Barangaroo
Lend Lease (Millers Point) Pty Limited
9 June 2011

# Human Health and Ecological Risk Assessment

Declaration Site (Development Works) Remediation Works Area - Barangaroo

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Prepared for

Lend Lease (Millers Point) Pty Limited

Prepared by

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# List of Acronyms

| Term | Description |
|---|---|
| ADI | Acceptable Daily Intake |
| ADWG | Australian Drinking Water Guidelines |
| AGL | Australian Gas Light Company |
| AHD | Australian Height Datum |
| ALS | Australian Laboratory Services |
| ANZECC | Australian and New Zealand Environment and Conservation Council |
| ARMCANZ | Agriculture and Resource Management Council of Australia and New Zealand |
| AS | Australian Standard |
| ASLP | Australian Standard Leaching Procedure |
| ASS | Acid Sulfate Soils |
| ATSDR | Agency for Toxic Substances and Disease Registry |
| B(a)P | Benzo-α-pyrene |
| BCA | Building Code of Australia |
| BDA | Barangaroo Delivery Authority |
| BH | Borehole |
| BLL | Bovis Lend Lease |
| BTEX | Benzene, Toluene, Ethyl benzene and Xylene |
| CAD | Computer Aided Design |
| CCME | Canadian Council of Ministers of the Environment |
| CoPC | Chemicals of Potential Concern |
| CSF | Cancer Slope Factor |
| CSM | Conceptual Site Model |
| DAF | Dermal Absorption Factor |
| Daf | Dilution Attenuation Factor |
| DEC | Department of Environment and Conservation NSW (superseded) |
| DECC | Department of Environment and Climate Change NSW (superseded) |
| DECCW | Department of Environment, Climate Change and Water, NSW |
| DGI | Data Gap Investigation |
| DNAPL | Dense Non Aqueous Phase Liquid |
| DNR | Department of Natural Resources |
| DP | Deposited Plan |
| DPI | Department of Primary Industries |
| DQI | Data Quality Indicators |

| Term | Description |
|---|---|
| DQO | Data Quality Objectives |
| DSI | Detailed Site Investigation |
| EPA | Environment Protection Authority |
| EPAV | EPA Victoria |
| EPC | Exposure Point Concentrations |
| EQL | Effective Quantitation Limit |
| ERA | Ecological Risk Assessment |
| ESA | Environmental Site Assessment |
| GDS | Groundwater Discharge Study |
| GIL | Groundwater Investigation Level |
| GW | Groundwater |
| HCB | Hexachlorobenzene |
| HHERA | Human Health and Ecological Risk Assessment |
| HIL | Health Investigation Level |
| HRA | Health Risk Assessment |
| IRIS | Integrated Risk Information System |
| ISQG | Interim Sediment Quality Guidelines |
| ITF | Intake Toxicity Factors |
| IUR | Inhalation Unit Risk |
| Kd | Soil-water Partition Coefficient |
| LL | Lend Lease (Millers Point) Pty Limited |
| Kow | Octanol water partition coefficient |
| LLD | Lend Lease Development Pty Limited |
| LOR | Limit of Reporting |
| m AHD | Metres Australian Height Datum |
| mbgs | Metres Below Ground Surface |
| m bTOC | Metres Below Top Of Casing |
| MAH | Monocyclic Aromatic Hydrocarbons |
| MW | Monitoring Well |
| MWQC | Marine Water Quality Criteria |
| NAPL | Non-Aqueous Phase Liquid |
| NATA | National Association of Testing Authorities |
| NE | North East |
| NEPC | National Environment Protection Council |
| NEPM | National Environmental Protection (Assessment of Site Contamination) Measure |

| Term | Description |
|---|---|
| NHMRC | National Health and Medical Research Council |
| NSW | New South Wales |
| OCP | Organochlorine Pesticides |
| OEH | Office of Environment and Heritage (NSW) |
| OPP | Organophosphorus Pesticides |
| ORWN | Other Remediation Works (North) Area |
| PAH | Polycyclic Aromatic Hydrocarbons |
| PASS | Potential Acid Sulfate Soils |
| PCB | Polychlorinated Biphenyl |
| PEF | Particulate Emission Factor |
| PQL | Practical Quantitation Limit |
| PSH | Phase Separated Hydrocarbons |
| PSI | Preliminary Site Assessment |
| QA | Quality Assurance |
| QA/QC | Quality Assurance/Quality Control |
| RA | Risk Assessment |
| RAIS | Risk Assessment Information System |
| RAP | Remedial Action Plan |
| RfC | Reference Concentration |
| RL | Relative Level |
| RPD | Relative Percentage Difference |
| RSL | Risk Screening Levels |
| RWP | Remediation Work Plan |
| SAQP | Sampling Analysis and Quality Plan |
| SC | Southern Cove |
| SHFA | Sydney Harbour Foreshore Authority |
| SHTC | Sydney Harbour Trust Commissioners |
| SROH | Significant Risk of Harm |
| SSESC | Site Specific Ecological Screening Criterion or Criteria |
| SSTC | Site Specific Target Criterion or Criteria |
| SVOC | Semi Volatile Organic Compound |
| TBT | Tributyl Tin |
| TC | Tolerable Concentration |
| TCE | Trichloroethene, Trichloroethylene |
| TCLP | Toxicity Characteristic Leaching Procedure |

| Term | Description | | |
|---|---|---|---|
| TDI | Total Daily Intake | | |
| TDS | Total Dissolved Solids | | |
| TEF | Toxic Equivalency Factor | | |
| TOC | Total Organic Carbon | | |
| TPH | Total Petroleum Hydrocarbons | | |
| TPHCWG | Total Petroleum Hydrocarbon Criteria Working Group | | |
| USEPA | United States Environmental Protection Agency | | |
| VF | Volatilisation Factor | | |
| VMP | Voluntary Management Proposal | | |
| VOC | Volatile Organic Compound | | |
| WAD | Weak Acid Dissociable | | |
| WHO | World Health Organisation | | |
| **Element Symbols** | | | |
| As | Arsenic | I | Iodine |
| Be | Beryllium | Mo | Molybdenum |
| CN | Cyanide | Ni | Nickel |
| Cl | Chlorine | P | Phosphorus |
| Cd | Cadmium | Pb | Lead |
| Cr | Chromium | Sn | Tin |
| Cu | Copper | Th | Thorium |
| F | Fluoride | Zn | Zinc |
| Hg | Mercury | | |
| **Units of Measurement** | | | |
| µg | Microgram | m | metres |
| cm | Centimetre | ML | Mega litre |
| ha | Hectare | mm | millimetre |
| hrs | Hours | ppm | parts per million |
| kg | Kilogram | % | Percent |
| km | kilometre | | |

# Executive Summary

AECOM Australia Pty Ltd (AECOM) has been commissioned by Lend Lease (Millers Point) Pty Limited (LL) to undertake Human Health and Ecological Risk Assessments (HHERA) for selected areas within the Barangaroo Stage 1 Development Precinct (Barangaroo), located at Hickson Road, Millers Point, New South Wales (NSW). The HHERA process will produce four reports focusing on areas designated by LL and the Barangaroo Delivery Authority (BDA), as follows:

- **HHERA Voluntary Management Proposal (VMP) Remediation Works Area** – relates to the OEH (formerly DECCW) Declaration Area (Declaration Number 21122) and designed to facilitate 'Declaration Removal' objectives as required by the Stage 1 Development.
- **HHERA Declaration Site (Development Works) Remediation Works Area**– relates to the same area as above but designed to facilitate the development remediation objectives as required by the Stage 1 Development (also referred to as Barangaroo South).
- **HHERA Addendum Other Remediation Works (South) (ORWS) Area** – relates to Blocks 1 to 3 of the Stage 1 Development area, outside the NSW OEH Declaration Area, and designed to facilitate the development of remediation objectives as required by the Stage 1 Development.
- **HHERA Other Remediation Works (North) (ORWN) Area** – relates to the Stage 1 Development area that is outside the NSW OEH Declaration Area and designed to facilitate the development remediation objectives as required by the Stage 1 Development plans.

This report comprises the HHERA for the **Declaration Site (Development Works) Remediation Works Area - Barangaroo** (henceforth referred to as the 'Site'). The Site is also referred in this and other documents as the "PDA Remediation Works Area".

In May 2009, the Department of Environment, Climate Change and Water (DECCW), now OEH[1] determined that part of the Barangaroo site (the site of a former gas works) and part of Hickson Road was contaminated in such a way as to present a significant risk of harm (SROH) to human health and the environment. As a consequence, DECCW declared the site to be a remediation site (Declaration Number 21122; Area Number 3221) under the then section 9 of the Contaminated Land Management Act 1997. The Declaration Site (Development Works) Remediation Works Area - Barangaroo (the 'Site') coincides with the area of the Declaration.

The objective of this HHERA was to develop human health based Site-specific target criteria (SSTC) and, if applicable, Site-specific ecological screening criteria (SSESC) (soil and groundwater concentrations) that remediation would have to achieve to allow redevelopment for the land uses described in the proposed Site Development Plans. The SSTCs and SSESCs are concentrations that would not give rise to unacceptable risks to both human health and the environment, respectively, under the specified land use.

As above, this HHERA specifically addresses issues relating to the Sites suitability for the proposed development. A separate HHERA for the VMP Remediation Works Area will be prepared to address 'significant risk of harm' issues required for removal of Declaration Number 21122.

The HHERA has been undertaken in accordance with relevant Australian guidance for health and ecological risk assessment.

Available analytical data from the relevant reports were evaluated by AECOM for the appropriateness of its quality for use in the risk assessment process. The data used in this assessment were considered to be valid and representative of concentrations of the analysed compounds at the sample locations tested. Overall, reported data were considered to be of an appropriate quality for use in the HHERA.

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[1] The Office of Environment and Heritage (OEH) is a division of the NSW Department of Premier and Cabinet. OEH was formed on the 4 April 2011 following an announcement of new administrative arrangements for the public service in NSW. OEH was formerly known as the Department of Environment, Climate Change and Water (DECCW). In regulatory matters for environment protection, OEH acts under the powers of the statutory Environment Protection Authority (EPA).

**Human Health Risk Assessment**

The human health risk assessment comprised the following key steps:

- Identification of chemicals of potential concern (CoPC) in environmental media, based on comparison to relevant human health based 'Tier 1' screening criteria.
- Qualitative and quantitative assessment of the toxicity of each CoPC.
- Development of Conceptual Site Models (CSMs) for land use scenarios relevant to future development of the Site.
- Quantitative Exposure Assessment for each land use scenario, in order to estimate the extent to which human receptors may be exposed to CoPC at the Site, including vapour and dust migration modelling where relevant.
- Adoption of acceptable risk levels to derive SSTC.
- Derivation of media and chemical specific SSTC for each CoPC based on consideration of toxicity criteria, exposure parameters, contaminant transport modelling and acceptable risk levels.

Current Site development plans (excluding Hickson Road and Block 5) propose land uses comprising mixed commercial and high density residential (with minimal access to soil) with associated open space area. Key components of the proposed development are expected to include:

- a mix of residential, commercial, retail (and potentially hotel) land uses;
- basement car parking ranging typically between depths of Relative Level (RL) -20.0 m (deep basement excavations) and RL -6.0 m (shallow basement excavations) with perimeter soil and groundwater retention systems generally constructed around the future basements and extending to bedrock; and
- excavation of a waterway (Southern Cove) extending eastward from Darling Harbour in the southern portion of the Site and adjacent area known as the Other Remediation Works North (ORWN) area.

It is noted that the northern portion of the Site (Block 5) is not part of the LL development, but it has been assumed for the purposes of this HHERA that future development in Block 5 will comprise a similar mixture of land uses, e.g. public open space, high density residential and commercial developments with basement car parking underlying some or all of the premises.

It should be noted that basement excavations extend into bedrock within the Site and exposed bedrock surfaces will be sealed with shotcrete. It is anticipated that perimeter walls and shotcrete covered bedrock, together with other controls forming standard practice for basement construction, will effectively isolate the basement from surrounding ground conditions. In addition, the basement groundwater retention wall system will be keyed into the underlying bedrock around the entire perimeter of the car park basement (effectively around the Site excluding Hickson Road). Consequently, it is expected that this system will effectively isolate both the basement car park and any material remaining *in situ* under it from the surrounding ground conditions and Darling Harbour. It is considered that there is no connection between these areas and the nearest environmental receptor (i.e. Darling Harbour).

Based on the above development plans, the broad land use scenarios for which SSTC have been derived are:

- lower-most basement car park level below the water table;
- upper-most basement car park level, partially above the water table;
- unpaved public domain / open space;
- paved public domain / open space;
- typical commercial slab on ground construction;
- short term ground-intrusive maintenance, and
- typical residential residence with basement construction.

Material and/or soil from the Site which meets relevant criteria may also be re-used in public domain / open space areas within the Site and/or in the adjacent ORWN area. SSTC derived for relevant scenarios (unpaved public open space, paved public open space, commercial slab on ground and intrusive maintenance) are considered applicable to identification of material suitable for placement within public domain areas, depending on the specific location.

It is noted that risk based acceptance criteria for material that might be placed in the future Headland Park will be developed separately by others.

**Odour Assessment**

An odour assessment was included as a component of the derivation of the soil and groundwater SSTC based on the potential development options (or land use scenarios) for different areas of the Site.

**Ecological Risk Assessment**

Consideration was also given to development of site-specific ecological screening criteria (SSESC) for the protection of the environment. Darling Harbour was identified as the nearest sensitive environmental receptor to the Site.

With the exception of Hickson Road, it is proposed that the entire Site be encapsulated by a basement groundwater retention wall system that will extend to and be keyed into bedrock and will ensure that groundwater will no longer be able to migrate from the east of the Site into Darling Harbour. The development of SSESCs for the areas of Site within the retention wall system is therefore not considered to be required for ecological protection. Furthermore, the basement groundwater retention wall system will effectively cut off direct migration from Hickson Road to Darling Harbour, requiring groundwater from Hickson Road to migrate to the north or south around the perimeter of the Stage 1 Development. Therefore, in consideration of the distance between the materials to remain *in situ* within Hickson Road and Darling Harbour, the development of SSESCs for Hickson Road is not considered to be required for ecological protection.

Ecological risk assessment will therefore be undertaken on a site-specific basis in those areas of Barangaroo South that will be in hydraulic connection with Darling Harbour following the development. That is, site-specific ecological risk assessments, including the derivation of site-specific SSESCs will be completed as part of the HHERAs to be prepared in relation to ORWN and ORWS (Addendum).

**Conclusions**

Based on comparison of derived health/odour criteria (SSTC) to available Site data and with consideration of the uncertainties and limitations of available data and information, the following conclusions are provided with respect to potential for human health, odour or aesthetic risks following redevelopment of the Site. As described above, the derivation of SSESC for ecological protection was not required in consideration of the proposed development design.

**Human Health Risks**

a) Potentially unacceptable human health risks have been identified under a number of redevelopment scenarios and remediation is required to make the Site fit for the proposed land uses. The following specific issues were identified:

   1) **Scenario 1 (Lower Basement):** The highest reported groundwater concentrations of benzene, 2-methylnaphthalene, naphthalene and TPH $C_{10}$-$C_{14}$ have the potential to result in unacceptable health risks from inhalation of vapours in the basement airspace.

   2) **Scenario 2 (Upper Basement):** The highest reported concentrations of benzene, 1,2,4-trimethylbenzene, naphthalene and TPH $C_{10}$-$C_{14}$ in soil and naphthalene and TPH $C_{10}$-$C_{14}$ groundwater have the potential to result in unacceptable health risks from inhalation of vapours in indoor airspaces.

   3) **Scenario 5 (Commercial Slab on Ground)**: The highest reported groundwater concentrations of naphthalene in soil and benzene, naphthalene and TPH $C_{10}$-$C_{14}$ in groundwater at the Site, have the potential to result in unacceptable health risks due to vapour intrusion. The unacceptable concentrations of naphthalene in soils were only observed where basements are intended and thus commercial slab on ground construction will not be present above these locations thus naphthalene in soil is not likely to be a concern in this scenario. It is considered likely that remediation of soils at the Site will result in a reduction in groundwater chemical concentrations; installation of the groundwater retention wall system will also reduce the likelihood of chemical contaminants in groundwater being present beneath commercial slab on ground buildings.

4) **Scenario 6 (Intrusive Maintenance)**: The highest reported groundwater concentrations of benzene, 2-methylnaphthalene, naphthalene, TPH $C_{10}$-$C_{14}$, TPH $C_{15}$-$C_{28}$ and TPH $C_{29}$-$C_{36}$ fractions and soil concentrations of carcinogenic polycyclic aromatic compounds (cPAHs) have the potential to result in adverse health risks to short-term intrusive maintenance workers, if workers come into direct contact with impacted soil or groundwater.

5) **Scenario 7 (High Density Residential)**: The highest reported soil concentrations of benzene, naphthalene and TPH $C_{10}$-$C_{14}$ and groundwater concentrations of naphthalene and TPH $C_{10}$-$C_{14}$ have the potential to result in unacceptable health risks due to vapour intrusion. It should be noted that the majority of location where exceedences of calculated SSTC were reported were within areas that LL development plans current indicate that basement construction will occur. Thus contaminated soil and groundwater is unlikely to be present in areas where residential buildings are planned to be constructed at the Site.

b) Unacceptable human health risks are not expected to be associated with Scenario 3 (Unpaved Recreation) and Scenario 4 (Paved Recreation) as SSTC for these scenario were not exceeded by reported Site concentrations, or the nature, extent and/or location of the exceedences were insignificant. The exposure duration for human health receptors for paved and unpaved areas of the Site are significantly less in duration than those considered in Scenario 2, 5 and 7.

c) The majority of soil/fill material from the Site is considered (based on human health considerations) to be suitable for beneficial reuse in the public domain (outside the Site) provided that the reused material meets human health based SSTC for public open space, commercial slab on ground or intrusive maintenance scenarios, as relevant to the specific location of reuse. Note that because the public domain areas will likely be in hydraulic connection with Darling Harbour, reused material should also meet ecological based SSESC derived by the applicable site-specific ecological risk assessment for the proposed beneficial reuse location.

d) The above conclusions are based on the exposure assumptions and vapour migration models described in this report. The exposure and modelling assumptions were selected to be conservative in order to account for potential uncertainties and provide a deliberate margin of safety. Recent building plans, supplied by LL, indicate that the current basement design is likely to provide significantly greater reduction in the potential for vapour intrusion than that modelled in this HHERA; thereby providing a further margin of safety.

**Odour Risks**

e) Minimal exceedences of theoretical (modelled) odour-based SSTC have been reported in soil and groundwater, however:

1) gasworks waste is inherently odorous material;

2) it is possible that some odorous material could remain at the Site following remediation; and

3) the extent to which odorous vapours may enter basement structures is difficult to predict and/or model.

f) Large scale source removal / remediation, as is proposed as part of the development, would be expected to significantly reduce the risk of future odours.

