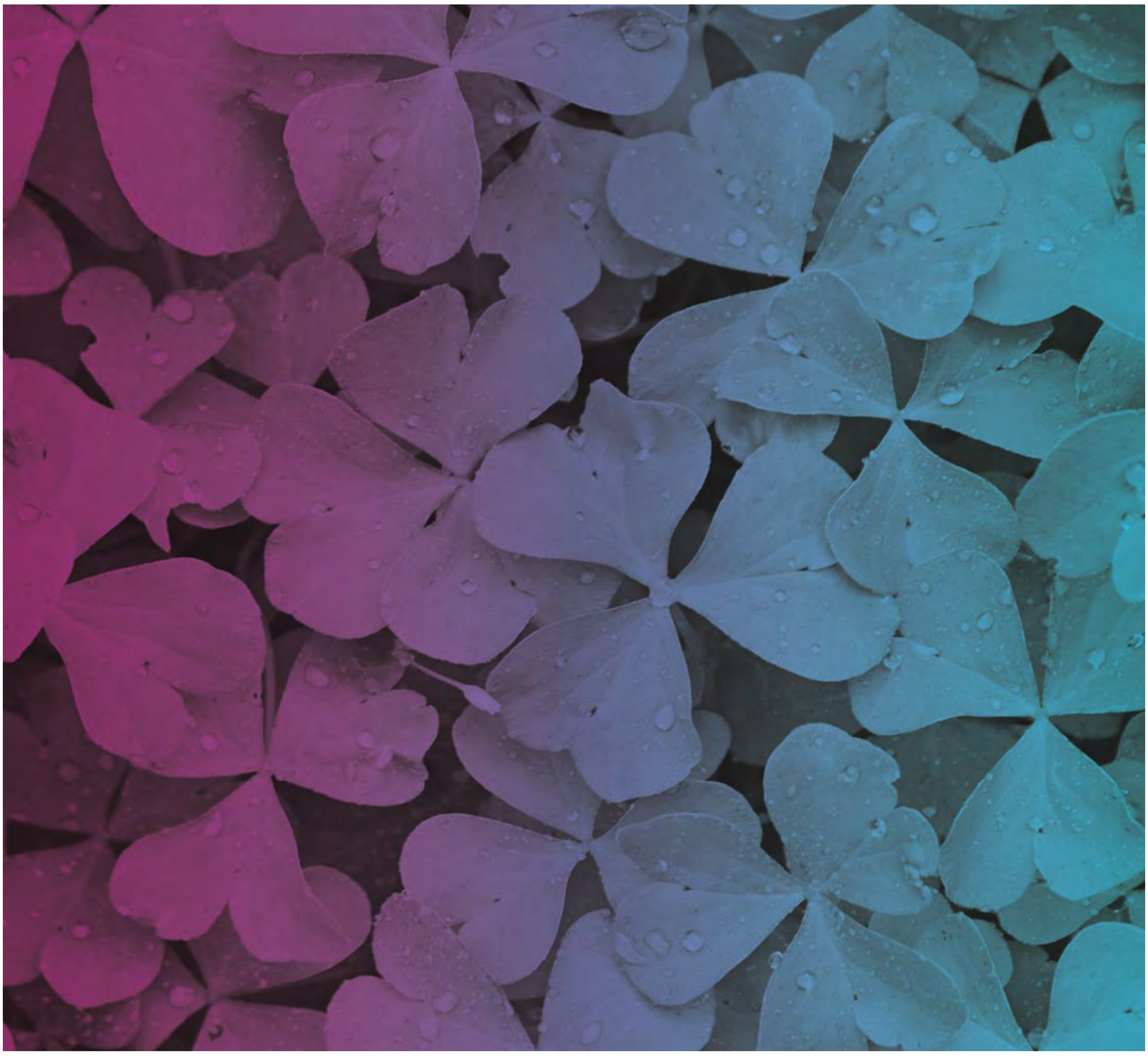
Sydney International Convention Exhibition and Entertainment Precinct (SICEEP) - PPP Sector

Lend Lease Project Management and Construction Pty Ltd

15 March 2013

# Human Health and Ecological Risk Assessment

Sydney International Convention Exhibition and Entertainment Precinct (SICEEP) - PPP Sector



# Human Health and Ecological Risk Assessment

Sydney International Convention Exhibition and Entertainment Precinct (SICEEP) - PPP Sector

Prepared for

Lend Lease Project Management and Construction Pty Ltd

Prepared by

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# Executive Summary

AECOM Australia Pty Ltd (AECOM) was engaged by Lend Lease Project Management and Construction Pty Ltd (LLPMC) to undertake a Human Health and Ecological Risk Assessment (HHERA) at the Sydney International Convention, Exhibition and Entertainment Precinct (SICEEP). It is understood that the SICEEP Site is planned for future redevelopment works including the removal of the current Sydney Convention and Exhibition Centre and redevelopment of the area for convention, exhibition and entertainment uses.

The SICEEP Site has been divided into two redevelopment sectors: 1) The Public Private Partnership (PPP) sector, and 2) The Project Delivery Agreement (PDA) sector. This HHERA is for the PPP sector only and encompasses the current Convention Centre, Exhibition Centre and public access areas including Tumbalong Park.

The project objectives were to assess the potential for unacceptable human health and ecological risks to identified on-Site and off-Site receptors following the proposed redevelopment works. In order to fulfil this project objective, a quantitative human health risk assessment was undertaken for future on-Site and off-Site receptors, and a qualitative ecological risk assessment was undertaken for on-Site vegetation and off-Site aquatic receptors.

A number of environmental investigations were conducted on the PPP between June 2012 and January 2013 to characterise soil and groundwater conditions, and the data from these investigations were provided to AECOM to form conclusions in this HHERA. It is understood that the observed impacts are a result of contaminated fill located at the PPP. Whilst the current data set available to characterise the fill material is limited, this HHERA has made a number of robust conservative assumptions as compensation, such as the exposure frequency, assumptions relating to direct surface soil exposure, vapour modelling assumptions and adoption of maximum reported site-wide concentrations (irrespective of soil depth) as exposure point concentrations; further assumptions are detailed throughout the report. The ultimate intent of adopting these conservative assumptions was to strengthen confidence in the conclusions presented in this HHERA.

## Human Health Risk Assessment

Following a review of the available analytical data, a number of data gaps were identified mostly relating to the paucity and reliability of data available to characterise the heterogeneous fill material. To compensate for the limited data available for use in this HHERA, a number of conservative assumptions were made when estimating the potential health risks to future human receptors. This included use of the maximum reported site-wide concentrations (irrespective of soil depth) as representative of conditions across the PPP and adopting the following exposure scenarios:

- For the recreational user it was assumed that the receptor would be exposed to polycyclic aromatic hydrocarbon (PAH) and total petroleum hydrocarbon (TPH) soil impacts for 2 hours once a week (i.e. one day every weekend a year) for 35 years. During this time they would have 0.5 mg of impacted soil covering each $cm^2$ of exposed skin (i.e. head, arms, hands, lower legs and feet), in addition to ingesting 100 mg of impacted soil (for a child) per day and inhaling vapours derived from surface soil impacts. The exposure frequency of recreational users of once a week is considered to be a reasonable assumption due to the other conservative assumptions made in the assessment, as well as, in winter months, recreational users are unlikely to be undertaking activities, such as picnics wearing short sleeves, shorts and no shoes.
- For the adult intrusive maintenance worker, it was assumed they would be exposed to TPH and PAH soil impacts for 10 hours per day, for 20 days per year over 30 years. During this time, it was assumed they would have 0.5 mg of impacted soil covering each $cm^2$ of exposed skin (i.e. head, forearms, hands and lower legs), in addition to ingesting 60 mg of impacted soil per day and inhaling vapours derived from surface soil impacts. This scenario is particularly conservative because it assumes that the same maintenance worker will be undertaking the works for the 35 year duration, which is an unlikely scenario.
- For the adult commercial worker, it was assumed that they would be exposed to TPH $C_{10}$-$C_{15}$ vapours derived from soil impacts for 8 hours per day indoors, for 240 days per year, for 30 years. The vapour modelling assumed that no biodegradation was occurring, that vapour may enter the building via advection and diffusion, and that the entire building footprint is above the vapour source.

This HHRA adopted an acceptable carcinogenic risk of 1:100,000 and a non-carcinogenic hazard index of 1. Based on these acceptable risk levels, the estimated potential health risks to future on-Site recreational users, commercial workers and intrusive maintenance workers were considered to be low and acceptable.

The limited data available to characterise the heterogeneous fill material is unlikely to influence the HHERA conclusions because:

- it is understood that the existing concrete slabs will remain in place following the redevelopment works, and consequently, any impacts within fill material that have not been characterised will be inaccessible for direct contact; and
- no volatile compounds were detected within groundwater, and only TPH $C_{10}$-$C_{14}$ was detected at one location in soil in an outdoor location. Therefore, it is unlikely that volatile compounds are present in any uncharacterised fill material beneath the existing building foundation slabs.

## Ecological Risk Assessment

The potential for ecological risks to terrestrial flora of Tumbalong Park and aquatic receptors in Cockle Bay was assessed qualitatively in this ERA by comparing reported soil and groundwater concentrations against generic Tier 1 screening criteria that is protective of ecological receptors.

The uptake of PAHs and hydrocarbons were considered to be relatively minor and therefore the ERA only considered the potential for metal uptake into flora of Tumbalong Park. The 95% upper confidence limit (UCL) concentrations for copper, mercury, nickel and zinc were all below the Tier 1 screening criteria protective of terrestrial plants. Consequently, AECOM considered that there is minimal ecological impact to flora within Tumbalong Park. This conclusion is supported by the presence of healthy and established flora recently observed in Tumbalong Park.

Although the reported concentrations in groundwater exceeded the Tier 1 ecological screening criteria, AECOM considered there would be minimal ecological impact to aquatic receptors within Cockle Bay given:

- the dilution potential for contaminants as groundwater migrates through the aquifer and enters Cockle Bay;
- a comparison of reported surface water zinc and copper concentrations in Darling Harbour are within groundwater concentrations reported in the PPP site (taking into consideration the dilution potential as groundwater migrates to Cockle Bay);
- the exceedances were only minor and the concentrations of PAHs within the filtered samples (i.e. the bioavailable fraction) were below the laboratory limits of reporting (LORs);
- soil leachate data suggested that PAHs have a limited ability to leach from soil into groundwater (as indicated by PAH concentrations being reported below the laboratory LORs). This indicates that the PAHs within the groundwater are most likely to be attached to the particles in the groundwater and therefore the distance they can travel is limited. The leaching potential of metals also appears to be minimal with only three, out of 12, samples being marginally above the laboratory LORs (for arsenic, chromium, copper and zinc); and
- Cockle Bay is an active non-pristine waterway and any potential contamination migrating from the PPP (where the fill has been in place for greater than 20 years) is likely to be minor.

It was therefore considered that the potential ecological risks from Site-derived groundwater impacts to Cockle Bay were low and acceptable.

The conclusions presented in this HHERA are based upon a number of site-specific assumptions including the future land use and design layout. Should any of these assumptions change that consequently influence the adopted exposure scenarios, the conclusions of this risk assessment may require revision.

# 1.0 Introduction

AECOM Australia Pty Ltd (AECOM) was engaged by Lend Lease Project Management and Construction Pty Ltd (LLPMC) to undertake a Human Health and Ecological Risk Assessment (HHERA) at the Sydney International Convention, Exhibition and Entertainment Precinct (SICEEP).

The SICEEP Site occupies an area of approximately 19.6 hectares and has been divided into two redevelopment sectors:

- The Public Private Partnership (PPP) sector. The PPP sector encompasses the current Convention Centre, Exhibition Centre and public access areas including Tumbalong Park. The PPP sector occupies an area of approximately 14.84 hectares; and
- The Project Delivery Agreement (PDA) sector. The PDA South sector (designated PDA South eastern and PDA South western sectors) encompasses the Entertainment Centre and associated multi-level car park. The PDA North sector includes the Hotel Precinct located in the most northern part of the SICEEP. The PDA area occupies an area of approximately 4.85 hectares.

This risk assessment is for the PPP sector only as shown on **Figure 1**, **Appendix A**.

## 1.1 Background

The existing Sydney Entertainment Centre (SEC) and the Sydney Convention and Exhibition Centre (SCEC) were constructed in 1983 and 1988, respectively, and both developments have been periodically upgraded.

Previous environmental assessments undertaken at the PPP have reported soil and groundwater contamination (Coffey, 2011b, Coffey, 2012b, Coffey, 2012c), and these assessments are further discussed in **Section 3.2**.

As part of the proposed redevelopment works of the PPP sector, it is understood that the SCEC will be demolished and the foundation slabs will remain.

AECOM understands that future redevelopment earthworks in the PPP sector will be limited to:

- Foundation piles extending to the depth of rock for the installation/construction of foundation/piles and lift pits;
- Relatively shallow excavations (assumed to be less than 1m depth) for the installation of utilities; and
- Minor cut and fill of soils at the proposed Public Realm landscape area that is currently occupied by Tumbalong Park.

