic Analysis Technical Support Document'. Physical properties from Risk Assessment Information System.
Chromium	1 * 10 ⁸	-	-	-	Half life from California Office of Environmental Health Hazard Assessment (2000) 'Air Toxics Hotspots Program Risk Assessment Guidelines Part IV: Exposure Assessment and Stochastic Analysis Technical Support Document'. Physical properties from Risk Assessment Information System.
Copper	1 * 10 ⁸	-	-	-	Half life assumed as based on other metals. Physical properties from Risk Assessment Information System.
Lead	1 * 10 ⁸	-	-	-	Half life from California Office of Environmental Health Hazard Assessment (2000) 'Air Toxics Hotspots Program Risk Assessment Guidelines Part IV: Exposure Assessment and Stochastic Analysis Technical Support Document'. Physical properties from Risk Assessment Information System.
Mercury	1 * 10 ⁸	-	-	-	Half life from California Office of Environmental Health Hazard Assessment (2000) 'Air Toxics Hotspots Program Risk Assessment Guidelines Part IV: Exposure Assessment and Stochastic Analysis Technical Support Document'. Physical properties from Risk Assessment Information System.
Nickel	1 * 10 ⁸	-	-	-	Half life assumed as based on other metals. Physical properties from Risk Assessment Information System.
Zinc	1 * 10 ⁸	-	-	-	Half life assumed as based on other metals. Physical properties from Risk Assessment Information System.
Cyanide	1 * 10 ⁸	5.44*10 ⁻³	10 ^{-0.25}	9.9	Half life data not available. Value used for other inorganics assumed. Physical properties from Risk Assessment Information System, based on free cyanide.
TPH C ₆ -C ₉	-	50-80	-	10 ^{3.6} -10 ^{4.5}	No data for half life. Physical properties as reported in TPHCWG (1997) 'Volume 3 Selection of Representative TPH Fractions Based on Fate and Transport Considerations'. Based on aliphatic fractions in C ₆ -C ₉ range.
TPH C ₁₀ -C ₁₄	-	0.14-120	-	10 ^{3.4} -10 ^{5.4}	No data for half life. Physical properties as reported in TPHCWG (1997) 'Volume 3 Selection of Representative TPH Fractions Based on Fate and Transport Considerations'. Based on aliphatic and aromatic fractions in C ₁₀ -C ₁₄ range.
TPH C ₁₅ -C ₂₈	-	1.3*10 ⁻² – 4,900	-	10 ^{3.7} -10 ^{8.8}	No data for half life. Physical properties as reported in TPHCWG (1997) 'Volume 3 Selection of Representative TPH Fractions Based on Fate and Transport Considerations'. Based on aliphatic and aromatic fractions in C ₁₅ -C ₂₈ range.
TPH C ₂₉ -C ₃₆	-	6.7*10 ⁻⁴	-	10 ^{5.1}	No data for half life. Physical properties as reported in TPHCWG (1997) 'Volume 3 Selection of Representative TPH Fractions Based on Fate and Transport Considerations'. Based on aliphatic and aromatic fractions in C ₂₉ -C ₃₆ range.
Benzene	190	0.227	10 ^{2.13}	1.46*10 ²	Half life from University of California (Dec 1994) 'Intermedia Transfer Factors for Contaminants Found at Hazardous Waste Sites Benzene'. Physical properties from Risk Assessment Information System.
Toluene	90	0.271	10 ^{2.73}	2.34*10 ²	Half life from UK Environment Agency (2009) 'Soil Guideline Values for toluene in soil'. Physical properties from Risk Assessment Information System.
Ethylbenzene	1,155	0.322	10 ^{3.15}	4.46*10 ²	Maximum value of half lives from UK Environment Agency (2009) 'Soil Guideline Values for ethylbenzene in soil'. Physical properties from Risk Assessment Information System.
Xylenes	510	0.212	10 ^{3.12}	3.83*10 ²	Maximum value of half lives from UK Environment Agency (2009) 'Soil Guideline Values for xylene in soil'.

COPC	Half-life	K _H	K _{ow}	K _{oc}	Comments / Source
					Physical properties from Risk Assessment Information System.
Acenaphthene	570	7.5*10 ⁻³	10 ^{3.92}	5.03*10 ³	Half life from recommended value for PAHs in California Office of Environmental Health Hazard Assessment (2000) 'Air Toxics Hotspots Program Risk Assessment Guidelines Part IV: Exposure Assessment and Stochastic Analysis Technical Support Document'. Physical properties from Risk Assessment Information System.
Acenaphthylene	570	4.66*10 ⁻³	10 ^{3.94}	5.03*10 ³	Half life from recommended value for PAHs in California Office of Environmental Health Hazard Assessment (2000) 'Air Toxics Hotspots Program Risk Assessment Guidelines Part IV: Exposure Assessment and Stochastic Analysis Technical Support Document'. Physical properties from Risk Assessment Information System.
Anthracene	570	2.27*10 ⁻³	10 ^{4.45}	1.64*10 ⁴	Half life from recommended value for PAHs in California Office of Environmental Health Hazard Assessment (2000) 'Air Toxics Hotspots Program Risk Assessment Guidelines Part IV: Exposure Assessment and Stochastic Analysis Technical Support Document'. Physical properties from Risk Assessment Information System.
Benz(a)anthracene	570	4.91*10 ⁻⁴	10 ^{5.76}	1.77*10 ⁵	Half life from recommended value for PAHs in California Office of Environmental Health Hazard Assessment (2000) 'Air Toxics Hotspots Program Risk Assessment Guidelines Part IV: Exposure Assessment and Stochastic Analysis Technical Support Document'. Physical properties from Risk Assessment Information System.
Benzo(a)pyrene	570	1.87*10 ⁻⁵	10 ^{6.13}	5.87*10 ⁵	Half life from recommended value for PAHs in California Office of Environmental Health Hazard Assessment (2000) 'Air Toxics Hotspots Program Risk Assessment Guidelines Part IV: Exposure Assessment and Stochastic Analysis Technical Support Document'. Physical properties from Risk Assessment Information System.
Benzo(b)fluoranthene	570	2.69*10 ⁻⁵	10 ^{5.78}	5.99*10 ⁵	Half life from recommended value for PAHs in California Office of Environmental Health Hazard Assessment (2000) 'Air Toxics Hotspots Program Risk Assessment Guidelines Part IV: Exposure Assessment and Stochastic Analysis Technical Support Document'. Physical properties from Risk Assessment Information System.
Benzo(g,h,i)perylene	570	1.35*10 ⁻⁵	10 ^{6.63}	1.95*10 ⁶	Half life from recommended value for PAHs in California Office of Environmental Health Hazard Assessment (2000) 'Air Toxics Hotspots Program Risk Assessment Guidelines Part IV: Exposure Assessment and Stochastic Analysis Technical Support Document'. Physical properties from Risk Assessment Information System.
Benzo(k)fluoranthene	570	2.39*10 ⁻⁵	10 ^{6.11}	5.87*10 ⁵	Half life from recommended value for PAHs in California Office of Environmental Health Hazard Assessment (2000) 'Air Toxics Hotspots Program Risk Assessment Guidelines Part IV: Exposure Assessment and Stochastic Analysis Technical Support Document'. Physical properties from Risk Assessment Information System.
Chrysene	570	2.14*10 ⁻⁴	10 ^{5.81}	1.81*10 ⁵	Half life from recommended value for PAHs in California Office of Environmental Health Hazard Assessment (2000) 'Air Toxics Hotspots Program Risk Assessment Guidelines Part IV: Exposure Assessment and Stochastic Analysis Technical Support Document'. Physical properties from Risk Assessment Information System.
Dibenz(a,h)anthracene	570	5.76*10 ⁻⁶	10 ^{6.75}	1.91*10 ⁶	Half life from recommended value for PAHs in California Office of Environmental Health Hazard Assessment (2000) 'Air Toxics Hotspots Program Risk Assessment Guidelines Part IV: Exposure Assessment and Stochastic Analysis Technical Support Document'. Physical properties from Risk Assessment Information System.
Fluorene	570	3.93*10 ⁻³	10 ^{4.18}	9.16*10 ³	Half life from recommended value for PAHs in California Office of Environmental Health Hazard Assessment (2000) 'Air Toxics Hotspots Program Risk Assessment Guidelines Part IV: Exposure Assessment and Stochastic Analysis Technical Support Document'. Physical properties from Risk Assessment Information System.
Fluoranthene	570	3.62*10 ⁻⁴	10 ^{5.16}	5.55*10 ⁴	Half life from recommended value for PAHs in California Office of Environmental Health Hazard Assessment (2000) 'Air Toxics Hotspots Program Risk Assessment Guidelines Part IV: Exposure Assessment and Stochastic Analysis Technical Support Document'.

COPC	Half-life	K _H	K _{ow}	K _{oc}	Comments / Source
					Physical properties from Risk Assessment Information System.
Indeno(1,2,3-c,d)pyrene	570	1.42*10 ⁻⁵	10 ^{6.7}	1.95*10 ⁶	Half life from recommended value for PAHs in California Office of Environmental Health Hazard Assessment (2000) 'Air Toxics Hotspots Program Risk Assessment Guidelines Part IV: Exposure Assessment and Stochastic Analysis Technical Support Document'. Physical properties from Risk Assessment Information System.
Naphthalene	108	1.80*10 ⁻²	10 ^{3.3}	1.54*10 ³	Half life from US EPA (1991) 'Drinking Water Health Advisory Volatile Organic Compounds'. Physical properties from Risk Assessment Information System.
Phenanthrene	570	1.73*10 ⁻³	10 ^{4.46}	1.67*10 ⁴	Half life from recommended value for PAHs in California Office of Environmental Health Hazard Assessment (2000) 'Air Toxics Hotspots Program Risk Assessment Guidelines Part IV: Exposure Assessment and Stochastic Analysis Technical Support Document'. Physical properties from Risk Assessment Information System.
Pyrene	570	4.87*10 ⁻⁴	10 ^{4.88}	5.43*10 ⁴	Half life from recommended value for PAHs in California Office of Environmental Health Hazard Assessment (2000) 'Air Toxics Hotspots Program Risk Assessment Guidelines Part IV: Exposure Assessment and Stochastic Analysis Technical Support Document'. Physical properties from Risk Assessment Information System.
Phenol	5	1.36*10 ⁻⁵	10 ^{1.46}	1.87*10 ²	Half life as reported for sub-surface soils in Howard P (1989) 'Handbook of environmental fate and exposure data for organic chemicals'. Physical properties from Risk Assessment Information System.
Cresols	8	4.91*10 ⁻⁵	10 ^{1.95}	3.07*10 ²	Time for complete degradation reported in Howard P (1989) 'Handbook of environmental fate and exposure data for organic chemicals'. Physical properties from Risk Assessment Information System.
2,4-dimethylphenol	4	3.89*10 ⁻⁵	10 ^{2.3}	4.92*10 ²	Time for complete degradation reported in Howard P (1989) 'Handbook of environmental fate and exposure data for organic chemicals'. Physical properties from Risk Assessment Information System.

Table 7.2: Summary of Ecological Exposure Routes Requiring Consideration

COPC	Primary Exposure Route	Secondary Exposure Route	Comments
Arsenic	Biomagnification	Direct toxicity	Known to biomagnify as per CSIRO (2009)
Chromium	Biomagnification	Direct toxicity	Unknown biomagnifier
Copper	Direct toxicity	-	Known to not biomagnify as per CSIRO (2009)
Lead	Biomagnification	Direct toxicity	Known to biomagnify as per CSIRO (2009)
Mercury	Biomagnification	Direct toxicity	Known to biomagnify as per CSIRO (2009)
Nickel	Biomagnification	Direct toxicity	Unknown biomagnifier
Zinc	Direct toxicity	-	Known to not biomagnify as per CSIRO (2009)
Cyanide	Biomagnification	Direct toxicity	Unknown biomagnifier
TPH C ₆ -C ₉	Direct toxicity	Metabolites	
TPH C ₁₀ -C ₁₄	Direct toxicity	Metabolites	
TPH C ₁₅ -C ₂₈	Direct toxicity	Metabolites	
TPH C ₂₉ -C ₃₆	Direct toxicity	Metabolites	
Benzene	Direct toxicity	Metabolites	
Toluene	Direct toxicity	Metabolites	
Ethylbenzene	Direct toxicity	Metabolites	
Xylenes	Direct toxicity	Metabolites	
Acenaphthene	Direct toxicity	Metabolites	
Acenaphthylene	Direct toxicity	Metabolites	
Anthracene	Direct toxicity	Biomagnification	
Benz(a)anthracene	Direct toxicity	Biomagnification	
Benzo(a)pyrene	Direct toxicity	Biomagnification	
Benzo(b)fluoranthene	Direct toxicity	Biomagnification	
Benzo(g,h,i)perylene	Direct toxicity	Biomagnification	
Benzo(k)fluoranthene	Direct toxicity	Biomagnification	
Chrysene	Direct toxicity	Biomagnification	
Dibenz(a,h)anthracene	Direct toxicity	Biomagnification	
Fluorene	Direct toxicity	Biomagnification	
Fluoranthene	Direct toxicity	Biomagnification	
Indeno(1,2,3-c,d)pyrene	Direct toxicity	Biomagnification	
Naphthalene	Direct toxicity	Metabolites	
Phenanthrene	Direct toxicity	Biomagnification	
Pyrene	Direct toxicity	Biomagnification	
Phenol	Direct toxicity	Metabolites	
Cresols	Direct toxicity	Metabolites	
2,4-dimethylphenol	Direct toxicity	Metabolites	

Table 7.3: Measured Background Concentrations of Heavy Metals in Soils (mg/kg)

COPC	Arithmetic Mean	50 th Percentile
Arsenic	7	6
Cadmium	0.31	0.25
Chromium	15	15
Copper	52	42
Lead	379	225
Mercury	1.9	0.1
Nickel	7	6
Zinc	230	183

7.5 Review of Ecological Toxicity

It is recommended in CSIRO (2009) that a review of ecological toxicity is undertaken for each COPC for the purposes of deriving EILs. However it is found that several of the principal organic COPCs for the site have very limited to no locally based Australian data available for terrestrial toxicity.

Instead of undertaking potentially non-representative and technically restricted data analysis, a review of all international ecological criteria for each of the COPCs, where DEC (2006) phytotoxicity data or EPA (1994) threshold concentrations are not already available, has been undertaken.

DEC (2006) phytotoxicity criteria and NSW EPA (1994) investigation thresholds for petroleum hydrocarbons and monocyclic aromatic hydrocarbons have been adopted as

the 'added contaminant limit' (ACL) as defined in CSIRO (2009). It is assumed that available DEC (2006) and EPA (1994) criteria are sufficiently conservative to account for the potential exposure routes listed in **Table 7.2**.

The review of internationally available ecological criteria for the remaining constituents (excluding heavy metals, petroleum hydrocarbons and monocyclic aromatic hydrocarbons) is summarised following for each of the COPCs. It is noted that the US EPA Region III BTAG criteria, as used in the screening assessment, have not been considered as these are found to be highly conservative criteria and based on several toxicological endpoints.

Though not strictly applicable to soils in an Australian context, the international studies cited in the following sections are considered to be highly conservative. Susceptible species have generally been selected for the assessment of the potential toxic impacts. This is considered to be sufficiently conservative to be protective of plant species that may occur on the Headland Park site.

7.5.1 Cyanide

A review of international criteria has been undertaken. The following criteria are available:

- Netherlands Ministry of Housing, Spatial Planning and the Environment (2000) 'Annex A: Target Values, Soil Remediation Intervention Values and Indicative Levels for Serious Contamination' target value for earth/sediment of 1mg/kg for cyanides-free and 5mg/kg for cyanides-complex.

The target values are reported as being the level where negligible risks to an ecosystem may occur, potentially equivalent to a meaning of no observed effect concentration (NOEC). CSIRO (2009) instructs that ecological criteria should be derived on the basis of EC10 criteria. NOEC criteria require division by a factor of 2 to be equivalent to EC10 as per CSIRO (2009).

Intervention values have not been referred to as these are reported to be based on a concentration in the soil above which 50% of the potentially present species and processes may experience negative effects. This is equivalent to an EC50. CSIRO (2009) instructs the use of EC10 to set EILs;

- US EPA Region IV (2001) 'Supplemental Guidance to RAGS: Region 4 Bulletins, Ecological Risk Assessment' provides a soil screening value of 0.9mg/kg for free cyanide and 5.0mg/kg for complex cyanide.

The value for free cyanide is reported to have been based on Canadian Council of Ministers of the Environment (1997). By review of CCME background documents including CCME (March 2006) 'Guidance Manual for Developing Site-Specific Soil Quality Remediation Objectives for Contaminated Sites in Canada' Canadian ecological criteria are derived on the basis of NOEL and lowest observed effect concentrations (LOECs). No guidance is readily available for the basis of the cyanide calculations. The NOEC is equivalent to the EC10 with division by 2 as recommended by CSIRO (2009). The LOEC is equivalent to the EC10 with division by 2.5 as advised by CSIRO (2009).

The value for total cyanide is reported to be based on US Department of the Interior Fish and Wildlife Service (July 1990) 'Evaluating Soil Contamination'. By review of this document the cyanide criteria has been based on the Dutch criteria;

- US EPA Region V (August 2003) provide a soil screening benchmark of 1.33mg/kg for total cyanide in soil. The soil ESL is reported to be based on the exposure to a meadow vole (*Microtus pennsylvanicus*). This study has been identified in US National Park Service (1997) 'Environmental Contaminants Encyclopaedia Entry on Cyanide(s) in General'. The study is found to have been based on a NOEC.