**Visual Amenity Issues/Risks**

g) Visual amenity issues are not considered likely to arise on the remainder of the Site, given the proposed future land uses and development plans.

**Recommendations**

Based on the above conclusions, and with consideration of the uncertainties and limitations of available data and information, the following recommendations are provided:

a) Basement design plans must include engineering controls to ensure that contaminated groundwater does not accumulate in compartments which are ventilated to basement airspaces since potentially adverse health risks and odours have been estimated to arise from low concentrations of volatile groundwater contaminants if water enters basements. The following is also recommended:

1) Basement levels should be maintained at a lower pressure than occupied areas above in accordance with AS 1668.2 (Standards Australia, 2002).

2) Sump rooms should be placed as far as possible from lift wells.

3) Air exchange rates within the basement areas should be maintained at a minimum of the Australian Standard 4 per hour.

b) Tar should be removed from the immediate vicinity of outer basement walls to the extent practicable, and basement design and engineering controls should ensure that tar seepage into basements does not occur.

c) Soil and groundwater remaining within the Site should be remediated to meet relevant health/odour criteria (SSTC) (**Table T20** and **Table T21**).The specific health/odour SSTC to be met in different Site locations will depend on the land use(s) relevant to the area. In the case where more than one Scenario is applicable to the area, the most conservative (i.e. the lowest value) of the applicable SSTCs will be adopted as the remediation goal.

d) Shallow groundwater within Hickson Road, if present at depths which may be directly contacted by intrusive workers, should meet SSTC for Scenario 6.

e) Unpaved open space (Scenario 3) areas will be covered in a minimum of 0.5 m of suitable fill. Suitable fill of greater than 0.5 m thickness is recommended in areas where deeper rooting trees will be planted. For the purposes of unpaved open space (Scenario 3), suitable fill is defined as either:

1) virgin excavated natural material (VENM); or

2) soil which contains contaminant concentrations below the terrestrial soil criteria (developed for the maintenance of plant health and human health refer to **Section7.3** and **Table 46**).

f) It is recommended that paved open space (Scenario 4) areas will be covered in a minimum of 0.5 m of suitable fill (directly under the pavement). This is to account for the potential that paved areas may in the future be unpaved areas. Therefore for the purposes of definition, suitable fill will be defined as for unpaved open space areas (see above).

g) Validation of soil and groundwater following remediation should be undertaken using appropriate statistical methodologies to ensure that the arithmetic average concentration of contaminants are below relevant screening criteria, in accordance with NSW EPA (1995) guidance. The validation process should therefore include:

1) use of systematic sampling patterns;

2) collection of an appropriate number of samples for estimation of the arithmetic average concentration of contaminant(s) within relevant environmental media and land use areas (land use areas should be determined based on specific development plans with consideration to areas of soil and groundwater from which vapours may enter a given basement structure and/or from which CoPC may enter surface water bodies);

3) estimation of the 95% upper confidence limit (UCL) of the arithmetic average concentration within relevant environmental media and exposure areas.

h) The human health-based SSTC have accounted for potential exposures to mixtures of chemicals.

i) Soil sourced from the Site for proposed beneficial reuse in Public Domain areas of ORWN or ORWS should meet relevant health/odour criteria (SSTC) and site-specific ecological screening criteria (SSESC) developed in the HHERAs for those beneficial reuse locations. The risk based acceptance criteria for material that might be placed in the future Headland Park will be developed separately by others.

j) The RAP should include consideration of mitigation measures for the appropriate management of:

1) asbestos that may be potentially encountered during the remediation works; and

2) odours that may accumulate in the basements following construction (while this is considered very unlikely, it is recommended that it be considered as part of the contingency measures included within the RAP in recognition of the uncertainties inherent in assessment of odour).

# 1.0 Introduction

## 1.1 Background

AECOM Australia Pty Ltd (AECOM) has been commissioned by Lend Lease (Millers Point) Pty Limited (LL) to undertake Human Health and Ecological Risk Assessments (HHERA) for selected areas within the Barangaroo Stage 1 Development Precinct (Barangaroo), located at Hickson Road, Millers Point, New South Wales (NSW). The HHERA process will produce three reports focusing on areas designated by LL and the Barangaroo Delivery Authority (BDA), as follows:

- **HHERA Voluntary Management Proposal (VMP) Remediation Works Area** – relates to the OEH (formerly DECCW) Declaration Area (Declaration Number 21122) and designed to facilitate 'Declaration Removal' objectives as required by the Stage 1 Development.
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- **HHERA Addendum Other Remediation Works (South) (ORWS) Area** – relates to Blocks 1 to 3 of the Stage 1 Development area, outside the NSW OEH Declaration Area, and designed to facilitate the development of remediation objectives as required by the Stage 1 Development.
- **HHERA Other Remediation Works (North) (ORWN) Area** – relates to the Stage 1 Development area that is outside the NSW OEH Declaration Area and designed to facilitate the development remediation objectives as required by the Stage 1 Development plans.

This HHERA focuses on the **Declaration Site (Development Works) Remediation Works Area** (henceforth referred to as the 'Site'. The Site is also referred in this and other documents as the "PDA Remediation Works Area").

While this report focuses on the Declaration Site (Development Works) Remediation Works Area (the Site), the following is noted:

- The VMP Area and the Site occupy the same footprint and this area will hereafter be referred to as the Site.
- Information relating to the adjacent ORWN Area has been included in some locations within this report to provide a more comprehensive picture of the Site setting and contamination status adjacent the Site, particularly between the Site and Darling Harbour.

As above, this HHERA specifically addresses issues relating to the Site's suitability for the proposed development. A separate HHERA for the VMP Remediation Works Area will be prepared to address 'significant risk of harm' issues required for removal of Declaration Number 21122. **Figure F 1** shows the location of the Barangaroo precinct and shows the precinct layout including the boundaries of the OEH Declaration Area, ORWS Area and ORWN Area. **Figure 2** in **Appendix A** shows the OEH Declaration Area with the overlay of the proposed basement and groundwater retention wall system.

Discussion with the NSW Department of Health and with the NSW Department of Environment, Climate Change and Water, were undertaken prior to completion of the HHERA in order to clarify several aspects of HHERA approach and methodology.

## 1.2 Objectives

The objective of this HHERA was to develop Site-specific target criteria (SSTC) and Site-specific ecological screening criteria (SSESC) (if relevant) for soil and groundwater for use in defining the remediation end-point for the Site. The remediation end-point is defined as that required to render the Site suitable for use following redevelopment in accordance with the proposed Site development plans. For the purposes of this HHERA, a 'suitable for use' endpoint is considered to be that required to ensure that unacceptable risks to human health or the environment will not occur. When the Site has been remediated so that the SSTC and SSESC (if relevant) have been satisfied a Site Auditor accredited by NSW OEH will consider issuance of a Section A Site Audit Statement certifying that the site is suitable for the proposed land uses and that a Long-term Environmental Management Plan is not required to be implemented.

## 1.3 Assumptions

The following assumptions are implicit in this report:

- The SSTC were developed based on the site conditions and CoPC detected during the site investigations detailed within this report.
- The SSTC were based on the plans and design assumptions provided by Lend Lease to AECOM as outlined in **Section 2.4** at the time of completion of this risk assessment. Further information related to the proposed development within the Site is contained within **Appendix A.**
- Future car-parking basements will include engineering controls to ensure that contaminated groundwater does not accumulate in habitable car park areas. Further information relating to the proposed development design is contained within **Section2.4 and Appendix A**.
- The development of SSTCs has assumed that tar will be removed from the immediate vicinity of outer basement walls to the extent practicable, and that basement design and engineering controls as described within this document will ensure that tar seepage into basements does not occur.
- There are significant biodegradation processes occurring within sub-surface soils based on measured oxygen concentrations beneath the sub-surface. To account for these biodegradation processes, a 10 fold factor (Davis 2009) has been adopted for site specific target criteria for soil for the paved and unpaved areas of the Site, where biodegradation processes are considered to be significant.
- The development of SSTCs have accounted for the presence of mixtures of chemicals at the Site within the same media.
- For the development of SSTC for unpaved areas (Scenario 3 as detailed in **Section 5.3.4**) it has been assumed that 0.5m of suitable fill will be present at the soil surface at these locations. For the purposes of this definition "suitable fill" is defined as:
  - VENM; or soil which contains contaminant concentrations below the terrestrial soil criteria (developed for the maintenance of plant health and human health refer to **Section 7.3 and Table 46).**
- For paved open space (Scenario 4 as detailed in **Section 5.3.4)** areas, it is recommended that a minimum of 0.5 m of suitable fill be provided directly under the pavement. This is to account for the potential that paved areas may in the future be unpaved areas. For the purposes of this definition," suitable fill" is defined as for unpaved areas (see above).
- The current theoretical estimation of vapour concentrations within indoor and outdoor air is based on partitioning modelling which has been demonstrated to overestimate concentrations between 10-1,000 fold. To account for this conservatism, an adjustment factor of 10 has been applied to all modelled soil results for BTEX, TPH $C_6$-$C_9$ and $C_{10}$-$C_{14}$. These compounds have been selected based on a number of studies which indicate that volatile petroleum related compounds partitioning modelling overestimates the predicted concentrations from 10 to 10,000 times.

## 1.4 Framework and Methodology

### 1.4.1 Human Health Risk Assessment

The human health component of the risk assessment has been undertaken in accordance with the following nationally adopted guidance documents:

- 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, 2004);
- National Environmental Protection (Assessment of Site Contamination) Measure 1999, Schedule B(4), Guideline on Health Risk Assessment Methodology. National Environment Protection Council (NEPC, 1999a); and
- National Environmental Protection (Assessment of Site Contamination) Measure 1999, Schedule B(7), Guideline on Health-Based Investigation Levels. (NEPC, 1999b).

The risk assessment framework recommended in the above documents comprises the following four stages:

- **Issues Identification (Data collection and evaluation)**. This includes the acquisition and analysis of information about chemicals present at the Site that may adversely affect human health and identification of those chemicals will be the focus of the risk assessment.
- **Toxicity assessment**. This entails evaluation of both qualitative and quantitative information to describe the nature and incidence of adverse effects occurring in humans at different exposure levels.
- **Exposure assessment**. This involves identification of exposed human populations (receptors) and pathways via which receptors may be exposed to chemical contaminants on or deriving from the Site. Environmental monitoring data and/or predictive fate and transport models are combined with estimates of the frequency, extent and duration of receptor exposure to derive quantitative estimates of human exposure to contaminants.
- **Risk characterisation.** This involves comparison of estimated exposure levels to relevant toxicity (dose-response) criteria to estimate the potential incidence and nature of adverse health effects to human receptors. An important component of the risk characterisation stage is the interpretation of risk estimates in the context of the uncertainties and assumptions of the risk assessment process.

In the case of SSTC derivation, the methodology, approach and assumptions are similar to the forward risk calculation process described above, with the exception that the exposure and risk algorithms are reversed in order to back-calculate acceptable concentrations in environmental media based on a set acceptable risk level.

### 1.4.2 Ecological Risk Assessment

Ecological risk assessment is undertaken in Australia with consideration to the following guidance documents:

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

## 1.5 Scope of Work

The scope of work for the HHERA was the following:

- **Historical Report Review and Data Evaluation**: Review and evaluation of data from the Other Remediation Works (South) Area Data Gap Investigation (DGI) (AECOM 2010a), the proposed Other Remediation Works (North) Area DGI (AECOM 2010c), the VMP and PDA Remediation Area DGI (also known as the EPA Declaration Area DGI) (AECOM 2010b) and other relevant historical reports including a DRAFT Supplementary VMP Data Gap Investigation (AECOM 2011).
- **Human Health Risk Assessment**, including:
  - Identification of chemicals of potential concern (CoPC) for human health, based on comparison of Site data to relevant ‘Tier 1’ screening levels derived for protection of human health.
  - Review of toxicological data for CoPC and identification of appropriate toxicity values to use in the HHERA.
  - Review of chemical and physical properties of each CoPC for risk assessment purposes.
  - Development of conceptual site models (CSMs) for the post-development status of the Site, including:
    - summarisation of the sources, nature and extent of contamination at the Site;
    - description of site physical conditions (including site geology and hydrogeology, existing physical structures and proposed structures to be constructed as part of the development) to be used in assessment of contaminant fate and transport; and
    - identification of human receptors and who may be exposed to Site contaminants following redevelopment and the pathways via which they may be exposed.
  - Quantitative exposure assessment, including:

    - establishment of relevant exposure parameters for identified receptors and exposure pathways; and
    - application of vapour and dust transport modelling to predict chemical concentrations in air which may result from identified soil and groundwater contamination.
  - Adoption of acceptable risk levels for SSTC derivation.
  - Estimation of SSTC based on consideration of toxicity, exposure, contaminant migration modelling and acceptable risk levels.
  - Comparison of SSTC for potential future development scenarios to chemical concentrations reported at the Site.
  - Discussion of SSTC exceedences and their significance and relevance to future development plans for the Site.
  - Consideration of aesthetic risks or issues.
- **Ecological Risk Assessment, including:**
  - Consideration of terrestrial and marine habitat issues relevant to the Site management objectives for the adjacent Darling Harbour.
  - Consideration of the implications of the proposed development design for the Site on ecological risk;
  - Development of terrestrial soil criteria for the definition of suitable fill to be placed in the upper 0.5m of open space areas.
  - Reporting and Meetings, including:
    - preparation of this report; and
    - attendance at meetings and telephone conferences to discuss the results with the Site Auditor, LL or other stakeholders.

The scope of works also included a physical inspection of the Site by the risk assessors to gain an understanding of the local conditions and Site layout.

# 2.0 Site Characterisation

## 2.1 Site Details

The Site identification details are provided in below.

**Table 1: Site Identification Details**

| Item | Description |
|---|---|
| Site Owner | Barangaroo and Hickson Rd: The Barangaroo Delivery Authority (BDA). |
| Client | Lend Lease (Millers Point) Pty Ltd (LL). |
| Site Address | Hickson Road (Sussex Street), Barangaroo, NSW 2000. |
| Legal Description (Lot and DP) | Part Lot 3, Lot 5 in Deposited Plan 876514<br>Section of Hickson Road in State Plan 118 and 162. |
| County and Parish | County of Cumberland, Parish of Saint Phillip. |
| Local Government Authority | City of Sydney. |
| Current Zoning | Site within Hickson Road: Maritime and Transport Zone [a].<br>Site within Barangaroo: Zone B4 Mixed Use [b]. |
| Current Land Use | Barangaroo: Vacant. Partial access for public recreation (walking and bike riding).<br>Hickson Road: Public Roadway. |
| Proposed Land Use | Parts of Block 3, 4 and 5: Possible high density residential (minimal access to soil) and commercial with basement car parking.<br>Part of Block 5 within the Site: Assumed high density residential (minimal access to soil) and commercial with basement car parking.<br>Hickson Road: Public Roadway.<br>(It is considered that the area contribution from Block 3 to the Site is insignificant and therefore it is not referred to again throughout this HHERA). |
| Site Area** | 24,213 $m^2$, made up of:<br>- Part Block 3: 183 $m^2$<br>- Part Block 4: 10,718 $m^2$ including Proposed Southern Cove area (2,984 $m^2$)<br>- Part Block 5: 4,583 $m^2$<br>- Part Hickson Road: 5,729 $m^2$<br>- Part Southern Cove: 2,984 $m^2$ |
| Approximate Average Elevation | 2 - 3 m AHD |
| Site Location | **Figure F 1** |
| Site Layout | **Figure F 2** |

Notes:** Derived from CAD plans provided by LL. Areas are based on Blocks as defined in the Stage 1 of Barangaroo redevelopment precinct, as they fall within the Site boundaries.
AHD – Australian Height Datum.
[a] City of Sydney 2005. *Sydney Local Environmental Plan 2005*, Gazetted 9 December 2005, as amended.

[b] – NSW Department of Planning 2007. Appendix 4. In: *State Environmental Planning Policy (Major Projects) 2005 (Amendment No 19)*, Gazetted 12 October 2007, as amended.

## 2.2 Site Description and Current Land Use

The Site covers an irregular shaped area of approximately 2.1 ha (based on existing LL supplied site plans). The location of the Site is presented on **Figure F 1** and the current Site layout is illustrated in **Figure F 2.**

The Site is currently open, vacant and variably paved with concrete and asphalt concrete. The concrete ground surface was observed to be in generally good condition with some cracking evident at the surface of the asphalt concrete.

At the time of the AECOM DGI (AECOM, 2010c and AECOM, 2010b), there was a building located at the Site which was used historically by Sydney Ports personnel for maintenance and then for meetings by the BDA personnel. This building has since been demolished and there are no buildings located on the Site.

Access to the Site (excluding Hickson Road) is limited by the presence of a cyclone wire fence on the eastern side. Three gatehouses are present along the fenced area to permit access to Barangaroo, which is controlled by a 24 hour security presence. During the field investigation undertaken as part of the DGI, a harbour walk was opened to the public. The publicly accessible area is controlled by the presence of temporary fencing.

A section of Hickson Road forms the easternmost portion of the Site. The road is actively used as a vehicle thoroughfare and for parking.

## 2.3 Surrounding Land Use

The Site is surrounded by the following land use:

- North: Barangaroo, including but not limited to the remainder of Block 5 (open space/concrete hardstand).
- South: Barangaroo Blocks 1 to 3 and the southern portion of Hickson Road followed by Sussex Street (public roads). A cruise ship terminal is located within Barangaroo Blocks 1 to 3 which has been relocated temporarily to Block 5.
- East: Commercial and high density residential buildings with Jenkins Street beyond.
- West: The remainder of Blocks 4 and Southern Cove (ORWN Area) and Block 5, followed by Darling Harbour.

## 2.4 Proposed Land Use and Development

The entire Barangaroo redevelopment area comprises a 22 hectare site, which has been divided into three distinct redevelopment areas: Headland Park, Barangaroo Central and Barangaroo South. Headland Park and Barangaroo Central are proposed to be separated by a waterway known as ‘Northern Cove’. A waterway known as ‘Southern Cove’ will be created at Barangaroo South (including part of the site). A canal may connect the eastern-most sections of the Northern and Southern Coves.

The Site falls within Barangaroo South (Block 4 and Southern Cove) and Barangaroo Central (Block 5). The Site also includes part of Hickson Road, which is not part of the Barangaroo site. LL has divided the Site into sub-sites based on the proposed re-development and corresponding proposed land use as follows:

- [Part of] Block 4: High density residential (minimal access to soil) and commercial with basement car parking.
- [Part of] Block 5: Assumed high density residential (minimal access to soil) and commercial with basement car parking.
- [Part of] Southern Cove: Recreational Open Space and publically accessible waterway.
- [Part of] Hickson Road: Roadway.