Redevelopment works will generate approximately 26,000 $m^3$ of spoil that will require either off-Site disposal or be reused on-Site. In addition, the current slabs presently located beneath the SCEC building will remain intact, therefore restricting access to any soil beneath the slab.

## 1.2 Project Objective

The project objective was to assess the potential for unacceptable human health and ecological risks to identified on-Site and off-Site receptors following the proposed redevelopment works.

In order to fulfil this project objective, a quantitative human health risk assessment will be undertaken for future on-Site and off-Site receptors, and a qualitative ecological risk assessment will be undertaken for on-Site vegetation and off-Site aquatic receptors.

## 1.3 Framework and Methodology

The human health risk assessment (HHRA) was undertaken in accordance with relevant nationally adopted guidelines for a health risk assessment, including:

- Environmental Health Risk Assessment: Guidelines for Assessing Human Health Risks from Environmental Hazards. Department of Health and Ageing and enHealth Council, Commonwealth of Australia (enHealth, 2012a);

- Australian Exposure Factor Guide. Department of Health and Ageing and enHealth Council, Commonwealth of Australia (enHealth, 2012b);
- National Environment Protection (Assessment of Site Contamination) Measure (NEPM), National Environment Protection Council (NEPC, 1999), specifically:
  - Schedule B(4), Guideline on Health Risk Assessment Methodology; and
  - Schedule B(7a), Health-Based Investigation Levels.

The ecological risk assessment (ERA) was undertaken in accordance with relevant nationally adopted guidelines for an ecological risk assessment, including:

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ), (ANZECC, 2000).
- National Environment Protection (Assessment of Site Contamination) Measure (NEPM), National Environment Protection Council (NEPC, 1999), Schedule B(5), Guideline on Ecological Risk Assessment.

Risk assessment is a tiered process that is illustrated for a HHRA and ERA in **Appendix C**.

## 1.4 Scope of Work

The scope of work presented in this HHERA was carried out in accordance with enHealth (2012a) and NEPC (1999) guidance and included the following stages. This HHERA report has been structured to reflect these risk assessment stages.

### 1.4.1 HHRA Stage 1: Data Evaluation

- Review of the available information relating to historical investigations which have been conducted on the PPP.
- Assessment of the quality and quantity of data used in the HHRA.
- Assessment of the data gaps and their significance in the HHRA.

### 1.4.2 HHRA Stage 2: Issues Identification

- Development of a Conceptual Site Model (CSM) for the HHRA. The CSM included a description of the following:
  - The source(s), nature and extent of Site contamination;
  - Potential contaminant transport and/or migration pathways; and
  - Potential human receptors that may be exposed to Site contaminants, and the complete and potentially significant pathways via which they may be exposed.
- Identification and justification of appropriate Tier 1 screening criteria for the PPP.
- Identification of Chemicals of Potential Concern (CoPC) for the HHRA based on comparison of reported chemical concentrations in environmental media against identified 'Tier 1' screening criteria.

### 1.4.3 HHRA Stage 3: Exposure Assessment

- Identification and justification of the expected frequency, extent and duration of exposure to environmental media by human receptors via identified exposure pathways.
- Identification of representative Exposure Point Concentrations (EPCs) in environmental media that will be used in the quantitative assessment to assess the potential for unacceptable human health risk from exposure to Site-derived contamination.
- Quantitative estimation of chemical intakes or exposure-adjusted air concentrations for human receptors and exposure pathways.

### 1.4.4 HHRA Stage 4: Toxicity Assessment

- Review of the potential hazards to human health associated with each CoPC, based on review of toxicity profiles published by Australian or international regulatory agencies (e.g. National Health and Medical Research Council (NHMRC), World Health Organisation (WHO), Agency for Toxic Substances and Disease Registry (ATSDR), United States Environmental Protection Agency (USEPA), etc.).
- Review of toxicological (dose-response) criteria for each CoPC and identification of appropriate quantitative toxicity criteria to use in the HHRA. It has been assumed that relevant toxicity criteria for identified CoPC will be available from sources recognised by Australian regulatory agencies (e.g. NHMRC, ANZECC, WHO, USEPA, ATSDR, etc.).

### 1.4.5 HHRA Stage 5: Risk Characterisation

- Characterisation of the nature and potential incidence of adverse health effects to receptors based on comparison of estimated contaminant intake or exposures to relevant toxicity (dose-response) criteria.
- Comparison of risk estimates against risk acceptance criteria recommended and/or adopted by state and federal regulatory agencies.
- Discussion of the key uncertainties associated with the HHRA process and the assumptions and exposure modelling undertaken for the HHRA.
- Consideration of the risk estimates in the context of the identified uncertainties.

### 1.4.6 ERA (Level 1, Screening Assessment)

- *Problem Identification*: establishes the objectives of the ERA and identifies the data required to achieve those objectives.
- *Ecological Receptor Identification*: focuses on what species may be at risk and identifies those species that require protection.
- *Exposure Assessment*: comparison of estimated soil and groundwater concentrations against adopted ecological Tier 1 screening criteria.
- *Risk Characterisation*: discussion of the overall potential for ecological risk to trees and the nearest surface water receptor, including a discussion of the key uncertainties associated with the ERA process.

# 2.0 Site Description

The PPP description details are provided in **Table 1** below:

**Table 1 Site Details**

| Item | Description |
|---|---|
| Site Identification | Sydney International Convention, Exhibition and Entertainment Precinct – PPP only |
| Site Address | Darling Drive, Darling Harbour, NSW 2000 |
| Title Identification Details (1) | Part of Lot 1010 DP 1147364 – SCEC area<br>Part of Lot 2 DP 1048307 – air space over and area around Western Distributer overpass<br>Part of Lot 900 DP 1132344 – Tumbalong Park area<br>Lot 901 DP 1132344 – small portion of Tumbalong Park area<br>Part of Lot 200 DP 1165804 – residue Pier Street underbridge<br>Part of Lot 1 – southern edge of Pier Street area<br>Part of Lot 602 DP 1009796 – Darling Drive area<br>Part of Lot 33 DP870306 – Darling Drive area |
| Site Owner (2) | Sydney Harbour Foreshore Authority (SHFA) |
| Zoning (2) | The PPP is affected by the Darling Harbour Development Plan No. 1, which is deemed a State Environmental Planning Policy under the Environmental Planning & Assessment Act. |
| Current Land Use (2) | Commercial, recreational and open space land use. |
| Site Area | Approximately 17.7 hectares |
| Site Elevation (2) | 0m to 10m AHD (Australian Height Datum). |
| Site Location | **Figure 1** (**Appendix A**). |
| Site Layout | **Figure 2** (**Appendix A**). |

Notes: 1. SIX (http://maps.six.nsw.gov.au)
2. Coffey (2012a)

## 2.1 Site Location and Surrounding Land uses

The PPP is located at Darling Harbour, NSW. The surrounding land uses are provided in **Table 2** below.

**Table 2 Surrounding Land Uses**

| Direction | Land Use |
|---|---|
| North | PDA North sector with the Novotel and Ibis hotels beyond, Harbourside Shopping Centre and Cockle Bay. |
| South | Harbour Street and Pier Street overpass with the PDA South sector (includes the existing SEC and associated car park) and Novotel hotel beyond. Paddy's Market and Market City Shopping Centre are further to the south. |
| East | Cockle Bay (northeast) open space, the IMAX Theatre (entertainment facility) and several restaurants are present to the north of the M4 Western Distributor Freeway. Darling Quarter, the Chinese Garden of Friendship and commercial office buildings are to the south of the M4, with Sydney Central Business District beyond Harbour Street. |
| West | Darling Drive, monorail and light rail line (including Exhibition Station) with Pyrmont Street beyond. Further to the west are Harris Street Motor Museum, Ian Thorpe Aquatic Centre, commercial properties and apartment buildings (northwest). |

## 2.2 Current Land Use and Site Features

At the time this HHERA was prepared, the PPP consisted of:

- SCEC within the northern part of the PPP, beyond the Western Distributor overpass;
- Sydney Exhibition Centre along the western part of the PPP;
- Tumbalong Park (comprising a grassed public open space) in the central eastern part of the PPP; and
- Public open space across the remainder of the PPP.

**Figure 2**, **Appendix A**, shows the PPP layout.

## 2.3 Site History

A summary of the site history for the PPP is presented in **Table 3**. This information is based on the aerial photograph review carried out by Coffey (2012a). It should be noted that this information also includes the PDA sectors as part of the Site.

**Table 3 Summary of Site History**

| Date | Site Observations | Surrounding Area Observations |
|---|---|---|
| 1942 | The Site is heavily industrialised with the presence of what appears to be significant railways related infrastructure including railway tracks, sheds and buildings. Three long narrow sheds are located immediately south of Pyrmont Bridge over the footprint of the current SCEC complex. | Reclamation of the southern end of Darling Harbour has occurred and the land to the south and east of the Site appears to be occupied for rail related purposes. Commercial/industrial land use is visible to the west of the Site, including the Ultimo Power Station*.<br>Several wharves are present along the southern and eastern foreshores of Darling Harbour. |
| 1955 | No significant change to the Site is visible. | No significant change to the surrounding area is visible. |
| 1961 | | Additional commercial/industrial buildings have been constructed to the immediate west of the Site. The Ultimo Power Station ceases operations. |
| 1965 | Long narrow sheds have been constructed within the central and southern parts of the Site. | Long narrow sheds have been constructed in the current location of the SEC and car park, extending into the southern and central portions of the Site. |
| 1978 | No significant change to the Site is visible. | No significant change to the surrounding area is visible. |
| 1982 | The Western Distributor elevated roadway has been constructed through the centre of the Site. The SEC and associated car park have been constructed on the south of the Site. | |
| 1986 | Railway related infrastructure previously located on-Site has been removed and redevelopment of the entire Darling Harbour precinct has commenced, including construction of the SCEC and SEC. | The area to the east of the Site has been cleared as part of the Darling Harbour/Cockle Bay Wharf precinct redevelopment. Construction in these areas has not commenced although the majority of the wharves along the Cockle Bay waterfront have been removed. |
| 1991 | Construction of the SCEC and surrounding landscaping, including Tumbalong Park, are established.<br>The SEC car park has been extended. | The Exhibition Centre monorail stop has been constructed to the immediate west of the Site.<br>The Chinese Garden of Friendship has been constructed to the east of the Site.<br>Construction of the Cockle Bay Wharf area to the northeast of the Site continues. |

| Date | Site Observations | Surrounding Area Observations |
|---|---|---|
| 1994 | No significant change to the Site is visible. | Construction of the Cockle Bay Wharf appears to be complete. The building immediately west of the southern end of the SEC appears to have been demolished and the Site remains vacant. |
| 1997 | | The IMAX Theatre and SEGA World complex have been constructed to the east of the Site. |
| 2004 | | No significant change to the surrounding area is visible. |
| 2009 | | The Ian Thorpe Aquatic centre has been constructed to the immediate west of the southern end of the SEC.<br>The SEGA World complex has been demolished. |

Notes:
* The Ultimo Power Station was commissioned in 1900 to supply electrical power for Sydney's trams. The power station remained in operation until c. 1961.

## 2.4 Site Topography

Coffey (2012b) reported that the PPP is a relatively flat parcel of land with an elevation between 0m and 10m AHD. The surrounding land generally exhibits an increasing elevation towards the south, east and west.

## 2.5 Surface Water

Cockle Bay is the nearest surface water feature and adjoins the PPP to the north. There are a number of water features within the PPP and the adjoining Chinese Garden of Friendship site, however, these water features hold aesthetic value and are understood to be hydraulically separated from the underlying groundwater.

## 2.6 Geology

### 2.6.1 Regional Geology

Coffey (2012b) reported that, based on Macquarie's Map of 1822, the PPP occupies what was originally known as Long Cove. The former bay and its tributaries originally extended almost 1km to the south-southeast from the southern boundary of the existing harbour.

The existing shoreline has been progressively formed by man-made fill since the 1820s. The 1:250,000 Sydney Geological Series Sheet (S1 56-5) indicates that the fill covers Quaternary-aged alluvium, gravel, sand, silt and clay deposits. These deposits are underlain by a residual soil and rock of Triassic-aged Hawkesbury Sandstone Formation which comprises sandstone, quartz and shale.

The stratigraphy at the PPP is complex, comprising an infilled palaeochannel, high groundwater level and an igneous dyke. The infill materials overlying the eroded sandstone valley floor comprise slopewash, estuarine deposits and man-made filling.

Underlying the fill materials, estuarine sediments and natural alluvial deposits are expected to comprise clayey sands and clays with occasional shell layers. Beneath the estuarine deposits, there may be variable thickness of slopewash/colluvial deposits and residual soils overlying the eroded sandstone rock surface. The slopewash is expected to comprise a mixture of clayey sand, sandy clay and clays.