7.5.2 PAHs

A review of international criteria has been undertaken. The following criteria are available:

- Texas Natural Resource Conservation Commission (2001) 'Guidance for Conducting Ecological Risk Assessments at Remediation Sites in Texas Toxicology and Risk Assessment Section', as adopted by US EPA region VI, provides an ecological benchmark for plants for acenaphthene of 20mg/kg. This value is reported to have been adopted from Efroymson, R., M.E.Will, G. Suter II and A. C. Wooten (1997) 'Toxicological Benchmarks for Contaminants of Potential Concern for Effects on Terrestrial Plants: 1997 Revision. Oak Ridge National Laboratory'. By review of Efroymson et al (1997) the acenaphthene value has been based on an LOEC value of 25mg/kg from studies of lettuce seedlings;
- Texas Natural Resource Conservation Commission (2001) provides an ecological benchmark for earthworms in soil of 30mg/kg for fluorene. This value is reported to have been sourced from Efroymson, R., M.E.Will, and G. Suter II (1997) 'Toxicological Benchmarks for Contaminants of Potential Concern for Effects on Soil and Litter Invertebrates and Heterotrophic Process: 1997 Revision. Oak Ridge National Laboratory'. The study results on which the ecological benchmark is set is found to have been based on studies which have reported LC50. The criteria have been set by applying a safety factor of 5 to the LC50. This is consistent with the guidance in CSIRO (2009) for converting an EC50 to the recommended EC10;
- US EPA Region V (August 2003) provide a soil screening benchmark of 682mg/kg for acenaphthene in soils. The benchmark is reported to be based on exposure to a masked shrew as reported in Sample, B.E., D.M. Opresko, and G.W Suter II. (1996) 'Toxicological Benchmarks for Wildlife: 1996 Revision. Oak Ridge National Laboratory, Oak Ridge'. The Masked Shrew was selected as it almost exclusively feeds on invertebrates. This paper reports that data used for the derivation of the benchmark were based on NOECs;
- US EPA Region V (August 2003) provide a soil screening benchmark of 682mg/kg for acenaphthylene in soils. This was derived similarly to acenaphthene;
- US EPA Region V (August 2003) provide a soil screening benchmark of 5.2mg/kg for benz(a)anthracene in soils. This was derived similarly to acenaphthene;
- US EPA Region V (August 2003) provide a soil screening benchmark of 1.52mg/kg for benzo(a)pyrene in soils. This was derived similarly to acenaphthene;
- US EPA Region V (August 2003) provide a soil screening benchmark of 59.8mg/kg for benzo(b)fluoranthene in soils. This was derived similarly to acenaphthene;
- US EPA Region V (August 2003) provide a soil screening benchmark of 119mg/kg for benzo(g,h,i)perylene in soils. This was derived similarly to acenaphthene;
- US EPA Region V (August 2003) provide a soil screening benchmark of 148mg/kg for benzo(k)fluoranthene in soils. This was derived similarly to acenaphthene;

- US EPA Region V (August 2003) provide a soil screening benchmark of 4.73mg/kg for chrysene in soils. This was derived similarly to acenaphthene;
- US EPA Region V (August 2003) provide a soil screening benchmark of 18.4mg/kg for dibenz(a,h)anthracene in soils. This was derived similarly to acenaphthene;
- US EPA Region V (August 2003) provide a soil screening benchmark of 122mg/kg for fluoranthene in soils. This was derived similarly to acenaphthene;
- US EPA Region V (August 2003) provide a soil screening benchmark of 122mg/kg for fluorene in soils. This was derived similarly to acenaphthene;
- US EPA Region V (August 2003) provide a soil screening benchmark of 109mg/kg for indeno(1,2,3-c,d)pyrene in soils. This was derived similarly to acenaphthene;
- US EPA Region V (August 2003) provide a soil screening benchmark of 0.1mg/kg for naphthalene in soils. This was derived similarly to acenaphthene;
- US EPA Region V (August 2003) provide a soil screening benchmark of 45.7mg/kg for phenanthrene in soils. This was derived similarly to acenaphthene; and
- US EPA Region V (August 2003) provide a soil screening benchmark of 78.5mg/kg for pyrene in soils. This was derived similarly to acenaphthene.

7.5.3 Phenols and Cresols

A review of international criteria has been undertaken. The following criteria are available:

- Netherlands Ministry of Housing, Spatial Planning and the Environment (2000) provides a target value of 0.05mg/kg for phenol in soils;
- Texas Natural Resource Conservation Commission (2001) provides an ecological benchmark for earthworms in soil of 30mg/kg for phenol as based on Efroymson et al (1997). The criteria have been set by applying a safety factor of 5 to the LC50. This is consistent with the guidance in CSIRO (2009) for converting an EC50 to the recommended EC10;
- Texas Natural Resource Conservation Commission (2001) as adopted by US EPA Region VI, provides a surface soil screening benchmark for phenol of 70mg/kg as based on Efroymson et al (1997). This value is reported to have been based on studies which reported EC50 values. Study results, based on growth of lettuce, have been extrapolated to LOEC levels of 79 and 168mg/kg. The adopted criterion can be considered representative of a LOEC level;
- US EPA Region V (August 2003) provide a soil screening benchmark of 120mg/kg for phenol in soils. This was derived similarly to acenaphthene;
- Netherlands Ministry of Housing, Spatial Planning and the Environment (2000) provide a target value of 0.05mg/kg for cresols in soils;
- US EPA Region V (August 2003) provide a soil screening benchmark of 3.5mg/kg for m-cresol in soils. This was derived similarly to acenaphthene. This is the lowest of the reported ecological benchmarks for cresols in soils; and
- US EPA Region V (August 2003) provide a soil screening benchmark of 0.01mg/kg for 2,4-dimethylphenol in soils. This is reported to have been derived on the basis of an exposure to a 'plant'. No further details are provided.

7.5.4 Summary of Adopted Added Contaminant Limits

Added contaminant limits (ACLs) have been adopted on the basis of the literature review. These are summarised in **Table 7.4**. As discussed previously:

- Heavy metals ACLs have been adopted directly from DEC (2006) phytotoxicity criteria. The phytotoxicity criteria for chromium (III) have been adopted for chromium. The impact at the site is found to be aged and it is more than likely that any historical chromium occurring as Cr(VI) has oxidised to Cr(III). This is supported by the speciated chromium analysis detailed in AECOM (2010);
- TPH and BTEX ACLs have been adopted directly from NSW EPA (1994) threshold concentrations;
- An ACL for cyanide has been proposed on the basis of free cyanide. An ACL of 0.5mg/kg has been adopted. This is based on the guideline value provided in Netherlands Ministry of Housing, Spatial Planning and the Environment (2000) and US EPA Region IV (2001) as divided by a factor of two to account for conversion of NOEC to EC10. Though not strictly applicable to Australian soils, this value is considered to be suitably conservative to be applied to soils and proposed plant species on the Headland Park;
- An ACL for PAHs has been prepared for acenaphthene and fluorene only. The data provided in Texas Natural Resource Conservation Commission (2001) as based on plant or earthworm studies have been used. Though not strictly applicable to Australian soils, this value is considered to be suitably conservative to be applied to soils and proposed plant species on the Headland Park.

The extensive US EPA Region V guidelines have not been used. Little information is available on the derivation of these criteria and it is considered that sufficient criteria are available by the consideration of acenaphthene and fluorene

Inclusion of the earthworm data allows consideration of potential biomagnification / secondary poisoning effects as identified as an exposure route for heavier PAHs.

A criterion of 10mg/kg has been adopted for acenaphthene, as derived by the conversion of the reported LOEC result by a factor to 2.5 to convert to an EC10 result, as recommended by CSIRO (2009).

A criterion of 30mg/kg for fluorene has been adopted. The study results have been converted in the source document by the same safety factor as recommended by CSIRO (2009) to generate an EC10 based value.

By review of PAH data available for the site, acenaphthene and fluorene are observed to occur with other PAHs. Restriction of ecological assessment to these constituents is considered to be protective of the potential impacts of other PAHs;

- An ACL for phenols has been provided on the basis of phenol only. Criteria for other phenols were generally only available from US EPA Region V. As discussed for PAHs there are little data on the derivation of these values.

The Netherlands Ministry of Housing, Spatial Planning and the Environment (2000) values have been overlooked as the Texas Natural Resource Conservation Commission (2001) values have supporting scientific studies which have been able to be reviewed.

Ecological levels have been provided by the Texas Natural Resource Conservation Commission (2001) for phenols on the basis of earthworm and lettuce studies.

An ACL of 14mg/kg has been adopted on the basis of the lettuce study based criteria, divided by a factor of 5, as advised by CSIRO (2009) to account for conversion of a EC50 result to a preferred EC10 result. The resultant criterion is less than the earthworm derived criterion of 30mg/kg which was adjusted by the authors by the same correction factor. Though not strictly applicable to Australian soils, this value is considered to be suitably conservative to be applied to soils and proposed plant species on the Headland Park.

Cresols and 2,4-dimethylphenol have been observed to occur with detections of phenol. Assessment of phenol for ecological impacts is considered to be sufficiently protective of potential ecological impacts of the other methyl and dimethylphenols.

7.5.5 Conversion to EC10

It is considered that the conversion of the available US EPA data to EC10 levels is conservative. This has been undertaken in line with the advice of best practice provided by CSIRO (2009). However it is also documented in CSIRO (2009) that a policy decision was made by CSIRO to derive ecological investigation levels for incorporation into the revised NEPM by the use of EC30 data.

The adoption of the lower EC10 data in this assessment is considered to be protective of potential limitations in the small data sets that have premised the cyanide and organic constituents ecological levels, and of potential biomagnification effects of cyanides which may not have been assessed by the studies reviewed.

The adoption of EC10 criteria is considered to be sufficient to meet the phytotoxicity assessment objectives of protection of 80% of species and soil microbial processes, and 85% protection for constituents where biomagnifications may occur.

7.5.6 Ageing and Leaching

The contaminants present in the soils proposed to be used to form the Headland Park have generally been present in the soils for a substantial period of time. CSIRO (2009) recommends the use of an ageing and leaching factor to account for the ageing and natural immobilisation (attenuation) of COPCs that would have occurred in the soils. The ageing and leaching factor is used to estimate the extent by which the bioavailability of the COPC has been reduced.

Limited ageing and leaching factors are available in CSIRO (2009) as summarised following:

- Zinc – 3;
- Copper – 2;
- Nickel – 1-3; and
- Lead – 4.2.

No ageing and leaching factors are available for organic constituents (CSIRO, 2009).

To remain conservative, ageing and leaching factors have not been considered in the derivation of the EILs for the Headland Park. The age of the soils on the Headland Park cannot be predicted.

7.6 Calculation of EILs for Phytotoxicity Effects

EILs have been calculated for phytotoxicity effects by the method advised in CSIRO (2009) of addition of the ACL and background concentration of a constituent. The background concentrations of heavy metals have been set at the level of arithmetic mean as per **Table 7.3**. The remaining constituents have been assumed to not be present in soils (i.e. zero background levels).

The calculation of the EILs, as based on potential phytotoxicity effects of soils, are summarised in **Table 7.4**.

Table 7.4: Summary of Adopted EILs (mg/kg)

COPC	ACL	Background	Adopted EIL
Arsenic	20	7	27
Chromium	400	15	415
Copper	100	52	152
Lead	600	379	979
Mercury	1	1.9	2.9
Nickel	60	7	67
Zinc	200	230	430
Cyanide (free)	0.5	Nil	0.5
TPH C ₆ -C ₉	65	Nil	65
TPH C ₁₀ -C ₃₆	1,000	Nil	1,000
Benzene	1	Nil	1
Toluene	1.4	Nil	1.4
Ethylbenzene	3.1	Nil	3.1
Xylenes	14	Nil	14
Acenaphthene	10	Nil	10
Fluorene	30	Nil	30
Phenol	14	Nil	14

7.7 Surface Water and Groundwater Exposure Pathways

Potential surface water and groundwater exposure pathways were also identified for the soils on the proposed Headland Park in **Section 7.2**. This is particularly relevant to the proposed re-use of harvested water on the site as irrigation water. Irrigation water applied by sprinklers, and present in the sub-surface at a depth to 1.5m (reported the maximum likely depth of root penetration in areas of large tree plantings only) will be required to have levels of dissolved contaminants that are sufficiently protective of the plant species.

It is considered that the total soil criteria as derived for the growing soils as detailed in **Table 7.4** will not generate levels of leachate that will be potentially toxic to plants. No further assessment is required of the leaching potential of these soils from a phytotoxicity basis.

Irrigation water will potentially contact deeper soils on the site prior to harvesting. Leaching of contaminants may occur with the contact to deeper soils. Criteria are required to be derived for irrigation water which will be protective of potential phytotoxicity effects on plants.

Irrigation water criteria which are protective of the phytotoxicity effects on plants are derived in **Section 8**.

8 Groundwater and Irrigation Water Ecological Assessment

Groundwater is currently present under the proposed area of the Headland Park as present in a shallow tidally influenced aquifer. ERM (2008 and 2009) have reported that substantial tidal mixing occurs within this subsurface groundwater. In addition, it was reported by ERM (2008 and 2009) that elevated levels of some constituents in the groundwater were unlikely to pose a potential ecological risk to Darling Harbour. This has not been definitively assessed for the proposed Headland Park Site development scheme. An approach has been advised in CSIRO (2009) to derive soil criteria that protect aquatic ecosystems. These criteria require to be derived to allow an assessment of the level of risk that in-situ soils pose to the marine environment of the adjoining Darling Harbour by the leaching and discharge of groundwater to Darling Harbour.

JBS has been advised that seepage water which is generated on the site by the majority of the proposed emplaced soils will be collected by engineered structures. Where this seepage water is discharged to Darling Harbour it will be required to meet the adopted ecological assessment as summarised in **Table 6.2**. On this basis, there is no requirement to derive EILs which are protective of surface water / groundwater for the majority of the emplaced soils. The engineering controls will achieve the required environmental values.

Seepage water which is collected by engineered structures is proposed to be re-used on the site as irrigation water. Criteria are required to be derived for the seepage water, which is re-used as seepage water, which will be protective of potential phytotoxicity effects to plants. Phytotoxicity data as available for plants and assessed in **Section 7** are presented as total soil concentrations. Potential differential uptake of constituents from soil as opposed to water based media required to be assessed to determine equivalent concentrations in water that will be protective of plants.

On the basis of the identified exposure pathways, leaching factors are required to be used in:

- The derivation of EILs for in-situ soils that are protective of surface water / aquatic ecologies (by groundwater discharge); and
- The derivation of EILs in irrigation water that will be protective of plants on the Headland Park.

8.1 Determining the Leaching Potential of Inorganic Contaminants

JBS Environmental (10 January 2011) 'Summary of Results of Soil Analysis of Chemical Constituent Leachability Barangaroo' (JBS 2011) provides a summary of data considered appropriate to predict leachability of soil constituents on the Barangaroo site. Data has been presented in JBS (2011) for data collected from the Headland Park and Barangaroo South and Central sites. This is summarised in **Table 8.1** following for available inorganic constituents.

Table 8.1: Summary of Measured Median ASLP Leachabilities Values for Inorganic Constituents

Inorganic COPC	Median Leachability – Headland Park Data (mg/l / mg/kg)	Median Leachability – Barangaroo Central and South (mg/l / mg/kg)
Arsenic	0.0005	0.00045
Chromium	0.00023	0.00005
Copper	0.00021	0.0003
Lead	0.00014	0.00017
Mercury	No data	0.0003
Nickel	0.00033	0.0005

Inorganic COPC	Median Leachability – Headland Park Data (mg/l / mg/kg)	Median Leachability – Barangaroo Central and South (mg/l / mg/kg)
Zinc	0.00076	0.00167
Cyanide (free)	No data	No data

Field estimates of leachability are available for all constituents apart from mercury on the Headland Park site and cyanide across the Barangaroo site.

A theoretical approach to the estimation of the leaching potential of inorganic constituents in soils to groundwater is provided in CSIRO (2009). The approach is based on the soil-water partition coefficient (K_d) of the constituent. This is the ratio of the concentration of a contaminant bound to soil, to the dissolved total in soil pore water, at equilibrium. It is related to the aqueous solubility of the particular contaminant.

CSIRO (2009) advises that inorganic constituents with a Log K_d of less than 3 have a high potential to leach. Log K_d values for each of the inorganic COPCs where no field data are available are listed in **Table 8.2** following.

Table 8.2: Summary of Log K_d Values for Inorganic Constituents

COPC	Log K_d	Source
Mercury	1.72	Risk Assessment Information System value for mercury and compounds
Cyanide (free)	1.00	Risk Assessment Information System value for cyanide (CN ⁻)

CSIRO instructs that contaminant leaching for the purposes of deriving EILs is required to be addressed for all constituents with a Log K_d less than 3. This includes each of the COPCs in **Table 8.2**.

Table 8.3 following summarises the theoretical leachabilities estimated for the inorganic COPCs.

Table 8.3: Theoretical Estimate of Potential Leaching of Inorganic Constituents

Constituent	Theoretical Leaching Factor (mg/l / 1 mg/kg)
Mercury	0.0098
Cyanide	31.3

It is noted that the theoretical estimates are likely to be highly conservative.

8.2 Determining the Leaching Potential of Organic Contaminants

As discussed for inorganic constituents, data is also presented in JBS (2011) for field measured estimates of organic constituent leachability, as prepared for data collected from the Headland Park and Barangaroo South and Central sites. This is summarised in **Table 8.4** following for available organic constituents.