The location and layout of the sub-sites are presented on **Figure F 3.**

### 2.4.1 Proposed Future Land Use

Based on the current LL development plans, it is understood that the proposed land use across the Site will comprise mixed commercial and high density residential (with minimal access to soil) with associated open space area. The eastern portion of the Site includes Hickson Road, which is proposed to continue as a roadway and public transport connection, with a pedestrian connection to Wynyard Station and the city.

Key components of the proposed Site development will include:

- Basement car parking across the Block 4 footprint (including underlying the proposed Southern Cove) to an approximate depth of RL -9.0 m. The car park basement will be constructed within a basement groundwater retention wall system that will extend around the perimeter of that part of the Site within Block 4.
- High density residential and commercial multi storey towers, together with associated open space areas, overlying the basement car parking in Block 4.
- A groundwater retention wall system constructed around the perimeter of that part of the Site within Block 5 (it is noted that while development of Block 5 will be by others, it has been assumed that future landuse of Block 5 will comprise high density residential and/or commercial with up to two levels of basement car parking); and
- A public waterfront with mixed residential, commercial and retail use associated with the eastern end of the Southern Cove which will extend over the aforementioned basement car park.

It is possible that the final details and configuration of land uses within the Site will be revised by LL as part of the continued development design. However, the proposed land uses - that is a mixture of commercial and high density residential and public open space overlying extensive basements - will remain generally consistent with that described by this HHERA.

### 2.4.2 Basement Groundwater Retention Wall System

The basement groundwater retention wall system will be constructed around the perimeter of the Block 4 and 5 portions of the Site and will extend to and be keyed into bedrock. The perimeter walls will include:

- diaphragm walls, extending to and keyed into bedrock and generally constructed around the southern, western and northern boundary; and
- a secant pile or equivalent walls, extending to and keyed into bedrock and generally constructed along the eastern boundary.

Where basement excavations extend into bedrock, exposed bedrock surfaces will be covered with shotcrete. It is anticipated that perimeter walls and shotcrete covered bedrock, together with other controls forming standard practice for basement construction, will effectively isolate the basement from surrounding ground.

**Above the depth of the bedrock:**

- Perimeter walls (diaphragm / secant piles) will be constructed with a minimum thickness of 600 mm and will be keyed into the bedrock (irrespective of the depth of the basement that will be constructed within them).
- In some areas a secondary reinforced concrete wall (treated with chemical additives for improved waterproofing) will be constructed within the perimeter walls as the internal car park basement wall.
- A sealed plenum will be constructed by a 200 mm thick block work wall (bagged to provide a relatively air tight zone) immediately inside the reinforced concrete car park basement wall. The sealed plenum will be configured to:
  - collect and drain seepage water that may permeate through the perimeter and basement car park walls. Seepage water (if any) will drain via a dish drain to a drainage sump located at the lowest basement level (away from the lift wells) from where it will be appropriately disposed of; and
  - vent vapours from seepage water that may permeate through the perimeter and basement car park walls. Vapour will be vented via a passive pipe riser to the height of the roof level of the above buildings.

**Below the depth of the bedrock:**

- The exposed vertical, sandstone surface will be shotcreted (100mm minimum thickness).
- A secondary 350 mm thick reinforced concrete wall (treated with chemicals additives for improved waterproofing) will be constructed within the shotcrete covered sandstone.
- A sealed plenum will be constructed by a 200 mm thick blockwork wall (bagged to provide a relatively air tight zone) immediately inside the reinforced concrete car park basement wall. The sealed plenum will be configured as described above for above the depth to bedrock.

In addition to the design features of the retention wall system(s) described above, a number of drainage features required by the construction process, but which will also act to mitigate the risk of water or vapour entering the basement car parks, will be constructed. These include:

- a 500 mm thick gravel filled void between the perimeter wall and the secondary reinforced concrete basement car park wall; and
- a drainage cell will be constructed between the exposed sandstone surface and the shotcrete cover. The purpose of the drainage net is to temporarily convey any seepage water away from the excavation face and facilitate construction of the shotcrete cover.

Considering the thickness and design of the retention wall system(s), together with the additional drainage measures required for construction of the system(s), it is considered that the basements (and fill material remaining *in* situ below the basements) will be effectively isolated from the surrounding ground conditions. In the unlikely event that groundwater or vapour does penetrate through the wall (into the sealed plenum), it will be prevented from entering the ventilation plenum and/or car park basement by the drainage and venting within the sealed plenum. A second plenum, herein referred to as the ventilation plenum, is proposed to be constructed adjacent to and inside the sealed plenum as part of the car park ventilation system.

Details of the proposed basement groundwater retention wall system are provided in **Appendix A**. It should be noted that basement groundwater retention wall system to be constructed in association with the Site will be equivalent to that proposed for Blocks 1 to 3 (which is detailed in **Appendix A**).

### 2.4.3 Services

It is expected that a network of new services will be constructed as part of the development. Of relevance to the risk assessment is the potential for these services to provide preferential pathways for the migration of vapour and or groundwater to either site occupants (human health receptor) or Darling harbour (ecological receptors). As described above, the majority of the Site (excluding on Hickson Road) will be encapsulated within a basement groundwater retention wall system. Further, as part of the development a basement car park will be constructed across the footprint of the Site that is within Block 4; and, as part of future developments, it is assumed that a basement car park will also be constructed across the footprint of the Site that is within Block 5.

In consideration of the proposed development, the risk of vapours or groundwater migrating to sensitive receptors via preferential pathways associated with the newly constructed services is considered extremely low. In particular:

- Services within Block 4 and 5 will be wholly contained within the basement car park. As such there will be no exposure of services to contaminated soil or groundwater and therefore no pathway for migration of vapour or groundwater to sensitive receptors.
- Services within Hickson Road are expected to be generally contained within the upper 1.5m of the soil profile above the groundwater table. As such there will be no (or limited) exposure of services to contaminated groundwater.
- Services within Hickson Road that require connection to the Barangaroo South development or passage through the Barangaroo South development to the harbour, will be required to penetrate through the basement groundwater retention wall system and through the basement car park. The basement groundwater retention wall system will be sealed around these penetrations, effectively eliminating the pathway for migration of vapour or groundwater to sensitive receptors.
- The SSTCs adopted as part of the remediation goals for Hickson Road will be:
  - protective of intrusive maintenance workers who may contact the Services within the Site; and

- will be designed to reduce soil and groundwater concentrations such that the risk from the migration of groundwater or vapour from the Site via preferential pathways associated with services is acceptable.

## 2.5 Site History

The Overarching Remedial Action Plan (RAP) (ERM, 2010) provides detail of historical activities at the Site, as summarised below:

- 1839 to 1921: A gasworks operated by The AGL was located on part of the Site and extended across what is now Hickson Road. The remainder of the Site was owned by merchants, compositors, manufacturers and various shipping companies. It is likely that the Site was also used for ship berthing and associated activities. Ownership was largely transferred to Sydney Harbour Trust Commissioners (SHTC) in approximately 1912, however, it is understood that the gasworks site was leased to AGL until September 1921. The Hickson Rd portion of the Site was owned by a tin smelter and engineer during 1875. Other owners include ship builders, a licensed victualler, shipowners and merchants.
- 1922 to 1925: The gas holders and purifier beds associated with the AGL gasworks were demolished to ground level and the gas holding tanks were backfilled. The fill in the gas holder pits has been reported to contain tarry material and exhibit odours from a depth of 2 m bgl. The Site was used for workshops and stores, with many warehouse buildings constructed on the former gasworks area.
- 1925 to 1936: The majority of the Site continued to be owned by the SHTC and was used for ship berthing and associated activities. According to the title search records, the Hickson Road portion of the Site has been used since 1925 as a road under the control and management of the City of Sydney Council.
- 1936 to 1998: Part of the Site was owned by the Maritime Services Board of NSW and subject to various commercial leases. The majority of the remainder of the Site initially consisted of finger wharves, which were removed over time with a significant portion of land reclaimed from the harbour with unclassified fill between 1951 and 1972. In 1996 a vehicle maintenance area including wash bay, waste oil store and above ground diesel fuel tanks was identified.
- 1998: Martine Ministerial Holding Corporation was the proprietor of Lots 1 and 6 in Deposited Plan 876514. SPC was proprietor of Lots 2, 3, 4 and 5.
- 2007–2008: The majority of the Site was vacated by Patrick Stevedores Operations. Four large warehouses were demolished and the Site cleared and levelled in preparation for future redevelopment.

## 2.6 Previous Investigations

Previous investigations relating to the Barangaroo site and adjacent areas are summarised in **Table 2** below. Recent investigations undertaken by AECOM over the last two years, which have included the Site, and/or immediately surrounding area, are further described in **Section 2.6.1** to **Section 2.6.9**.

**Table 2: Previous Investigations**

| Date of Publication | Consultant | Report Title and Key Issues |
|---|---|---|
| January, 1986 | ARUP Geotechnics | Upgrading Wharf 7/8 Darling Harbour, Geotechnical Site Investigation – detail of rock/soil design parameters, geotechnical analysis and recommendations on foundations for proposed development of Wharves 7 and 8. |
| June, 1996 | Noel Arnold & Associates Pty Ltd | Initial Environmental Assessment, Sydney Ports Corporation, Darling Harbour Berths 3-8 Hickson Road, Darling Harbour – details results of an initial contamination assessment and provides options for remedial management of the site. Known and potential contamination was not determined to be a risk to the ongoing use of the site by the then occupant providing subsurface materials were not disturbed. Impact was identified in the area of the former gas works. |
| March, 1998 | Coffey Partners International Pty Ltd | Wharf 8 Darling Harbour Environmental Soil Quality Assessment – A limited site assessment including soil sampling at Wharf 8 to identify contamination and provide options for disposal of excavated soil associated with proposed development. The Environmental Site Assessment (ESA) reported low level polycyclic aromatic hydrocarbons (PAH) contamination and identified material required for offsite disposal that would likely require industrial or hazardous waste classification. |
| July, 2001 | URS Australia Pty Ltd | Contamination Review for Darling Harbour – Berths 3/8 – Comprised a review of the contamination issues collated from 11 reports produced between 1993 and 2001. The review identified soil and groundwater contamination associated with the former gas works, including offsite migration and soil contamination associated with current vehicle maintenance operations. |
| August, 2006 | Jeffery and Katauskas Pty Ltd | *Geotechnical Investigation for Proposed Redevelopment of Wharves 3-8 at Hickson Road, Darling Harbour East, NSW* – Geotechnical investigation intended to identify the subsurface conditions of the site in preparation for the proposed redevelopment. |
| June, 2007 | ERM Australia Pty Ltd | *Environmental Site Assessment, East Darling Harbour, Sydney, NSW Final Report – Revision 1* – ESA intended to identify and report the environmental site conditions in preparation for the development planning. Works included the completion of a Stage 1 Investigation and Stage 2 ESA comprising drilling and sampling of soils and groundwater at 150 locations (inclusive of Lots 1, 2 , 4 and Northern portion of Lot 5). CoPC were identified in groundwater in the vicinity of the former gas works. |
| May 2008 | Coffey Environments Pty Ltd | Preliminary environmental investigation at 30-38 Hickson Road, conducted for the City of Sydney Council. Included the drilling and sampling of 15 boreholes and the installation of 6 groundwater monitoring wells. Area of investigation included Hickson Road and the courtyard area between 30 and 38 Hickson Road. |

| Date of Publication | Consultant | Report Title and Key Issues |
|---|---|---|
| July, 2008 | ERM Australia Pty Ltd | *Additional Investigation Works at Barangaroo, Hickson Road, Millers Point, NSW – Revision 3* – intended to address data gaps remaining following the Stage 2 ESA and included an additional 55 boreholes and construction of 13 monitoring wells across the site (inclusive of Lots 1, 2 , 4 and Northern portion of Lot 5). The report identified the former gas works and reclaimed areas between the finger wharves as key areas of concern. Exceedences of assessment criteria for soil were identified for lead, total petroleum hydrocarbons (TPH), PAH, benzene, toluene, ethylbenzene, xylenes (BTEX) and sulphate. The highest levels were identified in the vicinity of the former gas works and included the identification of phase separated hydrocarbons (PSH) in MW204D located within the gas works footprint. |
| August, 2008 | ERM Australia Pty Ltd | *Preliminary Sediment Screening Works at East Darling Harbour, Adjacent to Barangaroo, NSW, Draft, Rev 03* – preliminary sediment screening works were conducted at East Darling Harbour to identify potential offsite migration of contamination from the Site to sediments in Darling Harbour. Sediments cores were collected from the Harbour adjacent to the Site along 7 transects. Screening identified PAH, tributyl tin (TBT) and metals exceeding ANZECC (2000) and elevated levels of organochlorine pesticides (OCPs) and TPH $C_{10}$-$C_{36}$. |
| May 2010 | AECOM | *Data Gap Investigation, Other Remediation Works (South) Area Hickson Road, Millers Point NSW* (AECOM, 2010a).<br>The purpose of the DGI was to reduce uncertainties which exist in the current data set, confirm the characteristics of soil and groundwater underlying the site, provide the additional data required if a quantitative HHERA is developed and facilitate the development of an RAP and RWP (remediation work plan) which describe the remediation strategy to be implemented by LL as part of its proposed Stage 1 Development of the Barangaroo Precinct.<br>Refer to **Section 2.6.5** for further detail regarding the report findings. |
| September 2010 | AECOM | *Data Gap Investigation, EPA Declaration Area (Parts of Barangaroo Site and Hickson Road) , Millers Point NSW* (AECOM, 2010b)<br>Refer to **Section 2.6.6** for further detail regarding the report findings. |
| October 2010 | AECOM | *Data Gap Investigation, Other Remediation Works (North) Area, Hickson Road, Millers Point NSW* (AECOM, 2010c)<br>Refer to **Section 2.6.7** for further detail regarding the report findings. |
| November 2010 | AECOM | *Groundwater Discharge Study,Stage 1 Barangaroo Development, Hickson Road, Darling Harbour, NSW* (AECOM, 2010d).<br>Refer to **Section 2.6.8** for further detail regarding report findings. |
| 2011 | AECOM | *Supplementary Data Gap Investigation, EPA Declaration Area (Parts of Barangaroo Site and Hickson Road) , Millers Point NSW* (AECOM, AECOM 2011)<br>Refer to **Section 2.6.9** for further detail regarding the report findings. |

### 2.6.1 ERM 2007

ERM was commissioned by SHFA to undertake an ESA which consisted of a Stage 1 Preliminary Site Investigation (PSI) and Stage 2 Detailed Site Investigation (DSI) for the East Darling Harbour property (Barangaroo). The following provides information related to the Site.

The PSI component of the investigation reported that the Site was historically used for port/wharf activities and workshops. The AGL gasworks site was also located to the north of the Site (off-site) and reclamation activities had historically occurred at the Site for the construction of the wharfs.

Based on the historical information ERM concurred with URS (2001) investigation that the contaminants of potential concern (COPC) for the Site were TPH, BTEX, Heavy Metals, PAHs, PCBs, Cyanide, Sulfates, OCPs and OPPS.

The ESA made the following conclusions:

- Impacts to soil and groundwater were identified predominantly within the area of the former gasworks infrastructure and the reclaimed northwest portion of the Site, with the primary contaminants of concern confirmed as lead, TPH/BTEX and PAH;
- No Non aqueous phase liquids (NAPLs) were observed during the investigation, however concentrations of organic contaminants such as TPH indicated that NAPL was likely present in the vicinity of the former gasworks area located immediately north of the Site;
- The groundwater regime within the site was likely strongly influenced by tidal fluctuation; and
- There appeared to be potential for both migration of contamination onto the site from the east and migration of contamination from the site into adjacent properties and into Darling Harbour.
- The ESA included the following key recommendations:
- The extent of the risks to human health and the environment should be assessed through further investigations and a site specific quantitative risk assessment; and
- Additional delineation investigations and assessment of vapour flux from impacted areas and further assessment of hydrogeological conditions should be undertaken before developing a RAP.

### 2.6.2 Coffey (2008)

Coffey Environments Pty Ltd (Coffey) was commissioned by the Council of the City of Sydney to undertake a Preliminary Environmental Investigation (PEI) at the segment of Hickson Road (between numbers 30 to 38), Millers Point, NSW, which is located immediately northeast of the Site.

Soil samples were analysed for Heavy Metals, TPH, BTEX, PAH, phenols, chlorinated hydrocarbons and asbestos. Groundwater samples were analysed for Heavy Metals, TPH, BTEX, PAH, phenols, chlorinated hydrocarbons and ammonia.

The general ground conditions encountered during the intrusive investigation comprised asphalt overlaying concrete and fill ranging in depth between 3.1 and 9.4 m bgl. The fill generally consisted of gravelly sand and sandy gravels with minimal anthropogenic inclusions. The fill was generally underlain by sandstone, with the exception of residual clayey sand and sand soils at two locations (BH3 and BH2).

Tar was encountered in two boreholes which were located in the southern portion of the investigation area.

Concentrations of heavy metals, phenols and chlorinated hydrocarbons were either less than the laboratory limit of reporting (LOR) or the adopted assessment criteria in all samples analysed. Asbestos fibres were not detected in any sample analysed.

### 2.6.3 ERM 2008a

ERM was commissioned by SHFA to undertake additional soil and groundwater investigation works at Barangaroo. The objectives of the works were to fill in data gaps in soil and groundwater data to enable a RAP to be developed for the Site.

A summary of the results from within the Site are provided in Table 3 below, which also includes the ERM (2007) ESA results.