Sandstone bedrock to the south of the PPP (beneath the SEC) is intersected by the Great Sydney Dyke, which comprises a dolerite intrusion through the surrounding sandstone. The dyke is orientated in a southeast-northwest direction, has a width of between 3 m and 8 m and its upper zone has been weathered to a stiff clay to depths of 20 m to 28 m (Coffey, 2011a). The intrusion process of the dyke is likely to have created joints and shear zones in the adjacent sandstone which may form preferential paths for groundwater flow.

### 2.6.2 Local Geology

During previous investigations 43 bores (including locations that were terminated and repositioned) have been completed at the PPP. A summary of the geological findings, reported in previous investigation reports (listed in **Section 3.2**) and bore logs from the most recent investigation conducted by Coffey, is presented in **Table 4** below.

**Table 4 Summary of Site Geology**

| Geological Unit | Depth to Top of Unit (m bgs) | Description | Locations |
|---|---|---|---|
| Fill | 0.0 | Fill materials were encountered in all boreholes. Concrete with gravel sub-base was encountered in some locations. The fill material generally comprised heterogeneous mixtures of sand, sandy clay and sandy clay/silt with cobbles and occasional boulder sized rock fragments and concrete and brick fragments.<br>Concrete obstructions were encountered in three locations at depths between 0.2 m below ground surface (bgs) and 3.4m bgs. These obstructions typically comprised former reinforced concrete slabs, some suspected to be overlying underground services. In one location the concrete was penetrated fully and recorded as being 0.4 m thick. | All locations |
| Alluvium/ Estuarine | 1.0 to 14.5 | Alluviual/estuarine deposits were encountered sporadically across the PPP beneath the fill material. The deposits comprised clayey sands and clays with occasional shell layers and organic matter. The thickness of the alluvial soils was variable across the PPP, ranging from (where penetrated) 0.2 m (NBH14) to 12.5 m (NBH3). | NBH3, NBH4, NBH5, NBH6, NBH10, NBH14, NBH16, NBH17, NBH18, NBH20, NBH21, NBH22, NBH28, CBH6, BH106, BH109, BH111, BH112A, BH116, BH117 |
| Residual Soil | 1.4 to 14.7 | Derived from weathering of the underlying sandstone rock, residual soil was encountered either underlying fill material or the alluvial/estuarine deposits. The unit generally comprised clayey sand or sandy clay and had a stiff consistency. This unit was encountered in the far north of the PPP (BH104, BH105 and BH106) and the south of the PPP (NBH14, NBH16, NBH17, NBH28 and CBH6) and was not encountered within the central area of the PPP. Where penetrated, thicknesses ranged between 1.7 m (BH104) and 5.3 m (NBH17). | NBH1, NBH14, NBH16, NBH17, NBH28, BH104, BH105, BH106, CBH6 |
| Sandstone * | 0.3 to 21.5 | Hawkesbury Sandstone ranging from extremely weathered to fresh with low strength shale bands was reported in NBH1 at a depth of 7.0 m bgs and NBH17 at a depth of 16.8 m bgs.<br>Rock levels vary significantly across the PPP with bedrock near surface in the western part of the PPP and beneath the main exhibition centre building, approximately 15m bgs in the south east and central eastern area, and greater than 20m bgs in the northeast of the PPP. | NBH1, NBH3, NBH9, NBH10, NBH11, NBH14, NBH16, NBH17, NBH19, BH102, BH104, BH111, BH112, BH113, BH114, BH115. |
| Notes:<br>* See Coffey (2012b) for subdivisions of this unit based on strength, fracturing and defects in accordance with Pells et al (1998). | | | |

## 2.7 Hydrogeology

### 2.7.1 Regional Hydrogeology

Review of the NSW Natural Resource Atlas website (http://www.nratlas.nsw.gov.au) in January 2013 indicated that there are no licensed groundwater abstraction bores within a 1km radius of the PPP.

### 2.7.2 Local Hydrogeology

**Table 5** summaries the groundwater conditions observed across the SICEEP Site, including the PPP, PDA South and PDA North sectors during the most recent groundwater assessment conducted in January 2013.

**Table 5 Summary of Site Hydrogeological Conditions**

| Hydrogeological Condition | Description |
|---|---|
| Depth to Groundwater | Standing water levels ranged between 1.868 m below top of casing (btoc) (MW20) and 4.324 m btoc (MW25) which was generally consistent with previous gauging events (1.74 m btoc (MW20) and 4.0 m btoc (MW25) during August 2012 and 1.71 m btoc (MW20) and 4.16 m btoc (MW25) during May 2012). |
| Groundwater Occurrence | Based on observations during drilling, a water bearing layer exists within fill material and alluvium over the sandstone bedrock. |
| Evidence of Contamination | During purging, a faint organic odour was noted in MW20. No other indications of contamination were noted during gauging. |
| Groundwater Flow Direction | Based on the local setting, it was expected that net groundwater flow would generally be to the north towards Cockle Bay, although some variation in groundwater gradients would be expected over the tidal phase. |
| Groundwater Quality Parameters | DO – 0.0 ppm to 3.2 ppm – Indicative of low oxygen content in groundwater.<br>EC – 0.736 mS/cm to 43.6 mS/cm – Indicative of brackish to saline water.<br>Eh – -121 mV to 207 mV – Indicative of slightly reducing to oxidising conditions.<br>pH – 6.12 to 7.55 – Indicative of neutral conditions.<br>Temperature – 19.7 ºC to 26.9 ºC. |

Notes:
DO – Dissolved Oxygen
EC – Electrical Conductivity
Eh – Redox Potential

# 3.0 Data Evaluation

## 3.1 Data Considered in the Risk Assessment

Results and discussions of works previously completed at the PPP that were considered within the HHERA are listed in **Section 3.2**. The data from these investigations were used to form conclusions regarding potential health risks in this risk assessment.

As this assessment is limited to the PPP sector, only data from the PPP sector was used. However, data from the PDA North and PDA South sectors may be referred to in the previous investigation report summaries below.

For the purpose of this assessment, the PPP was split into two areas, as shown on **Figure 2**, **Appendix A**:

- The commercial area which occupies the majority of the western part of the PPP; and
- The recreational area which occupies the majority of the eastern part of the PPP.

Due to the heterogeneous nature of the fill material and the paucity of soil data across the PPP area, AECOM considered the site-wide soil concentrations (in both the saturated and unsaturated zones) when assessing the potential risks to all identified human receptors. This included soil data both in the open space areas and soil data collected from beneath the existing (and remaining) hard-stand and building footprint areas (irrespective of soil depth).

Due to the limited groundwater data across the PPP site, AECOM has assumed that all receptors are potentially exposed to all groundwater and therefore the groundwater data were also assessed on a site-wide basis.

## 3.2 Previous Environmental Investigations

The following environmental investigations have been conducted on the SICEEP Site to date:

- Coffey (2011b). Contamination Investigation. Sydney International Convention and Entertainment Centre. Coffey Environments Australia Pty Ltd. 23 August 2011.
- Coffey (2012b). Stage 2 - Detailed Site Investigation. Sydney International Conference Exhibition and Entertainment Precinct (SICEEP), darling harbour, Sydney. Coffey Geotechnics Pty Ltd. 1 June 2012.
- Coffey (2012c). Supplementary Site Investigation. Sydney International Conference Exhibition and Entertainment Precinct, Darling Harbour. Coffey Geotechnics Pty Ltd. 17 August 2012.
- Coffey (2013). Supplementary Site Investigation: Factual Report. Sydney International Conference Exhibition and Entertainment Precinct, Darling Harbour. Coffey Geotechnics Pty Ltd. 30 January 2013.

A summary of each investigation is provided below.

### 3.2.1 Coffey, August 2011 (PDA South sector only)

- Scope of work:
  - Drilling 15 geotechnical boreholes (BH1 to BH6, BH8 to BH15 and BH17) and three environmental boreholes (EB1 to EB3) – No boreholes were within the PPP sector;
  - Analysis of selected soil samples;
  - Installation of three groundwater monitoring wells (MW01, MW12 and MW13) – MW13 is referred to as MW13-2011 due to naming duplication in more recent investigations – no monitoring wells were within the PPP sector;
  - Sampling of three groundwater monitoring wells (MW01, MW12 and MW13); and
  - Analysis of groundwater samples.

- Contamination conclusions for PDA South sector:
  - Concentrations of total petroleum hydrocarbons (TPH) $C_{10}$-$C_{36}$, benzo(a)pyrene and total polycyclic aromatic hydrocarbons (PAHs) were reported above the adopted soil assessment criteria in three locations (EB1 1.4-1.5m, BH10 1.1-1.3m and BH11 1.0m);
  - Amosite and chrysotile asbestos fibre bundles were detected in two samples (BH13 1.5m and 2.5m);
  - Concentrations of heavy metals, TPH $C_6$-$C_9$, benzene, toluene, ethylbenzene and xylene (BTEX), volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) were below the adopted assessment criteria;
  - Concentrations of chromium, copper, lead and zinc in groundwater were above the adopted assessment criteria which were attributed to background concentrations; and
  - Concentrations of TPH, PAH and BTEX in groundwater were below the laboratory limits of reporting (LORs).

#### 3.2.2 Coffey, June 2012

- Scope of work:
  - Drilling 30 boreholes (NBH1 to NBH30) – 21 boreholes were within the PPP sector (NBH1, NBH3, NBH4, NBH5, NBH6, NBH7, NBH9, NBH10, NBH11, NBH12, NBH13, NBH14, NBH15, NBH16, NBH17, NBH18, NBH19, NBH20, NBH21, NBH22 and NBH28;
  - Analysis of selected soil samples for the following CoPC:
    - Heavy metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc) – 95 samples (including intra and inter laboratory duplicate samples), 64 within the PPP sector;
    - TPH – 95 samples (including intra and inter laboratory duplicate samples), 64 within the PPP sector;
    - BTEX – 95 samples (including intra and inter laboratory duplicate samples), 64 within the PPP sector;
    - PAHs – 95 samples (including intra and inter laboratory duplicate samples), 64 within the PPP sector;
    - VOCs – four samples (including intra and inter laboratory duplicate samples), three within the PPP sector;
    - Volatile Halogenated Compounds (VHCs) – two samples (including intra and inter laboratory duplicate samples), both within the PPP sector;
    - Organochlorine Pesticides (OCPs) – four samples (including intra and inter laboratory duplicate samples), three within the PPP sector;
    - Organophorphorous Pesticides (OPPs) – four samples (including intra and inter laboratory duplicate samples), three within the PPP sector;
    - Polychlorinated Biphenyls (PCBs) – four samples (including intra and inter laboratory duplicate samples), three within the PPP sector;
    - Asbestos – 38 samples, 25 within the PPP sector;
    - Acid Sulphate Soil – six samples, four within the PPP sector; and
    - Toxicity Characteristics Leaching Potential (TCLP) – 10 samples, six within the PPP sector.
  - Installation of eight groundwater monitoring wells (MW05, MW08, MW11, MW13, MW16, MW20, MW25 and MW30) – five monitoring wells were within the PPP sector (MW5, MW11, MW13, MW16 and MW20);
  - Sampling of seven groundwater monitoring wells (MW05, MW08, MW13, MW16, MW20, MW25 and MW30) – four monitoring wells were within the PPP sector (MW5, MW13, MW16 and MW20); and

- Analysis of groundwater samples for the following CoPC:
  - pH and total dissolved solids (TDS) – eight samples (including intra and inter laboratory duplicate samples), four within the PPP sector;
  - Heavy metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc) – eight samples (including intra and inter laboratory duplicate samples), four within the PPP sector;
  - TPH – eight samples (including intra and inter laboratory duplicate samples), four within the PPP sector;
  - BTEX – eight samples (including intra and inter laboratory duplicate samples), four within the PPP sector;
  - PAHs – eight samples (including intra and inter laboratory duplicate samples), four within the PPP sector;
  - VOCs – one sample, none within the PPP Sector;
  - VHCs – one sample, none within the PPP Sector;
  - OCPs – one sample, none within the PPP Sector;
  - OPPs – one sample, none within the PPP Sector; and
  - PCBs – one sample, none within the PPP Sector.

- Contamination conclusions:
  - Concentrations of TPH $C_{10}$-$C_{36}$, benzo(a)pyrene and/or total PAHs were reported above the adopted soil assessment criteria in four samples taken from three locations (NBH24 1.5-1.95m, NBH29 0.4-0.5m, NBH29 0.9-1.0m and NBH10 0.4-0.5m) – NBH10 was the only exceedance in the PPP sector;
  - No asbestos was detected in any analysed soil samples;
  - Concentrations of heavy metals, TPH $C_6$-$C_9$, BTEX, VOCs and SVOCs in soil were below the adopted assessment criteria;
  - Concentrations of copper and zinc in groundwater were above the adopted assessment criteria (MW5, MW8, MW13, MW16 and MW30);
  - Concentrations of TPH and BTEX in groundwater were below the laboratory LORs and concentrations of PAHs were below the adopted assessment criteria;
  - One sample (MW30) was analysed for OCPs, OPPs, PCBs, VHCs, SVOCs and VOCs and concentrations were reported below the laboratory LORs; and
  - Potential acid sulphate soils (PASS) were identified.