Table 8.4: Summary of Measured Median ASLP Leachabilities Values for Organic Constituents

Organic COPC	Median Leachability – Headland Park Data (mg/l / mg/kg)	Median Leachability – Barangaroo Central and South (mg/l / mg/kg)
Benzene	No data	No data
Toluene	No data	No data
Ethylbenzene	No data	No data
Xylenes	No data	No data
Acenaphthene	0.0029	0.00091
Acenaphthylene	0.001	0.00171
Anthracene	0.0006	0.00043
Benz(a)anthracene	No data	No data
Benzo(a)pyrene	No data	No data
Benzo(b)fluoranthene	No data	No data
Benzo(g,h,i)perylene	No data	No data
Benzo(k)fluoranthene	No data	No data
Chrysene	No data	No data
Dibenz(a,h)anthracene	No data	No data
Fluorene	0.0021	0.00156
Fluoranthene	0.0002	0.00031
Indeno(1,2,3-c,d)pyrene	No data	No data
Naphthalene	0.0012	0.0096
Phenanthrene	0.0006	0.00166

Organic COPC	Median Leachability – Headland Park Data (mg/l / mg/kg)	Median Leachability – Barangaroo Central and South (mg/l / mg/kg)
Pyrene	0.0001	0.00025
Phenol	No data	No data
Cresols	No data	No data
2,4-dimethylphenol	No data	No data
TPH C ₆ -C ₉ (aliphatic)	No data	No data
TPH C ₁₀ -C ₁₄ (aliphatic)	No data	No data
TPH C _{>16} (aliphatic)	Insufficient data	No data
TPH C ₁₀ -C ₁₄ (aromatic)	No data	No data
TPH C _{>16} (aromatic)	Insufficient data	No data

Field estimates of leachability are available for lighter PAHs only including naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene and pyrene.

A theoretical approach to the estimation of the leaching potential of organic constituents in soils to groundwater is provided in CSIRO (2009). The approach is based on two partition co-efficients related to leaching of organic constituents including the:

- Octanol-water coefficient (K_{OW}) which is used as a surrogate to estimate the potential for contaminants to accumulate in tissue; and
- Carbon-water partition co-efficient (K_{OC}).

K_{OW} and K_{OC} values for site contaminants were provided in **Table 7.1**. The mobility of potential contaminants is defined by CSIRO (2009) as:

- $\text{Log } K_{OW} < 2$ / $\text{Log } K_{OC} < 2.4$ – mobile;
- $\text{Log } K_{OW} 2-2.7$ / $\text{Log } K_{OC} 2.4-3.05$ – medium mobility;
- $\text{Log } K_{OW} 2.7-3.7$ / $\text{Log } K_{OC} 3.05-3.95$ – low mobility; and
- $\text{Log } K_{OW} > 3.7$ / $\text{Log } K_{OC} > 3.95$ – immobile.

It is recommended that organic constituents with a large half life (>45 days, summarised in **Table 7.1**) and a $\text{Log } K_{OC} < 4$ ($K_{OC} < 10,000$) or $\text{Log } K_{OW} < 4$ require to be assessed for contaminant leaching in the derivation of EILs as protective of surface water receptors.

By review of **Table 7.1** this includes TPH (C₆-C₉, C₁₀-C₁₄ and C₁₅-C₂₈), benzene, toluene, ethylbenzene, xylenes, acenaphthene, acenaphthylene, fluorene and naphthalene. **Table 6.4** indicates several additional PAHs to those identified by the CSIRO (2009) screening process as being recorded in groundwater on the site indicating likely leachability. These PAHs are also found to generally have low ecological assessment criteria (**Table 6.2**). On this basis, EILs for the protection of surface water have been derived for each of the remaining PAHs where field data has predicted potential leachability. On this basis, phenanthrene, anthracene, fluoranthene and pyrene have been additionally assessed.

8.3 Organic Leachability Data

Similarly for heavy metals, theoretical leachabilities of organic constituents have been calculated for constituents requiring derivation of ecological criteria where no field data is available. This is summarised in **Table 8.5**.

Table 8.5: Theoretical Estimate of Potential Leaching of Organic Constituents

Constituent	Theoretical Leaching Factor (mg/l / mg/kg)
Benzene	1.86
Toluene	1.24
Ethylbenzene	0.69
Xylenes	0.80
Phenol	1.63
Cresols	1.03
2,4-dimethylphenol	0.65
TPH C ₆ -C ₉ (aliphatic)	4.61*10 ⁻²
TPH C ₁₀ -C ₁₄ (aliphatic)	1.29*10 ⁻³
TPH C _{>16} (aliphatic)	5.28*10 ⁻⁷
TPH C ₁₀ -C ₁₄ (aromatic)	0.13
TPH C _{>16} (aromatic)	2.10*10 ⁻³

As noted that the theoretical estimates of inorganic constituent leachability, the estimates of organic constituent leachability are likely to be highly conservative.

8.4 Determination of EILs for In-Situ Soils Protective of Surface Water

8.4.1 Inorganic Constituents

The following relationship has been provided in CSIRO (2009) to estimate EIL's on the basis of soil leaching for inorganic constituents:

$$EIL = C_w \cdot [K_d + (\theta_w + \theta_a \cdot H') / \rho_b] \cdot DAF$$

Where: EIL – ecological investigation level (mg/kg)'

C_w – target leachate concentration, set equal to ANZECC/ARMCANZ 95% protection marine value unless use of 99% advised (mg/l);

K_d – soil to water partition coefficient (L/kg);

θ_a – air filled porosity;

θ_w – water filled porosity;

H' – Henry's Law Constant (unitless);

ρ_b – soil bulk density (kg/l); and

DAF – dilution attenuation factor including dilution from catchment and tidal dilution at discharge

Within this equation the component $[K_d + (\theta_w + \theta_a \cdot H') / \rho_b]$ is an estimate of the leachability of the constituent. These have been detailed for inorganic constituents in **Tables 8.1** and **8.3**, generally by site specific data for each portion of the Barangaroo site.

8.4.2 Organic Constituents

The following relationship has been provided in CSIRO (2009) to estimate EIL's on the basis of soil leaching for organic constituents:

$$EIL = C_w \cdot [(K_{OC} \cdot f_{OC}) + (\theta_w + \theta_a \cdot H') / \rho_b] \cdot DAF$$

Where: EIL – ecological investigation level (mg/kg)'

C_w – target leachate concentration, set equal to ANZECC/ARMCANZ 95% protection marine value unless use of 99% advised (mg/l);

K_{OC} – organic carbon to water partition coefficient (L/kg);

f_{OC} – fraction of organic carbon (g/g)

θ_a – air filled porosity;

θ_w – water filled porosity;

H' – Henry's Law Constant (unitless);

ρ_b – soil bulk density (kg/l); and

DAF – dilution attenuation factor including dilution from catchment and tidal dilution at discharge.

Within this equation the component $[(K_{OC} \cdot f_{OC}) + (\theta_w + \theta_a \cdot H') / \rho_b]$ is an estimate of the leachability of the constituent. These have been detailed for organic constituents in **Tables 8.4** and **8.5**, generally by site specific data for the lighter PAHs, and some theoretical relationship for other constituents.

8.4.3 Dilution Attenuation Factor (DAF)

CSIRO (2009) notes that groundwater catchments most likely contain both contaminated and uncontaminated soils. This is considered to be the case for the proposed Barangaroo Headland Park, where it would be reasonably presumed that existing hydrogeologically land area to the east and south-east of the site is uncontaminated. Consequent of this, the pore water concentrations of constituents will not necessarily be equal to the seepage water concentrations as may discharge into Darling Harbour, or infiltrate into underlying tidally influenced groundwater. A dilution attenuation factor (DAF) is recommended to be used to take this into account. The following equation is provided by CSIRO (2009):

$$DAF = 100 / \text{percent of contaminated soil in catchment.}$$

A site specific measurement of potential dilution of leaching constituents prior to discharge to receiving waters has been provided in AECOM (2010d) as five. This factor is intended to be applied to dilution of leachate generated within the saturated zone prior to discharge to receiving waters.

AECOM (30 July 2010) 'Human Health and Ecological Risk Assessment' further nominates that the factor of five be further modified with an additional factor of four, creating a total dilution factor of 20, when applied to soils present in the unsaturated zone, interpreted as being above the current depth of groundwater. This factor is presumably to account for additional dilution during vertical migration to the saturated zone.

The AECOM dilution factors have been adopted in preference to a DAF estimated by the CSIRO (2009) method.

8.5 Calculation of EILs Protective of Surface Water Receptors

The calculation of EIL's protective of surface waters is summarised in **Table 8.6** for soils present in the saturated zone on the Headland Park site (i.e. below the current depth of groundwater on the site). The dilution factor of five has been incorporated into these calculations. Based on the connectivity of groundwater to Darling Harbour and the predicted 2100 sea water level of 1.9m AHD, this should be taken to be soils present below a depth of 1.9m AHD.

Table 8.6: Calculation of EILs for Potential Leaching of COPCs in Saturated Zone

Constituent	Target Concentration C _w (mg/l)	Leaching Factor – Headland Park (mg/l / mg/kg)	Leaching Factor – Barangaroo Central and South (mg/l / mg/kg)	EIL Protective of Surface Water – Headland Park Soils(mg/kg)	EIL Protective of Surface Water – Fill Material from Barangaroo Central and South (mg/kg)
Arsenic	0.0023 ¹	0.0005	0.00045	23	26
Copper	0.0013 ¹	0.00021	0.0003	31	22
Lead	0.0044 ¹	0.00014	0.00017	157	129
Mercury	0.0004 ¹	0.0098	0.0003	0.2	7
Nickel	0.07 ¹	0.00033	0.0005	1061	700
Zinc	0.015 ¹	0.00076	0.00167	99	45
Cyanide	0.004 ¹	31.3	31.3	<LOR	<LOR
Benzene	0.5 ¹	1.86	1.86	1.3	1.3
Toluene	0.18 ¹	1.24	1.24	0.7	0.7
Ethylbenzene	0.005 ¹	0.69	0.69	<LOR	<LOR
Xylene	0.075 ¹	0.8	0.8	<LOR	<LOR
Acenaphthene	0.0404 ¹	0.0029	0.00091	70	222
Acenaphthylene	0.001 ²	0.001	0.00171	5.0	2.9
Anthracene	0.005 ⁵	0.0006	0.00043	42	58
Fluoranthene	0.0014 ¹	0.0002	0.00031	35	23
Fluorene	0.001 ²	0.0021	0.00156	2.4	3.2
Naphthalene	0.05 ¹	0.0012	0.0096	208	26
Phenanthrene	0.002 ¹	0.0006	0.00166	17	6
Pyrene	0.00024 ¹	0.0001	0.00025	12	4.8
Phenol	0.4 ³	1.63	1.63	1.2	1.2
Cresols	0.2 ⁵	1.03	1.03	1.0	1.0
2,4-dimethylphenol	0.002 ⁴	0.65	0.65	<LOR	<LOR
TPH C ₆ -C ₉ (aliphatic)	0.6 ¹	0.046	0.046	65	65
TPH C ₁₀ -C ₁₄ (aliphatic)	0.6 ¹	0.0013	0.0013	2308	2308
TPH C _{>16} (aliphatic)	0.6 ¹	0.00000053	0.00000053	>MAX	>MAX
TPH C ₁₀ -C ₁₄ (aromatic)	0.6 ¹	0.13	0.13	23	23
TPH C _{>16} (aromatic)	0.6 ¹	0.0021	0.0021	1429	1429

Note: 1. As per Table 6.2
 2. Set as laboratory detection limit in lieu of ecological criteria.
 3. ANZECC/ARMCANZ (2000) 95% protection, moderate reliability trigger value
 4. ANZACC/ARMCANZ (2000) low reliability trigger value
 5. Netherlands MHSP&E (2000) intervention value
 > LOR – below typical laboratory limit of reporting
 > MAX – above likely maximum level

The calculation of EIL's protective of surface waters is summarised in **Table 8.7** for soils present in the unsaturated zone on the Headland Park site (i.e. above the current depth of groundwater on the site). The dilution factor of 20 (4 * 5) has been incorporated into these calculations. This should be taken to be soils present above a depth of 1.9m AHD. This need not be applied to soils within the seepage water controlled area of the Park.

Table 8.7: Calculation of EILs for Potential Leaching of COPCs in Unsaturated Zone

Constituent	Target Concentration C_w (mg/l)	Leaching Factor – Headland Park (mg/l / mg/kg)	Leaching Factor – Barangaroo Central and South (mg/l / mg/kg)	EIL Protective of Surface Water – Headland Park Soils (mg/kg)	EIL Protective of Surface Water – Fill Material from Barangaroo Central and South (mg/kg)
Arsenic	0.0023 ¹	0.0005	0.00045	92	102
Copper	0.0013 ¹	0.00021	0.0003	124	87
Lead	0.0044 ¹	0.00014	0.00017	629	518
Mercury	0.0004 ¹	0.0098	0.0003	0.8	27
Nickel	0.07 ¹	0.00033	0.0005	4242	2800
Zinc	0.015 ¹	0.00076	0.00167	395	180
Cyanide	0.004 ¹	31.3	31.3	<LOR	<LOR
Benzene	0.5 ¹	1.86	1.86	5.4	5.4
Toluene	0.18 ¹	1.24	1.24	2.9	2.9
Ethylbenzene	0.005 ¹	0.69	0.69	<LOR	<LOR
Xylene	0.075 ¹	0.8	0.8	1.9	1.9
Acenaphthene	0.0404 ¹	0.0029	0.00091	279	888
Acenaphthylene	0.001 ²	0.001	0.00171	20	12
Anthracene	0.005 ⁵	0.0006	0.00043	167	233
Fluoranthene	0.0014 ¹	0.0002	0.00031	140	90
Fluorene	0.001 ²	0.0021	0.00156	10	13
Naphthalene	0.05 ¹	0.0012	0.0096	833	104
Phenanthrene	0.002 ¹	0.0006	0.00166	67	24
Pyrene	0.00024 ¹	0.0001	0.00025	48	19
Phenol	0.4 ³	1.63	1.63	4.9	4.9
Cresols	0.2 ⁵	1.03	1.03	3.9	3.9
2,4-dimethylphenol	0.002 ⁴	0.65	0.65	<LOR	<LOR
TPH C ₆ -C ₉ (aliphatic)	0.6 ¹	0.046	0.046	261	261
TPH C ₁₀ -C ₁₄ (aliphatic)	0.6 ¹	0.0013	0.0013	9231	9231
TPH C _{>16} (aliphatic)	0.6 ¹	0.00000053	0.00000053	>MAX	>MAX
TPH C ₁₀ -C ₁₄ (aromatic)	0.6 ¹	0.13	0.13	92	92
TPH C _{>16} (aromatic)	0.6 ¹	0.0021	0.0021	5714	5714

- Note:
1. As per Table 8.2
 2. Set as laboratory detection limit in lieu of ecological criteria.
 3. ANZECC/ARMCANZ (2000) 95% protection, moderate reliability trigger value
 4. ANZACC/ARMCANZ (2000) low reliability trigger value
 5. Netherlands MHSP&E (2000) intervention value
- > LOR – below typical laboratory limit of reporting
 > MAX – above likely maximum level

These EILs require to be considered for soils on the site which are not subject to the proposed engineered seepage water controls. This includes the clay liner soils, soils underlying the car park and in-situ / current soils on the site and emplaced soils in proximity of the site boundary outside of the extent of seepage water controls.

8.6 Derivation of Irrigation Water Criteria Protective of Plants

Irrigation water criteria for the protection of phytotoxicity effects of plants on the site have been determined by use of the phytotoxicity criteria derived for soils and adjustment for differential uptake of contaminants from soil based media relative to groundwater. Constituent uptake from soil and water sources differs. To assess the differences estimates are required for the relative levels of soil to plant uptake factors and water to plant uptake factors.

Baes CF, Sharp RD, Sjoreen AL and Shor RW (1984) 'A Review and Analysis of Parameters for Assessing Transport of Environmentally Radionuclides through Agriculture' presents soil to plant concentration factors for the elements of the periodic table as Baes uptake factors.

Briggs GG, Bromilow RH and Evans AA (1982) 'Relationships between Lipophilicity and Root Uptake and Translocation of Non-Ionised Chemicals by Barley' provides a relationship for constituent uptake by plants for constituents with non-zero K_{OW} values (i.e. organic constituents).

US EPA (1993) 'Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions' presents an adjustment of these relationships to differentiate uptake by water and soil sources. For inorganic constituents, to convert from uptake factors expressed in units of [mg chemical / kg wet weight plant per mg chemical / kg soil] to an uptake factor expressed in units of [mg chemical / kg plant per mg chemical / l water] it is recommended that soil based based uptake factor is multiplied by K_d (l/kg). For organic constituents, it is recommended that a factor of $(K_{OC} * f_{OC}) / 0.01$ is used to perform the same adjustment.

These factors require to be incorporated in the seepage water / irrigation water calculations to account for the use of soil based ecotoxicology criteria to derive criteria for application to a water source.

It is noted in adopting a value for f_{OC} a value consistent with the soils used for the derivation of ecotoxicological data requires to be adopted. Based on general sand based soil reported as being used, a value of 0.003 as used to characterise sands in the human health risk assessment has been adopted.

The irrigation water criteria to be protective of plants are summarised in **Table 8.8** following on the basis of the calculated phytotoxicity criteria for soils and adjustment for differing uptake of constituents from water source.

Table 8.8: Summary of Irrigation Water to be Protective of Phytotoxicity Effects

COPC	Phytotoxicity EIL (mg/kg)	K_d or $(K_{OC} * f_{OC}) / 0.01$ (l/kg)	Protection of Phytotoxicity Irrigation Water Criteria (mg/l)
Arsenic	27	29	0.93
Chromium	415	19	0.053
Copper	152	35	4.3
Lead	979	900	1.1
Mercury	2.9	52	0.056
Nickel	67	65	1.0
Zinc	430	62	6.9
Cyanide (free)	0.5	9.9	0.051
TPH C ₆ -C ₉	65	-	-
TPH C ₁₀ -C ₃₆	1,000	-	-
Benzene	1	44	0.023
Toluene	1.4	70	0.020
Ethylbenzene	3.1	134	0.023
Xylenes	14	115	0.12
Acenaphthene	10	1509	0.0066
Fluorene	30	2748	0.011
Phenol	14	56	0.25

Note: 1. Derived on basis of DEC (2006) phytotoxicity criteria of 1mg/kg for hexavalent chromium

No criteria have been derived for TPH on the basis of the range of K_{OC} values available for the extent of fractions assessed within the adopted criteria. It is considered that compliance with the coincident monocyclic and polycyclic aromatic hydrocarbons will be sufficiently protective of potential impacts of TPH.