**Table 3: Summary of soil analytical results from ERM 2007 and 2008 investigations and ERM (2007) groundwater results**

| Analyte | No. Soil Results | Soil Results | Groundwater Results |
|---|---|---|---|
| Heavy Metals | 73 | Concentrations of metals in samples were all less than NSW (DEC) $SIL_4$ Criteria with the following concentration ranges:<br>Lead (<5 -1320 mg/kg)<br>Arsenic (<5 – 16 mg/kg)<br>Cadmium (<1– 2 mg/kg)<br>Total Chromium (<2 – 81 mg/kg)<br>Copper (<5 – 228 mg/kg)<br>Mercury (<0.1 – 5.9 mg/kg)<br>Nickel (<2 – 22 mg/kg)<br>Zinc (<5 - 1890 mg/kg) | Arsenic – all results <LOR<br>Cadmium – all results less than LOR with exception of MW09 (1.3 ug/L)<br>Chromium - all results less than LOR with exception of MW20 (2 ug/L)<br>Copper – all results less than LOR with exception of MW17 (2 ug/L)<br>Mercury – all results less than LOR<br>Nickel – results ranged between <10 to 24 ug/L<br>Zinc – Concentrations ranged between 0.015 (MW10) and 0.128 (MW09) |
| TPH $C_6$-$C_9$ | 53 | All concentrations were <LOR with exception of 3 results<br>BH117_10-10.5 (10mg/kg)<br>BH117_15-15.5 (244 mg/kg)<br>BH110_23.3-23.8 (46 mg/kg) | All concentrations < LOR with exception of:<br>MW21 – 60 ug/L |
| TPH $C_{10}$-$C_{36}$ | 53 | All concentrations were <LOR with exception of 13 results which ranged between 150 mg/kg to 5580 mg/kg.<br>Results greater than EPA (1994) Criteria were from BH100_3-3.45 (1005 mg/kg), BH117_15-15.5 (5580 mg/kg) and BH195_10.5 (2215 mg/kg). | All concentrations < LOR with exception of:<br>MW09 – 985 ug/L<br>MW20 – 2870 ug/L<br>MW21 – 385 ug/L |
| BTEX | 53 | Benzene: All <LOR with exception of 2 results BH110_23.3-23.8 (7.8 mg/kg) and BH117_15-15.5 (19.4 mg/kg) which exceed the NSW EPA (1994) Criteria.<br>Ethylbenzene, Toluene and Total Xylene were detected in 3 samples at concentrations less than the NSW (EPA) 1994 Criteria. | All concentrations < LOR with exception of:<br>MW21 – Benzene (3 ug/L), Toluene (8 ug/L), Ethylbenzene (2 ug/L) and Total Xylene (21 ug/L) |
| PAHs | 38 | Concentrations of Total PAHs ranged between 4.35 mg/kg and 826.3 mg/kg. One sample exceeded the NSW (DEC) $SIL_4$ Criteria (BH117_15-15.5 – 826.3 mg/kg).<br>Benzo(a)pyrene ranged between <0.5 and11.4 mg/kg.<br>Three samples exceeded the NSW (DEC) $SIL_4$ Criteria (BH100 3.0_3.45, BH117_15-15.5 and BH195_10.5). | All concentrations < LOR with exception of:<br>MW21- Total PAH (25.1 ug/L) and B(a)P (0.7 ug/L)<br>MW18 - Total PAH (8.65 ug/L) and Naphthalene (0.7 ug/L) |

| Analyte | No. Soil Results | Soil Results | Groundwater Results |
|---|---|---|---|
| Phenols | 18 | Concentrations of Phenols were < LOR in all samples. | - |
| PCBs | 8 | Concentrations of PCBs were < LOR in all samples. | All results less than LOR |
| OCPs/ OPPs | 1 | Concentrations were all < LOR. | All results less than LOR in MW20 |

The ERM Additional Investigation made the following recommendations:

- A quantitative human health and ecological risk assessment (HHERA) should be undertaken once further details of future redevelopment are known;
- Results of the investigation should be assessed with reference to previous investigations undertaken for Barangaroo;
- Routine groundwater monitoring should be considered to assess temporal variations in CoPC;
- Considering asbestos was identified in only one sample, it was unlikely that asbestos contamination was wide spread, however it was recommended that further work is required to determine the extent and nature of asbestos in fill; and
- A RAP should be developed and following completion of a RAP, a Remedial Work Plan (RWP) should be developed.

### 2.6.4 ERM 2008b

PAH and metal concentrations reported in sediments directly adjacent to Barangaroo (i.e. sediments that may impacted by Barangaroo-derived contaminants) and in sediments within regional sampling locations within Sydney Harbour are summarised in the Table 4 below, along with ANZECC (2000) ISQG trigger values for sediment.

Maximum reported concentrations of arsenic, chromium, copper, lead, mercury and zinc exceeded ISQG (Low) trigger values and maximum reported concentrations of copper, lead and zinc exceeded ISQG (High) trigger values. However, minimum, mean and maximum concentrations of metals/metalloids were consistent with respective concentrations reported by McReady et al (2006) for the Sydney Harbour regional area. Overall, reported concentrations of metals in sediments adjacent Barangaroo were comparable to those reported regionally and are not considered to indicate grossly elevated impacts due to Barangaroo-derived contamination.

With respect to PAHs, reported concentrations adjacent the Barganaroo are slightly higher than those reported in other locations.  Maximum and mean concentrations are generally within the same order of magnitude as regional concentrations. Overall, the data indicate that PAH concentrations are marginally elevated adjacent to Barangaroo, but significant gross accumulation of PAHs in sediments has not been reported.

It is noted that some of the PAH hot spots adjacent to Barangaroo may have been deposited during original refilling/reclaiming of the Barangaroo site and do not necessarily represent impacts to sediments due to ongoing discharge of PAH impacted groundwater from Barangaroo.

**Table 4: PAHs and Metals in Sediments adjacent to Barangaroo and in Regional Samples (Sydney Harbour)**

| Chem | ERM (2008) Sediment Data (Adjacent Site) | | | | Sydney Harbour Regional Data (McReady et al 2006) | | | | | ISQG Low – ISQG High |
|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Max | Mean | Std Dev | Min | Max | Mean | Std Dev | | |
| **PAHs** | | | | | | | | | | |
| ACE | 0.005 | 9.36 | 0.29 | 1 | 0.006 | 0.33 | 0.092 | 0.88 | (a) | 0.016 – 0.5 |
| ACY | 0.015 | 37.3 | 1.5 | 4.2 | 0.012 | 5.78 | 0.6 | 0.74 | (a) | 0.044 – 0.64 |
| ANT | 0.011 | 56.5 | 2 | 6.4 | 0.012 | 3.18 | 0.66 | 0.70 | (a) | 0.085 – 1.1 |
| BAA | 0.031 | 80 | 3.6 | 9.1 | 0.019 | 8.78 | 1.8 | 2.2 | (a) | 0.261 – 1.6 |
| BAP | 0.01 | 59.2 | 3.2 | 6.8 | 0.011 | 11.2 | 2.4 | 2.7 | (a) | 0.43 – 1.6 |
| BBF | 0.051 | 63.8 | 3.5 | 7.3 | 0.119 | 12.8 | 3 | 3.4 | (b) | -- |
| BEP | 0.028 | 29.7 | 1.6 | 3.4 | 0.023 | 5.01 | 1.1 | 1.2 | (a) | -- |
| BGP | 0.054 | 26.3 | 1.6 | 3.1 | 0.032 | 7.86 | 1.5 | 1.8 | (a) | -- |
| BKF | 0.027 | 22.4 | 1.5 | 2.6 | 0.026 | 16.5 | 1.5 | 2.2 | (a) | -- |
| CHR | 0.028 | 53.6 | 2.7 | 6.1 | 0.012 | 9.37 | 1.9 | 2.1 | (a) | 0.384 – 2.8 |
| DAH | 0.019 | 8.52 | 0.64 | 1.1 | 0.021 | 1.76 | 0.29 | 0.34 | (a) | 0.063 – 0.26 |
| FLT | 0.054 | 185 | 8 | 21 | 0.121 | 16.2 | 4.1 | 4.7 | (a) | 0.6 – 5.1 |
| FLU | 0.005 | 22.4 | 0.78 | 2.6 | 0.011 | 0.731 | 0.15 | 0.15 | (b) | 0.019 – 0.54 |
| ICDP | 0.048 | 23.6 | 1.5 | 2.8 | 0.03 | 6.34 | 1.3 | 1.6 | (a) | -- |
| NAP | 0.013 | 3.35 | 0.37 | 0.47 | 0.016 | 1.10 | 0.22 | 0.21 | (a) | 0.16 – 2.1 |
| 2-MNP | 0.005 | 1.69 | 0.12 | 0.2 | 0.011 | 7.55 | 0.16 | 0.85 | (a) | -- |
| PER | 0.012 | 17.8 | 0.84 | 2 | 0.012 | 6.57 | 1.4 | 1.7 | (a) | -- |
| PHE | 0.02 | 146 | 5 | 17 | 0.013 | 7.47 | 1.4 | 1.8 | (a) | 0.24 – 1.5 |
| PYR | 0.055 | 139 | 6.4 | 16 | 0.161 | 233 | 4.9 | 5.9 | (b) | 0.665 – 2.6 |
| Sum PAH | 0.528 | 992 | 46 | 113 | 0.668 | 361 | 28.5 | 35.2 | (c) | 4 – 45 |
| | | | | | | | | | | |
| **Metals and Metalloids** | | | | | | | | | | |
| As | 9 | 46 | 16 | 5.6 | 5 | 48 | 21 | 9 | (a) | 20 – 70 |
| Cd | 1 | 1 | 0.51 | 0.054 | 0.2 | 10 | 2.8 | 2.4 | (a) | 1.5 – 10 |
| Cr (III+VI) | 8 | 134 | 34 | 13 | 6 | 298 | 81 | 63 | (a) | 80 – 370 |
| Cu | 7 | 626 | 83 | 72 | 20 | 701 | 200 | 150 | (b) | 65 – 270 |
| Pb | 17 | 236 | 123 | 39 | 78 | 1050 | 380 | 260 | (b) | 50 – 220 |
| Hg | 0.08 | 2.05 | 1.1 | 0.38 | 0.1 | 5.9 | 1.4 | 1.2 | (a) | 0.15 – 1 |
| Ni | 4 | 14 | 7.2 | 2.2 | 2 | 75 | 20 | 12 | (a) | 21 – 52 |
| Zn | 26 | 603 | 259 | 92 | 75 | 8,820 | 880 | 1,100 | (b) | 200 – 410 |

Notes:

ACE: acenaphthene; ACY: acenaphthylene; ANT: anthracene; BAA: benzo(a)anthracene; BAP: benzo(a)pyrene; BBF: benzo(b)fluoranthene; BEP: benzo(e)pyrene; BGP: benzo(g,h,i)perylene; BKF: benzo(k)fluoranthene; CHR: chrysene; DAH; dibenzo(a,h)anthracene; FLT: fluoranthene; FLU: fluorene; ICDP: indeno(1,2,3-cd)pyrene; NAP: naphthalene; 2-MNP: 2-methylnaphthalene; PER: perylene; PHE: phenanthrene; PYR: pyrene; Sum PAH: Sum of PAHs.
(a) Statistical results include values in Sydney Harbour, Cooks River and NSW south coast estuaries and lakes (n=103).
(b) Statistical results based on Sydney Harbour samples only (n=69).
(c) Statistics for Sum of PAHs not reported by McReady et al (2006). Values are sums of each statistical measure for individual PAHs.
"—" No ISQG Low or High value available.

### 2.6.5 AECOM (2010a)

AECOM was engaged by LL to undertake a DGI for the proposed Blocks 1, 2 and 3 (including associated Public Domain areas) within Stage 1 of the Barangaroo redevelopment precinct, that is immediately south of the current Site (also referred to as the ORWS Area).

The purpose of the DGI was to reduce uncertainties which existed in the available data set, confirm the characteristics of soil and groundwater underlying the site, provide the additional data required for a quantitative HHERA to be developed and facilitate the development of an RAP and RWP which describe the remediation strategy to be implemented by LL as part of its proposed Stage 1 Development of the Barangaroo Precinct.

The results of the DGI intrusive investigation are briefly summarised:

- Fill was encountered at the site overlying natural sands, gravelly sands, clays, weathered and sandstone bedrock. The fill was generally shallower (up to 3 meters below ground surface (mbgs) in the eastern portion of the site (near Hickson Road) and trending deeper (up to 19.2 mbgs) towards Darling Harbour.
- Soil impacts appeared to be associated with the historical presence of the former gasworks north of the site (located within the Site) and the presence of fill materials used for land reclamation activities.
- Soil vapour results indicated some gasworks-derived impacts in locations closest to the former gasworks area and low concentrations of CoPC (below soil vapour and ambient air guidelines) in some locations.
- Groundwater was present beneath the site within fill materials at approximately two metres below the ground surface and was subject to tidal fluctuation. Tidal influence extended as far east (inland) as Hickson Road.
- Groundwater impacts associated with the former gasworks infrastructure were limited to the north-eastern corner of the Blocks 1, 2 and 3 site. Groundwater contamination associated with the remaining gasworks infrastructure located to the north of the Blocks 1, 2 and 3 site did not appear to be migrating into the harbour in the area of the site.

The DGI assessment of risk presented the following findings based on considerations of future land use and environment:

- ***Residential/Commercial Land Use at the development area***: Whilst the current asphaltic concrete and concrete ground surface was considered adequate to limit exposure by site users to underlying contamination, future earthworks/remediation/development at the Site may complete the exposure pathway.
- ***Passive Recreation Land Use at the Public Domain:*** The area designated as Public Domain is currently covered with concrete and/or asphalt concrete with no complete exposure pathway to underlying soil or groundwater. Given the limited extent of contamination identified within the Public Domain, AECOM considered this area of the site presents a low risk to human health in its current condition.
- ***Environment:*** The DGI identified potential risks to the down gradient environmental receptor (Darling Harbour). Based on the proposed development plan (i.e. excavation of basements), up gradient contaminant sources will be removed and therefore reduce the potential risk in the future.

The following recommendations were made:

- A RAP should be prepared to address hotspot remediation and potentially impacted materials that may be encountered during the excavation of the site for future development.
- Additional assessment of the materials should be undertaken in accordance with the RAP in the event that materials be encountered during the excavation and remediation works that are different to those found during the DGI and/or previous investigations.
- An Acid Sulfate Soil Management Plan may be required for the management of Potential Acid Sulfate Soils (PASS) during future excavation works in natural materials.

#### 2.6.6 AECOM (2010b)

AECOM was engaged by LL to undertake a DGI for NSW DECCW (now OEH) Declaration Area 21122 (also known as the former Millers Point gasworks), at Hickson Road, Millers Point. This area is also variously designated as the: VMP and PDA Remediation Works Area; EPA Declaration Area; and the Declaration Site (Development Works) Remediation Works Area.

The purpose of the DGI was to reduce uncertainties which exist in the current data set, confirm the characteristics of soil and groundwater underlying the site, provide the additional data required if a quantitative HHERA is developed and facilitate the development of an RAP and RWP which describe the remediation strategy to be implemented by LL in order to address the significant contamination on the VMP and PDA Remediation Works Area (the Site) and as part of its proposed Stage 1 Development of the Barangaroo Precinct.

OEH had previously determined this area to be contaminated in such a way as to present a significant risk of harm to human health and the environment. The reported results of this DGI and previous investigations were found to support this determination.

The DGI confirmed that elevated concentrations of contaminants in soil and groundwater associated with the former gasworks site, notably BTEX, naphthalene and PAHs, were present in locations which included areas near the boundaries of the Declaration Area.

The results of the DGI are discussed in further detail in **Section 3.2** of this report.

In summary, the DGI identified elevated concentrations of CoPC in soil and groundwater exceeding the adopted Site investigation criteria. The reported results were considered to be primarily associated with the area's former land use as a gas manufacturing plant and with the importation of fill materials to level the Site.

- The DGI recommended completion of the following:
    - Site-specific HHERA addressing remediation of the Site in order to address the significant contamination.
    - Site-specific HHERA addressing remediation for the proposed future land use.
    - RAP detailing options for remediation and/or management and recommended preferred strategy to facilitate removal of the OEH Declaration.
    - RAP detailing options for remediation and/or management and recommended preferred strategy to render the area suitable for their intended land use.

#### 2.6.7 AECOM (2010c)

AECOM was engaged by LL to undertake a DGI of the Barangaroo Other Remediation Works (North) Area (ORWN Area). The ORWN Area covers that portion of the Barangaroo Block 4 which is outside the Declaration Area (including associated Public Domain areas).

The purpose of the DGI was to reduce uncertainties which exist in the current data set, confirm the characteristics of soil and groundwater underlying the site, provide the additional data required if a quantitative HHERA is developed and facilitate the development of an RAP and RWP which describe the remediation strategy to be implemented by LL as part of its proposed Stage 1 Development of the Barangaroo Precinct.

The results of the investigations conducted by AECOM and others across the ORWN Area indicated the following:

- Encountered fill depths ranged from 10.0 to 23.5 mbgs. Fill materials were generally shallower in the eastern portion of the ORWN site closest to Hickson Road and deeper in the western portion of the ORWN site closest to Darling Harbour.

- Natural soils encountered across the ORWN site comprised silty sands, gravelly sands, clays, weathered sandstone and sand with components of clay. Sandstone bedrock was encountered across the ORWN site with encountered depths ranging from 10.0 mbgs to 25.0 mbgs. Bedrock was generally shallower in the eastern portion of the ORWN site closest to Hickson Road and deeper in the western portion of the ORWN site closest to Darling Harbour.
- The reported contaminants of potential concern (CoPC) were generally consistent with those identified during previous reports encompassing the Site and surrounding gasworks, variably exceeding the adopted ORWN site investigation Criteria across the ORWN site.
- The maximum concentrations of CoPC were generally located in proximity to and down gradient from the former gasworks infrastructure in Blocks 4 and 5 outside the Declaration Area.
- A reported concentration of naphthalene above the soil vapour criterion was detected in the single soil vapour well located down-gradient of the former gasworks within the ORWN site, indicating the potential presence of gasworks-derived impacts. Concentrations of toluene (below soil vapour guidelines) were also detected.
- Groundwater was encountered at depths ranging from (1.823 to 2.975 m bgs) and was subject to tidal fluctuation.

The most significant groundwater contamination was reported in wells screened deeper within the aquifer, across the base of the fill and natural sediments immediately overlying bedrock. The identified contaminants were considered to be associated with the footprint of the former gasworks. Monitoring wells screened entirely within the top 10 m of the aquifer generally reported TPH, PAH and BTEX concentrations less than the laboratory Limit of Reporting (LOR). In order to make the ORWN site suitable for the proposed land use, the DGI also recommended:

- A site-specific HHERA addressing remediation of the ORWN site for the proposed future land use.
- A RAP detailing options for remediation and/or management and a recommended preferred strategy that would:
  - render the various areas of the ORWN site suitable for their intended land use;
  - detail validation requirements to be implemented to demonstrate successful completion of the remedial works; and
  - detail the requirement (if any) for potential future monitoring or management.
- A RWP providing a technical specification that is suitable for issue by LL to its contractors and that provides specific details of the work that must be completed to facilitate delivery of the remediation works prescribed by the RAP for the site.
- An Acid Sulfate Soil Management Plan for the management of PASS during future excavation works.

#### 2.6.8 AECOM (2010d)

As part of the DGIs undertaken for the remediation of the PDA Area and ORWN Areas and in support of this HHERA, AECOM undertook a Groundwater Discharge Study (GDS).