### 3.2.3 Coffey, August 2012

- Scope of work:
  - Drilling 11 complete boreholes (CBH1, CBH2B, CBH3, CBH4, CBH5A, CBH6, CBH7A, CBH8, CBH9, CBH10 and CBH11) – five boreholes were within the PPP sector (CBH1, CBH2B, CBH3, CBH4 and CBH6);
  - Boreholes CBH2, CBH2A, CBH5 and CBH7 were terminated early due to obstructions/drilling refusal and repositioned;
  - Analysis of selected soil samples for the following CoPC:
    - TPH – 55 samples (including intra and inter laboratory duplicate samples), 20 within the PPP sector;
    - BTEX – 55 samples (including intra and inter laboratory duplicate samples), 20 within the PPP sector;
    - PAHs – 55 samples (including intra and inter laboratory duplicate samples), 20 within the PPP sector;

    - VOCs – three samples (including intra and inter laboratory duplicate samples), three within the PPP sector;
    - SVOCs – three samples (including intra and inter laboratory duplicate samples), three within the PPP sector;
    - Asbestos – 21 samples, five within the PPP sector;
    - Acid Sulphate Soil – 15 samples, six within the PPP sector; and
    - TCLP – eight samples, three within the PPP sector.
  - Installation of two groundwater monitoring wells (MW06 and MW09) –one of the monitoring wells was within the PPP sector (MW06);
  - Sampling of nine groundwater monitoring wells (MW05, MW06, MW08, MW09, MW13, MW16, MW20, MW25 and MW30) – five of the monitoring wells were within the PPP sector (MW05, MW06, MW13, MW16 and MW20); and
  - Analysis of groundwater samples for the following CoPC:
    - TPH – 10 samples (including intra and inter laboratory duplicate samples), five within the PPP sector;
    - BTEX – 10 samples (including intra and inter laboratory duplicate samples), five within the PPP sector; and
    - PAHs – 10 samples (including intra and inter laboratory duplicate samples), five within the PPP sector.
- Contamination conclusions:
  - Concentrations of TPH $C_{10}$-$C_{36}$, benzo(a)pyrene and total PAHs in soils were reported above investigation levels (CBH9 1.0-1.1m, CBH10 0.5-0.6m, CBH10 1.0-1.1m, CBH11 1.0m-1.1m and CBH2B 3.5-3.6m) – only CBH2B was within the PPP sector;
  - No asbestos containing materials nor asbestos fibres were detected in any of the samples analysed;
  - Concentrations of TPH $C_6$-$C_9$, BTEX, VOCs and SVOCs in soil were below the adopted assessment criteria;
  - Concentrations of TPH, PAH and BTEX in groundwater were below the laboratory LORs; and
  - Analytical results and geology at the PPP indicate that PASS and actual acid sulphate soils (ASS) are almost certain to be encountered in the natural alluvial soils beneath the PPP.

#### 3.2.4 Coffey, January 2013

- Scope of work:
  - Drilling 29 complete boreholes (BH101A, BH102, BH103, BH103, BH104, BH105, BH106, BH107, BH108A, BH109, BH110A, BH111, BH112A, BH113, BH114, BH115, BH116, BH117, BH118, BH119, BH120, BH121A, BH122A, BH123A, BH124, BH125, BH126, BH127, BH128 and BH129) – 15 boreholes were within the PPP sector (BH102, BH104, BH105, BH106, BH107, BH108A, BH109, BH110A, BH111, BH112A, BH113, BH114, BH115, BH116 and BH117);
  - Boreholes BH101, BH108, BH110, BH112, BH121, BH122, BH123, BH12 and BH125 were terminated early due to obstructions/drilling refusal and repositioned;
  - Analysis of selected soil samples for the following CoPC:
    - Heavy metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc) – 135 samples (including intra and inter laboratory duplicate samples), 67 within the PPP sector;
    - TPH – 220 samples (including intra and inter laboratory duplicate samples), 108 within the PPP sector;
    - BTEX – 218 samples (including intra and inter laboratory duplicate samples), 108 within the PPP sector;

        - PAHs – 218 samples (including intra and inter laboratory duplicate samples), 108 within the PPP sector;
        - VOCs – 11 samples (including intra and inter laboratory duplicate samples), five within the PPP sector;
        - SVOCs – 15 samples (including intra and inter laboratory duplicate samples), two within the PPP sector;
        - OCPs – 15 samples (including intra and inter laboratory duplicate samples), two within the PPP sector;
        - OPPs – 15 samples (including intra and inter laboratory duplicate samples), two within the PPP sector;
        - VCHs – 11 samples (including intra and inter laboratory duplicate samples), five within the PPP sector;
        - Asbestos – 58 samples, 25 within the PPP sector;
        - Australian standard leaching procedure (ASLP) – 15 samples, 12 within the PPP sector; and
        - TCLP – eight samples, six within the PPP sector.
    - Installation of 10 groundwater monitoring wells (MW102, MW104, MW105, MW106, MW107, MW109, MW110A, MW117, MW120 and MW124) – eight of the monitoring wells were within the PPP sector (MW102, MW104, MW105, MW106, MW107, MW109, MW110A and MW117);
    - Sampling of 17 groundwater monitoring wells (MW05, MW06, MW08, MW09, MW13, MW16, MW20, MW25, MW30, MW104, MW105, MW106, MW107, MW109, MW110A, MW117 and MW120) – 13 of the monitoring wells were within the PPP sector (MW05, MW06, MW13, MW16, MW20, MW30, MW104, MW105, MW106, MW107, MW109, MW110A and MW117); and
    - Analysis of groundwater samples for the following CoPC:
        - Heavy metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc) – 20 samples (including intra and inter laboratory duplicate samples), 15 within the PPP sector;
        - TPH – 19 samples (including intra and inter laboratory duplicate samples), 14 within the PPP sector;
        - BTEX – 20 samples (including intra and inter laboratory duplicate samples), 15 within the PPP sector; and
        - PAHs – 36 samples (including intra and inter laboratory duplicate samples), 26 within the PPP sector.
- The Coffey 2013 report was factual and contained no conclusions regarding contamination.

## 3.3 Data Quality

The available analytical data was reviewed within each individual report and assessed to ensure that the data is in compliance with method requirements and project specifications. The data validation process included checking the analytical procedure compliance and an assessment of the accuracy and precision of the analytical data from a range of quality control measurements generated from both the sampling and analytical programs.

The data validation review undertaken for all previous reports did not indicate significant impact on the overall precision and accuracy of the primary data sets, thus, the analytical results incorporated into the current risk assessment were considered to be valid and representative of concentrations of the analysed compounds at the sample locations tested.

AECOM noted that the analytical data that was presented in one electronic laboratory file (that was used to import data into a database) was not consistent with the data in the corresponding laboratory reports. Therefore, AECOM conducted a full quality check on the data from the incorrect laboratory file against the results reported in the laboratory report (MGT report 346471 from Coffey, 2012c) to ensure that the correct values were used in the risk assessment.

## 3.4 Data Quantity

As discussed in **Section 3.2,** three previous investigations have taken place within the PPP sector between June 2012 and January 2013. Following a review of the available analytical data, AECOM considers that the subsurface Site conditions may not have been fully characterised due to the heterogeneous nature of the fill material. This limitation has been noted as a potential data gap in **Section 3.5.**

As a consequence of this data gap, AECOM adopted several conservative assumptions when estimating the potential for unacceptable human health and ecological risks including conservative human behavioural assumptions (refer to **Section 5.1**) and the adoption of maximum analytical site-wide concentrations.

Soil data from all investigations conducted across the PPP sector were used in this HHERA to provide the most comprehensive coverage of the PPP possible because the NSW Environment Protection Authority (EPA) (1995) Sampling Design Guidelines for the number of sample locations was not met.

Groundwater data from all investigations conducted across the PPP sector were used in this HHERA to facilitate the adoption of conservative exposure point concentrations for this risk assessment.

## 3.5 Data Gaps

**Table 6 Summary of Data Gaps**

| Data Gap | Potential Significance | Manner in which addressed in the HHERA |
|---|---|---|
| Sampling density | The number of sampling locations conducted by Coffey did not meet the NSW EPA (1995) Sampling Design Guidance for site characterisation. | All available sampling locations within the PPP sector were considered within the risk assessment, and the maximum concentrations were used to assess potential health risks. |
| Variability of fill material | Concentrations identified in contaminated areas may be present in fill in areas not investigated across the PPP. | Maximum reported site-wide concentrations (from all soil depths) were used to assess potential health risks, including soil data in open space areas and soil data collected beneath the existing (and remaining) hard-stand and building footprint areas. Refer to **Appendix K** for further discussion. |
| Sampling techniques | Fill samples from the Coffey 2011 investigation were noted as being collected directly from the auger flight. There is uncertainty related to sample representativeness and the analysis results. | Data from the 2011 investigation was not used in the current HHERA as all data from the investigation was for the PDA South sector. |
| Analysis of CoPC | Soil samples were not tested for cyanide. As elevated PAH concentrations were identified and both cyanide and PAHs are typically encountered in gasworks waste (that may have potentially been imported onto the PPP) it would be prudent to submit samples for cyanide analysis. | Cyanide has not been assessed as part of the HHERA as no data was available. This is only an issue if gasworks waste is present at the Site which is unlikely given the concentrations detected, nature of the PAH compounds and lack of visual observation of tar during fieldworks. |

| Data Gap | Potential Significance | Manner in which addressed in the HHERA |
|---|---|---|
| Laboratory analysis results | AECOM noted that TPH and PAH concentrations do not appear to correlate within some samples. For example, where TPH is present at elevated concentrations PAHs would be expected to be elevated and vice-versa. | Maximum reported concentrations were used to assess potential health risks. |
| Groundwater samples | The majority of the groundwater wells have only been sampled once, therefore trends in contamination cannot be assessed | Data from all available monitoring wells and dates were considered in the risk assessment, and the maximum concentrations were used to assess potential health risks. |
| ASLP analysis | Only 12 ASLP leachability tests were conducted within the PPP sector. | All available ASLP leachate data, was considered within the HHERA. |

# 4.0 Issues Identification

Issues Identification identifies the key issues for the risk assessment and establishes a context for the risk assessment by a process of identifying the concerns that the risk assessment needs to address (enHealth, 2012a). Fundamental to identifying the risk assessment issues is the development of a CSM.

A CSM is a site-specific qualitative description of the source(s) of contamination, the pathway(s) by which contaminants may migrate through the environmental media, and the populations (human or ecological) that may potentially be exposed. This relationship is commonly known as a Source-Pathway-Receptor (SPR) linkage. Where one or more elements of the SPR linkage are missing, the exposure pathway is considered to be incomplete and no further assessment is required.

The CSM is described in detail below and is illustrated in **Figure 4**, **Appendix A**.

## 4.1 Contamination Sources

A review of previous reports indicated that the following CoPC were reported at concentrations above the assessment criteria:

- TPH (soil);
- PAHs (soil); and
- Metals (chromium, copper, lead and zinc) (groundwater).

The source of the identified CoPC was considered to be the fill material present at the PPP and the historical use of the PPP as for industrial and rail activities. To AECOM's knowledge, no single significant contamination incident has occurred on the PPP.

### 4.1.1 Soil

One contamination area was identified by Coffey in the fill material in the central part of the PPP, beneath the current Exhibition Centre (NBH10 and CBH2B). The contamination comprised a benzo(a)pyrene concentration of 6.5 mg/kg at a depth of 0.5 m bgs at sampling location NBH10. Additional delineation works undertaken in this area by Coffey (Coffey, 2012c) indicated that PAH (330mg/kg) and TPH $C_{10}$-$C_{36}$ (4,000mg/kg) impacts were also present at a depth of 3.5-3.6 m bgs at nearby CBH2B. The recent investigation conducted by Coffey also identified additional TPH $C_{10}$-$C_{36}$ impacts (1,100 to 2,300 mg/kg) from 0.25 to 1.0 m bgs in the fill material in the central part of the PPP (BH117), beneath the current Exhibition Centre. It is understood that the current foundation slabs located in this area will remain intact, therefore restricting access to the contaminated soils in this area.

A contamination area was identified at a depth of 1.5 m bgs at NBH/MW13 (located at Tumbalong Park). PAH including benzo(a)pyrene concentrations exceeded recreational/open park space Tier 1 screening criteria at this location. The recent investigation conducted by Coffey also identified additional TPH impacts (2,900 mg/kg) from 0.12 to 0.22 m bgs in the fill materials in the northern paved part of the PPP (BH104), and benzo(a)pyrene impacts (2.2 mg/kg) from 2 to 2.1 m bgs in the fill materials south of Tumbalong Park.