9 Sensitivity Analysis

An assessment has been required to be undertaken of the sensitivity of the risk assessment outcomes. Risk assessment calculations can be observed to have been based on:

- Levels of COPCs as estimated by soil and groundwater sampling programs completed on the site;
- Toxicological parameters used to characterise COPCs;
- Anticipated and assessed current and future land-uses;
- Exposure parameters used to characterise future population behaviours on the site;
- Physical parameters used to characterise site areas and buildings where exposures may occur; and
- Equations and related relationships used to estimate levels of COPCs from reported levels in soils and groundwater to points of exposure.

Each of these is discussed further following.

9.1 Sampling Programs

Soil and groundwater data used for the risk assessment have been obtained from sampling programs previously completed by ERM, AECOM and Douglas Partners. The soil and groundwater data have been used for the selection of constituents of potential concern. Soil and groundwater data are required to be appropriately representative of site conditions. The soil data are considered to more than likely overstate the extent of impact on the site because assessment locations have been targeted only to areas of the site where site impact is most likely. This causes the data to positively bias the actual extent of impact that may be present on the site. This is magnified by the use of analytical data as collected from the declaration area, present within the Barangaroo Central area and substantially off-site from the Headland Park, to assess levels of soil impact potentially occurring on the Headland Park.

Groundwater monitoring wells have likewise only been installed in areas of the site where the occurrence of impact is considered most likely, and likewise, groundwater characterisation is considered to have biased the actual distribution of impact across the site.

It is also noted that a potentially limited analytical suite has been undertaken by the previous consultants on the Headland Park site. This has included analysis for a limited range of monocyclic aromatic hydrocarbons (MAHs) and semi-volatile organic compounds (SVOCs). It is noted that other monocyclic aromatic hydrocarbons will most likely also be present with site contamination, potentially including trimethylbenzenes, propyl benzenes etc. This is confirmed by observation of results of extended analytical suites performed on samples on the Barangaroo Central and South sites, as reported in AECOM (2010a, 2010b and 2010c). On this basis the extent of constituents considered for ecological criteria are considered to appropriately account for other constituents that may be present.

This potential under-representation of the full extent of all hydrocarbon constituents is considered to have been at least partially accounted for by the inclusion of assessment for TPH fractions. It is also noted that regulators in Australia commonly only provide

speciated criteria and advise assessment for the limited range of hydrocarbon constituents, as assessed by this risk assessment.

9.2 Toxicological Parameters

In assessing toxicity data for phytotoxicity effects, all overseas based data has been corrected to a conservative EC10 measure. This has resulted in conservative criteria. It is noted that CSIRO (2009) advises that a less conservative EC30 measure of toxicity data has been used to derive phytotoxicity criteria for the proposed revision of NEPC (1997).

Ecological toxicity studies have also generally been based on highly susceptible plant types that are not anticipated to be grown within the Headland Park. For example, several phytotoxicity studies consider lettuce.

9.3 Land-Use

The risk assessment outcomes are only valid for the assumed future land-use of the site. Potentially sensitive land-uses such as the use of the Park for agricultural purposes associated with the production of edible produce have not been considered. The risk assessment would require to be revised where the site ecological profile was to differ from that substantially from that described in the ERA.

9.4 Conclusion

There are several factors which may have caused the criteria derived in this risk assessment to be overestimated. However, it is more than likely that any underestimation caused by the risk assessment process and limitations of available data and modelling techniques has been overcome by the use of conservative assumptions throughout the assessment.

It is concluded that the risk estimates provided are overestimates of actual risk levels and can be used for future decision making for the site.

10 Conclusions and Recommendations

An ecological risk assessment has been completed for the proposed Barangaroo Headland Park. The risk assessment has considered a range of ecological exposure scenarios for the proposed development of the Headland Park. The key facets of the proposed Headland Park development that have been considered in the risk assessment include:

- Provision of growing medium to areas of site plantings designated as grasses, shrubs, or large tree plantings;
- Control of sub-surface water on the site by engineered controls to prevent uncontrolled discharge to adjoining surface waters in some areas of the Headland Park; and
- Harvesting of surface and sub-surface water flows and re-use on the Park as irrigation water.

On the basis of these land-use parameters and the conceptual plans for the Headland Park and the limitations provided in **Section 12**, the following risk based ecological criteria have been derived for use on the site as summarised in **Table 10.1**. It is intended that each of the criteria are to be applied as follows:

- Ecological Investigation Level (EIL) Protective of Potential Phytotoxicity Effects – to be applied to soils classified as growing medium;
- EIL Protective of Surface Water – Headland Park Soils, Saturated Zone – to be applied to soils sourced from / located within the Headland Park that are present below the depth of groundwater (assumed to be 1.9m AHD based on 2100 high water mark) and not subject to sub-surface drainage controls;
- EIL Protective of Surface Water – Fill Material from Barangaroo Central and South, Saturated Zone – to be applied to soils sourced from the Barangaroo South / Central site and used as fill within the Headland Park in a location below the depth of groundwater (assumed to be 1.9m AHD based on 2100 high water mark) and not subject to sub-surface drainage controls;
- EIL Protective of Surface Water – Headland Park Soils, Unsaturated Zone – to be applied to soils sourced from / located within the Headland Park that are present above the depth of groundwater (assumed to be 1.9m AHD based on 2100 high water mark) and not subject to sub-surface drainage controls;
- EIL Protective of Surface Water – Fill Material from Barangaroo Central and South, Unsaturated Zone – to be applied to soils sourced from the Barangaroo South / Central site and used as fill within the Headland Park in a location above the depth of groundwater (assumed to be 1.9m AHD based on 2100 high water mark) and not subject to sub-surface drainage controls; and
- Protection of Phytotoxicity Irrigation Water Criteria – to be applied to irrigation water used within the Headland Park in vegetated areas.

In addition to these risk based criteria for soils, all discharges from the site are required to meet ecological criteria as defined by DECCW guidelines and standards.

Table 10.1: Summary of Ecological Risk Based Criteria for Headland Park

Constituent	Ecological Criteria					
	Ecological Investigation Level Protective of Potential Phytotoxicity Effects	EIL Protective of Surface Water – Headland Park Soils, Saturated Zone	EIL Protective of Surface Water – Fill Material from Barangaroo Central and South, Saturated Zone	EIL Protective of Surface Water – Headland Park Soils, Unsaturated Zone	EIL Protective of Surface Water – Fill Material from Barangaroo Central and South, Unsaturated Zone	Protection of Phytotoxicity Irrigation Water Criteria
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/L
Arsenic	27	23	26	92	102	0.93
Chromium	415	-	-	-	-	0.053
Copper	152	31	22	124	87	4.3
Lead	979	157	129	629	518	1.1
Mercury	2.9	0.2	7	0.8	27	0.056
Nickel	67	1061	700	4242	2800	1.0
Zinc	430	99	45	395	180	6.9
Cyanide	0.5	<LOR	<LOR	<LOR	<LOR	0.051
Benzene	1	1.3	1.3	5.4	5.4	0.023
Toluene	1.4	0.7	0.7	2.9	2.9	0.020
Ethylbenzene	3.1	<LOR	<LOR	<LOR	<LOR	0.023
Xylene	14	<LOR	<LOR	1.9	1.9	0.12
Acenaphthene	10	70	222	279	888	0.0066
Acenaphthylene	-	5.0	2.9	20	12	-
Anthracene	-	42	58	167	233	-
Fluoranthene	-	35	23	140	90	-
Fluorene	30	2.4	3.2	10	13	0.011
Naphthalene	-	208	26	833	104	-
Phenanthrene	-	17	6	67	24	-
Pyrene	14	12	4.8	48	19	-
Phenol	-	1.2	1.2	4.9	4.9	0.25
Cresols	-	1.0	1.0	3.9	3.9	-
2,4-dimethylphenol	-	<LOR	<LOR	<LOR	<LOR	-
TPH C ₆ -C ₉ (aliphatic)	-	65	65	261	261	-
TPH C ₁₀ -C ₁₄ (aliphatic)	-	2308	2308	9231	9231	-
TPH C _{>16} (aliphatic)	-	>MAX	>MAX	>MAX	>MAX	-
TPH C ₁₀ -C ₁₄ (aromatic)	-	23	23	92	92	-
TPH C _{>16} (aromatic)	-	1429	1429	5714	5714	-
TPH C ₆ -C ₉	65	-	-	-	-	-
TPH C ₁₀ -C ₃₆	1000	-	-	-	-	-

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12 Limitations

This report has been prepared for use by the client who commissioned the works in accordance with the project brief only and has been based in part on information obtained from other parties. The advice herein relates only to this project and all results conclusions and recommendations made should be reviewed by a competent person with experience in environmental investigations, before being used for any other purpose.

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Sampling and chemical analysis of environmental media is based on appropriate guidance documents made and approved by the relevant regulatory authorities. Conclusions arising from the review and assessment of environmental data are based on the sampling and analysis considered appropriate based on the regulatory requirements and site history, not on sampling and analysis of all media at all locations for all potential contaminants.

Changes to the subsurface conditions may occur subsequent to the investigations described herein, through natural processes or through the intentional or accidental addition of contaminants. The conclusions and recommendations reached in this report are based on the information obtained at the time of the investigations.

This report does not provide a complete assessment of the environmental status of the site, and it is limited to the scope defined herein. Should information become available regarding conditions at the site including previously unknown sources of contamination, JBS Environmental Pty Ltd reserves the right to review the report in the context of the additional information.

Figures

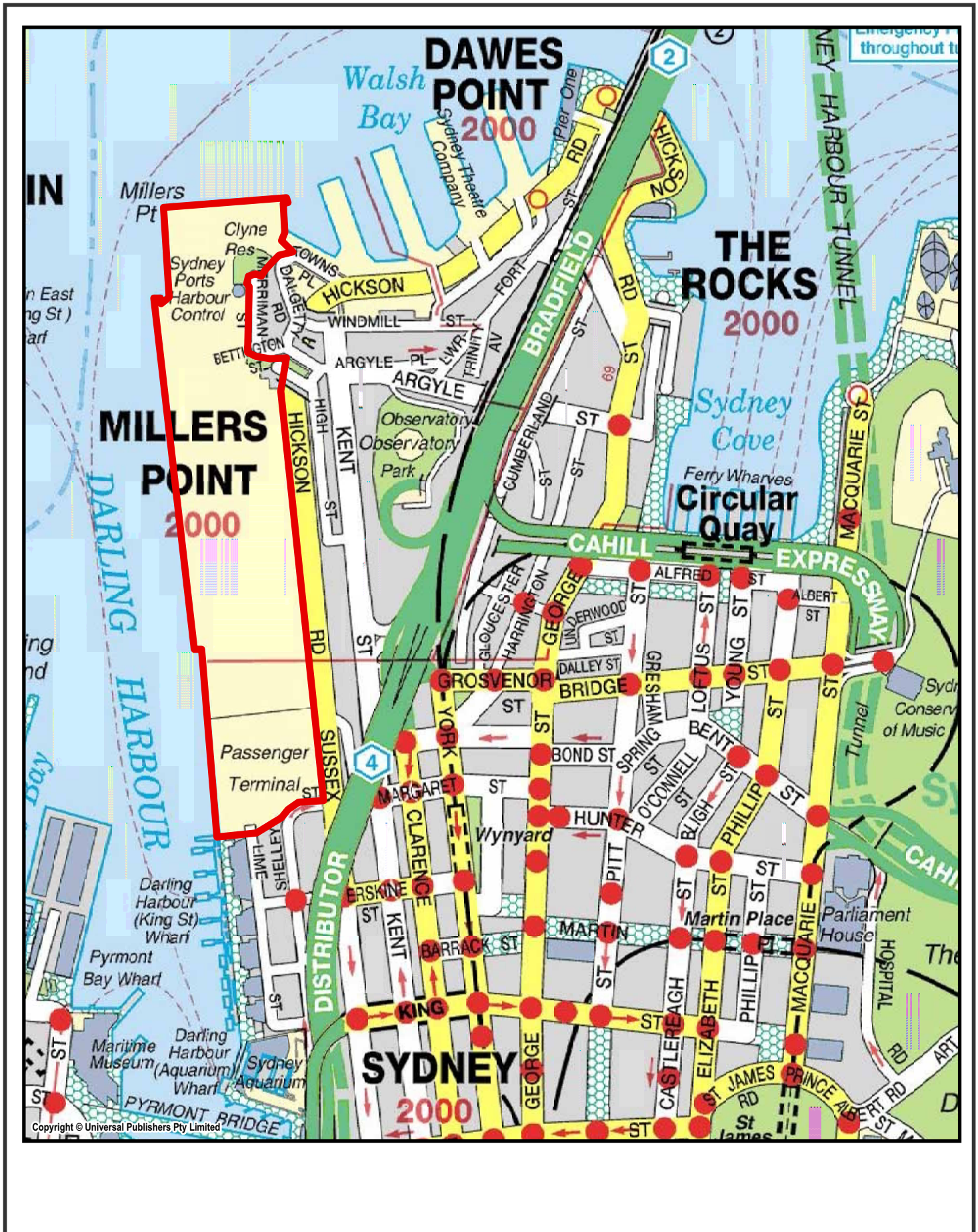


Figure 1 Location of Barangaroo Site



Figure 2

<p>1:500 @ A0</p>	<p>BARANGAROO HEADLAND</p> <p>PWP Landscape Architecture 739 Allston Way, Berkeley, California 94710</p> <p>Johnson Pilton Walker Level 10, Plaza Building Australia Square, 95 Pitt Street, Sydney NSW 2000</p>	<p>DESIGN DEVELOPMENT HEADLAND PARK_{DD-PWP-L-S3-1003} PLAN</p> <p>REV. 00 28th SEPTEMBER 2010</p>
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Figure 3A



Figure 3B



Figure 3C

1:500 @ A3



BARANGAROO HEADLAND

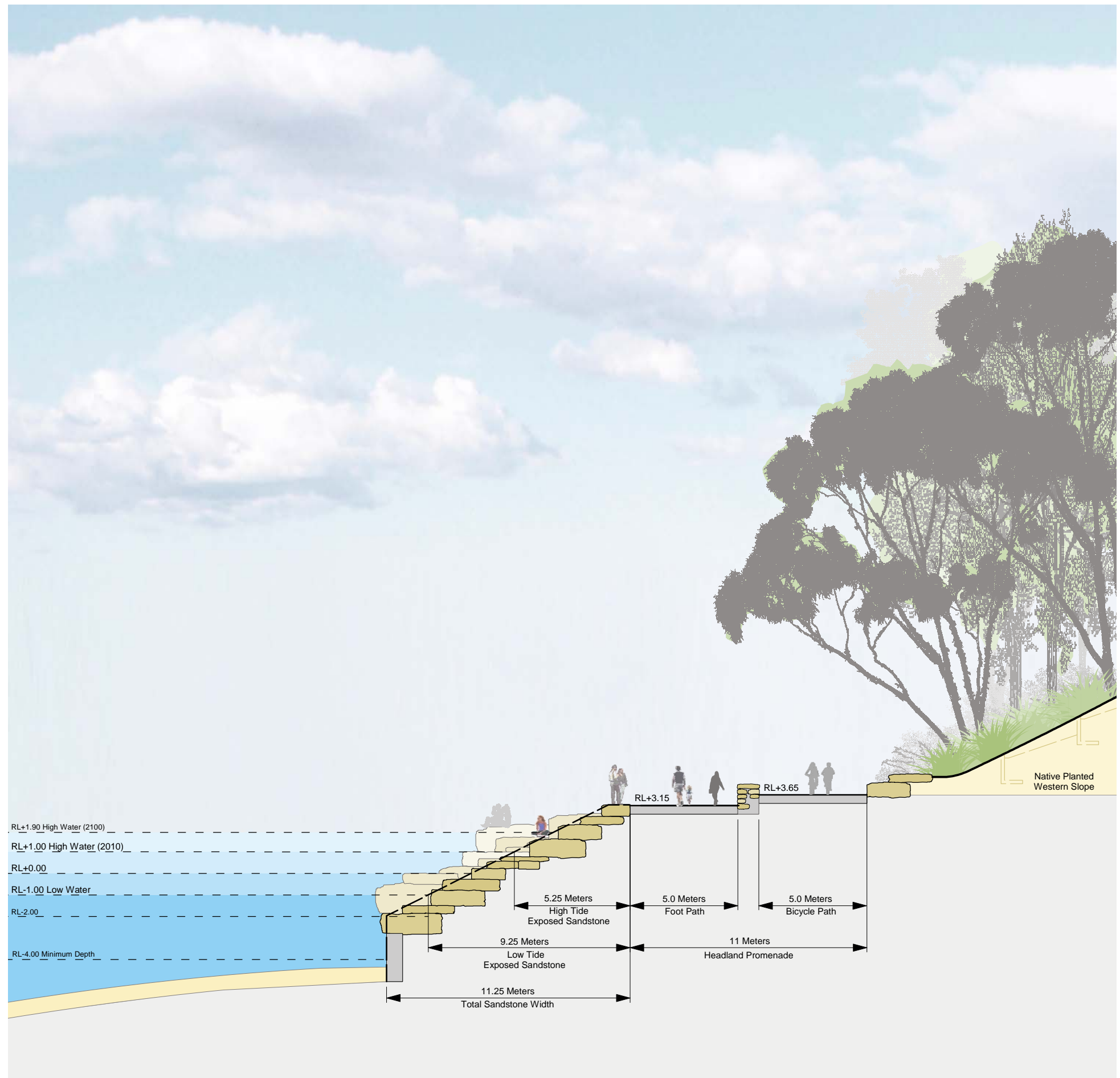
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 739 Allston Way, Berkeley, California 94710
 Johnson Pilton Walker
 Level 10, Plaza Building Australia Square, 95 Pitt Street, Sydney NSW 2000