The objectives of the GDS were to:

- provide more detailed data on the vertical distribution of contaminants and other parameters in the terrestrial groundwater environment;
- assess the degree of exchange (recharge and discharge) between Darling Harbour and the aquifer system due to tidal movements;
- assess the impact of this tidal exchange on the fate and transport of dissolved phase groundwater contaminants;
- attempt to quantify the amount of groundwater discharge and contaminant mass flux, from the site to Darling Harbour;
- attempt to quantify the degree of contaminant attenuation by seawater mixing prior to discharge; and

- provide an updated conceptual model for this portion of the site, to inform the ecological risk assessment process.

The conclusions of the GDS were as follows:

- Drilling at IT1 and IT2 confirmed that a thick sequence of fill material (up to 15 m) was present adjacent to the harbour in the west of the site. This was underlain by natural clayey marine sediments of variable thickness.
- A very efficient hydraulic connection exists between the harbour and the fill aquifer immediately adjacent, with head in this portion of the aquifer responding rapidly to changes in the tide; the caisson structure in this area is therefore highly permeable.
- Significant changes in water level in the unconfined fill aquifer (>1.0 m in some cases) suggested significant quantities of water are exchanged across the aquifer – harbour interface. The volume of water discharged to the harbour during a typical ebb tide was estimated at 25 ML (50 ML/day).
- By comparison to the fill aquifer, exchange occurring via the underlying marine sediments was almost negligible, with a discharge component estimated at 1.6 $m^3$/day, due to the low hydraulic conductivity and gradient. Groundwater discharge occurring via the basal Hawkesbury Sandstone is not considered significant in the context of site-derived contaminant flux to Darling Harbour.
- The proportion of groundwater to seawater (mixing model) discharging during the low tide cycle to Darling Harbour has been derived from a connate water displacement model. The estimated proportion of groundwater (which in this instance is connate water) is similar to studies elsewhere, suggesting that much of the water discharged during ebb tides comprises seawater which infiltrated during the previous flood tide. The mixing analysis indicates that the groundwater component of any discharge is likely to be 10-20% of the total, broadly consistent with similar studies conducted elsewhere.
- Contaminant mass flux is difficult to estimate on a site wide basis due to the heterogeneity of the fill, but mass flux is likely to be strongly limited by dilution occurring up-gradient of the tidal exchange prism. Where leachable source material is present within the tidal exchange prism, any resultant groundwater contamination is expected to discharge largely without further dilution.
- Based on a conservatively-derived five-fold dilution of dissolved phase contamination migrating from an up-gradient source zone into Darling Harbour, SSESC for groundwater and leachable concentration data at the Site could be reasonably approximated as the ANZECC (2000) trigger values multiplied by a factor of five.
- Based on the discharge study, contamination which has migrated into, or is otherwise present within the tidal exchange prism (estimated to be a zone at least six metres wide, on average, along the landside of the western caisson), is not expect to undergo further dilution prior to discharging to the harbour.

### 2.6.9 AECOM (2011)

AECOM was engaged by LL to undertake a Supplementary VMP DGI for areas adjacent to the western and southern boundaries of the OEH Declaration Area (the Site).

The Supplementary DGI was undertaken to provide improved delineation of the vertical and lateral extent of identified contaminated materials around (both within and outside) the Site and to assess whether these impacts will require remediation to facilitate removal of the OEH Declaration. The objectives of the investigation were to:

- Refine the extent of remediation works required within the Site;
- Refine the extent of remediation works required outside the Site;
- Further assess groundwater quality immediately down gradient of the Site; and
- Assess the opportunity for beneficial reuse of materials that might be removed from the Site.

As the time of publishing this HHERA, the fieldwork program was ongoing and the conclusions from the investigation no yet documented in a report. While some results from the initial stages of this investigation have been referenced in this HHERA, the complete results will be fully documented as part of the final report.

## 2.7 Geology

### 2.7.1 Regional Geology

Reference to the *1:100,000 Geological Survey of NSW (Sydney) Sheet 9130 (Ed 1) (*Herbert 1983*)* indicated that the stratigraphy of the Site comprised man-made fill material, marine clays and Hawkesbury Sandstone.

Information from previous investigations indicated that the former 1880s shoreline ran approximately along the western edge of Hickson Road (i.e. along the eastern edge of the proposed Stage 1 Development). The area to the west of Hickson Road is understood to have been progressively reclaimed. Aerial photographs from the 1950s indicate that the area between Hickson Road and the current shoreline was occupied by a number of finger wharves, extending from Hickson Road. It is understood that the space between the historical finger wharfs and seawalls was infilled in several stages between the 1960 and 1980 with various types of material. The former Southern Cove is understood to have been filled in 1988.

### 2.7.2 Local Geology

ERM (2008a) identified and summarised the following subsurface conditions across the wider Barangaroo precinct:

- hardstand (0 to 0.46 mbgs): consisting of concrete, asphalt concrete, generally in good condition with minimal staining;
- road base fill (0 to 0.5 mbgs);
- fill (0 to 18 mbgs): fill materials consisting of sandstone, building rubble, bricks and concrete, silty gravelly sand. Black staining and odours (particularly around the former gasworks);
- marine clay/sand (3.0 to18.4 mbgs): interbedded clayey sand and sandy clay, dark greyish brown, saturated, some shell fragments and organic matter, sandy clay (soft, high plasticity), clayey sand and sand (lose to dense, low plasticity, fine to coarse sand, low to non plasticity);
- marine clay/sand (4.9 to 32.75 mbgs): interbedded clayey sand, sandy clay and sand, pale yellowish brown, white, reddish brown or dark greyish brown. Sandy clay-stiff to hard, medium to high plasticity. Clayey sand and sand – loose to dense, fine to coarse sand, low or no plasticity;
- bedrock (1.3 to 32.75 mbgs): weathered sandstone, white, light yellowish, brown, olive brown and reddish brown, white, wet, fine to coarse grained, some fracturing noted;

Recent intrusive investigations within Barangaroo Block 3 (located adjacent and south of the Site AECOM (2010a) encountered the following lithological profile:

- surficial hardstand consisting of asphalt concrete;
- fill extending to 3 mbgs on the eastern portion and 17.3 mbgs on the western portion of Block 3. Fill consisted of mixed materials including road-base gravel, sandstone, building rubble, bricks and concrete, silt, clay, sand and gravels. Black staining and odours were noted in a number of borehole locations across Block 3, notably in the proximity of the original gasworks, and to a lesser extent at Blocks 1 and 2;
- interbeds of natural clays and sands extending to 14.2 mbgs across the centre of Block 3 and up to 24.0 mbgs on the western portion of Block 3; and
- sandstone bedrock from 3.0 mbgs on the eastern portion and from 20.4 mbgs on the western portion of Block 3. Shale bedrock was also encountered on the western portion of the block, from 12.5 mbgs.

AECOM (2010b) reported variable stratigraphic conditions across the Site; however, stratigraphy generally comprised fill material overlying natural weathered sandstone with clay components. Sandstone bedrock was generally present underlying natural weathered bedrock materials or in some instances directly underneath fill materials. In summary:

- Fill material - the depth of fill materials encountered during the conduct of the VMP and PDA DGI was variable and ranged from 0.43 mbgs (AECOM BH67) to 19.0 mbgs (AECOM BH60/MW60). Fill materials were generally shallower in the eastern portion of the Site closest to Hickson Road, thickening toward the western portion of the area.
- Natural material - natural soils underlying the Site (AECOM 2010b) comprised silty sands, gravelly sands, clays, weathered sandstone and sand with components of clay.

- Bedrock underlying the Site consisted of sandstone with some shale. The depth to bedrock was variable across the Site and ranged from 3.0 mbgs (BH11) to 19.2 mbgs (BH28). Bedrock was generally shallower in the eastern portion of the Site closest to Hickson Road and deeper in the western portion of the Site.

In summary, the geological conditions encountered during previous intrusive investigations within the Site are generally consistent with those encountered within the ORWS Area and across the broader Barangaroo precinct.

## 2.8 Hydrogeology

The following groundwater conditions have been described at Barangaroo in previous investigations (ERM 2007):

- measured groundwater elevations in July 2006 during a high tide ranged between 0.083 m AHD (MW21) and 0.64 m AHD (MW10);
- measured groundwater levels ranged between 2.094 m below Top of Casing (bTOC) (MW09) and 2.545 m bTOC (MW20) in July 2006 during a high tide;
- the water table across the Site has been shown to be influenced by tidal fluctuations;
- groundwater flow direction has been shown to flow to the west towards Darling Harbour and to the east, towards Hickson Road in the south eastern portion of the Site; and
- potential subsurface service trenches may present preferential pathways for transport of contaminants in groundwater.

Results of the recent AECOM DGI (AECOM 2010b) indicated groundwater was present beneath the Site within the fill and underlying natural materials. Groundwater was encountered at depths ranging from 1.38 to 2.92 mbgs and was subject to tidal fluctuation. Water level monitoring within selected wells over a three day period confirmed that groundwater underlying the area was tidally influenced as far east (inland) as Hickson Road, although the degree of fluctuation is lessens toward the east.

The hydrogeological conditions encountered during previous investigations within the Site are generally consistent with those encountered within the ORWS Area and across the broader Barangaroo precinct.

A search of the NSW Department of Natural Resources (DNR) groundwater bore data base was reported in ERM (2007) and indicated that there were 32 registered groundwater bores within a 4 km radius of Barangaroo. Groundwater bore information indicated that the bores were registered for either recreation, irrigation or monitoring purposes and none of the identified bores are considered to contain groundwater that had discharged from the Barangaroo site.

## 2.9 Soil Vapour

AECOM (2010a, 2010b and 2010c) conducted sampling of soil vapour from beneath the declaration area (six locations) and from outside the declaration area (five locations) at depths ranging from 0.6 mbgs to 1.7 mbgs. The soil vapour wells were installed using permanent soil gas implants with construction details of each soil vapour well being contained within the various reports.

The soil vapour sampling was conducted on one occasion using summa canisters sampled over an eight hour period by a modified USEPA TO-14 method utilising the USEPA TO-15 analyte list. The results collected indicated exceedences of the adopted ambient air guidelines (converted ATSDR 2005 MRL) for naphthalene at locations SV05 and SV11 located within the declaration area and SV08 located in the public domain and SV01 and SV02 located within the other remediation works south area.

Prior to sampling, the oxygen measurements within the subsurface ranged from 4.2% to 17.6%, indicating that the there is oxygen present within the upper layers of the soil at the site. All of the eleven locations were located beneath the existing slab across the site.

High oxygen measurements were recorded at the end of one sampling day in two of the nested soil vapour wells located at the site. These high oxygen measurements correlated with expected ambient air levels >20% and have been removed from the data set. It has been determined that the landfill gas meter must have deviated from its original calibration. It is considered that the data set (excluding the anomalies) is suitable and representative for interpretative use.

# 3.0 Data Evaluation

## 3.1 Data Used in the Risk Assessment

In preparing this HHERA, AECOM has included data from the following reports:

- ERM 2007. Environmental Site Assessment, East Darling Harbour, Sydney, NSW. June 2007.
- Coffey Environments. 2008b. Preliminary Environmental Investigation, 30-38 Hickson Road, Millers Point, NSW 2000. May 2008.
- ERM. 2008a. Additional Investigation Works at Barangaroo, Hickson Road, Millers Point, NSW. July 2008.
- AECOM 2010b. Data Gap Investigation, EPA Declaration Area (Parts of Barangaroo Site and Hickson Road), Millers Point, NSW. September 2010.
- AECOM 2010c. Data Gap Investigation Other Remediation Works North, Hickson Road, Millers Point, NSW. October 2010.
- AECOM 2010d, Groundwater Discharge Study, Study 1 Barangaroo Development, 3 November 2010.

The quality and quantity of the analytical data collected as part of the above investigation is discussed in the following sections.

## 3.2 Data Quality

Available analytical data from the above reports were evaluated by AECOM for compliance with method requirements and project specifications. The data evaluation process included checking of 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. Data useability for the risk assessment process was assessed against criteria as recommended in the NSW Auditor Guidelines (2006), AS4482.1 (Guideline to sampling and investigation of potentially contaminated soil, Part 1: Semi-volatile substances) and the United States Environment Protection Agency (USEPA, 1990) *Guidance for Data Useability in Risk Assessment.*

The data evaluation (refer to Table 5 found no significant potential impacts to the overall precision and accuracy of the primary data set. Data evaluated were considered to be valid and representative of concentrations of the analysed compounds at the sample locations tested. AECOM considers that the data set generated by the previous reports and the DGIs undertaken within the Site (AECOM 2010b, 2010c) had derived sufficient data to comply with the reporting quality protocols, address identified existing data gaps and confirm the general characteristics of soil, fill, soil vapour and groundwater underlying the Site in order to allow for development of a Site specific HHERA.

In summary, reported data was therefore considered to be of an appropriate quality for use in the HHERA.

**Table 5: Data Confirmation**

| Considerations | Coffey (2008b) | ERM (2007) | ERM (2008) | AECOM (2010b) | AECOM (2010c) |
|---|---|---|---|---|---|
| Data Quality Objectives | Quality Assurance/Quality Control (QA/QC) program generated as outcome of the seven-step Data Quality Objectives (DQO) process, with reference to NSW DEC (2006). | QA/QC program generated as outcome of the seven-step DQO process, with reference to NSW DEC (2006). | QA/QC program generated as outcome of the seven-step DQO process, with reference to relevant guidelines published by the NSW DECC, ANZECC and National Environment Protection Council (NEPC). | The QA/QC program implemented as part of the AECOM DGIs (AECOM 2010b, 2010c) were generated as the outcome of the seven-step DQO process, as described in the Sampling Analysis and Quality Plan (SAQP) (AECOM, 2010e) and as in accordance with NSW DEC (2006). | |
| Representativeness | The Coffey sampling locations were targeted to assess specific potential areas of concern such as historical gas holder and tar tanks the presence of site wide fill and to provide general coverage of accessible areas on site. | The scope included 100 geotechnical and environmental boreholes in a grid pattern, with 25 boreholes located in the vicinity of the former gasworks site. The remainder were located across other areas of concern. Locations of monitoring wells targeted the site boundary with the harbour and the gasworks. | Strategy for soil sampling involved grid based drilling and locations targeted to address data gaps. | The strategy for soil, groundwater and soil vapour sampling involved intrusive investigations at targeted locations to further address data gaps associated with previous environmental investigations. Analysis for the contaminants of concern was selectively conducted on soil samples as indicated in analytical tables. Assessment of soil leachabilities for metals and PAHs was selectively conducted to be suitably representative of the site, includes a suitable concentration range of CoPC including assessment at or near maximum soil CoPC concentrations for the site, and is considered adequate for graphical and statistical analysis. Results as a whole were considered more representative of subsurface Site conditions than previous reports. | |

| Considerations | Coffey (2008b) | ERM (2007) | ERM (2008) | AECOM (2010b) | AECOM (2010c) |
|---|---|---|---|---|---|
| Chain of Custody protocols | Signed chain of custody forms, laboratory analytical reports, calibration certificates, soil and well logs and well sampling sheets were present. | Signed chain of custody forms, laboratory analytical reports, calibration certificates, soil and well logs and well sampling sheets were present – refer to Appendix I of the report. | Signed chain of custody forms, laboratory analytical reports, selected calibration certificates, soil and well logs and well sampling sheets sighted. | Signed chain of custody forms, laboratory analytical reports, calibration certificates, soil and well logs and well sampling sheets were present. | |
| Analytical Laboratories | Analyses of primary and intra-laboratory duplicate soil and groundwater samples were undertaken by Australian Laboratory Services Environmental (ALS). Triplicate samples were analysed by SGS Laboratories. All laboratories were National Association of Testing Authorities (NATA) accredited for the analyses undertaken. | Analyses of primary and intra-laboratory duplicate soil and groundwater samples were undertaken by ALS. Triplicate samples were analysed by Labmark Laboratories. All laboratories were NATA accredited for the analyses undertaken. | Analyses of primary and intra-laboratory duplicate soil and groundwater samples were undertaken by ALS. Triplicate samples were analysed by Labmark Laboratories. All laboratories were NATA accredited for the analyses undertaken. | Analyses of primary and intra-laboratory duplicate soil and groundwater samples were undertaken by ALS. Triplicate samples were analysed by Labmark Laboratories. SGS undertook the analysis of soil vapour samples and Australian Soil Testing analysed samples collected for geotechnical purposes. All laboratories were NATA accredited for the analyses undertaken. | |
| Collection of quality control samples | Collection rate of Quality Assurance (QA) samples as listed under Data Quality Indicators was considered adequate. | Collection rates are detailed in Annex J of the ERM report. | Collection rate of QA samples was considered adequate. | Collection rate of QA samples as listed under Data Quality Indicators was considered adequate. | |

| Considerations | Coffey (2008b) | ERM (2007) | ERM (2008) | AECOM (2010b) | AECOM (2010c) |
|---|---|---|---|---|---|
| Chemical analytes considered | Metals (arsenic[As], copper [Cu], chromium [Cr], cadmium [Cd], mercury [Hg], lead [Pb], nickel [Ni], zinc [Zn]), TPH, BTEX, PAH, polychlorinated biphenyl (PCB), OCP, organophosphorus pesticides (OPP), phenols, asbestos, acid sulphate soils (ASS), cyanide (CN), ammonia/ammonium salts, S compounds, tin smelting analytes (tin [Sn], fluorine [F],chlorine [Cl], iodine [I], thorium [Th], beryllium [Be], molybdenum [Mo],Arsenic [As],phosphorus [P])<br>***Results***:<br>No tin smelting analytes detected above criteria.<br>No asbestos detected.<br>***Groundwater***<br>Metals, TPH, BTEX, PAH, phenols, chlorinated hydrocarbons and ammonia detected above groundwater criteria.<br>***Soil***<br>TPH, BTEX, phenols and chlorinated hydrocarbons detected above soil criteria. | Metals (As, Cu, Cr, Cd, Hg, Pb, Ni, Zn),CN, sulphates, TPH, BTEX, PAH, phenols. PCBs, OCP/OPP, asbestos<br><br>***Results:***<br>No OCC/OPP, phenols or PCBs detected.<br>***Groundwater***<br>Metals, TPH, BTEX, PAH, CN detected above groundwater criteria.<br>***Soil***<br>Metals, TPH, BTEX, sulphate detected above soil criteria | Metals (As, Cu, Cr, Cd, Hg, Pb, Ni, Zn),CN, sulphates, TPH, BTEX, PAH, phenols, PCBs, asbestos .<br>***Results***:<br>No PCBs detected.<br>***Groundwater***<br>Largely TPH, BTEX, CN,PAH, ammonia detected above groundwater criteria<br>***Soil***<br>Lead, TPH, PAH, BTEX, sulphate, detected above soil criteria. | Metals (As, Cu, Cr, Cd, Hg, Pb, Ni, Zn), sulphates, CN, ammonia, TPH, BTEX, PAH, phenols. PCBs, OCPs, asbestos, VOCs, SVOCs, ASS<br>***Results***:<br>No PCBs, OCPs detected.<br>***Groundwater***<br>Largely metals, BTEX, PAH detected above groundwater criteria.<br>***Soil***<br>Largely metals, BTEX, PAH, SVOC, VOC detected above soil criteria.<br>***Soil Vapour***<br>Naphthalene above soil vapour guidelines detected. | |