### 4.1.2 Groundwater

A review of the Coffey reports (2012b and 2012c) and the recent groundwater data indicates that the majority of dissolved heavy metals, PAHs and TPH were detected below the laboratory LORs, with the exception of benzo(a)pyrene detected at three locations (0.0.2-0.03 µg/L), TPH $C_{15}$-$C_{28}$ detected at one location (100 µg/L), and benz(a)anthracene detected at one location (1 µg/L). These minor exceedences of the groundwater Tier 1 screening criteria were noted in wells in the central portion of the PPP, in the vicinity of Tumbalong Park and in the northern corner of the PPP.

## 4.2 Potential Human Receptors

The following human receptors were considered in this HHRA:

- On-Site future recreational users of Tumbalong Park
- On-Site future commercial workers
- On-Site future intrusive maintenance workers

Commercial workers were presumed to be present within the commercial area and recreational users were assumed to be present within the recreational area as illustrated on **Figure 2**, **Appendix A**. Intrusive maintenance workers were assumed to have access to both the commercial and recreational areas.

Off-Site future recreational users of Cockle Bay were not considered as part of this assessment, as several restrictions are in place for activities that can be undertaken on Cockle Bay (SHFA, 2011). Clause 18 of the "*Sydney Harbour Foreshore Authority Regulation 2011*" states that:

- A person must not do any of the following, except as authorised by the Authority:
  - (a) swim or paddle in the waters of Cockle Bay,
  - (b) sail a sailboard, windsurfer or other like craft in the waters of Cockle Bay,
  - (c) deposit or throw any article or substance into the waters of Cockle Bay,
  - (d) ride a personal watercraft in the waters of Cockle Bay,
  - (e) row or paddle any row boat, canoe, kayak or similar craft in the waters of Cockle Bay,
  - (f) participate in any activity in the waters of Cockle Bay involving the use of a vessel to tow a person (such as water skiing or paragliding).

Although other potential scenarios where human recreational users may come into contact with the water (e.g. 'man overboard' scenarios and boat races during festivals), their frequency and duration are considered to be very low, consequently any resulting human health risks are unlikely.

## 4.3 Contaminants of Potential Concern (CoPC)

The 'source' is identified by comparison of observed CoPC concentrations in media of concern (soil and groundwater) at the PPP against conservative generic screening criteria, termed "Tier 1 screening criteria". A potential 'source' is identified when the CoPC concentration is reported to be present in the environmental media at the PPP above Tier 1 screening criteria which have been derived based on protection of human health and/or ecological protection. Further assessment of the CoPC that exceed the Tier 1 screening criteria is undertaken in the Tier 2 HHERA.

For vapour pathways, a CoPC was considered to be sufficiently volatile if its Henry's law constant is $1 \times 10^{-5}$ atm-$m^3$/mol and the vapour pressure is greater than 1 mm Hg at room temperature (DECCW, 2010) with the exception of naphthalene which was considered sufficiently volatile.

CoPC in soil and groundwater were selected based on comparison to commercial, and recreational screening criteria in accordance with current and future land uses, as well as screening criteria for intrusive maintenance workers, where available.

Due to the heterogeneous fill material and paucity of soil and groundwater data across the Site, AECOM assessed the potential health risks due to exposure from site-wide impacts (from all soil depths). This includes the soil data from open space areas and soil collected from beneath the existing (and remaining) hard-stand and building foundations, in both the saturated and unsaturated zones.

### 4.3.1 Soil Screening Criteria Selection

The following Tier 1 soil screening criteria hierarchy was adopted:

- Health Investigation Levels (HILs) published by the NEPC (1999) Schedule B(7a) Guideline on Health-Based Investigation Levels, specifically:
  - HIL 'E' levels for recreational use of land (parks, open space and playing fields)
  - HIL 'F' levels for commercial/industrial use of land
- Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE) Technical Report No.10 - Health Screening Levels (HSLs) for Petroleum Hydrocarbons in Soil and Groundwater. September 2011. (Friebel, E. and Nadebaum, P., 2011), specifically:
  - HSL C (Sand, 0-1 m): soil HSLs for vapour intrusion for recreational/open space receptors
  - HSL D (Sand, 0-1 m): soil HSLs for vapour intrusion for commercial/industrial receptors

- Intrusive Maintenance Worker (Shallow Trench) (Sand, 0 to <2 m): soil HSLs for vapour intrusion
- HSL C: soil HSLs for direct contact for recreational/open space receptors
- HSL D: soil HSLs for vapour intrusion for commercial/industrial receptors
- Intrusive Maintenance Worker (Shallow Trench): direct contact with soil within a shallow (1 m depth) trench.

Due to the CRC CARE values for TPH being calculated based on specific petroleum products, only HSLs values for individual compounds were adopted from Friebel, E. and Nadebaum, P. (2011) (i.e. benzene, toluene, ethylbenzene and naphthalene). Due to the absence of appropriate TPH Tier 1 screening criteria in soils, the laboratory limit of reporting was used as the Tier 1 screening criteria for TPH fractions.

- USEPA Regional Screening Levels (RSLs) (USEPA, 2012) (last updated November 2012) specifically:
  - Industrial Soil (adjusted for a carcinogenic risk of $1 \times 10^{-5}$)
  - Recreational Soil calculated using the RSL calculator based on the exposure parameters presented in **Appendix D**. Both vapour inhalation and direct contact with soil was considered during derivation.

The soil screening criteria selection process is shown in **Table T1**, **Appendix B** and the results for the soil Tier 1 screening assessment are presented in **Table T2** (Direct Contact) and **Table T3** (Vapour Pathways) **Appendix B**.

#### 4.3.2 Groundwater Screening Criteria

Groundwater Health Screening Levels (HSLs) for vapour intrusion (BTEX, TPH and naphthalene) are available for sites where groundwater is deeper than 2.0m bgs (Friebel, E. and Nadebaum, P., 2011). Consequently they are not applicable for this Site because the depths to groundwater were measured between 1.868m btoc and 3.812m btoc in the most recent groundwater monitoring event. In the absence of appropriate vapour intrusion Tier 1 groundwater screening criteria, the drinking water guidelines were selected as conservative groundwater screening criteria, the hierarchy was as follows:

- Australian Drinking Water Guidelines, National Health and Medical Research Council (NHMRC, 2011);
- WHO Guidelines for Petroleum Products in Drinking Water (WHO, 2008) were adopted as no TPH guidelines have been endorsed by the NSW EPA and;
- United States Environmental Protection Agency (USEPA) Regional Screening Levels – for Tap Water Quality (USEPA, 2012).

It is acknowledged that the adopted groundwater guidelines were based on a drinking water end point which is conservative, and not likely to be representative of exposures at the PPP where direct contact with groundwater is unlikely.

The groundwater screening criteria selection process is shown in **Table T4**, **Appendix B** and the results for the groundwater Tier 1 screening assessment are presented in **Table T5**, **Appendix B**.

#### 4.3.3 Tier 1 Screening Assessment Summary Results

The results of the Tier 1 screening assessment are presented in **Table T6** (Soils – Direct Contact) and **Table T7** (Soils – Vapour Pathways), **Table T8** (Groundwater – Vapour Pathways), **Appendix B**.

The total PAH concentrations exceeded the Tier 1 screening value for recreational users at BH13 (1.4-1.5 mbgs) and for intrusive maintenance workers at CBH2B (3.5-3.6 mbgs). Therefore all detected PAHs above the laboratory LOR at these locations were considered to fail the Tier 1 screening process (i.e. 16 PAHs). As a conservative approach, the maximum detected PAH concentration site-wide was therefore used to assess potential health risks.

Direct contact with groundwater is not expected for the PPP because:

- Groundwater was reported to be below 1.868 m in the most recent investigation;
- Intrusive maintenance workers are assumed to be present within a trench that is 1 m deep;
- Any aesthetic water features proposed for the PPP are assumed to operate from a reticulated supply and not be in hydraulic continuity with the groundwater below the PPP; and
- There are no reported groundwater abstraction bores on the PPP site.

Consequently, the potential health risks associated with direct contact with groundwater were not assessed further. In addition, no groundwater CoPC were carried past the Tier 1 screening assessment, therefore pathways relating to inhalation of groundwater-derived vapours were not assessed further.

## 4.4 Exposure Pathways

### 4.4.1 Potential Contaminant Transport Pathways

Potential transport mechanisms by which CoPC may migrate on and off-Site are summarised in **Table 7** below.

**Table 7 Potential Contaminant Transport Pathways**

| Transport Mechanism | Comments | Likelihood or Significance |
|---|---|---|
| Volatilisation and vapour migration | Volatile contaminants reported in soil may migrate through the subsurface and accumulate in buildings, structures, utility/service pits or trenches. Volatile groundwater contaminants were not detected above Tier 1 screening criteria. | Possible given the reported presence of volatile contaminants in soil. |
| Leaching from soil to groundwater | Minor dissolved PAH and TPH concentrations have been reported above detection limits in groundwater beneath the PPP. | Minimal as only minor impacts to groundwater have been reported on-Site, and PAH concentrations were below detection limits in leachate samples. |
| Transport of leached contamination within groundwater | Groundwater monitoring at the PPP has shown some minor impacts within the groundwater. | Likely as impacts in groundwater have been reported in a down-gradient monitoring well (i.e. MW104). |

### 4.4.2 Potential Human Health Exposure Pathways

In order for a human receptor to be exposed to a chemical contaminant deriving from a site, a complete exposure pathway must exist. An exposure pathway describes the course a chemical or physical agent takes from the source to the exposed individual and generally includes the following elements (USEPA, 1989):

- A source and mechanism of chemical release;
- A retention or transport medium (or media where chemicals are transferred between media);
- A point of potential human contact with the contaminated media; and
- An exposure route (e.g. ingestion, inhalation) at the point of exposure.

Pathways that have been considered to be complete for the receptors identified in **Section 4.2** and therefore assessed in the HHRA are as follows:

**Table 8 Potential Exposure Pathways**

| Exposure Pathway | On-Site Commercial Worker | On-Site Recreational Users | On-Site Intrusive Maintenance Worker |
|---|---|---|---|
| Dermal contact with impacted soil | ✗ (a) | ✓ (g) | ✓ |
| Incidental ingestion of impacted soil | ✗ (a) | ✓ (g) | ✓ |
| Inhalation of soil-derived dust in indoor air | ✗ (b) | ✗ (c) | ✗ (c) |
| Inhalation of soil-derived dust in outdoor air/within an excavation | ✗ (b) | ✓ (g) | ✓ |
| Inhalation of soil-derived vapours in indoor air | ✓ | ✗ (c) | ✗ (c) |
| Inhalation of soil-derived vapours in outdoor air/within an excavation | ✗ (d) | ✓ | ✓ |

| Exposure Pathway | On-Site Commercial Worker | On-Site Recreational Users | On-Site Intrusive Maintenance Worker |
|---|---|---|---|
| Dermal contact with impacted groundwater | x (e,f) | x (e,f) | x (e,f) |
| Incidental ingestion of impacted groundwater | x (e,f) | x (e,f) | x (e,f) |
| Ingestion of potable water | x (f) | x (f) | x (f) |
| Inhalation of groundwater-derived vapours in indoor air | x (d) | x (d) | x (d) |
| Inhalation of groundwater-derived vapours in outdoor air/within an excavation | x (d) | x (d) | x (d) |

Notes:

a) Commercial workers are not assumed to have direct contact with soils as they are considered to spend the majority of time indoors, the commercial area is paved and the likelihood of exposure to surface soils is low.

b) Dust generated from surface soil is assumed to be negligible for commercial workers given that the Site is likely to be covered with buildings, pavements and landscaped areas.

c) Recreational receptors and intrusive maintenance workers are assumed to be outdoors while on Site.

d) No volatile CoPC in groundwater were carried past the Tier 1 screening assessment and therefore the pathway is incomplete.

e) Groundwater has been reported to be below 1.868 m in the most recent investigation therefore direct contact with groundwater is not expected at the PPP.

f) No registered groundwater abstraction bores have been recorded on the PPP.

g) As a conservative approach (due to the limited data available and the heterogeneous nature of the fill material), it was assumed that recreational users could have direct contact with surface soils in areas covered with grass and/or landscaped areas, during activities such as picnics, ball games etc.

# 5.0 Exposure Assessment

Exposure Assessment involves the estimation of magnitude, frequency, extent, and duration of exposure to Site-derived contamination (enHealth, 2012a).