MAIN WORKS APPLICATION
 BARANGAROO HEADLAND PARK
 HEADLAND SECTION 2

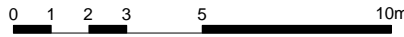
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22nd September 2010



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BARANGAROO HEADLAND

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HEADLAND SECTION 3**

MW-PWP-L-S3-2003

REV. 00

22nd September 2010

Figure 3D

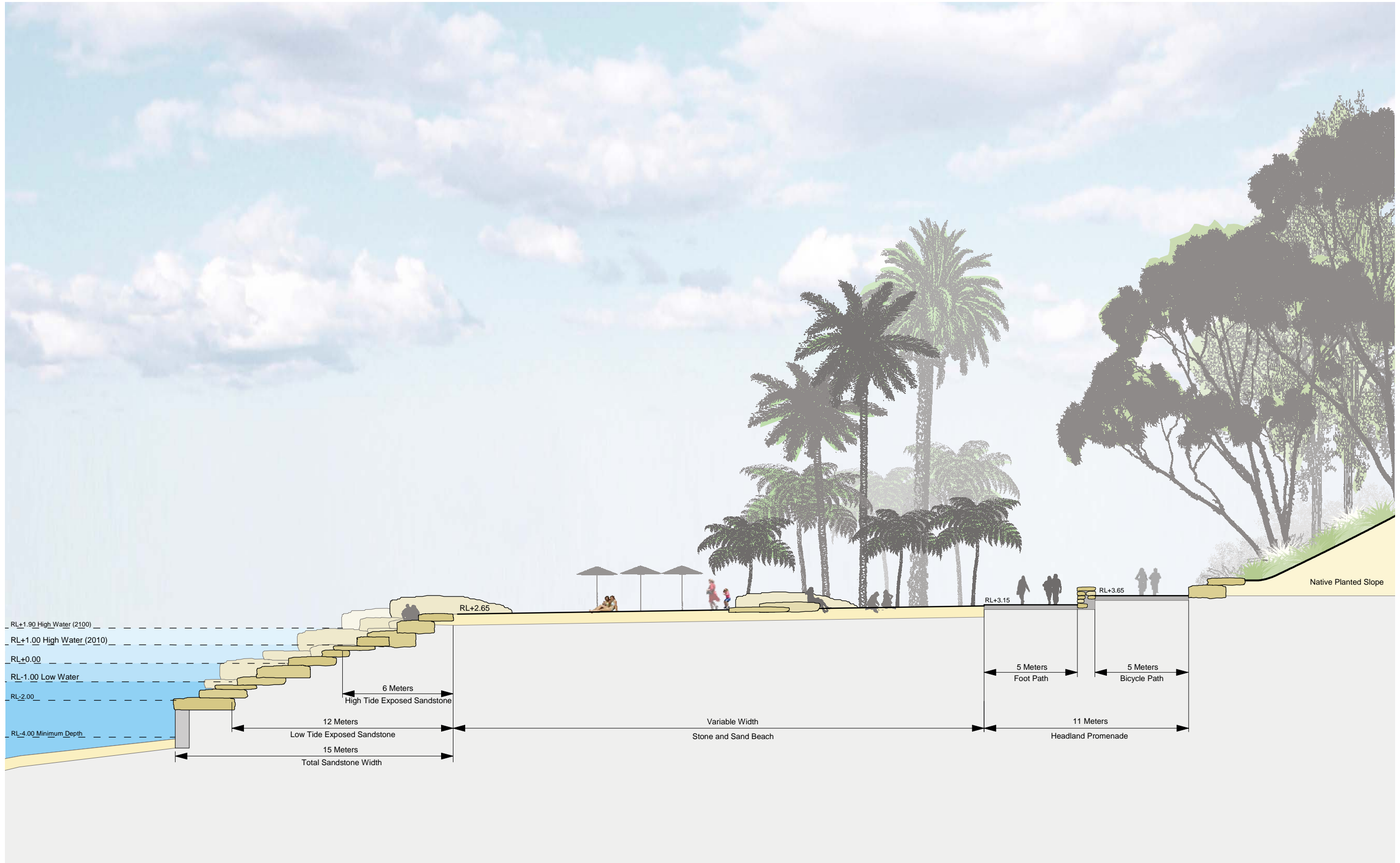


Figure 3E

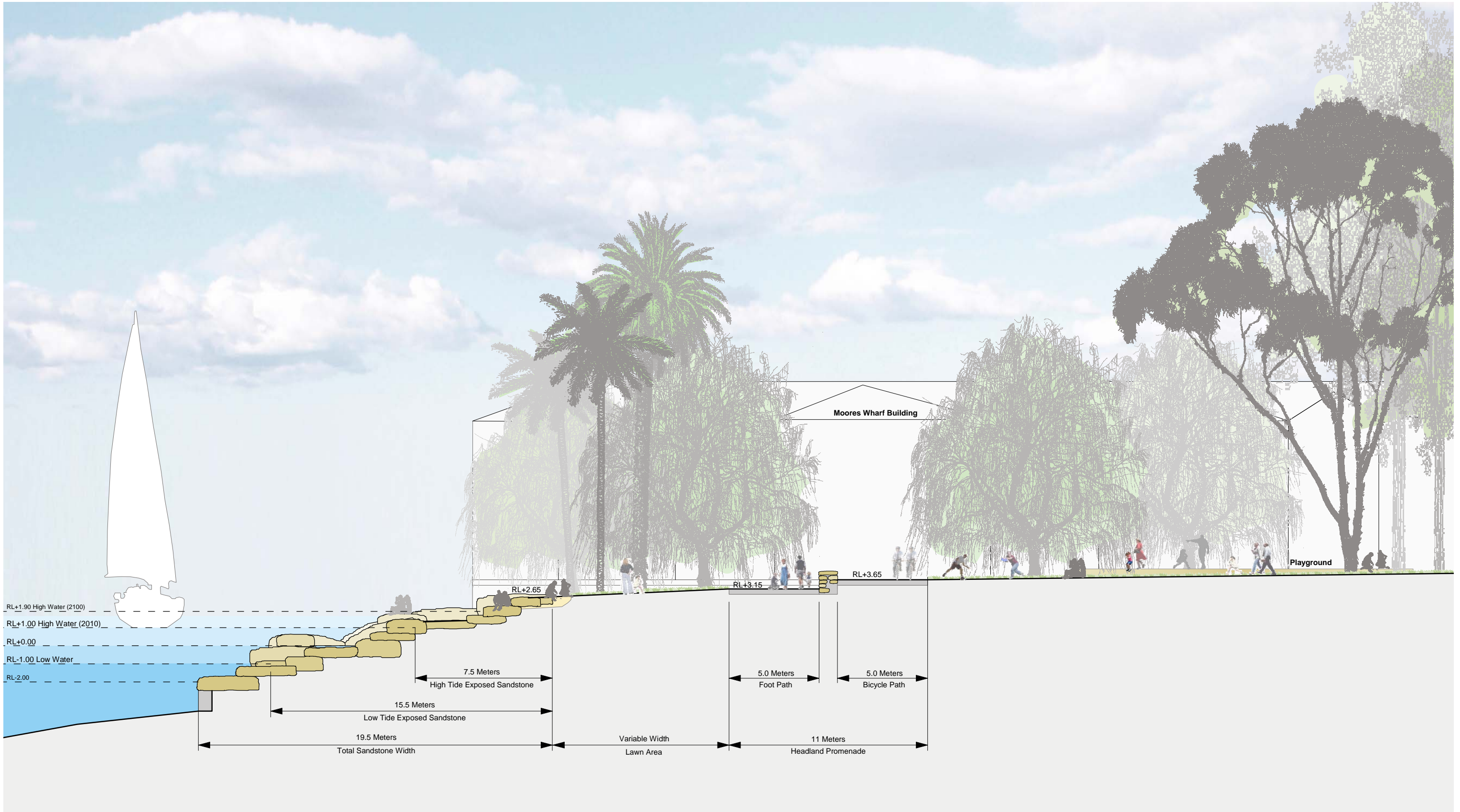


Figure 3F

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BARANGAROO HEADLAND

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MAIN WORKS APPLICATION
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HEADLAND SECTION 5

MW-PWP-L-S3-2005

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22nd September 2010

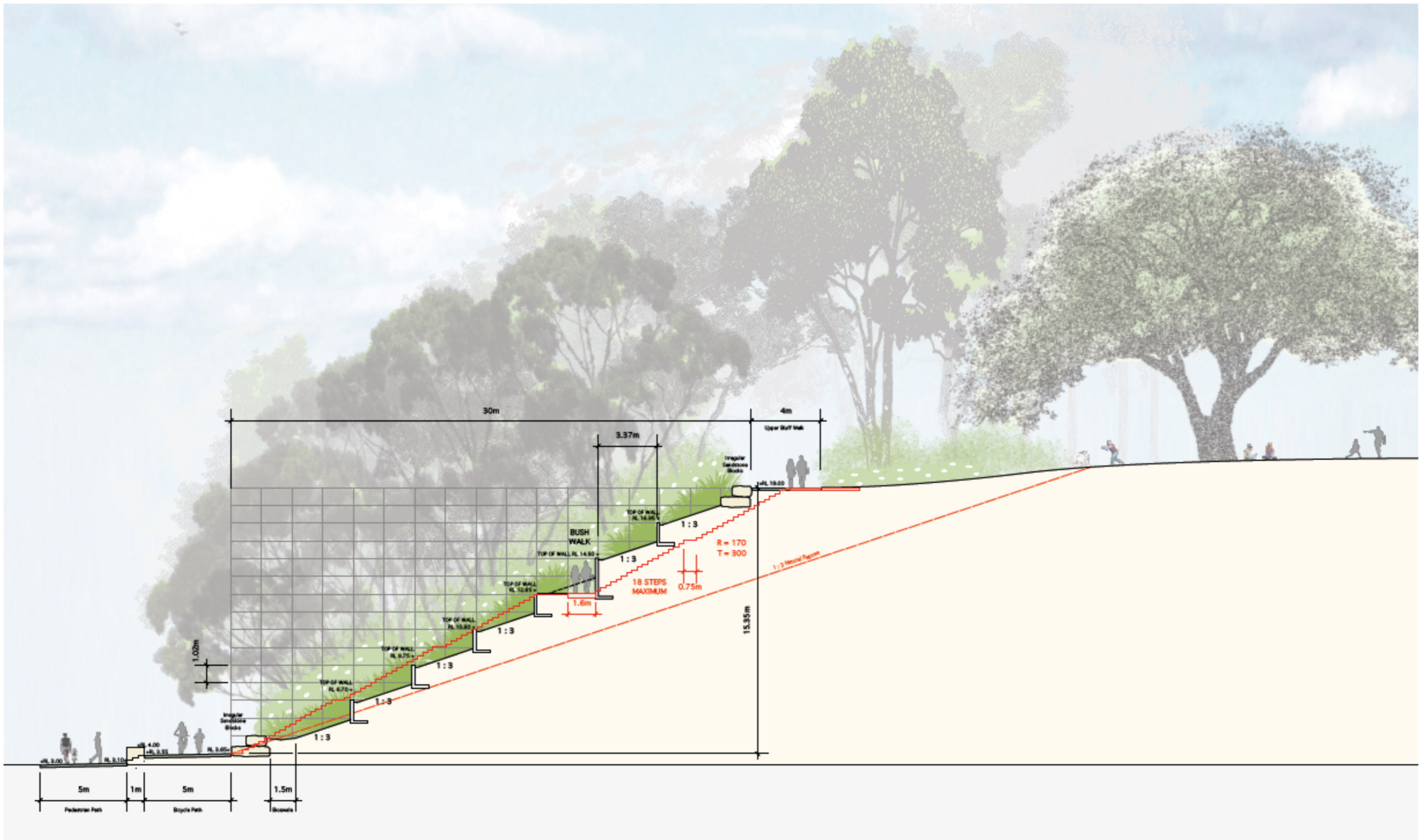


Figure 4

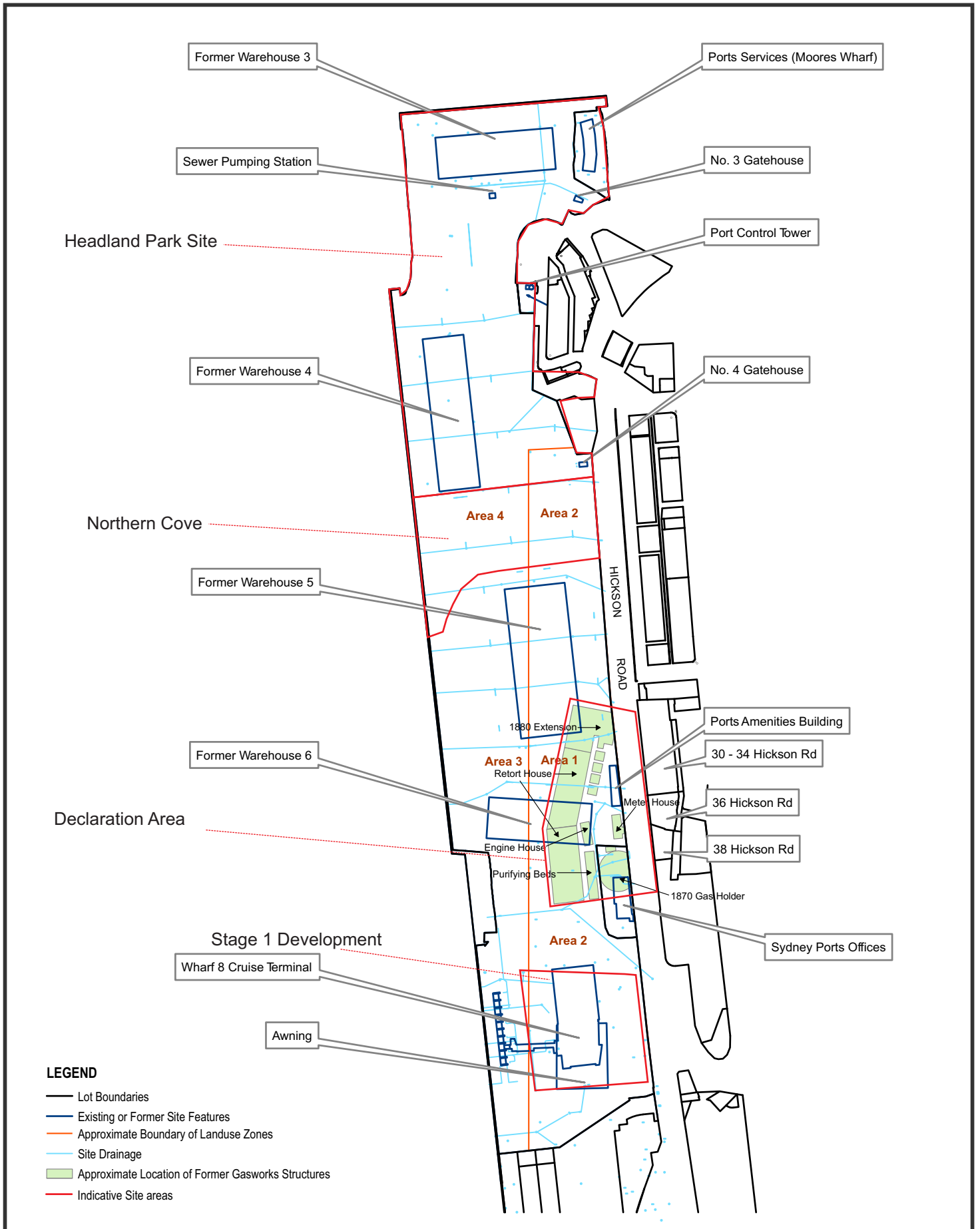
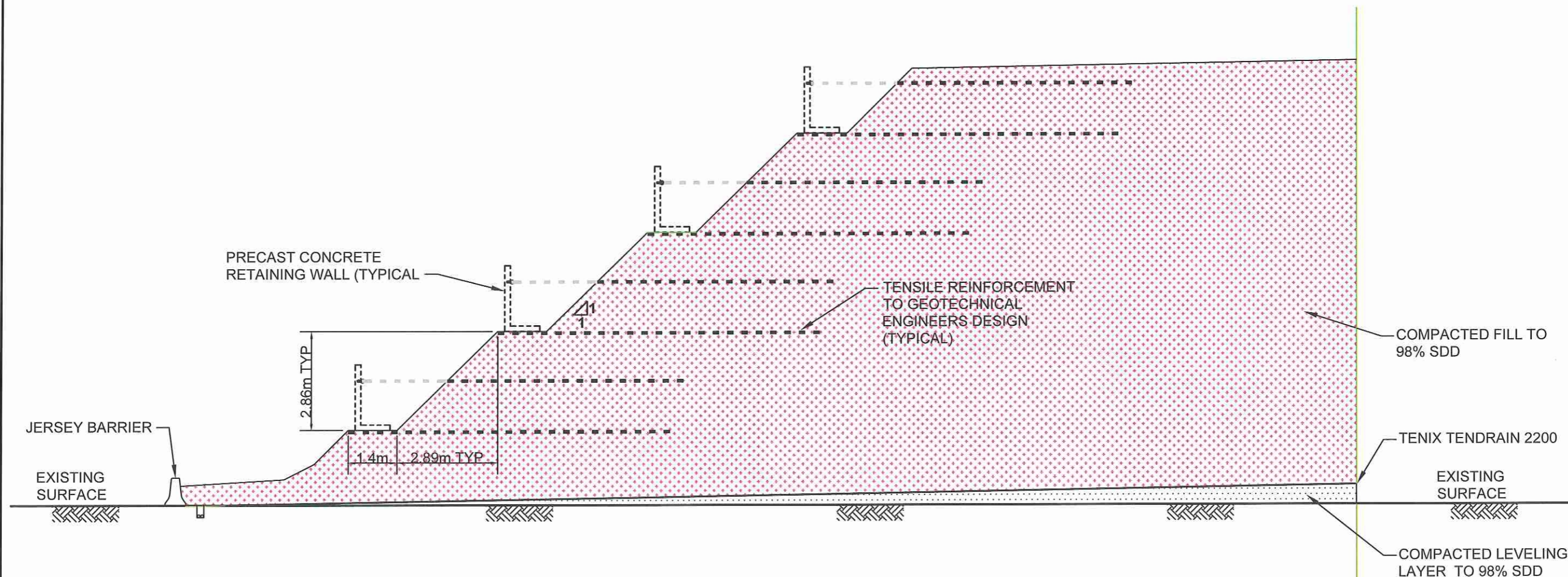


Figure 5 **Current Site Layout showing Current Site Features**

ERM (2008)
 Note- All locations shown are approximate only

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FILL BATTER TYPICAL SECTION

N.T.S.