| Considerations | Coffey (2008b) | ERM (2007) | ERM (2008) | AECOM (2010b) | AECOM (2010c) |
|---|---|---|---|---|---|
| Data Validation | Data validation procedure employed is summarised in Section 10 and Appendix G of Coffey (2008) and was considered to be sufficient. | All rinsate blanks utilised reported trace metal content; however ERM (2007) did not consider the results as significant as they were below groundwater criteria concentrations. Overall data reported was judged to have met the DQOs adopted for the investigation. | Data validation procedure employed is summarised in Annex F of ERM (2008). Sample integrity and handling requirements were met. Few sample holding times, some Relative Percentage Difference (RPD) result and some laboratory QA/QC samples were either reported outside acceptable margin or did not meet criteria in some cases but were not considered to jeopardise data reliability. Overall data were considered to be of sufficient quality to comply with ERM quality protocols and the QAQC data was free of systematic and method biases. | The data validation procedure employed for the assessment of the AECOM (2010b, 2010c) field and laboratory QA/QC data indicated that the reported analytical results are representative of soil conditions at the sample locations and that the overall quality of the analytical data produced is acceptably reliable for the purpose of the DGI. | |

| Considerations | Coffey (2008b) | ERM (2007) | ERM (2008) | AECOM (2010b) | AECOM (2010c) |
|---|---|---|---|---|---|
| Further comment | The Practical Quantitation Limit (PQLs) for, benzo (a) pyrene and anthracene in groundwater were greater than the investigation levels for marine water. However, this is unlikely to affect the outcome of the assessment as the levels exceed the Groundwater Investigation Levels (GILs).<br>The PQLs for trichlorophenol (2-4-5 and 2-4-6), in groundwater was greater than the recreational water quality guidelines. | Refer to rinsate blank comment, above. | Sulphate concentrations from the inter-laboratory reported significantly lower than the primary lab results, which was earmarked as needing further investigation.<br>The ERM dataset was reported to have been reviewed by an independent expert on behalf of Sydney Harbour Foreshore Authority (SHFA), including data quality.<br>Preceding the DGIs, AECOM randomly assessed and verified a portion of the ERM data including data from ERM (2008) by cross-checking the ESDAT result database against survey data obtained from LL.<br>AECOM accepts the ERM dataset based on the random review and the review of SHFA's independent expert. | Some holding time, RPD result and some laboratory QA/QC samples were either reported outside acceptable margin or did not meet criteria in some cases, but in the majority of cases were not considered to jeopardise data reliability.<br>Laboratory LORs for some VOCs (1,3-butadiene, trichloroethylene (TCE), 1,2-dichloroethane, hexachlorobenzene (HCB) and 1,2-dibromomethane) were greater than the adopted air and soil screening criteria but these were not considered to be CoPCs at the Site and results would not significantly affect the dataset interpretation.<br>Total organic carbon (TOC) soil results for approximately 50% of samples were reported outside analytical holding times due to laboratory delay. Results were used for reference only and not for quantitative purposes.<br>A number of CN compound soil and water samples were reported outside analytical holding times, results were not expected to affect data quality as. CN was not detected in samples. | |

## 3.3 Data Quantity

The **ERM (2007)** Stage 2 Detailed Site Investigation (DSI) for Barangaroo comprised the following scope of work:

- advancement of environmental soil bores to maximum depth of 13 mbgs; and
- advancement of environmental soil bores for conversion to monitoring wells to a maximum depth of 33.65 mbgs.

The **ERM (2008a)** Additional Investigation was undertaken to fill in data gaps in the historical soil and groundwater data set to enable an RAP to be developed for Barangaroo. The scope of work for the additional investigation comprised:

- Advancement of 55 boreholes, of which 34 were cited as systematic (grid based) sampling locations and 21 were cited as judgemental (targeted) sampling locations within previously identified areas of concern and soil samples were analysed for a range of CoPCs.
- Rock coring in 13 targeted boreholes within the former gasworks area, to maximum depth of 22.5 mbgs, analysis for CoPC.
- Installation of 13 new monitoring wells, gauging, sampling and analysis for CoPC.
- Gauging and sampling of the 13 new monitoring wells and 23 existing monitoring wells for a range of CoPCs.

AECOM notes that only a proportion of these sampling locations were situated across the HHERA study site. Rock coring was undertaken where the potential for impact into bedrock was considered high, this being within the former gasworks area.

The **Coffey (2008b)** Preliminary Environmental Investigation was undertaken at the segment of Hickson Road (between numbers 30 to 38), Millers Point, NSW, located on the eastern portion of the Site. The scope of work from this investigation that relates to the Site included:

***Hickson Road***

- Advancement of 15 boreholes, ranging from 6 to 12 m in depth, sampling and analysis for CoPC.
- Conversion of 5 boreholes into new monitoring wells, gauging, sampling and analysis for CoPC.

The Coffey sampling locations were targeted to assess specific potential areas of concern such as historical gas holder and tar tanks and presence of site wide fill and to provide general coverage of accessible areas on site.

The DGI intrusive investigations undertaken by AECOM **(AECOM 2010b)** were designed to acquire targeted data to address potential data gaps at a number of locations across the Site:

***The Site (excluding Hickson Road)***

- advancement and sampling of a total of 25 boreholes across the Site;
- conversion of nine boreholes to groundwater monitoring wells;
- installation and sampling of seven soil vapour wells;
- sampling of a further five groundwater monitoring well locations located down gradient of the Site.
- monitoring of groundwater including completion of rising head tests and tidal fluctuation monitoring within selected groundwater monitoring wells; and
- installation and sampling of six soil vapour wells to maximum 2.2 m depth. Analyses of soil vapour for VOCs (TO14A list plus naphthalene).

The AECOM investigation points were selected on a judgemental (targeted) basis to attempt to fill data gaps and to target known or suspected areas of contamination  to try to capture worse case soil, groundwater and soil vapour concentrations.

The spatial coverage of soil and groundwater investigation locations (see **Figure F 3** and **Figure F 17**) is considered generally sufficient to characterise the nature and extent of contamination within the Site. The available bulk soil data includes samples from 86 locations.  While it is noted that the overall sampling pattern was not entirely grid-based, 86 borehole locations, if grid based would be expected to detect circular hot spots of diameter greater than 9 $m^2$ with 95% confidence (AS4482.1-2005). In addition, given that a high proportion of the soil samples were collected from locations targeted towards suspected source areas, the data are likely to be biased towards hot spots and areas where highest contaminant concentrations might be expected.

It is noted that, while a number of soil bores have extended into bedrock within the Site, the lateral and vertical extent of gasworks-derived contamination within the fractured bedrock underlying the Site is not known with certainty.

The available groundwater monitoring data include a network of 23 groundwater monitoring bores, of which nine were screened entirely in fill material, two entirely in natural soils (sands and clays overlying sandstone bedrock), five entirely in sandstone, four across the fill/natural interface and two across fill, natural and bedrock (sandstone) lithologies (see Table 6 below).

**Table 6: Summary of Groundwater Screening Depths and Lithologies**

| Bore ID | Approximate Screen Interval (mbgs) | Screened Lithology | Report |
|---|---|---|---|
| BH45/MW45 | 1 - 12.8 | FILL/NATURAL/SANDSTONE | AECOM (2010b) |
| BH52/MW52 | 1.5 - 4.9 | FILL | AECOM (2010b) |
| BH53/MW53 | 1.1 - 5.4 | FILL | AECOM (2010b) |
| BH54/MW54 | 1.9 - 2.8 | NATURAL | AECOM (2010b) |
| BH58/MW58 | 10.2 - 11.4 | FILL | AECOM (2010b) |
| BH61/MW61 | 0.75 - 3.4 | FILL/NATURAL | AECOM (2010b) |
| BH62/MW62 | 1.5 - 5.5 | FILL | AECOM (2010b) |
| BH64/MW64 | 1.5 - 10 | FILL | AECOM (2010b) |
| BH68/MW68 | 1.2 - 7.5 | FILL/NATURAL | AECOM (2010b) |
| BH10 | 2 - 9.5 | FILL | Coffey (2008b) |
| BH15 | 2.5 - 12 | SANDSTONE | Coffey (2008b) |
| BH3 | 1 - 3 | FILL/NATURAL | Coffey (2008b) |
| BH6 | 1 - 4.6 | FILL | Coffey (2008b) |
| BH7 | 1 - 5.5 | FILL | Coffey (2008b) |
| BH198/MW198 | 1.6 - 6.8 | FILL/NATURAL | ERM (2008a) |
| BH200/MW200 | 4.5 - 7.3 | SANDSTONE | ERM (2008a) |
| BH204/MW204 | 2.8 - 4.4 | SANDSTONE | ERM (2008a) |
| BH204D/MW204D | 1 - 4 | FILL | ERM (2008a) |
| BH205/MW205 | 15 - 19.4 | SANDSTONE | ERM (2008a) |
| BH206/MW206 | 7 - 8 | NATURAL | ERM (2008a) |
| BH209/MW209 | 1.8 - 8.6 | FILL/NATURAL/SANDSTONE | ERM (2008a) |
| BH210/MW210 | 14.8 - 17.6 | SANDSTONE | ERM (2008a) |
| BH87/MW15 | 3 - 9 | unknown | ERM (2007) |

## 3.4 Data Gaps

Some data gaps which may impact this HHERA have been identified based on review of the available report and data. These are summarised in Table 7. The manner in which data gaps have been addressed in the HHERA is also summarised below.

**Table 7: Summary of Identified Data Gaps of Issues**

| Identified Data Gap or Issue | Potential Significance to HHERA | Manner in Which Addressed in HHERA |
|---|---|---|
| Vertical extent of gasworks derived material (e.g. tar) within fractured bedrock underlying the Site is not known with certainty (due to practical constraints). | Does not impact ability to derive SSTC for gasworks contaminants, but should be considered in overall remedial planning for the Site. | Noted as uncertainty; potential for impacts to be present needs to be considered during remediation and construction activities. |
| Contaminant concentrations in groundwater within the deeper bedrock aquifer have not been investigated in all areas. | | |

# 4.0 Nature and Extent of Contamination

## 4.1 Contamination Sources

The Site is situated over the former AGL gasworks footprint. This area falls across a section of the Barangaroo precinct and Hickson Road. (see **Figure F 2** and **Figure F 3**).

Buried gasworks infrastructure is understood to remain underlying the Site. URS (2001) estimated the footprint of the former gasworks to encompass approximately 5420 $m^2$ and comprised of the following structures:

- Retort House;
- Meter House;
- Gasholders;
- Purifier Beds.

Other historical structures associated with the former gasworks site included but are not limited to miscellaneous storage sheds, warehouses and roadways. Gasworks infrastructure underlying Hickson Road include part of the annulus of the former gasholder, a smaller secondary gasholder and a tar well (Broomham 2007, Coffey 2008).

The former gasworks are recognised as the main source of CoPC at Barangaroo (i.e. NA&A 1996, ERM 2007, Coffey 2008b, ERM 2008a, AECOM 2010a, 2010b, 2010c). This and other CoPC sources on Site have been identified by historical studies, as summarised in **Table 8**.

**Table 8: Summary of Potential Contamination Sources on Site [a]**

| Description of Potentially Contaminating Activity | CoPC | Comments |
|---|---|---|
| Former gasworks | Metals, TPH, BTEX, PAHs, phenols, sulphate, cyanide, ammonia. | Associated with gasworks waste. Gasworks contamination is likely to be concentrated in the vicinity gasworks infrastructure across the Site. |
| Importation of fill materials for reclamation activities | Metals, TPH, BTEX, PAHs, PCBs, OCPs, VOCs, SVOCs, asbestos. | Fill materials of unknown origin have been used for land reclamation of the existing wharf areas. |
| Demolition of former buildings potentially containing hazardous materials | Lead, PCBs, asbestos. | Hazardous materials, including asbestos cement sheeting and lead based paints, may have been used in the construction of historical warehouses, buildings and/or industrial infrastructure on the Site and may have been introduced to the sub-surface during demolition works or as a result of leaching or weathering while the building structures were still in place. |
| Reclamation activities | ASS | Given the proximity of the Site to Darling Harbour the potential for ASS is present. Potential ASS (PASS) is likely to be present in the natural silts, sands and clays overlying the bedrock at depth on the Site. |

Notes:
a Source: AECOM (2010b)
Metals – arsenic (As), copper (Cu), chromium (Cr), cadmium (Cd), lead (Pb), mercury (Hg), nickel (Ni) and zinc (Zn).
PAHs – polycyclic aromatic hydrocarbons.
TPH – total petroleum hydrocarbons.
BTEX – benzene, toluene, ethylbenzene and xylenes
OCPs – organochlorine pesticides
OPPs – organophosphorus pesticides
PCBs – polychlorinated biphenyls

SVOC – semi volatile organic compounds
VOCs – volatile organic compounds
ASS – acid sulphate soils

It should also be noted that the area east of the Site was historically occupied by a mixture of commercial, industrial and residential facilities, which may currently or could have historically been a source of contaminants. Potential contaminants are likely to include those summarised above.

## 4.2 Impacted Media

### 4.2.1 Soil

AECOM (2010b) reported odour, staining and sheen in soil samples as being common in fill materials across the Site.

AECOM (2010b) reported that the maximum concentrations of CoPC were generally located in proximity to and down gradient of the former gasworks infrastructure in Block 4 and Hickson Road. CoPCs including: lead, TPH ($C_6$-$C_9$ and $C_{10}$-$C_{36}$), BTEX compounds, PAHs (including benzo(a)pyrene [B(a)P]) and sulphate variably exceeded the adopted Site investigation criteria. The results reported within the former gasworks area were generally consistent with the findings of previous investigations (i.e. ERM 2007, ERM 2008, Coffey 2008).

Free tar was identified at eight locations (BH7, BH15, BH6, BH10, BH/MW204D, BH/MW206, BH/MW205) within the former gasworks area, which was consistent with findings reported for historical investigations (i.e. BH10, BH7 in Coffey 2008).

**Soil leachability**

There has been a total of forty five Australian Standard Leaching Procedure (ASLP) analysis conducted on soil samples collected within the Site for the purpose of waste classification according to the NSW DECC (2008) guidelines. Samples were selected based on field observations including odour, colour/staining and PID readings to select samples representative of chemical impact.

The initial 39 samples were collected during investigations conducted at the Site from 2008 until 2010 and are summarised within AECOM 2010(b). Concentrations of metals including As, Ba, Cd, Cr, Co, Cu, Hg, Pb, Mn, Ni, Vn and Zn and PAHs including acenaphthene, acenaphthylene, anthracene, fluoranthene, fluorene, naphthalene, phenanthrene and pyrene were reported to be leaching at concentrations above the laboratory LOR.

The remaining ASLP analysis was conducted during the AECOM Supplementary DGI, 2011 and included six locations within the Site. The additional locations were analysed for ultra-trace (low level) PAH, phenols, BTEX, inorganics and metals. The additional analyses were undertaken on soil samples taken from locations selected to be representative of significant contamination identified from previous field observations (PID, visual and odour). The soil samples selected for the additional analyses were taken from locations where it was expected (based on field notes) that high leach results would correspond with high soil concentrations.

Based on the samples analysed, the soil and fill material at the Site are considered to have the potential to leach BTEX, inorganics, metals, PAHS (acenaphthene, acenaphthylene, anthracene, , fluorene, naphthalene, phenanthrene, 2 methylnaphthalene) and phenols (phenol, 2,4 dimethylphenol, 2 methylphenol, 3&4 methylphenol) under the laboratory ASLP conditions.

### 4.2.2 Soil Vapour

AECOM (2010a and 2010c) soil vapour analysis reported some gasworks-derived impacts which exceeded the adopted ambient air guidelines (adjusted using an attenuation factor of 0.01) for naphthalene (converted ATSDR MRL 2005) at two locations within the declaration area and one location in the public domain and two locations within the other remediation works south area. Oxygen measurements taken from the 11 locations within the Barangaroo site from depths of 0.6 to 1.7 mbgs ranged from 4.2% to 17.6%. This suggests that there is sufficient oxygen movement through the upper soils present across the site beneath the current slab on grade foundation (which was observed to be of varying quality) to support biodegradation processes.

### 4.2.3 Groundwater

- Previous reports found that dissolved-phase concentrations of contaminants at the Site were variably above the Site investigation criteria (e.g. lead, cadmium, chromium (III+VI), cobalt, copper, mercury, nickel, zinc, benzene, naphthalene and phenol) (AECOM 2010b, Coffey 2008b).
- The most significant groundwater contamination was identified in the immediate vicinity of the former gasworks infrastructure and contamination, including BTEX, naphthalene, PAHs and metals, present in both dissolved and free phase forms (Coffey 2008b, ERM 2008a, AECOM 2010b). Concentrations of contaminants in excess of the assessment criteria were also identified in wells down-gradient of the gasworks footprint, indicating the westerly migration of contamination (AECOM 2010b). The results of the AECOM (2010b) investigation indicated that the variable nature and distribution of fill materials at the Site caused localised variations in groundwater flow and associated contaminant migration, which is further complicated by tidal movements.
- AECOM (2010b) identified free tar at eight locations within Hickson Road and Block 4 in the vicinity of the tar tank, purifying beds and 1870 gasholder indicating these locations are the main source areas of contamination (in wells ERM MW204D, ERM MW205, ERM MW206, AECOM MW53, Coffey MW15, Coffey BH7, Coffey BH10 and Coffey BH6). That was consistent with historical reports (Hickson Road samples reported in Coffey 2008, MW204D in ERM 2008). Tar was observed within wells installed at varied depths throughout the profile, indicating dense non aqueous phase liquid (DNAPL) is present at the Site within the fill materials, natural sediments and bedrock (AECOM 2010b).

### 4.2.4 Considerations for Contaminant Mobility

***Soil***

The AECOM (2010b) investigation reported free tar in a number of locations within the former gasworks area, indicating these locations were source areas for contamination. Maximum concentrations of CoPC were generally located within proximity to and to a lesser extent, downgradient (west) of the former gasworks footprint, the results of which suggested that lateral migration was occurring. The results of the Blocks 1 to 3 DGI (AECOM 2010a) also confirmed gasworks associated CoPC and staining were present in soils immediately south of the Site, within the northeast portion of Block 3 that was closest to the former gasworks.