"*Direct measurement of the exposures of the (potentially) affected population provides the best exposure data but this is not always available or practicable and default exposure factor data is often required*." (Langley, AJ, 1993). In absence of direct measurement data, environmental sampling and predictive models are commonly used to estimate intakes of CoPC by the exposed populations. The key elements of exposure assessment in the context of contaminated land risk assessment are to:

- identify input values for contaminant concentrations and pathways
- identify input values for exposed populations
- estimate exposure concentrations
- estimate chemical intake

## 5.1 Exposure Assumptions

Human behavioural exposure assumptions adopted in this risk assessment were obtained from the following recognised Australian and international resources:

- enHealth, 2012a. *Environmental Health Risk Assessment, Guidelines for Assessing Human Health Risks from Environmental Hazards*. Department of Health and Ageing and enHealth Council. 2012.
- enHealth, 2012b. *Australian Exposure Factor Guide*. Department of Health and Ageing and enHealth Council. 2012.
- NEPC, 1999. *National Environmental Protection (Assessment of Site Contamination) Measure*. National Environment Protection Council. December 1999.
- USEPA, 1989. *Risk Assessment Guidance for Superfund Volume I – Human Health Evaluation Manual Part A*. United States Environmental Protection Agency Office of Emergency and Remedial Response. Washington DC, Revised December 1989; and associated updates.

Where specific guidance was not available from the above or other literature sources, conservative estimates for exposure parameters were adopted.

The human behavioural assumptions and site assumptions used for the exposure assessment algorithms are provided in **Appendix E** (On-Site Recreational Users), **Appendix F** (On-Site Commercial Workers) and **Appendix G** (On-Site Intrusive Maintenance Worker).

## 5.2 Exposure Point Concentrations

A key element of the exposure assessment process is estimating the concentration of Site-derived CoPC in environmental media. This concentration is commonly termed the exposure point concentration (EPC) and should be selected as a conservative estimate of the average chemical concentration in an environmental medium at the point of exposure. EPCs are identified for each site-impacted 'exposure unit', which is defined as the area throughout which a receptor moves and encounters an environmental medium for the duration of exposure. Typically, an individual receptor is assumed to be equally exposed to media within all portions of the exposure unit over the time frame of the risk assessment.

It should be noted that the EPCs adopted in this HHERA are very conservative because they consider that direct contact with reported soil concentrations beneath the existing (and remaining) hardstand and building foundations is possible, including soil down to depths of 7.8 mbgs. This conservative approach was adopted to compensate for the heterogeneous nature of the fill material and the paucity of soil data across the PPP.

The adoption or derivation of EPCs in soil is further described in the following sections.

### 5.2.1 Soil

The EPCs for CoPC identified in soils on-Site represented the maximum soil concentrations reported across the PPP area, at all depths, and in both open space areas and beneath the existing (and remaining) hard-stand and building footprint areas. The soil EPCs are presented in **Table 9** below.

**Table 9 Selected EPCs for CoPC in On-Site Soil**

| CoPC | Selected EPC (mg/kg) | Justification |
|---|---|---|
| **Recreational Users and Intrusive Maintenance Workers** | | |
| TPH $C_{10}$-$C_{14}$ | 410 | Vapour pathway and direct contact - Maximum concentration detected in soils (BH104 at 0.12-0.22 mbgs) |
| TPH $C_{15}$-$C_{28}$ | 2500 | Direct contact pathway only – Maximum concentration detected in soils (BH104 at 0.12-0.22 mbgs) |
| TPH $C_{29}$-$C_{36}$ | 1600 | Direct contact pathway only – Maximum concentration detected in soils (CBH2B at 3.5-3.6 mbgs) |
| Acenaphthene | 0.6 | Direct contact pathway only – Maximum concentration detected in soils (BH13 at 1.4-1.5 mbgs) |
| Acenaphthylene | 1.3 | Direct contact pathway only – Maximum concentration detected in soils (BH13 at 1.4-1.5 mbgs) |
| Anthracene | 3.4 | Direct contact pathway only – Maximum concentration detected in soils (NBH10 at 0.4-0.5 mbgs) |
| Benz(a)anthracene | 39 | Direct contact pathway only – Maximum concentration detected in soils (CBH2B at 3.5-3.6 mbgs) |
| Benzo(a)pyrene | 6.5 | Direct contact pathway only – Maximum concentration detected in soils (NBH10 at 0.4-0.5 mbgs) |
| Benzo(b)fluoranthene | 9.3 | Direct contact pathway only – Maximum concentration detected in soils (NBH10 at 0.4-0.5 mbgs) |
| Benzo(k)fluoranthene | 62 | Direct contact pathway only – Maximum concentration detected in soils (CBH2B at 3.5-3.6 mbgs) |
| Benzo(g,h,i)perylene | 3.9 | Direct contact pathway only – Maximum concentration detected in soils (NBH10 at 0.4-0.5 mbgs) |
| Chrysene | 6.0 | Direct contact pathway only – Maximum concentration detected in soils (NBH10 at 0.4-0.5 mbgs) |
| Dibenz(a,h)anthracene | 1.0 | Direct contact pathway only – Maximum concentration detected in soils (NBH10 at 0.4-0.5 mbgs) |
| Fluoranthene | 94 | Direct contact pathway only – Maximum concentration detected in soils (CBH2B at 3.5-3.6 mbgs) |
| Fluorene | 1.8 | Direct contact pathway only – Maximum concentration detected in soils (BH13 at 0.5-0.6 mbgs) |
| Indeno(1,2,3-cd)pyrene | 3.5 | Direct contact pathway only – Maximum concentration detected in soils (NBH10 at 0.4-0.5 mbgs) |

| CoPC | Selected EPC (mg/kg) | Justification |
|---|---|---|
| Naphthalene | 3.6 | Direct contact pathway only – Maximum concentration detected in soils (BH110A at 5.6-6.0 mbgs)<br>Note: naphthalene concentration does not exceed the vapour inhalation Tier 1 criteria, and therefore is only assessed via the direct contact pathway because the total PAH concentration exceeded the Tier 1 criteria. |
| Phenanthrene | 51 | Direct contact pathway only – Maximum concentration detected in soils (CBH2B at 3.5-3.6 mbgs) |
| Pyrene | 84 | Direct contact pathway only – Maximum concentration detected in soils (CBH2B at 3.5-3.6 mbgs) |
| **Intrusive Maintenance Workers** | | |
| TPH $C_{10}$-$C_{14}$ | 410 | Vapour pathway and direct contact – Maximum concentration detected in soils (BH104 at 0.12-0.22 mbgs) |

## 5.3 Vapour Modelling

### 5.3.1 Estimating Vapour Concentrations

Vapour phase chemical concentrations in indoor and outdoor air were modelled using vapour transport models based on the fundamental theoretical developments of Johnson and Ettinger, 1991 as described in the following documents:

- ASTM, 2010. Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites. E1739 – 95 (reapproved 2010).
- USEPA, 2004. User's Guide for Evaluating Subsurface Vapour Intrusion into Buildings. Office of Emergency and Remedial Response. Revised February 22, 2004.

The ASTM and USEPA documents were also used as reference sources for input parameters for the vapour transport modelling.

The methodology and algorithms used for vapour modelling are described in more detail in **Appendix H**, and the vapour modelling calculations and assumptions are detailed within **Appendix E** to **Appendix G**.

The future building proposed for the PPP area is likely to have multiple floors, lifts and permanent temperature controls; therefore, there is the potential for vapour intrusion via advective processes. The vapour modelling adopted in this HHERA therefore assumes that vapours move into the building via diffusion and advection. Advection processes are likely to draw soil vapours and ambient air (i.e. oxygen) into the building, and therefore the assumption that advection is occurring, without the inclusion of biodegradation, is a conservative approach.

## 5.4 Estimation of Chemical Intakes

Modelled intake concentrations relevant to the assessment of exposure to CoPC by relevant receptors and pathways are presented in **Appendix E** to **Appendix G** and were estimated using the equations presented in **Appendix H** for the following exposure pathways:

- Incidental ingestion of surface soil;
- Dermal contact with surface soil;
- Outdoor inhalation of surface-derived dust (including within an excavation); and
- Inhalation of indoor and outdoor soil-derived vapours (including within an excavation).

# 6.0 Toxicity Assessment

The toxicity assessment stage of a risk assessment is separated into two components; hazard identification and dose-response assessment. The hazard identification stage is a qualitative description of the capacity of a contaminant or agent to cause harm. The dose-response assessment includes the selection of appropriate toxicity criteria from a hierarchy of sources, in accordance with enHealth (2012a) and NEPC guidance (NEPC, 1999).

## 6.1 Hazard Identification

The hazard identification process requires a review of existing toxicological information from a variety of appropriate sources to describe the capacity of a specific agent to produce adverse health effects.

Toxicological profiles for the specific CoPC quantitatively assessed in this HHERA are provided in **Appendix I**.

## 6.2 Dose-Response Assessment

The objective of the dose-response assessment is to identify the toxicity values for each CoPC to be used for the quantification of human health risk. The numerical values derived from toxicity dose-response studies are referred to collectively as toxicity values. The toxicity values adopted are based on two different approaches to the characterisation of dose-response (NHMRC, 1999 and USEPA, 2005):

- For chemicals that have the potential to result in carcinogenic effects that are associated with a genotoxic mechanism, any level of exposure is assumed to result in some incremental lifetime risk. These chemicals are therefore assessed on the basis of a non-threshold dose-response relationship.
- For other chemicals that may be associated with non-carcinogenic effect or other carcinogenic effects that are not genotoxic, a threshold is considered relevant. The threshold level is considered a level whereby exposure below the threshold will not result in any adverse effects. Exceedance of the threshold level does not imply that adverse effects will occur, as there are a number of uncertainties and safety factors incorporated into the threshold value adopted, rather that exposure needs to be further evaluated.

The toxicity values adopted for the CoPC in this risk assessment, and the source of the adopted values are presented in **Table T9**, **Appendix B**. The values have been obtained (where available) from the following information sources (listed in order of preference, as per NEPC (1999) and enHealth (2012a) guidance:

- National Health and Medical Research council (NHMRC) publications and documents from other joint Commonwealth, State and Territory health organisations;
- World Health Organisation (WHO) publications;
- Criteria published by the Agency for Toxic Substances and Disease Registry (ATSDR); and
- Criteria published by USEPA sources, primarily those published by the USEPA Integrated Risk Information system (IRIS) (USEPA, 2013)

It is noted that, where relevant, toxicity data available from a number of sources have been reviewed with respect to currency and adequacy to identify the most appropriate value to be used in the HHRA.

The following sections present additional information on the approach adopted in this assessment to the application of non-threshold and threshold dose-response (toxicity) values.

### 6.2.1 Non-Threshold Dose-Response Values

The assessment of potential health effects associated with genotoxic carcinogens requires the use of non-threshold toxicity values. The values available are essentially the slope of the cancer dose-response curve for the chemical (based on relevant studies and approaches to extrapolate effects from high doses to low doses) and are termed either a cancer slope factor (CSF) or an inhalation unit risk (IUR). The CSF (expressed as $(mg/kg/day)^{-1}$), or IUR (expressed as $(\mu g/m^3)^{-1}$) is used to estimate the probability of an individual developing cancer at some point in a lifetime as a result of a specific exposure.

As described in **Appendix I**, of the CoPC identified at the PPP, benzo(a)pyrene is considered to be a potential genotoxic carcinogen, and has been assessed based on non-threshold toxicity criteria.

### 6.2.2 Threshold Dose-Response Values

Potential health effects that are assessed on the basis of a threshold dose response utilise a threshold value which is typically termed an acceptable or tolerable daily intake (ADI or TDI) or reference dose (RfD). For the purpose of this assessment, the threshold value adopted has been termed a TDI. A TDI is a chemical intake below which it is considered unlikely that adverse effects would occur in human populations, including sensitive sub-groups (e.g. the very young or elderly). Hence, the TDI relates to intakes from all sources, the PPP related impacts as well as background intakes (where relevant).

Where relevant to inhalation exposures the threshold value is typically termed a tolerable concentration in air (TC) or reference concentration (RfC), which is an estimate of a continuous inhalation exposure concentration to people (including sensitive subgroups) that is likely to be without risk of deleterious effects during a lifetime.

Of the CoPC identified at the PPP, TPH $C_{10}$-$C_{14}$, TPH $C_{15}$-$C_{29}$ and TPH $C_{29}$-$C_{36}$ fractions have been assessed on the basis of threshold dose-response values. The source(s) of these values are further detailed in **Appendix I**.

The toxicity criteria adopted for TPH (from TPHCWG, 1997a) relate to aromatic and aliphatic fractions. However, no fractionation of aromatic and aliphatic TPH has been undertaken during previous investigations at the PPP and the ratio of aromatic to aliphatic compounds in the reported TPH fractions therefore need to be estimated. The approach adopted for the fractionation of TPH $C_{10+}$ in groundwater into aromatic and aliphatic components is summarised below:

- TPH $C_{10+}$: It has been conservatively assumed that the reported TPH concentration may comprise either 100% aliphatic or 100% aromatic components. This conservative screening assumption results in a potential ‘double-counting’ of risks associated with TPH at the PPP. However, the approach has been adopted due to the level of uncertainty and lack of Site specific data associated with predicting the ratio of aliphatic and aromatic constituents in environmental media. This uncertainty is a result of the differential effects of hydrocarbon partitioning, solubility, volatilisation and degradation within the environment. Where this conservative screening assumption results in an estimated health risk which is potentially unacceptable, the potential for this assumption to have overestimated the actual risk associated with TPH will be further considered and discussed in the risk characterisation and uncertainty sections of this report.