Figure 6

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Rev.	Revision Description	Date
P1	FOR INFORMATION	01.10.10

Client:	BARANGAROO SYDNEY AUSTRALIA
Project/Job:	BARANGAROO PUBLIC DOMAIN HEADLAND PARK
Subject:	FILL BATTER TYPICAL SECTION

Designed:	PD	Date:	OCT 2010
Drafted:	PD	Scale:	AS NOTED
Job No:	10400	Dwg No:	SK3
Rev:	P1		

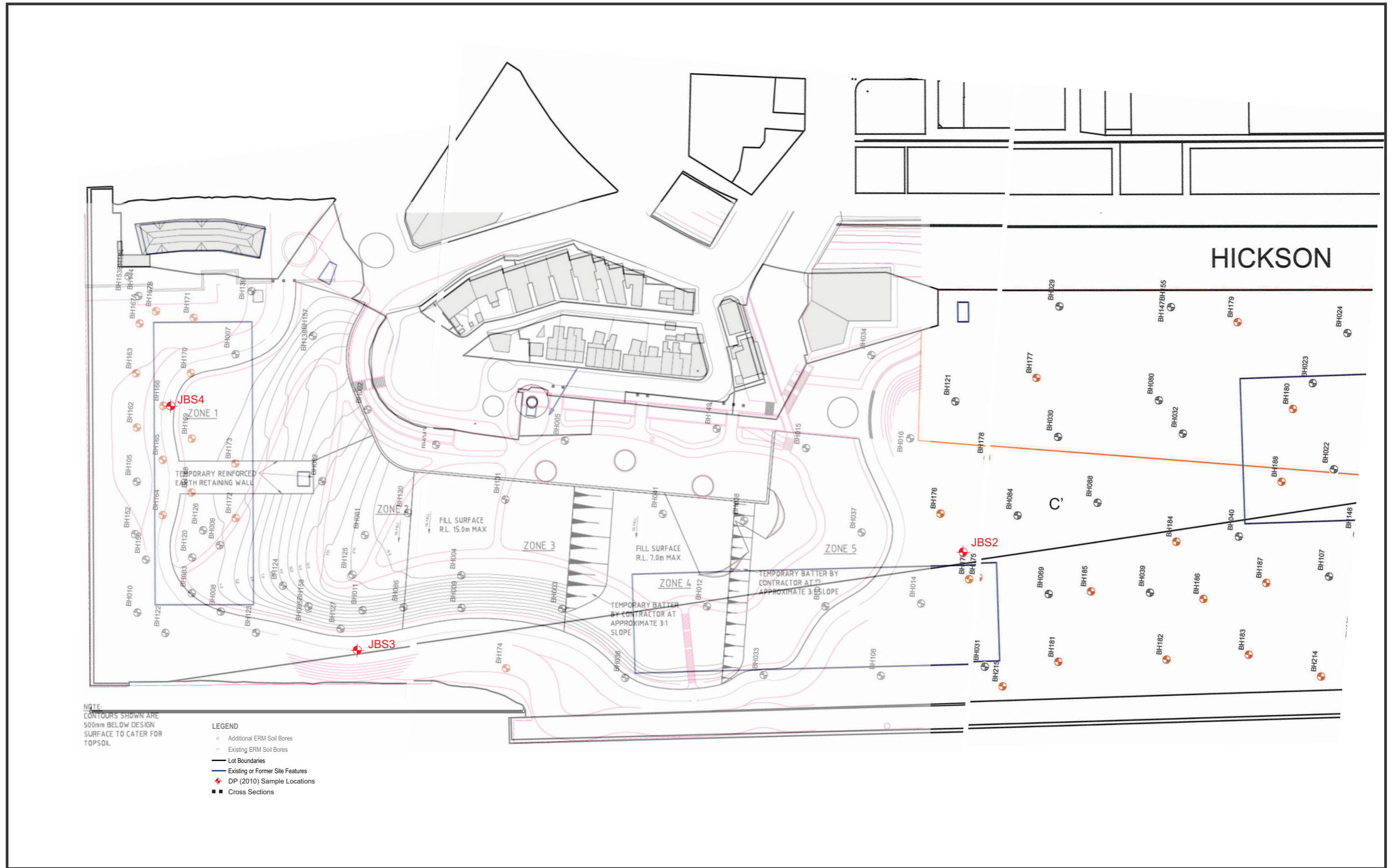


Figure 7 **Historical Soil Sample Locations as Overlaid on Approximate Proposed Park Dimensions**

ERM (2008) & Robert Bird Group (2010)
Note- All locations shown are approximate only

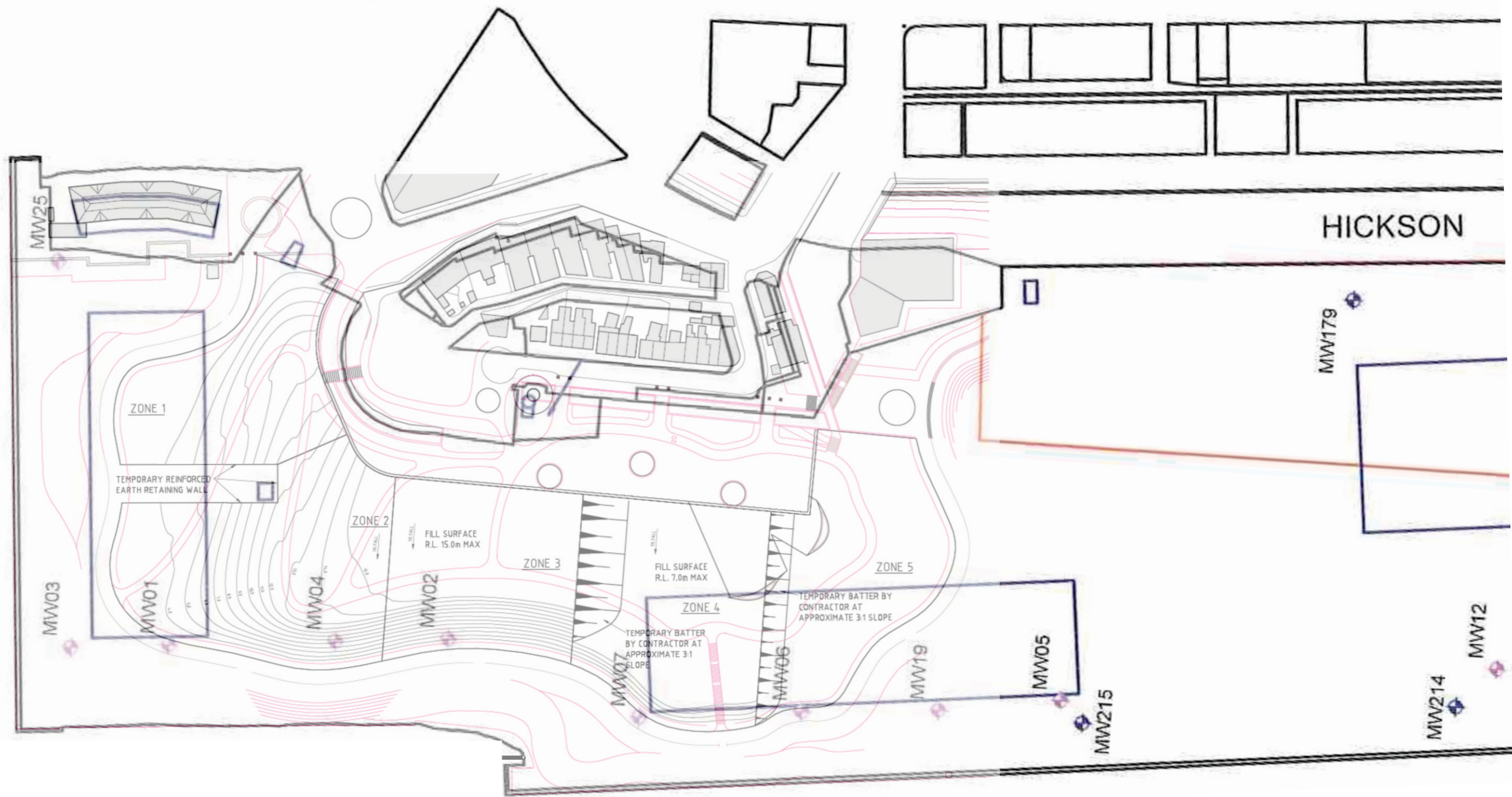









Figure 8 **Historical Groundwater Monitoring Well Locations as Overlaid on Approximate Proposed Park Dimensions**

ERM (2008) & Robert Bird Group (2010)
Note- All locations shown are approximate only

LEGEND

-  Depth to Base of Fill Contour (m AHD)
-  Proposed Site Boundary as Based on 2010 High Water Mark (1m AHD)
-  Site Boundary as Defined as Limit of Works
-  Proposed Excavation -7.6m AHD
-  Proposed Excavation -2m AHD
-  Likely extent of clay liner
-  Shading to Indicate Depth to Natural Soils (Alluvium / Sandstone) / Fill Thickness

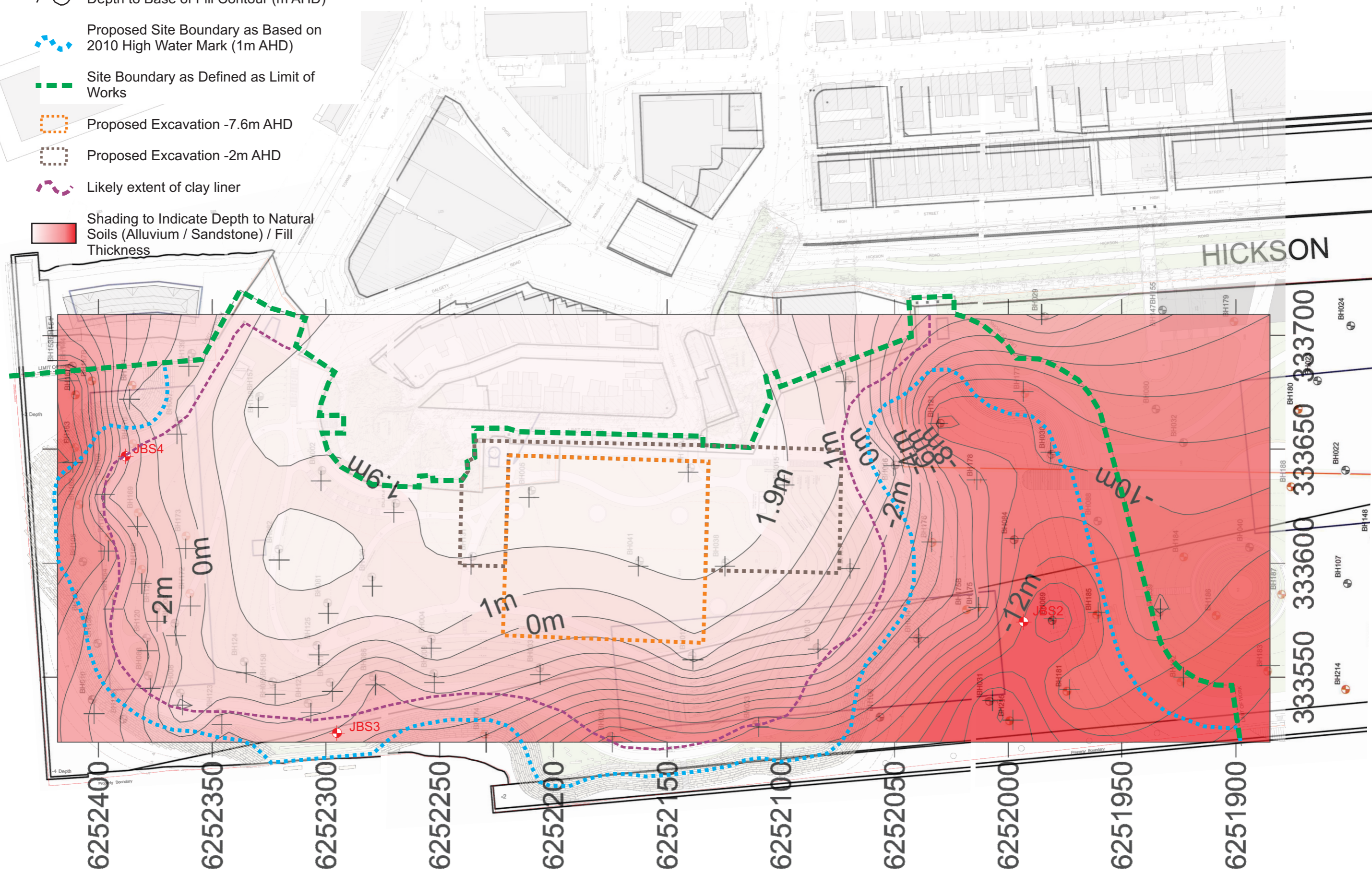


Figure 9 **Depth to Base of Fill Contours Overlaid on Proposed Site Dimensions and Soil Sample Locations**
Johnson Pilton Walker (2010) and ERM (2008)
Note- All locations shown are approximate only