***Soil Leachability***

AECOM (2010b, 2010a) ASLP tests on Site soils further indicated there is potential for mobility of key CoPC from soil sources, at levels which exceed the adopted groundwater screening criteria. AECOM (2010b) confirmed that locations of elevated concentrations of contaminants in soil associated with the former gasworks site, notably BTEX, naphthalene and PAHs, included areas near the boundary of the Declaration Area.

Additional ASLP analyses undertaken by AECOM as part of the Supplementary VMP DGI (AECOM 2011) provided further confirmation of whether or not a particular contaminant is leachable, particularly in cases where the groundwater screening criteria is at or near the laboratory standard LOR.

These results are shown in the **Tables T22 and T23**. Sample Locations are shown on **Figure F 17.**

The results confirm:

- that for cyanide there was no detection above the LOR in leachate;
- high molecular weight PAHs and some phenols exhibited very limited if any leachability behaviour;
- ammonia exhibited limited leachability behaviour;
- in 4 out of the 10 samples the laboratory was unable to achieve the ultra trace LOR. Matrix effects, possibly related to seawater salinity effects and/or the presence of organic compounds, interfered with (raised) the achievable LOR; and
- The results of the standard ASLP leaching analyses summarised in **Section 4.2.1** above with respect to the leachability of contamination.

Overall, some metals, low molecular weight PAHs and some phenols exhibited potential mobility via leaching to groundwater.

***Groundwater***

Dissolved phase contamination associated with the former gasworks, was reported by AECOM (2010b) as being present across the Site. Significant concentrations of lead, cadmium, total chromium, cobalt, copper, mercury, nickel, zinc, benzene, naphthalene and phenol were reported in groundwater underlying the former footprint of the gasworks infrastructure. Similarly, free phase tar was reported in several wells located within the footprint of the former gasworks site (across Blocks 4 and Hickson Road).

Additional analyses in consideration of contaminant mobility in groundwater was undertaken by AECOM as part of the Supplementary VMP DGI (AECOM 2011). The additional analysis included:

- Standard (Limit of Reporting) PAH and phenol analysis of unfiltered groundwater samples (here on referred to as unfiltered results).
- Ultra-trace (low level) PAH and phenol analysis of twice laboratory filtered (using 0.45µm filter paper) groundwater samples (here on referred to as "Filtered" results). The Laboratory Limit of Reporting (LOR) for all ultra-trace analysis was less than the ANZECC (2000) guidelines.
- Analysis of the residue retained on laboratory filter papers ("Suspended Material") from each Filtered sample for PAHs.

The additional analysis was undertaken on groundwater samples taken from 13 groundwater monitoring wells selected to include more significant contamination identified by the previous investigation works at the Site. The locations of the additional groundwater monitoring wells are presented in **Figure F 17.** Review of the results indicates that:

- PAHs and phenols were detected in all but two unfiltered groundwater samples analysed (MW62 and MW68);
- The concentrations of PAHs reported in the filtered samples were significantly lower than the concentrations reported in the unfiltered samples and were typically less than the MWQC. The concentrations of phenols reported within the filtered samples were marginally lower than those in the unfiltered samples. The exceptions to this where exceedances of the MWQG were observed in the filtrate samples were the low molecular weight PAHs (such as acenaphthene, acenaphthylene, anthracene and naphthalene) and Phenols including (3 methylphenol, 2,4 dimethylphenol, 2-methylnaphthalene, 2 methylphenol, 4 methylphenol and phenol);
- The differences in concentrations with filtration are summarised in **Table 9** below. The table presents the range in ratios of the unfiltered sample concentrations and filtered sample concentrations for the range of individual PAHs and phenols. For example, in Sample IT3S, the ratio of unfiltered sample PAH concentrations to filtered sample PAH concentrations ranged from 14 to 76. That is, the concentration of PAHs in the unfiltered samples was between 14 and 76 times greater than the concentration reported in the filtered sample.

**Table 9: Reduction in Concentration of PAHs and Phenols in Unfiltered verses Filtered Samples**

| Sample | Detected PAHs | Detected Phenols |
|---|---|---|
| IT3S | 14 to 76 | All < LOR |
| IT3M | 10 | All < LOR |
| IT3D | 4.7 to 418 | 1.3 to 1.7 |
| MW69 | 40 to 372 | All <LOR |
| MW08 | 22 to 31 (with exception of naphthalene which increased by 1.2 times) | (Increase by 0.4 to 0.9) |
| MW198 | 3.5 | All < LOR |
| MW200 | 1.6 to 2.7 | 1.8 |
| MW204 | 7.8 to 546 | 1.1 |
| MW209 | 5.4 to 62 | 3 |
| MW210 | 10.3 to 42 | All < LOR |

| Sample | Detected PAHs | Detected Phenols |
|---|---|---|
| MW401 | 4.1 to 94 | 2.2 to 2.3 |
| MW62 | All < LOR | All <LOR |
| MW68 | All < LOR | All <LOR |

- The results of the analysis of the Suspended Material demonstrate that the difference between the unfiltered and filtered groundwater concentrations can be explained by the contaminant concentrations reported in the suspended material;
- individual PAHs (specifically: benzo(a)pyrene, benz(a)anthracene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, fluoranthene, indeno (1,2,3-cd)pyrene, and pyrene) were not detected above the MWQC in any of the Filtered samples. One sample exhibited matrix effects with elevated LOR above the MWQC;
- these findings are consistent with the published chemical properties of benzo(a)pyrene (and the other identified PAHs) which are not considered as leachable / mobile if bound to soil/sediment based on its reported log Kow >3.7 / log Koc >3.95 (based on Heemsbergen D, *et al* 2009);
- several phenolic compounds (specifically: phenol, 2,4-dimethylphenol, 2-methylphenol, 3-methylphenol and phenol) were detected above the MWQC in the Filtered samples. These findings are consistent with the published chemical properties of these chemicals;
- PAHs and phenols which are bound in the solid phase are less bioavailable to the adjacent receptor Darling Harbour than those in the dissolved phase because the solid phase is considered to be more impeded by the fill soils with respect to access to harbour water than is the soluble phase;
- because the listed PAHs are not present in the dissolved phase they are not able to migrate to Darling Harbour in groundwater and therefore there is no requirement to derive SSESC for these analytes in order to be protective of the environment.

***Free Phase Tar***

AECOM (2010b) considered that the migration of DNAPL has occurred both vertically and horizontally through the profile under the influence of gravity. The slope of the bedrock interface at the Site towards the west is also likely to be influencing DNAPL migration. AECOM (2010b) confirmed that locations of elevated concentrations of contaminants in soil associated with the former gasworks site, notably BTEX, naphthalene and PAHs, included areas near the western boundary of the Declaration Area in the direction of groundwater flow to the harbour.

AECOM acknowledges the NSW DEC (2007) Guidelines for the Assessment and Management of Groundwater Contamination which require that non aqueous phase liquid (NAPL) "*be removed or treated as much as practicable*." It is a recommendation of this HHERA that any free phase tar (or NAPL) encountered during the remediation works should be remediated to the extent practical.

It is noted that the capacity for removal of NAPL will be limited by factors such as:

- the vertical and horizontal extent of the NAPL;
- surface infrastructure such as Hickson Rd;
- the proximity of Darling Harbour; and
- the capacity of the preferred remediation technologies.

The relevant RAP will further define any limitations associated with the recommended removal of NAPL to the extent practical from within the Site.

Notwithstanding, it should be noted that with the exception of Hickson Road, the Site will be encapsulated by a basement groundwater retention wall system keyed into bedrock. This design feature will ensure that any NAPL that can not be practically removed will be prevented from migrating into Darling Harbour.

### 4.2.5 Consideration of Co-occurrence of Chemicals

There is potential for chemicals to be present in soil and groundwater at the same location at the Site. The significance of this potential is likely to be reduced post-remediation and development of the Site. The following observations and assumptions have been made regarding the potential for co-occurring chemicals in line with LL development plans (refer to **Section 2.4** and **Appendix A)**:

- The derivation of SSTCs in the current HHERA for soil and groundwater at the Site is considered to be sufficiently conservative such that the potential for chemical contaminants to occur in both soil and groundwater at any one location is protective of human health risks. The LL development plans for the Site indicate that the Site within Block 4 (which includes the most eastern impacted area) will be excavated to RL -9 m (**Figure 7** to **Figure 9** in **Appendix A**). However, as this area will be excavated down to the depth of the underlying bedrock, all soil and hence contaminants in soil will be removed.
- As a result, the majority of this area will be excavated down to the depth of the underlying bedrock, which will remove the majority of contaminated materials and therefore remove the potential for chemicals to co-occur.
- The potential for contaminated soil and groundwater to be adjacent to upper basement walls has been reduced through the installation of the basement groundwater retention wall system to encompass the perimeter of the Blocks 4 and 5 basement areas. The potential for contaminants to co-occur in soil and groundwater beside the upper basement to the east will also be mitigated with the proposed remediation works in Hickson Road. All basement modelling has assumed that there is potential for 2 walls to be exposed at any one time, thus it has been considered appropriate to assume that SSTCs derived for soil and groundwater will be protective of upper basement users if chemicals do co-occur.
- The proposed construction of a basement groundwater retention wall system along the eastern boundary of the Site to the northern extent of the Site will effectively eliminate the flow of groundwater into this area. Consequently, chemical contaminant concentrations in groundwater will also decrease as a result of the source removal works.
- Any soils likely to remain in place post-development within the proposed Southern Cove footprint in Block 4 will be entirely encapsulated by the groundwater retention wall system and basement car park and therefore covered by water and thus not pose a vapour risk.
- The mitigation measures built into the LL development plans combined with the conservative assumptions (**Section 5.3**) used to derive site specific SSTCs are likely to ensure that human health risks are not present post-remediation and development of the Site.

In addition, AECOM have also considered the potential for mixtures of chemicals to be present within the environmental media. This is further described in **Sections 5.2.4** and **5.2.5**.

# 5.0 Human Health Risk Assessment

The human health risk assessment component of this project has comprised derivation of site-specific target criteria (SSTC) for soil and groundwater based on potential development options for different areas of the Site.

SSTC were derived in general accordance with NEPC (1999a, 1999b) guidelines for risk assessment and derivation of health-based criteria in environmental media. The methodology included the following key steps:

- Identification of CoPC in environmental media, based on comparison to relevant human health based 'Tier 1' screening criteria.
- Qualitative and quantitative assessment of the toxicity of each CoPC.
- Development of Conceptual Site Models (CSMs) for land use scenarios relevant to future development of the Site.
- Quantitative Exposure Assessment for each land use scenario, in order to estimate the extent to which human receptors may be exposed to CoPC at the Site and including vapour and dust migration modelling where relevant to the CSM).
- Adoption of acceptable risk levels upon which to base derived SSTC.
- Derivation of media and chemical specific SSTC for each CoPC based on consideration of toxicity criteria, exposure parameters, contaminant transport modelling and acceptable risk levels.

The above steps are further described in the **Section 5.1** to **Section 5.5** below.

The algorithms used for vapour modelling and for estimation of risk and SSTC are detailed in **Appendix B** and spreadsheets used for SSTC derivation are provided in **Appendix C** to **Appendix I**.

## 5.1 Chemicals of Potential Concern

For the purposes of the human health risk assessment, CoPC are considered to be those chemicals which are known or suspected to be present at concentrations which may warrant inclusion in the human health risk assessment. In general, a chemical is selected as a CoPC if it has been reported to be present in environmental media at the site above relevant screening criteria for protection of human health. The CoPC screening process was undertaken based on the entire dataset for the Barangaroo development area, i.e. based on soil and groundwater analytical data for the PDA, Other Remediation Works (North), Other Remediation Works (South) Area and locations outside the Stage 1 area. This conservative approach to CoPC selection was applied in order to facilitate application of SSTC derived in this assessment to areas outside the Site if required in the future.

The CoPC selection process is further detailed in the following sections for soil and groundwater.

### 5.1.1 Chemicals of Potential Concern in Soil

CoPC in soil were selected based on comparison to screening criteria for the most sensitive potential land use scenario considered relevant to current or potential future use of the site. The screening criteria adopted for CoPC selection in soil were the following (in order of preference):

- Health Investigation Levels (HILs) published by NEPC (1999d), specifically:
    - NEPM 'E' level for recreational use of land (note that these are more conservative than the NEPM 'D' levels for high density residential land use).
- For those chemicals for which no NEPM HILs have been published, the United States Environment Protection Agency (USEPA) Regional Screening Levels (RSLs; USEPA, 2010b) for residential soil were adopted (note that USEPA RSLs have not been derived for recreational land use, so the most conservative low density residential RSLs were adopted. Within the derivation of the RSLs for inhalation exposures, there was no consideration of inhalation indoors, only outdoors).
- For TPH, the NSW EPA Guidelines for Assessing Service Station Sites (NSW EPA, 1994) were adopted. It is noted that these guidelines are for sensitive land use and are therefore considered conservative for assessment of the land use scenarios applicable to future site development.

Available historical soil analytical data are summarised and compared to the adopted soil investigation levels in **Table T1**and **Table T2**.

Chemicals of potential concern were retained or excluded from the risk assessment as follows:

- Chemicals which were not reported above laboratory limits of reporting (LORs) in any samples were excluded as CoPC.
- Chemicals which were not reported above LORs but where LORs exceeded adopted screening criteria were generally not included unless they were considered likely to be Site-related CoPC (see below).
- Chemicals for which the maximum reported concentration did not exceed the adopted screening criterion were excluded as CoPC.
- Chemicals which were reported above the adopted screening criterion were selected as CoPC and further considered in the quantitative risk assessment.
- Chemicals which were reported above laboratory detection limits, but for which no screening criterion was available, were evaluated on a case by case basis to assess whether the frequency of detection and reported concentrations warranted further consideration.
- A total of five samples (collected from locations where buried fill and rubble were identified) were analysed for asbestos during the AECOM DGI. No asbestos was detected in the samples analysed. A single result (AECOM BH48_11.5-11.7) reported the presence of unidentified mineral fibres. The corresponding bore log notes for this sample noted the presence of plastic, minor silt, crushed brick and road base gravels. No visual evidence of bonded fibre cement or possible asbestos fibres was observed by AECOM during the DGI investigation. ERM (2008a) previously analysed a total of 39 samples (12 samples from the Declaration Area) and detected chrysotile and amosite asbestos in a single location (BH203_1.5). Consequently, asbestos containing materials are not considered to be widespread within fill materials at the Site. Therefore asbestos has not been considered further with respect to human health risks from the proposed future development of the site. It is considered that the AECOM (RAP) currently being completed for the declaration area will determine appropriate field screening and management tools should asbestos be noted to be present during remediation. It is noted that in unpaved and paved areas of the site, there will be a minimum of 0.5 m of clean fill material placed across the site. Therefore it is not considered that any exposure to potential asbestos present within the soil will not occur during normal activities

Based on the comparison of site data to adopted health-based investigation levels for recreational and/or residential use of land (see **Table T1** and **Table T2**), the following CoPC have been identified in soil:

- Petroleum Hydrocarbon Groups
  - BTEX.
  - PAHs.
  - TPH ($C_6$-$C_9$ and $C_{10}$-$C_{36}$ fractions).
- Other Organics
  - Carbazole: Review of the 18 locations at which this chemical was reported above the laboratory limit of reporting indicates that remediation of TPH, PAH and BTEX is likely to result in reduction or removal of carbazole from soils across the Site. There is limited toxicological information available for this compound, and given its co-location, further consideration is not warranted.
  - Dibenzofuran.
  - 2-Methylnaphthalene.
  - 3&4-Methylphenol (m&p-cresol).
  - 2-Picoline: This chemical has not been further assessed in the current HHERA as AECOM is not aware of any suitably published peer reviewed toxicity data relevant for use in modelling exposures. 2-Picoline was only reported in 3 locations across the Site and thus it was not considered to be a significant contaminant. Further assessment of the locations at which 2-picoline was reported indicates that remediation of soils for BTEX, TPH and PAH is likely to result in reduction or removal of this chemical from soils at the Site.

  - 1,2,4-Trimethylbenzene.
- Metals and/or Inorganic Compounds
  - Chromium (hexavalent).
  - Lead.
  - Vanadium.

The following chemicals were each reported above laboratory detection limits in only one sample and at a concentration only marginally above (generally within two to three times) the detection limit and were therefore excluded as soil CoPC:

- 1-Naphthylamine.
- p-Isopropyltoluene.
- alpha-BHC.
- Endosulfan sulphate.
- Pirimphos-ethyl.
- 3,3-Dichlorobenzidine.
- 4-(Dimethylamino) azobenzene.
- 4-Aminobiphenyl.
- Total PCBs.
- Iron (was present in more than one sample, however is not considered to have sufficient toxicity to present a risk to human health, so has not been considered further).

It should be noted that a number of chemicals were not reported in soil above laboratory detection limits, but laboratory detection limits achieved in one or more samples exceeded relevant assessment criteria. The chemicals to which this applies generally fall into one of the following categories:

- A small number of chemicals were reported with elevated limits of reporting (LORs) as a result of matrix effects associated with high TPH concentrations in these samples. This was generally relevant to less than three locations per chemical, and was applicable primarily to chlorinated and brominated hydrocarbons. These chemicals are considered unlikely to be of significant concern at the Site and have therefore not been considered quantitatively in this assessment because:
  - the Site and surrounding area history is not known to include significant use of chlorinated solvents or compounds;
  - these compounds have not been reported to be present in samples with normal LORs; and
  - only a limited number of samples had elevated detection limits.
- Chemicals for which practical quantitation limits for the NATA accredited methods used by laboratories exceeded relevant assessment criteria and LORs for all samples therefore exceeded these criteria (generally applicable to selected OCP, OPPs and non-standard PAHs (e.g. 7,12-dimethylbenz(a) anthracene, 2-(acetylamino)fluorene)). With respect to OCPs and OPPs, these are not expected to be significant CoPC at the site based on site history considerations (i.e. extensive pesticide use has not been reported).
- The nature of works undertaken at the Site during operation of the gasworks indicates that the potential for PAHs other than the primary 16 to be present at the Site exists. However it is considered likely that they would be present at much lower concentrations than the 16 key PAHs. Where analysed, PAHs other then the primary 16 were not reported above detection limits, even in material heavily impacted by PAHs. It has therefore been assumed that the detection of the most common and well studied PAHs at high concentrations would drive human health risks and thus remediation of the site for the 16 priority PAHs is considered likely to adequately address potential risks posed by other PAHs should they be present.

Further justification on the selection of CoPC within soil is detailed within **Appendix R**.

### 5.1.2 Chemicals of Potential Concern in Groundwater

Beneficial uses of groundwater for which screening or investigation levels have been published by Australian regulatory agencies (e.g. potable use, irrigation, stock watering, etc) are not considered relevant to the Site, as current and future extractive uses of groundwater are precluded by high salinity. However, current and/or future Site users may be exposed to groundwater via the vapour migration pathway or via direct contact during intrusive maintenance or construction activities.