## 6.3 Background Exposure

When evaluating potential health effects or deriving health-based investigation levels for chemicals assessed on the basis of a threshold dose-response criteria, total exposure to a given chemical (i.e. the sum of the background exposure and the substance exposure from contaminated media) should not exceed the TDI (enHealth, 2012a; NEPC, 1999). The approach take to assess the allocation of background exposure for the CoPC assessed in this HHERA is presented in **Appendix J**.

# 7.0 Risk Characterisation

Risk characterisation is the final step in the risk assessment process whereby information gathered and derived from the toxicity assessment and exposure assessment is used to derive quantitative estimates of risk to human health. Conclusions reached during the risk characterisation process conveys the nature and existence of (or lack of) human health risks in a manner useful for decision makers.

## 7.1 Methodology

The methodology and equations used to estimate risks for the HHRA are presented in **Appendix H** for threshold and non-threshold CoPC.

## 7.2 Risk Acceptability Criteria

For non-threshold (carcinogenic) CoPC, the incremental lifetime cancer risk estimates for each receptor have been compared to an acceptable carcinogenic risk level of 1 in 100,000 ($1 \times 10^{-5}$).

For threshold (non-carcinogens), potentially unacceptable chemical intake/exposure is indicated if the exposure level exceeds the TDI or TC (i.e. if the HQ is greater than 1).

Where the risk acceptability criteria for threshold and non-threshold CoPC are exceeded, a more detailed and critical evaluation of the risk may be conducted, or appropriate risk management measures may be recommended.

## 7.3 Summary of Risk Estimates

The risk calculation results are presented in **Appendix E** to **Appendix G**.

A summary of the calculated reasonable maximum threshold risks (hazard indices) and non-threshold risks (incremental lifetime excess cancer risks) is presented in **Table 10** below.

**Table 10 Risk Characterisation Summary**

| Exposure Scenario | Non-Threshold (ILCR) | Threshold Risk (Hazard Index) | |
|---|---|---|---|
| | | Adult | Child |
| On-Site Recreational User | $8.1 \times 10^{-6}$ | 0.32 | 0.79 |
| On-Site Intrusive Maintenance Worker | $1.3 \times 10^{-6}$ | 0.087 | - |
| On-Site Commercial Worker | - | 0.72 | - |

Estimated conservative screening (upper-bound) incremental lifetime cancer risk (ILCR) estimates for on-Site recreational users, commercial workers and intrusive maintenance workers considered in this assessment were found to be below the adopted acceptable cancer risk level $1 \times 10^{-5}$, and hazard indices were below the adopted acceptable hazard index of one.

These risk estimates were based on a number of conservative assumptions and were considered to overestimate actual risk to receptors, therefore it is not considered necessary to further refine the assumptions given that the risk estimates were below adopted acceptable levels.

Overall the estimated health risks to future on-Site recreational users, commercial workers and intrusive maintenance workers were considered to be low and acceptable.

## 7.4 Uncertainties and Sensitivity Analysis

The risk assessment process involves a number of assumptions regarding Site conditions, human exposure and chemical toxicity. These assumptions are based on Site-specific information (where available), but it is not always possible to fully predict or describe site conditions and human activities at a site for the exposure period considered in the risk assessment. The assumptions adopted for this risk assessment were therefore generally selected to be conservative in nature, in order to evaluate an assumed reasonable maximum exposure scenario and provide a deliberate margin of safety.

A discussion of some of the key uncertainties associated with different components of the risk assessment process, and an input parameter sensitivity analysis, is provided in **Appendix K**.

# 8.0 Ecological Risk Assessment

NEPM (1999) defines ERA as "*a set of formal scientific methods for defining and estimating the probabilities and magnitudes of adverse impacts on plants and/or the ecology of a specified area posed by a particular stressor(s) and frequency of exposure to the stressor(s). It is a process that identifies the ecological receptors of concern, estimates the concentrations that the ecological receptors are exposed to and, based on the magnitude of these concentrations determines whether the ecological receptors and ecological values may be at risk*".

The ERA presented in this HHERA comprises a 'Level 1 ERA' which is defined by NEPM (1999) as a simple screening assessment that is designed to suit generic situations and protect all biota likely to inhabit the area of concern.

The potential for ecological risks to terrestrial flora of Tumbalong Park and aquatic receptors in Cockle Bay will be assessed qualitatively in this ERA by comparing reported soil and groundwater concentrations against generic Tier 1 screening criteria that is protective of ecological receptors.

The process for conducting the ERA follows the recommended approach outlined in NEPM (1999) *Schedule B(5) Ecological Risk Assessment*. The ERA conceptual site model for the PPP and down-gradient environment is illustrated in **Figure F4**, **Appendix A** and described below.

## 8.1 Problem Identification

### 8.1.1 Nature and Extent of Contamination

As discussed in **Section 4.1**, previous investigations have identified minor soil and groundwater impacts at the PPP.

High molecular weight and lipophilic organic compounds such as PAHs (and benzo(a)pyrene) have a low water solubility, high Henry's law constant and a high Kow (>$10^4$), and consequently bind strongly to the root surface and/or soils. Therefore, these compounds do not readily translocate within plants and the uptake of PAHs and hydrocarbons into plants is considered to be relatively minor (Schnoor, 1997; CCME, 2010). Consequently, an assessment of the potential for metal uptake into the flora of the PPP will only be undertaken for this ERA.

AECOM notes that the vegetation currently on the PPP appears to be healthy and established, and that Cockle Bay is an active waterway and any potential contamination migrating from the PPP is likely to be minor in comparison to the contribution from the overall surrounding area and use of the waterway.

### 8.1.2 Inferred Direction of Groundwater Flow

As discussed in **Section 2.7.2**, groundwater is expected to flow to the north, towards Cockle Bay.

## 8.2 Ecological Receptor Identification

Tumbalong Park is within the PPP boundary and comprises a grassed area for recreation and several trees and landscaped vegetated areas.

Due to the proximity to the PPP and groundwater flow direction, aquatic receptors in Cockle Bay have been considered as the down-gradient receptor in the ERA.

## 8.3 Exposure Assessment

### 8.3.1 Selected Monitoring Locations

For the assessment of metal uptake into the flora within Tumbalong Park, locations within the 'Recreational Area' shown on **Figure 2**, **Appendix A** were used.

For the assessment of concentrations of CoPC in groundwater entering Cockle Bay, the nearest groundwater monitoring wells to the aquatic receptor were used (MW104, MW105, MW106 and MW107) as these were considered to be most representative of potential off-Site groundwater concentrations.

#### 8.3.2 Tier 1 Ecological Screening Criteria

The selected Tier 1 screening criteria for the assessment of metal uptake into flora within Tumbalong Park included:

- NEPC, 1999.Ecological Investigation Levels (EILs) Schedule B(1) Guidelines on the Investigation Levels for Soil and Groundwater.

The selected Tier 1 screening criteria and the Tier 1 screen are presented in **Table T10**, **Appendix B**.

The adopted hierarchy of screening criteria for aquatic receptors within Cockle Bay was as follows:

- ANZECC, 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ). ANZECC & ARMCANZ (2000) Trigger Levels for Marine Waters. Trigger Levels with a 95% level of species protection:
    - High Reliability Trigger values;
    - Moderate Reliability Trigger values; and
    - Low Reliability Trigger values (where appropriate).
- RIVM, 2001. Technical evaluation of the Intervention Values for Soil/sediment and Groundwater. Human and ecotoxicological risk assessment and derivation of risk limits for soil, aquatic sediment and groundwater. RIVM Report 711701 023. National Institute of Public Health and the Environment. February 2001.
- CCME, 2007. Canadian Water Quality Guidelines for the Protection of Aquatic Life. Part of Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment (CCME).

The selected Tier 1 screening criteria are presented in **Table T11**, **Appendix B** and the Tier 1 screen is presented in **Table T12**, **Appendix B**.

#### 8.3.3 Identification of Ecological CoPC in Soil and Groundwater

CoPC were considered to be those chemicals which are known or suspected to be present at concentrations which would warrant inclusion in the ERA. In general, a chemical was selected as a CoPC if it was reported to be present in environmental media at the PPP above relevant Tier 1 screening criteria which were derived based on the protection of ecological receptors or because no screening levels were available. The following were identified as CoPC:

- For flora within Tumbalong Park:
    - Copper (two exceedances within 63 samples; 120 mg/kg and130 mg/kg)
    - Mercury (1 exceedance within 63 samples; 1.3 mg/kg)
    - Nickel (6 exceedances within 63 samples; 69 mg/kg to180 mg/kg)
    - Zinc (3 exceedances within 63 samples; 230 mg/kg to 630 mg/kg)
- For aquatic receptors within Cockle Bay:
    - Fluoranthene (MW104; 2 µg/L)
    - Pyrene (MW104 and MW105; 0.09 µg/L to 2 µg/L)
    - Copper (MW104, MW105 and MW107; 0.002 mg/L to 0.004 mg/L)
    - Zinc (MW104 and MW105; 0.028 mg/L to 0.042 mg/L)

## 8.4 Risk Characterisation

#### 8.4.1 Flora within Tumbalong Park

Although reported concentrations of metals (copper, mercury, nickel and zinc) were above the Tier 1 screening criteria, the concentrations were only found in a small number of samples compared to the number analysed. AECOM therefore applied statistical analysis to the concentrations to obtain more Site representative values. Upper confidence limits (UCL) concentrations derived through ProUCL for the CoPC are presented in **Appendix L**.

**Table 11** below shows the adopted UCL concentrations for each contaminant and comparison to the adopted Tier 1 screening criteria.

**Table 11 Summary of Statistical Analysis Results**

| CoPC | UCL (mg/kg) | UCL Type | Tier 1 Screening Criteria (mg/kg) | Screening Criteria Exceeded |
|---|---|---|---|---|
| Copper | 46.14 | 95% Chebyshev (Mean, Sd) UCL | 100 | No |
| Mercury | 0.241 | 95% Chebyshev (Mean, Sd) UCL | 1 | No |
| Nickel | 44.76 | 95% Chebyshev (Mean, Sd) UCL | 60 | No |
| Zinc | 111.5 | 95% Chebyshev (Mean, Sd) UCL | 200 | No |

The 95% UCL concentrations for copper, mercury, nickel and zinc were all below the Tier 1 screening criteria protective of terrestrial plants.

Consequently, AECOM considered that there is minimal ecological impact to flora within Tumbalong Park given the results of the statistical analysis. This conclusion is supported by the presence of healthy and established flora recently observed in Tumbalong Park.

### 8.4.2 Aquatic Receptors within Cockle Bay

Although the reported concentrations of fluoranthene, pyrene, copper and zinc in groundwater exceeded the Tier 1 ecological screening criteria, AECOM considered there would be minimal ecological impact to aquatic receptors within Cockle Bay given:

- The distance between MW104, which is the location where CoPC were detected above ecological screening criteria, and Cockle Bay is approximately 60 m. As groundwater travels to Cockle Bay from MW104, there is the potential for soil leachate and groundwater concentrations to attenuate through adsorption, degradation and dilution factors. The USEPA (1996) guidance indicates that the reduction in concentrations from soil leachate to groundwater and finally to the receptor can be expressed succinctly by a dilution attenuation factor (Daf). A Daf is defined as the ratio of contaminant concentration in soil leachate to the concentration in groundwater at the receptor point.

  The USEPA (1996) guidance recommends a default Daf of 20 to account for the leaching of soil contaminants and attenuation during transport through the saturated zone to a compliance point (i.e., receptor receiving water such as Cockle Bay). This adjustment is considered by USEPA to conservatively reflect a soil contaminant's threat to groundwater resources at most sites. The Daf of 20 was selected by the USEPA using a "weight of evidence" approach and is considered protective for sources up to 0.5 acres in size and for larger sources on a case-by-case basis (USEPA 1996). Assuming that the dilution and attenuation of groundwater beneath the PPP is at 25% of the USEPA (1996) recommended Daf (i.e. 5), groundwater concentrations of copper, zinc and fluoranthene are likely to be below the ANZECC trigger values at Cockle Bay. The pyrene concentration at MW104, with the Daf applied, was above the ANZECC trigger value; however, due to the reasons stated below, this is not considered to present an unacceptable ecological risk to aquatic receptors in Cockle Bay.

- A study on the dissolved trace metal surface water distributions in Port Jackson estuary conducted between 1999 and 2001 (including a sample location within Darling Harbour) reported concentrations of copper between 0.932 µg/L and 2.55 µg/L, and zinc concentrations between 3.27 µg/L to 9.66 µg/L (Hatje *et al,* 2003). Considering the dilution potential for groundwater as it enters Cockle Bay (refer above), the reported zinc (28-42 µg/L) and copper (2-4 µg/L) groundwater concentrations are likely to be within those reported in the Hatje *et al* (2003) study once groundwater enters Cockle Bay.