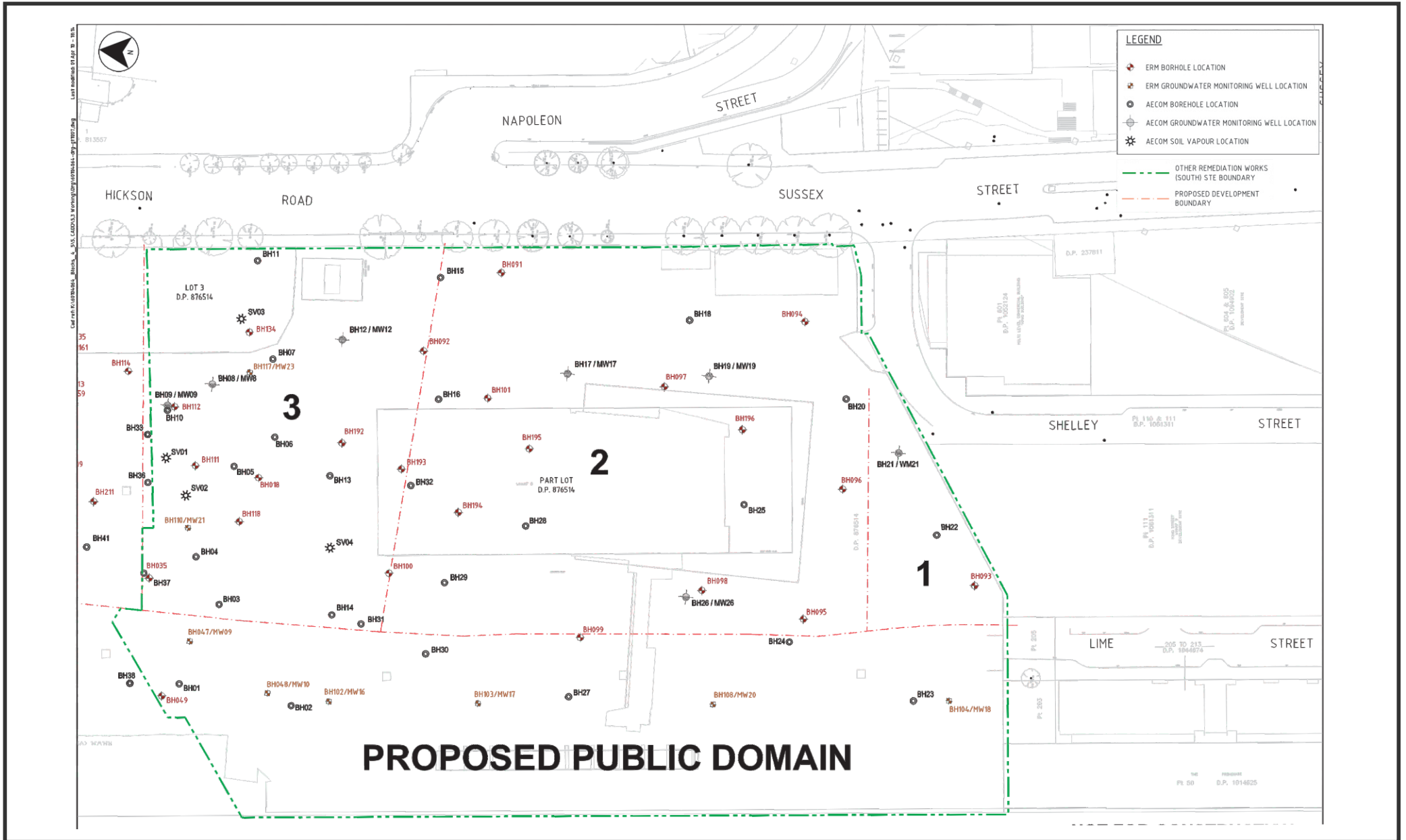


Figure 10 AECOM Soil Sampling Locations, Southern Portion

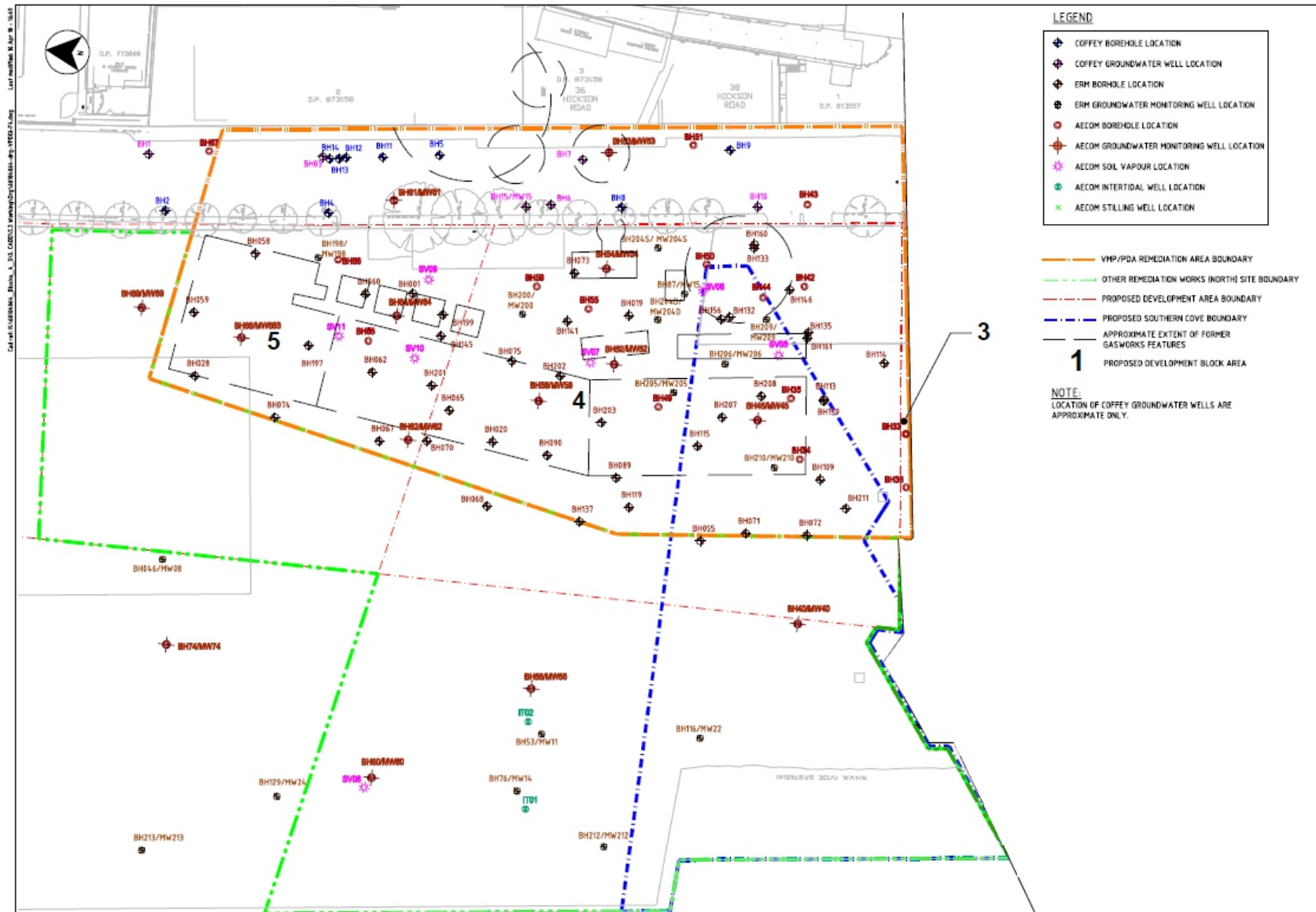
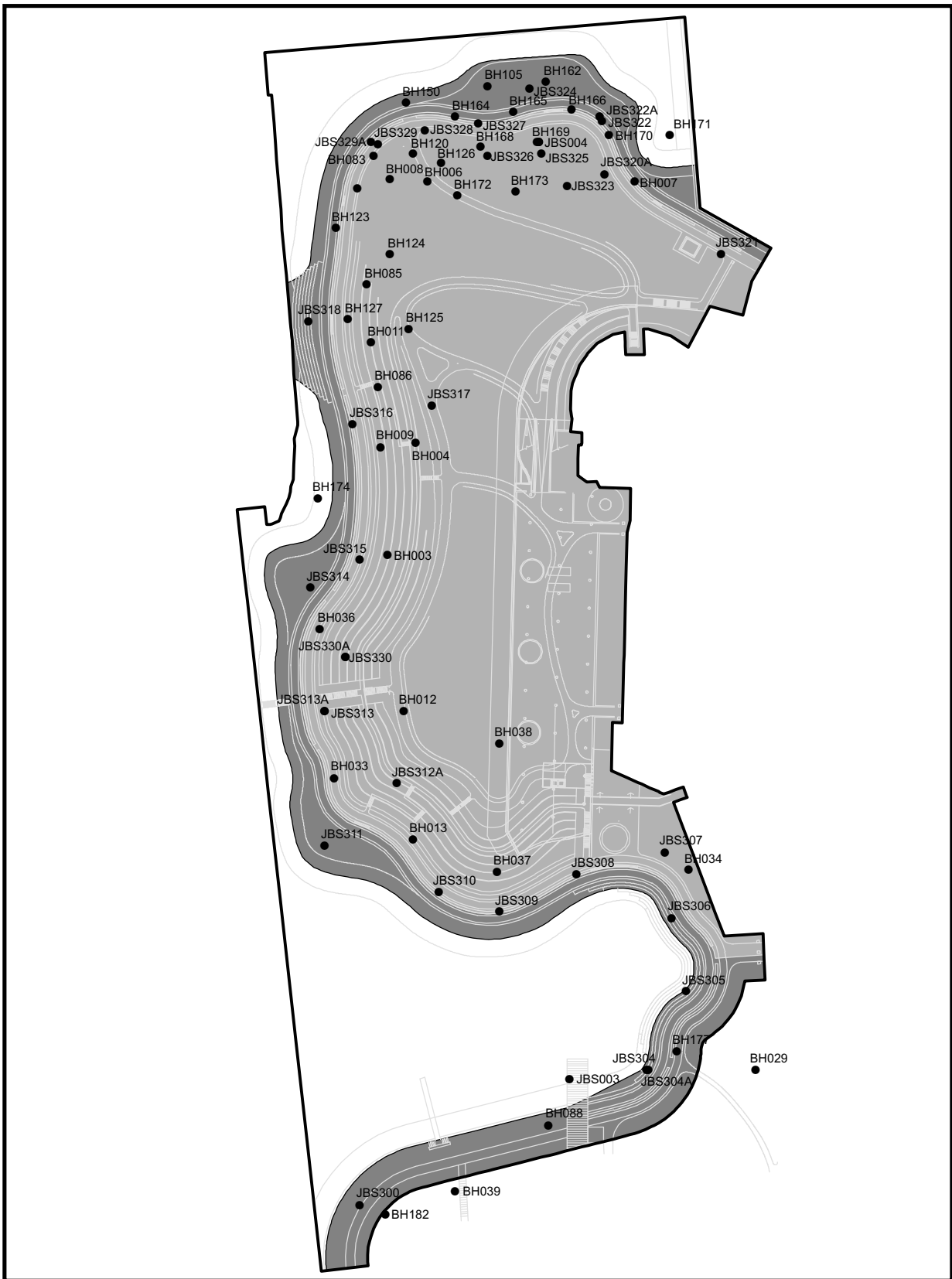
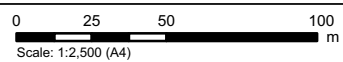


Figure 11 AECOM Soil Sampling Locations, Declaration Area

M G Planning (March 2010) and Department of Lands (2010)
 Note- All locations shown are approximate only



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Datum: MGA94 Zone 56

A4

D1	Original Issue	RF	20-1-2011
Rev	Description	By	Date

Legend:





-  Extent of Clay Layer
-  Site Boundary
-  Proposed Site Layout
-  Sample Location



Figure 12: Douglas Partners Sampling Locations

Client: Barangaroo Delivery Authority

Project: Barangaroo Headland Park

Job No: 41181

File Name: 41181_11



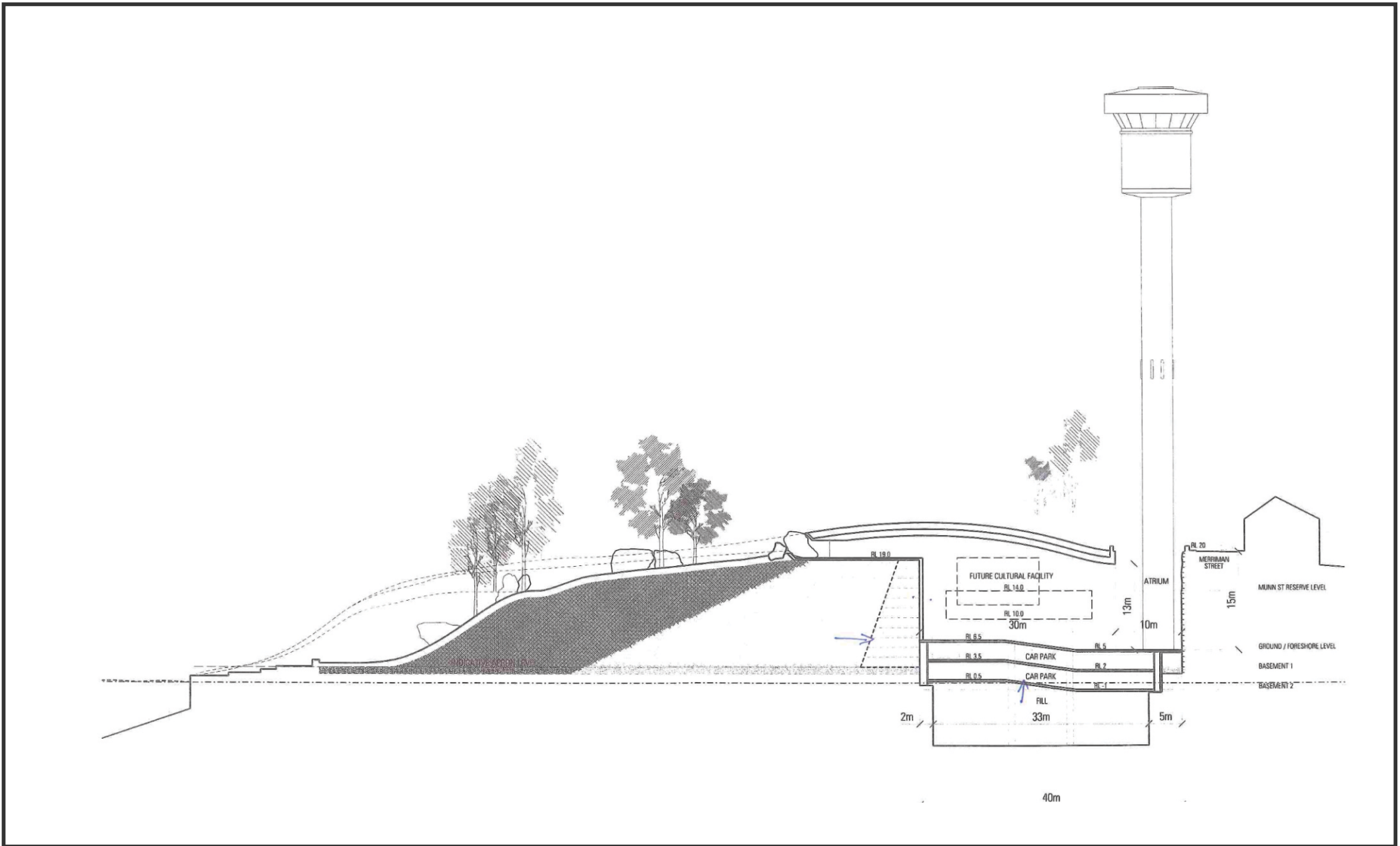


Figure 13 Proposed Complete Park Section

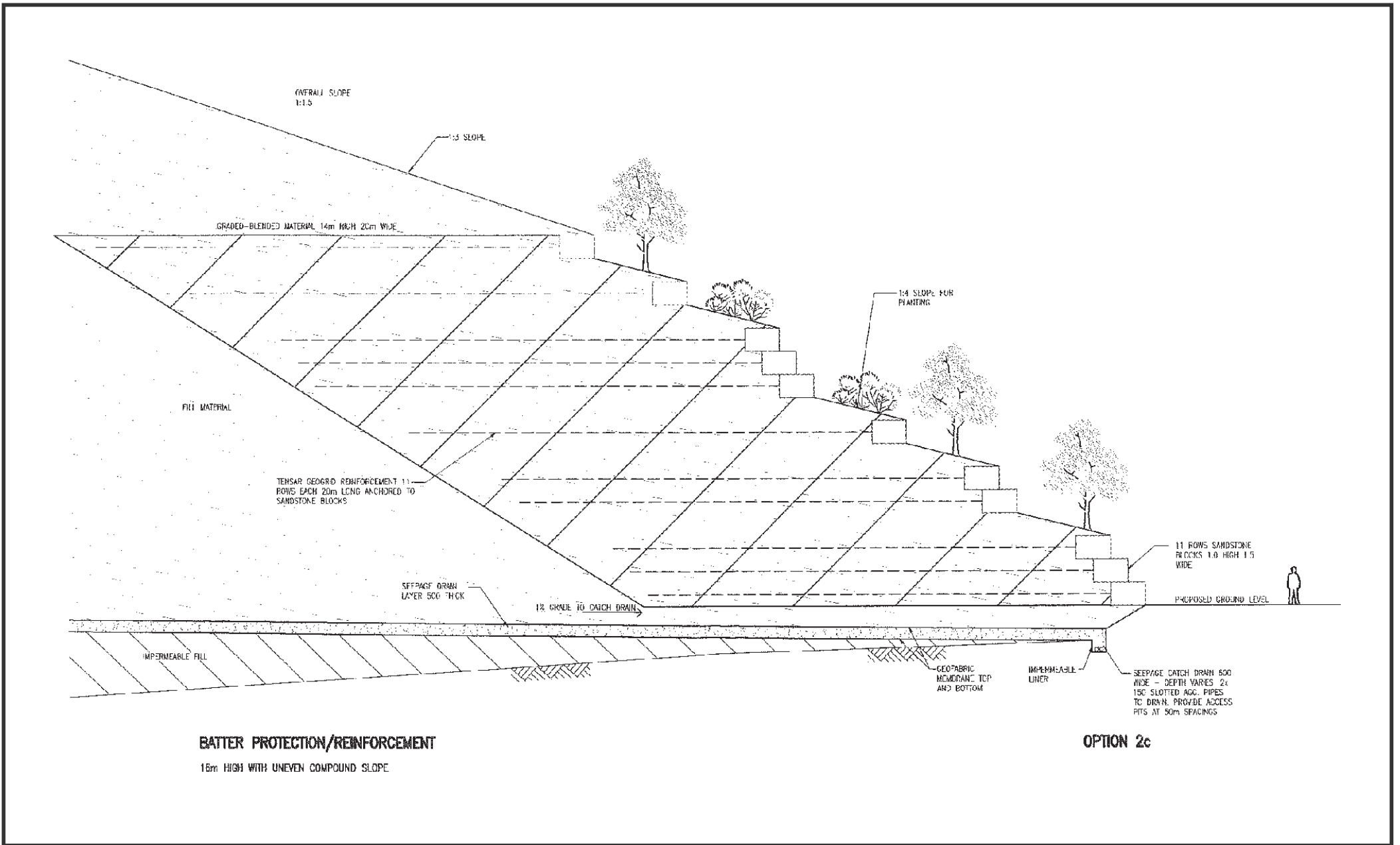


Figure 14 Proposed Park Cross-Section on Slope

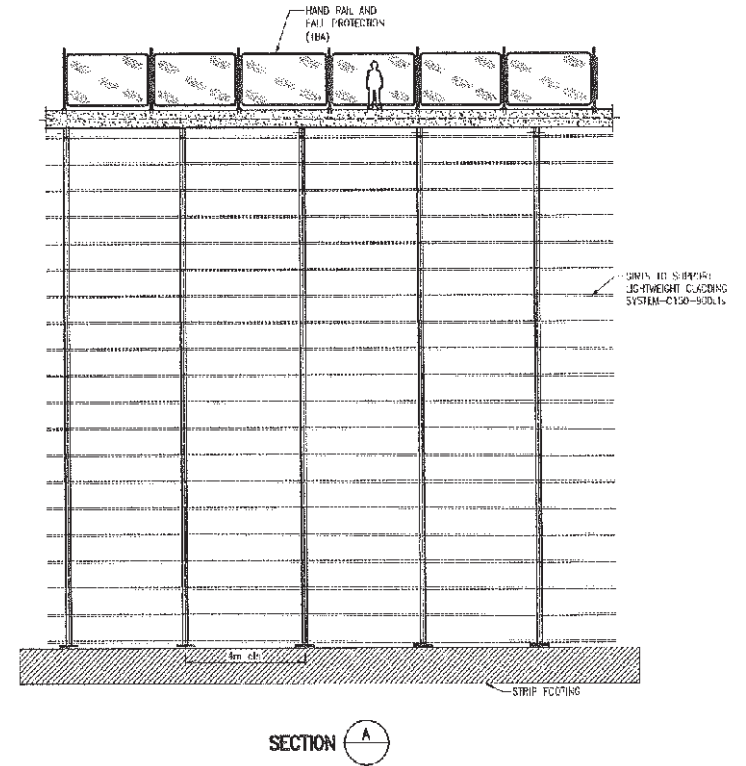
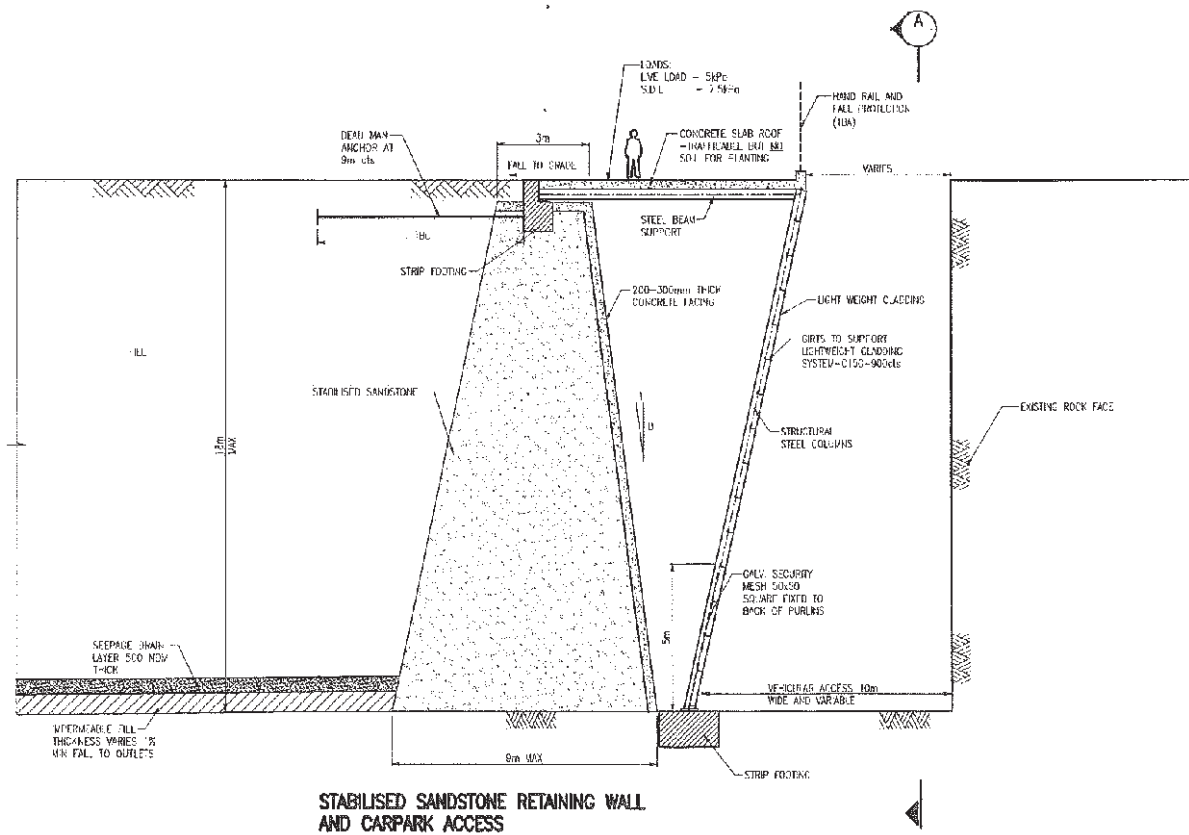


Figure 15 Proposed Cross Section Adjoining Car Park

Appendix A
Proposed Headland Park Water Balance



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Ph/Fax – 46 571 381
ABN - 98 919 877 543
mick@agenviro.com

Louis Panagopoulos
Director Civil and Water Engineer
Warren Smith and Partners
Level 1, 123 Clarence St
SYDNEY 2000

29th September 2010

Re: Barangaroo water balance

Dear Louis,

Please find enclosed a summary of the updated water balance modelling for Barangaroo Headland Park.

If we can be of any further assistance please do not hesitate to contact myself on either 0425 363 161 or 46 571 381.

Yours sincerely

A handwritten signature in black ink, appearing to read "M. Battam".

Dr Mick Battam
Principal Soil Scientist

1. Background

Barangaroo is located at the northern end of Cockle Bay. The proposed headland park will include a cultural centre and an underground carpark. Warren Smith and Partners commissioned Dr Mick Battam of AgEnviro Solutions to perform a water balance for the site in order to estimate:

- landscape watering requirements;
- effluent top-up; and
- tank storage requirements.

Irrigation requirements

A sandy topsoil is proposed, with a sandy by slightly heavier textured subsoil (Leake, 2010a, b). The topsoil depth will vary from 200 to 400 mm depth, with the subsoil being similar or deeper (Leake, 2010b).

Based on its texture, the growing media soil was assumed to have:

- a saturated hydraulic conductivity of at least 10 to 20 mm hr⁻¹ (Leake pers. com.); and
- at least 45 mm m⁻¹ of readily available water holding capacity (NSW Agriculture 2001).

Based on the proposed plantings and the exposed microclimate the watering (rain or irrigation) requirements of the site have been estimated (Table 1).

Table 1. Watering requirements.

Description	Summer and spring	Autumn and winter
Turf (kikuyu)–2.64 Ha*	7 mm of water twice a week	7 mm of water once a week
Indigenous plantings–1.26 Ha*	12 mm of water once a fortnight	None

* Areas based on areas in 10th September quantity estimate report (PWP and JPW 2010a) and draft quantity estimates cost plan 6 (PWP and JPW 2010b).

Drainage capture

It is proposed that the underlying fill be sufficiently compacted to limit the infiltration of water. For the purposes of this report it is assumed that:

- all drainage and surface water from the upper sections of the park (2.04 Ha of turf, 1.10 Ha indigenous plantings and 0.5426 Ha of paths) is captured for reuse in either the turf bioswales, the drains proposed behind the retaining walls on each tier of the steep indigenous planted slope and/or in the bio-swale on the bottom tier of the steep planted slope (PWP and JPW, 2010c). To assist in drainage capture a compacted clay layer is assumed to be present under the base of the drains and bio-swales (saturated hydraulic conductivity of 10⁻⁸ ms⁻¹);
- runoff from the foreshore paths (0.8495 Ha) is captured directly in surface drains; and
- based on the meeting discussion (1st September, 2010), drainage water is not captured from the lower sections of the park (0.60 Ha turf and 0.16 Ha indigenous plantings).

The bio-swale locations and slopes on site were estimated based on PWP and JPW (2010c). Beneath the growing media the profile consists of:

- fill that has a saturated hydraulic conductivity of 10^{-7} ms^{-1} (John Braybrooke email, 27th July 2010), an approximate silt and clay content of about 20% (John Braybrooke, pers. com.) and can be aptly described using a Campbell function; overlying
- a drainage layer that is 300 to 500 mm thick with a permeability of 10^{-1} to 10^{-2} ms^{-1} (MoM, 23rd August 2010); overlying
- a clay drainage liner that is about 500 mm thick with a permeability of 10^{-8} (MoM, 23rd August 2010) and has a slope of 1 in 100 as specified in Bruce Gunn's email (26th August, 2010).

It is assumed that the water captured by the deep underlying drainage layer can be reused in the irrigation system (Paul Sancandi, pers. comm.).

2. Methodology

Water balance modelling

In addition to the above assumptions, the water balance was based on:

- 34 years (1975 to 2008) of daily weather data from the Bureau of Meteorology station at Sydney Airport
- daily rainfall data from Observatory Hill; and
- using the proposed irrigation schedule (Table 1) and assuming irrigation events were skipped if significant (>10 mm) rainfall events occurred.

A schematic representation of the model is presented associated with Table 2 (Figure 2). The degree to which the irrigation requirements for the site could be met by effluent was estimated for a range of storage sizes.

Irrigation system performance

A distribution uniformity (DU) of 72% was assumed for the proposed sprinkler irrigation system, which is slightly less than the minimum requirements specified in the Sydney Water Open Space Best Practices Guideline (due for release in late 2010). Of the irrigation water applied, 15% is assumed to be lost as evaporation.

3. Preliminary findings

Water fluxes

A summary of the water fluxes (ML/yr) through the headland park is provided in Table 2. The average annual irrigation requirements are estimated to be 19.6 ML, which is less than the annual drainage/runoff capture in bio-swales, drains associated with the retaining walls (RBG, 18th August, 2010), paths and stone paving areas of about 41.0 ML.

An additional 7.3 ML annually would be captured by the lower clay drainage layer and could be reused in the irrigation system (Paul Sancandi, pers. comm.), but treatment may be required. About 1.6 ML annually will move through the lower clay layer (Table 2).

Despite the net capture of water, effluent top-up is required because significant amounts of drainage capture occurs during periods when little irrigation is required, such as during:

- cooler months; and/or
- following large rainfall events.

Tank sizing

The relationship between tank size and reuse was calculated based on the assumption that at least 250 kL of effluent top-up can occur within a 24 hour period (2.9 L/sec).

The tank should be at least 300 kL in size, with 256 kL representing a single watering event for the turf areas. A tank of 1250 kL would provide storage for two weeks in summer without rain and would enable almost 80% of the site water requirements to be met by drainage capture (Figure 1), but this would vary from year to year.

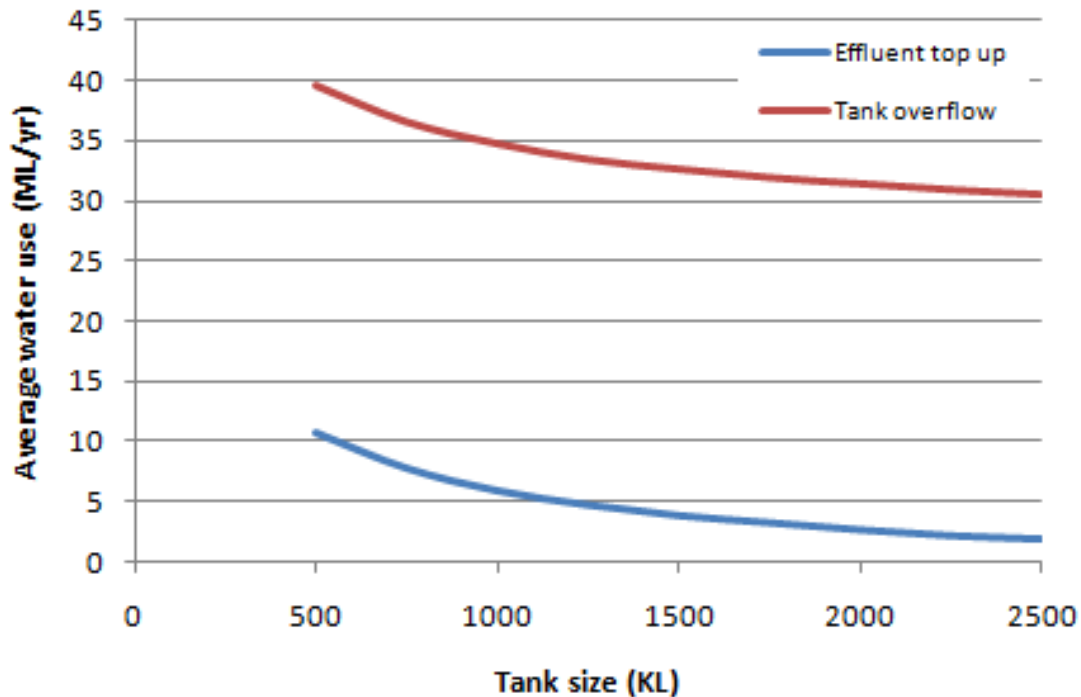


Figure 1. Effect of tank size on the requirements for effluent top-up at Barangaroo headland park (includes drainage capture from the 1 in 100 sloped clay layer)

4. References

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- PWP and JPW (2010c) Design development headland park plan, 21st September 2010.

Table 2. Average annual water fluxes (ML) for the headland park.

	Inputs			Outputs						
	Rain	Irrigation	Run-on	Run-off	Evapotranspiration	Irri evap losses	Interface flow	Fill infiltr ²		
Paths & stone paving (0.5426 Ha)	6.6	0	0	6	0.6	0	0	0		
Turf and plantings (1.8358 Ha)	22.4	12.2	0	3.4	12	1.8	0	5.4		
Turf bio-swales ³ (0.2 Ha)	2.4	1.3	7.9	0	1.3	0.2	23.43 ¹	0.26		
Indigenous slopes (1.0987 Ha)	13.35	1.79	1.5	0	4.5	0.27	8.08 ¹	3.19		
Foreshore path etc (0.8495 Ha)	10.35	0	0	0	0.96	0	9.4 ¹	0		
Turf and plantings (0.6042 Ha)	7.36	4.0	0	1.1 ⁴	4.0	0.6	2.96 ⁴	2.7		
Indigenous plants (0.1643 Ha)	2	0.27	0	0.3 ⁴	1.1	0.04	0.76 ⁴	0.5		
	Total inputs:			93.5	Total outputs:					94.8

1 interface flow is captured in drainage system

2 indicates movement through the underlying fill based on a saturated hydraulic conductivity function of 10^{-7} ms^{-1} .

3 to assist in drainage capture, a saturated hydraulic conductivity of 10^{-8} ms^{-1} was assumed for the material underlying the bioswales.

4 indicates water movement into the harbour

5 water captured in deep drain that is treated and reused

	Clay seepage	Deep drain capture
Paths & stone paving (0.5426 Ha)	0.0	0.0
Turf and plantings (1.8358 Ha)	0.9	4.5 ⁵
Turf bio-swales ³ (0.2 Ha)	0.2	0.0
Indigenous slopes (1.0987 Ha)	0.5	2.8 ⁵
Total:	1.6	7.3

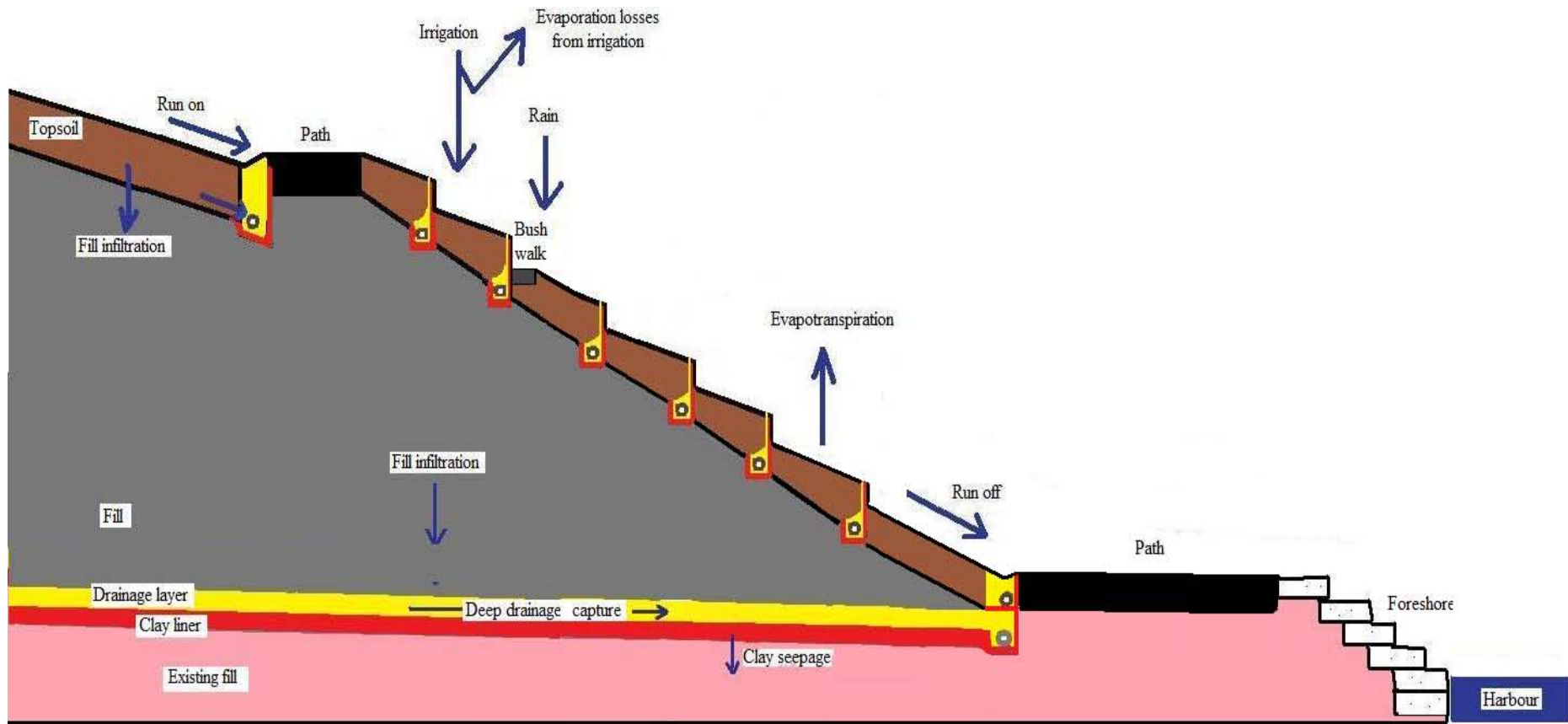


Figure 2. Schematic of water balance model showing various input components. The park is essentially divided into three areas: the upper sections (mostly turf) where runoff and interface flow are captured in bioswales. The steeper sloped areas consisting mainly of indigenous plants, where runoff is captured in drains associated with the retaining walls and a lower bioswale. The lower sections of the site where the path surface runoff is captured.

Underlying the upper and steep slope sections of the site is a clay liner (and overlying drainage layer) that assists in drainage capture, with this water reused in the irrigation system.

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Document Status

Rev No.	Author	Reviewer	Approved for Issue		
		Name	Name	Signature	Date
A	Matt Parkinson	Andrew Lau	For Auditor consideration as working draft	--	21/01/2011
B	Matt Parkinson	Sumi Dorairaj	-	-	21/1/2011
C	Matt Parkinson	Sumi Dorairaj	For Auditor consideration as working draft	--	9/2/2011



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