- The groundwater exceedences of PAHs were noted in unfiltered samples, and these total concentrations are likely to overestimate the bioavailable fraction within groundwater that is primarily responsible for any ecotoxic effects. Concentrations of PAHs within the filtered samples (i.e. the majority of the bioavailable fraction) were below the laboratory limits of reporting. This indicates that the PAHs within the groundwater are most likely to be attached to the particles in the groundwater and therefore the distance they can travel is limited. The LOR for pyrene was above the adopted screening criteria, however, none of the PAHs in the filtered samples were detected, and therefore AECOM considers that the concentration of bioavailable pyrene within the filtered groundwater is likely to be below the adopted screening criteria;

- Soil leachate data (presented in **Table T13**, **Appendix B**) suggested that PAHs have a limited ability to leach from soil into groundwater (as indicated by no PAH concentrations being detected above the laboratory LORs of 1 µg/L for each individual PAH and 2µg/L for benzo(b&k)fluoranthene). The leaching potential of metals also appears to be minimal with only three, out of 12, samples being marginally above the laboratory LORs (for arsenic, chromium, copper and zinc) and less than 1% of the original soil concentration being present in the leachate samples; and
- Cockle Bay is an active waterway and any potential contamination migrating from the PPP (where the fill has been in place for greater than 20 years) is likely to be minor.

It was therefore considered that the potential ecological risks from Site-derived groundwater impacts to Cockle Bay were low and acceptable.

# 9.0 Qualitative Discussion for On-Site Construction Workers

## 9.1 Introduction

During future redevelopment works of the PPP sector, it is understood that construction workers are likely to have exposure to excavated and stockpiled soil that may potentially be impacted. Such exposure is considered to be acute whereby health effects are likely to occur within minutes, hours or days over a relatively short period of exposure. Chronic health effects occur as a result of prolonged or repeated exposures over many days, months or years and symptoms may not be immediately apparent. Therefore the assessment of chronic health risks for the construction workers was not considered appropriate for inclusion in the HHERA as only acute exposure is likely to occur.

However, to provide additional health and safety guidance for the on-Site construction workers, AECOM has used the human health risk assessment results presented in this HHERA to formulate a number of recommendations. These recommendations assume that industry standard occupational health and safety (OH&S) procedures are followed.

### 9.1.1 Direct Contact with Soil and Groundwater

The risk driving exposure pathway was identified as dermal contact with impacted soil, in particular benzo(a)pyrene impacts. Therefore, care should be taken to ensure that construction workers wear the appropriate personal protective equipment (PPE) when handling the soil (e.g. protective gloves, long sleeves, long pants and footwear) to minimise the exposed skin surface area available for soil contact. Furthermore, good hygiene practices should be followed, in particular the washing of hands prior to the ingestion of food during breaks.

During the most recent GME conducted in January 2013, the depths to groundwater ranged 1.868 m below top of casing (btoc) (MW20) and 4.324 m btoc (MW25); and therefore any construction works in the top meter of soil is unlikely to intersect the groundwater table.

The groundwater analytical data was screened against published Australian and International drinking water guidelines, and benzo(a)pyrene (0.02µg/L to 0.03µg/L) was detected marginally above the drinking water guideline of 0.01µg/L at three locations. This guideline value assumes consumption of 2L of water per day which is overly conservative for the construction worker scenario that may incidentally ingest minor quantities or have limited dermal contact with groundwater potentially on their hands (it is unlikely that the construction workers will stand or wade in any accumulated groundwater within a trench). Therefore, should construction workers intersect groundwater during redevelopment activities, the potential for health risks are considered to be low. However, it is recommended that workers take care to avoid any splashing of groundwater and follow the appropriate OH&S procedures. This includes the adoption of appropriate PPE to minimise the exposed skin surface area available for dermal contact with groundwater.

### 9.1.2 Inhalation of Dust and Vapours

The stockpiled material should be placed away from areas accessible by the public and kept damp/covered in order to minimise the generation of dust that may consequently be inhaled by the construction workers and human receptors in the down-wind area (e.g. commercial employees and recreational users).

No volatile contaminants were reported in groundwater and only minor concentrations of volatile contaminants were reported in the soil. Therefore the potential for vapour generation when the soil is excavated is considered to be low; however, if odourous materials are encountered, workers should follow the appropriate procedures for working with volatile compounds and the processes for unexpected contamination finds.

# 10.0 Conclusions

AECOM was engaged by LLPMC to undertake a Human Health and Ecological Risk Assessment (HHERA) at the Sydney International Convention, Exhibition and Entertainment Precinct (SICEEP). It is understood that the SICEEP Site is planned for future redevelopment works including the removal of the current Sydney Convention and Exhibition Centre and redevelopment of the area for convention, exhibition and entertainment uses.

The SICEEP Site has been divided into two redevelopment sectors: 1) The Public Private Partnership (PPP) sector, and 2) The Project Delivery Agreement (PDA) sector. This HHERA is for the PPP sector only and encompasses the current Convention Centre, Exhibition Centre and public access areas including Tumbalong Park.

The project objectives were to assess the potential for unacceptable human health and ecological risks to identified on-Site and off-Site receptors following the proposed redevelopment works. In order to fulfil this project objective, a quantitative human health risk assessment was undertaken for future on-Site and off-Site receptors, and a qualitative ecological risk assessment was undertaken for on-Site vegetation and off-Site aquatic receptors.

A number of environmental investigations were conducted on the PPP between June 2012 and January 2013 to characterise soil and groundwater conditions, and the data from these investigations were provided to AECOM to form conclusions in this HHERA. It is understood that the observed impacts are a result of contaminated fill located at the PPP. Whilst the current data set available to characterise the fill material is limited, this HHERA has made a number of robust conservative assumptions as compensation, such as the exposure frequency, assumptions relating to direct surface soil exposure, vapour modelling assumptions and adoption of maximum reported site-wide concentrations (irrespective of soil depth) as exposure point concentrations; further assumptions are detailed throughout the report. The ultimate intent of adopting these conservative assumptions was to strengthen confidence in the conclusions presented in this HHERA.

## Human Health Risk Assessment

Following a review of the available analytical data, a number of data gaps were identified mostly relating to the paucity and reliability of data available to characterise the heterogeneous fill material. To compensate for the limited data available for use in this HHERA, a number of conservative assumptions were made when estimating the potential health risks to future human receptors. These included using the maximum reported concentrations (from all soil depths) as representative conditions across the PPP and adopting the following exposure scenarios:

- For the recreational user it was assumed that the receptor would be exposed to PAH and TPH soil impacts for 2 hours once a week (i.e. one day every weekend a year) for 35 years. During this time they would have 0.5 mg of impacted soil covering each $cm^2$ of exposed skin (i.e. head, arms, hands, lower legs and feet), in addition to ingesting 100 mg of impacted soil (for a child) per day and inhaling vapours derived from surface soil impacts. The exposure frequency of recreational users of once a week is considered to be a reasonable assumption due to the other conservative assumptions made in the assessment, as well as, in winter months, recreational users are unlikely to be undertaking activities, such as picnics wearing short sleeves, shorts and no shoes.
- For the adult intrusive maintenance worker, it was assumed they would be exposed to TPH and PAH soil impacts for 10 hours per day, for 20 days per year over 30 years. During this time, it was assumed they would have 0.5 mg of impacted soil covering each $cm^2$ of exposed skin (i.e. head, forearms, hands and lower legs), in addition to ingesting 60 mg of impacted soil per day and inhaling vapours derived from surface soil impacts. This scenario is particularly conservative because it assumes that the same maintenance worker will be undertaking the works for the 35 year duration, which is an unlikely scenario.
- For the adult commercial worker, it was assumed that they would be exposed to TPH $C_{10}$-$C_{15}$ vapours derived from soil impacts for 8 hours per day indoors, for 240 days per year, for 30 years. The vapour modelling assumed that no biodegradation was occurring, that vapour may enter the building via advection and diffusion, and that the entire building footprint is above the vapour source.

This HHRA adopted an acceptable carcinogenic risk of 1:100,000 and a non-carcinogenic hazard index of 1. Based on these acceptable risk levels, and the qualitative Tier 1 assessment for the commercial worker, the estimated potential health risks to future on-Site recreational users, commercial workers and intrusive maintenance workers were considered to be low and acceptable.

The limited data available to characterise the heterogeneous fill material is unlikely to influence the HHERA conclusions because:

- it is understood that the existing concrete slabs will remain in place following the redevelopment works, and consequently any impacts within any fill material that have not been characterised will be inaccessible for direct contact; and
- no volatile compounds were detected within groundwater, and only TPH $C_{10}$-$C_{14}$ was detected at one location in soil in an outdoor location. Therefore, it is unlikely that volatile compounds are present in any uncharacterised fill material beneath the existing building foundation slabs.

## Ecological Risk Assessment

The potential for ecological risks to terrestrial flora of Tumbalong Park and aquatic receptors in Cockle Bay was assessed qualitatively in this ERA by comparing reported soil and groundwater concentrations against generic Tier 1 screening criteria that is protective of ecological receptors.

The uptake of PAHs and hydrocarbons were considered to be relatively minor and therefore the ERA only considered the potential for metal uptake into flora of Tumbalong Park. The 95% UCL concentrations for copper, mercury, nickel and zinc were all below the Tier 1 screening criteria protective of terrestrial plants. Consequently, AECOM considered that there is minimal ecological impact to flora within Tumbalong Park. This conclusion is supported by the presence of healthy and established flora recently observed in Tumbalong Park.

Although the reported concentrations in groundwater exceeded the Tier 1 ecological screening criteria, AECOM considered there would be minimal ecological impact to aquatic receptors within Cockle Bay given:

- the dilution potential for contaminants as groundwater migrates through the aquifer and enters Cockle Bay;
- a comparison of reported surface water zinc and copper concentrations in Darling Harbour are within groundwater concentrations reported in the PPP site (taking into consideration the dilution potential as groundwater migrates to Cockle Bay);
- the exceedances were only minor and the concentrations of PAHs within the filtered samples (i.e. the bioavailable fraction) were below the laboratory LORs;
- soil leachate data suggested that PAHs have a limited ability to leach from soil into groundwater (as indicated by PAH concentrations being reported below the laboratory LORs). This indicates that the PAHs within the groundwater are most likely to be attached to the particles in the groundwater and therefore the distance they can travel is limited. The leaching potential of metals also appears to be minimal with only three, out of 12, samples being marginally above the laboratory LORs (for arsenic, chromium, copper and zinc); and
- Cockle Bay is an active non-pristine waterway and any potential contamination migrating from the PPP (where the fill has been in place for greater than 20 years) is likely to be minor.

It was therefore considered that the potential ecological risks from Site-derived groundwater impacts to Cockle Bay were low and acceptable.

The conclusions presented in this HHERA are based upon a number of site-specific assumptions including the future land use and design layout. Should any of these assumptions change that consequently influence the adopted exposure scenarios, the conclusions of this risk assessment may require revision.

# 11.0 Limitations

This document was prepared for the sole use of Lend Lease Project Management and Construction Pty Ltd. This party is the only intended beneficiary of our work. Any advice, opinions or recommendations contained in this document should be read and relied upon only in the context of the document as a whole and are considered current to the date of this document. Any other party should satisfy themselves that the scope of work conducted and reported herein meets their specific needs. AECOM cannot be held liable for third party reliance on this document, as AECOM is not aware of the specific needs of the third party.

This document was prepared for the purpose described herein and as agreed to by Lend Lease Project Management and Construction Pty Ltd. From a technical perspective, the subsurface environment at any site may present substantial uncertainty. It is a heterogeneous, complex environment, in which small subsurface features or changes in geological conditions can have substantial impacts on water and chemical movement. Uncertainties may also affect source characterisation assessment of chemical fate and transport in the environment, assessment of exposure risks and health effects, and remedial action performance.

AECOM's professional opinions are based upon its professional judgement, experience and training. It is possible that additional testing and analysis might produce different results and/or different opinions. AECOM has limited its assessment to the scope agreed upon with it client. AECOM believes that its opinions are reasonably supported by the testing and analysis that have been done and that those opinions have been developed according to the professional standard of care for the environmental consulting profession in this area at this time. That standard of care may change and new methods and practices of exploration, testing, analysis and remediation may develop in the future, which might produce different results. AECOM's professional opinions contained in this document are subject to modification if additional information is obtained through further investigation, observations, or testing and analysis during any future assessment or remedial activities.

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## Appendix A

# Figures

# Appendix A Figures


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AECOM

# SITE LOCATION

Human Health and Ecological Risk Assessment
Public Private Partnership Area, Sydney International Convention, Exhibition and Entertainment Precinct
Darling Harbour, New South Wales

FIGURE 1