AECOM is not aware of investigation levels developed by NSW or Australian regulatory agencies to be protective of exposures via the vapour intrusion pathway. Therefore, a more conservative approach has been adopted whereby investigation criteria for potable water uses (i.e. the most conservative of available human health based guideline values) have been compared to reported Site chemical concentration for Tier 1 screening of CoPC in groundwater.

The adoption of guidelines which have been derived to be protective of exposure via ingestion routes is considered conservative when used for the screening of inhalation exposures. Guidelines derived to be protective of ingestion pathways are based on a percentage of the allowable intake for a specific chemical with consideration of potential exposures from other routes (i.e. dermal and inhalation). As it is considered most likely that Site related receptors will only be exposed via the inhalation route this screening is therefore conservative for the purposes of identifying potential CoPC at the site as they are protective of multiple direct contact exposure pathways.

Specifically, the following health-based guidelines or screening levels have been adopted (in order of preference):

- National Health and Medical Research Council (NHMRC, 2004), *Australian Drinking Water Guidelines (ADWG)*.
- World Health Organization (WHO, 2006), *Guidelines for Drinking-water Quality.*
- WHO (2008), Petroleum Products in Drinking-water.
- USEPA (2010), *Regional Screening Levels* (for Tap Water).

Available historical groundwater analytical data are summarised and compared to the adopted investigation levels in **Table T3** and **Table T4**.

CoPC in groundwater were retained or excluded from the risk assessment as follows:

- Chemicals which were not reported above laboratory detection limits in any samples were excluded as CoPC.
- Chemicals which were not reported above LORs but where LORs exceeded adopted screening criteria were generally not included unless they were considered likely to be Site-related CoPC (see below).
- Chemicals for which the maximum reported concentration did not exceed the adopted investigation level were excluded as CoPC.
- Chemicals which were reported in one or more samples above the adopted investigation level were selected as CoPC and further considered in the quantitative risk assessment.
- Chemicals which were reported above laboratory detection limits, but for which no investigation level was available were further evaluated on a case by case basis to assess whether the nature of the compound, frequency of detection and/or reported concentrations warranted further consideration in the risk assessment.

Based on the comparison of site data to adopted health-based investigation levels (see **Table T3** and **Table T4**), the following CoPC have been identified in groundwater:

- Petroleum Hydrocarbon Groups
- BTEX.
- PAHs.
- TPH ($C_6$-$C_9$ and $C_{10}$-$C_{36}$ fractions).
- Other Organics
    - Aniline.

- Bis(2-ethylhexyl)phthalate.
- Carbazole.:There is limited toxicological data for modelling exposures to carbozole. Review of the 20 locations at which this chemical was reported indicates that remediation of TPH, PAH and BTEX is likely to result in reduction or removal of carbazole from groundwater across the Site.
- Dibenzofuran.
- 2,4-Dimethylphenol.
- 2-Methylnaphthalene.
- 2-Methylphenol (o-cresol).
- 3&4-Methylphenol (m&p-cresol).
- 1-Napthylamine: This chemical has not been further assessed in the current HHERA as AECOM are not aware of any published toxicological data relevant for use in modelling exposures1-Naphthylamine was only reported in a single location (MW200) across the Site. This location reported significant concentrations of TPH, PAH and BTEX and this it is considered appropriate to assume that remediation of the site for these compounds is likely to result in reduction or removal of 1-naphthylamine from the site.
- Phenol.
- 2-Picoline: This chemical has not been further assessed in the current HHERA as AECOM is not aware of any suitably published peer reviewed toxicity data relevant for use in modelling exposures. 2-Picoline was only reported in 3 locations across the Site and thus it was not considered to be a significant contaminant. Further assessment of the locations at which 2-picoline was reported indicates that remediation of groundwater for BTEX, TPH and PAH is likely to result in reduction or removal of this chemical from groundwater at the Site.
- Styrene.
- 1,2,4-Trimethylbenzene.

- Metals and/or Inorganic Compounds
  - Ammonia.
  - Arsenic.
  - Barium.
  - Cadmium.
  - Chromium (hexavalent).
  - Cobalt.
  - Lead.
  - Manganese.
  - Nickel.
  - Vanadium.

The following compounds were reported above guideline values and/or were above detection limits with no guideline value available, but were not included as CoPC for the reasons stated below:

- Mercury: was reported in one sample marginally above the adopted drinking water guideline (reported at 1.1 µg/L compared to drinking water guideline value of 1 µg/L), but has not been included as a CoPC based on the marginal nature of the exceedence and that concentrations in the majority of samples were below the adopted guideline value.
- Cyanide. It is noted that free cyanide concentrations did not exceed health-based guidelines and the maximum reported weak acid dissociable (WAD) cyanide concentration only marginally exceeded the drinking water guideline. The presence of significant concentrations of iron in groundwater at the Site indicates that it is highly unlikely that free cyanide would be present at the Site. Cyanide forms tight bonds

with iron which produces less toxic cyanide complexes that under the conditions observed at the Site are difficult to break. A number of studies have also shown that free cyanide is not generally present at gasworks sites (CCME, 1999a; Ghosh, 1999; Ghosh, 2004; Kjeldsen, 1999; Meeussen, 1994; Meeussen, 1995; Shifrin, 1996). It is therefore considered unlikely that the bioavailable fraction of cyanide exceeds the relevant investigation criteria. Cyanide has therefore not been further assessed as a CoPC in the current HHERA.

- Calcium, magnesium and potassium have not been selected as CoPC. No drinking water guideline values are available for these chemicals as they are not volatile and considered to be of low toxicity and therefore not of concern for intermittent intrusive maintenance exposure and/or vapour intrusion.
- Water quality parameters (e.g. pH, alkalinity, total anions/cations, ionic balance, bicarbonate, chloride, sodium, sulphate, total dissolved solids [TDS], TOC) and nutrients (ferrous iron, nitrate/nitrate, reactive phosphorus and iron) were not selected as CoPC as they are not considered to be associated with toxic effects. Nutrient concentrations will be considered separately with respect to potential ecological impacts later in this report.
- Benzo(e)pyrene: Reported above detection limits in only one sample (MW20), at concentration of 0.3 µg/L (close to detection limit of 0.1 µg/L). Consideration of other PAHs in this assessment should account for this compound.
- Perylene: Reported above detection limits in only one sample (MW20), at a concentration of 0.1 µg/L (equal to detection limit). Consideration of other PAHs in this assessment should account for this compound.

It should be noted that a number of chemicals were not reported in groundwater above laboratory detection limits, but laboratory detection limits achieved in one or more samples exceeded relevant assessment criteria. This applied to a number of amino aliphatics, anilines, chlorinated and halogenated hydrocarbons, explosives, pesticides and PCBs (see **Table T4**). While this introduces some uncertainty as to the presence (or not) of these compounds above health-based levels, these compounds were not quantitatively included in the human health risk assessment since:

- The chemicals for which this situation occurred are not considered to be key Site CoPC based on the known history of the Site.

Further justification on the selection of CoPC within groundwater is detailed within **Appendix R**.

### 5.1.3 Approach to the assessment of volatile chemicals

It is noted in **Section 5.3** that the dominant exposure pathway to future and existing human receptors identified is the inhalation of volatile contaminants within the indoor and outdoor air environment. Consideration of which CoPC were sufficiently volatile to migrate into indoor and outdoor air was made, CoPC that were not sufficiently volatile were therefore not included in this exposure pathway.

CoPC were considered to be sufficiently volatile if its Henry's law constant is 1 x $10^{-5}$ atm-$m^3$/mole or greater (USEPA, 2004).

It is assumed that TPH $C_{15+}$ are not sufficiently volatile based on TPHWG (1997) which states that TPH fractions greater than TPH $C_{15}$ are not considered to be volatile and inhalation was not considered to be a relevant exposure pathway.

Volatile compounds are usually classified as chemicals which have a boiling point range less than 250 degrees Celcius (Health Canada 1995). Volatile chemicals are also considered to readily volatilise or partition into air under normal temperatures. Further international guidance exists which suggests that compounds with a molecular weight greater than 200 g/mol are not volatile enough to be a vapour intrusion issue (HKEPD 2007).

Therefore with the exception of Scenario 6 (**Section 5.3.4**, where direct contact pathways with soil and groundwater have been considered) the following CoPC have been selected as they are considered to be sufficiently volatile for intrusion into indoor and outdoor air:

- Acenaphthene
- Acenaphthylene
- Ammonia
- Anthracene

- Benzene
- Cyanide
- Dibenzofuran
- Ethylbenzene
- Fluorene
- 2-methyl naphthalene
- Naphthalene
- Phenathrene
- Pyrene
- Styrene
- Toluene
- TPH $C_6$-$C_9$ (aliphatic)
- TPH $C_{10}$-$C_{14}$ (aromatic and aliphatic)
- 1,2,4 trimethylbenzene
- Xylenes

## 5.2 Toxicity Assessment

### 5.2.1 Introduction

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 NEPC (1999a) and enHealth (2004) guidance.

### 5.2.2 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 CoPCs other than TPH (listed in **Section 5.1** above) are provided in **Appendix J.**

The toxicity of individual components which may be present in TPH mixtures has been described by TPHCWG (1997a). The methodology recommended by TPHCWG (1997a) for assessment of risk associated with TPH mixtures is a indicator/surrogate approach, whereby indicator compounds within petroleum which are known to be carcinogens or can be evaluated individually (primarily BTEX and PAHs) are considered separately and potential hazards associated with the remaining mixture (i.e. the mass of petroleum remaining after evaluation of the indicators) are assessed using a surrogate approach (i.e. based on the toxicity of compounds known or expected to be present within TPH fractions for which analytical data are available). This approach and the recommended surrogate toxicity criteria used in this assessment are further detailed by TPHCWG (1997a).

It is noted that in the assessment of TPH, consideration of the aliphatic and aromatic content of each hydrocarbon fraction was undertaken with regards to derivation of SSTC for soil and groundwater. As the aliphatic and aromatic TPH analysis is a non-routine test, it is considered that for validation purposes as a conservative measure, the lowest of the derived TPH fraction value should be used for screening. In the event that the levels are exceeded, additional laboratory analysis may be required to speciate the aliphatic and aromatic constituents of TPH within the validation samples.

### 5.2.3 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 derived 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 of cancer. These chemicals are assessed on the basis of a non-threshold dose-response relationship.
- For other chemicals that may be associated with non-carcinogenic effects, or with other carcinogenic effects that are not genotoxic, a threshold criterion is considered relevant. The threshold level is considered to be a level below which adverse health effects are not expected to occur. Exceedence 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 are discussed in toxicological profiles provided in **Appendix J** and summarised in **Table T5**. Values have been obtained (where available) from the following information sources (listed in order of preference, as per NEPC, 1999a and enHealth, 2004 guidance):

- National Health & Medical Research Council (NHMRC) publications and documents from other joint Commonwealth, State and Territory health organisations.
- World Health Organisation (WHO) publications.
- Agency for Toxic Substances and Disease Registry toxicological profiles.
- Criteria published by USEPA sources, including those published by the USEPA Integrated Risk Information System (IRIS) and those adopted by USEPA regional offices in the derivation of Regional Screening Levels (RSLs).

Toxicity values for TPH were not available from the above listed sources and have been based on values recommended by the Total Petroleum Hydrocarbon Criteria Working Group (TPHCWG, 1997a).

### 5.2.4 Non-Threshold Toxicity Criteria

The assessment of potential effects associated with genotoxic carcinogens requires the use of a non-threshold toxicity value. 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 $(ug/m^3)^{-1}$) 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 J**, of the CoPC identified at the Site, benzene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chromium VI, chrysene, dibenz(a,h) anthracene and indeno (1,2,3-cd)pyrene are considered to be genotoxic carcinogens and have published IURs and/or CSFs. These compounds have therefore been assessed based on non-threshold toxicity criteria where available.

While CSFs or IURs have not been published for carcinogenic PAHs (CPAH) other than benzo(a)pyrene, the potential carcinogenic effects of these compounds (benzo(a)anthracene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene and indeno(1,2,3-cd)pyrene) are considered to act as genotoxic carcinogens by ATSDR (1995). In order to account for the potential presence of mixtures of CPAHs, they have been assessed as BaP equivalent and summed for comparison to the BaP CSF as a single total CPAH value.

Adopted non-threshold toxicity criteria and the source of the adopted values are summarised in **Table T5**.

### 5.2.5 Threshold Toxicity Criteria

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 an ADI. An ADI 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 ADI relates to intakes from all sources, the site 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.

In order to account for potential cumulative exposures to multiple chemicals deriving from either soil, groundwater or both, AECOM have adopted the following approach to allocate proportional risks to chemical present on Site:

- Benzene, toluene, ethylbenzene and xylene were assigned a hazard index of 0.25 each.
- TPH fractions $C_6$-$C_9$, $C_{10}$-$C_{14}$, $C_{15}$-$C_{28}$, $C_{29}$-$C_{36}$) were assigned a hazard index of 0.25 each (0.125 for aliphatic and 0.125 for aromatic).
- All non carcinogenic PAH's were assigned a hazard index of 0.2.
- All other threshold chemicals were assigned a hazard index of 1,0.

Adopted threshold toxicity criteria and the source of the adopted values, are shown in **Table T5**.

### 5.2.6 Dermal Toxicity of PAHs

The assessment of dermal toxicity associated with carcinogenic PAHs has been assessed based on available oral toxicity (dose-response) criteria, in light of the fact that only oral and inhalation cancer potency estimates for benzo (a) pyrene have been published. This approach is consistent with that typically adopted for human health risk assessment in Australia given that dermal dose-response factors are generally not published by regulatory agencies endorsed by NEPM and enHealth health risk assessment guidance. In accordance with USEPA (2004b) guidance, dermal dose-response criteria toxicity criteria are therefore derived from oral dose-response criteria, with correction for chemical-specific gastrointestinal absorption where possible (this converts the oral dose-response criterion, which is based on applied dose, to an absorbed dose equivalent for comparison to dermally absorbed exposure estimates).

While the adopted approach is consistent with relevant Australian and international health risk assessment guidance, a recent study by Knafla et al. (2006) has indicated that the cancer potency of carcinogenic PAHs via the dermal pathway may be higher than that via the oral pathway, based on review of dermal carcinogenesis studies in mice. The dermal slope factor derived by Knafla et al. (2006) for benzo(a)pyrene was 25 $(mg/kg/day)^{-1}$, is 50 times higher than the adopted oral slope factor (from NHMRC, 2004) for benzo(a)pyrene of 0.43 $(mg/kg/day)^{-1}$. While there are some key uncertainties associated with the application of this dermal slope factor to human health risk assessment, particularly given that the value was derived from mouse studies and has not been scaled to account for interspecies differences in body weight and/or skin surface area which may affect skin metabolic capacities, AECOM has conservatively adopted the Knafla dermal slope factor value for the assessment of dermal exposure to soils. It is considered that the slope factor should not be applied to groundwater SSTC derivation as discussed in **Section 8.1.5.1.**

### 5.2.7 Chemicals for Which Published Toxicity Criteria Are Not Available

Suitably published peer reviewed quantitative dose response criteria have not been published to AECOMs knowledge for Dibenzofuran.

Screening for Dibenzofuran in soil and groundwater identified 5 soil (BH42_3.2-3.3, BH53_4.0-4.4, BH55_2.2-2.4, BH59_3.4-3.5, BH70_16.0-16.2) and 6 groundwater (BH3, MW54, MW206, MW205, MW204S, MS15) locations where dibenzofuran was reported above adopted screening criteria. Dibenzofuran is considered to be volatile based on a Henry's law constant greater than $1x10^{-5}$ atm-$m^3$/mol (University of Tennessee, 2010; USEPA, 2004a) and thus was considered to have the potential to cause a vapour intrusion risk, therefore this chemical was included as a CoPC.

Inhalation and oral toxicity data for dibenzofuran has not been published by ATSDR or IRIS and thus a surrogate approach was considered appropriate. It has been assumed that the toxicity of dibenzofuran is similar to that of non-carcinogenic PAHs, based on the following:

- Dibenzofuran falls into the structural class of polycyclic aromatic hydrocarbons.
- Available evidence does not suggest that dibenzofuran is mutagenic or carcinogenic (NTP, 2001).

The geometric mean of oral RfDs and inhalation RfCs adopted for non-carcinogenic PAHs (0.06 mg/kg/day and 0.21 mg/m$^3$, respectively) have therefore been adopted for dibenzofuran (see toxicity profile for PAHs in **Appendix J**).

An RfD for this compound has been published in the USEPA RSLs (2010b) (the USEPA adopted the provisional peer reviewed toxicity value (PPRTV) and from this a RfC has been determined via route to route extrapolation (RTR) (as published in the USEPA RSL tables (2010b)). However, there is no publicly available information as to the derivation of these toxicity values thus their appropriateness for use in this situation could not be determined.

It has been noted that the PPRTV RfC of 0.001 is lower than that used in the current risk assessment. It should however be noted that use of these PPRTV in the current risk models has determined that calculated SSTCs for dibenzofuran will still be above the theoretical limit of solubility and saturation in soil and groundwater.

It should also be noted that all locations where dibenzofuran has been reported above adopted screening criteria also had significant concentrations of TPH, PAH and BTEX concentrations. Therefore the surrogate approach adopted in the current HHERA is considered to be appropriate for the assessment of dibenzofuran.

## 5.3 Conceptual Site Models and Quantitative Exposure Assessments for Potential Future Land Use

### 5.3.1 Redevelopment Considerations within the Human Health Risk Assessment

As noted in **Section 2.4**, a large portion of the Site is intended to be excavated and basement carparking areas will be constructed as per the diagrams attached in **Appendix A.** A basement groundwater retention wall system will be installed that has been designed to prevent groundwater from migrating from the east of the Site into Darling Harbour. In addition to these plans, the following assumptions relevant to the basement construction have been adopted:

- Outer basement walls are anticipated to comprise either:
    - 600mm thick reinforced concrete.
    - 100 mm thick shotcrete over exposed sandstone bedrock plus a secondary 350mm thick reinforced concrete wall.
- To be conservative, the risk assessment has considered the basement walls and floors construction to be approximately 150mm thick.
- The concrete walls and/or shotcrete covering are assumed to be of sufficient strength/density to prevent tar seepage into the concrete.
- A sealed plenum air space (expected to be approximately 400 mm wide) will be constructed inside the basement by constructing a concrete block wall inside the 600mm thick reinforced concrete wall or shotcreted sandstone / secondary wall.
- There may be two ventilation plenums (in addition to the separate sealed plenums) constructed per basement floor, one fed by an intake and one which is vented by exhaust, both above ground level (in accordance with AS 1668.2).
- Mechanical air ventilation draws air from outside the basement via the ventilation plenum and forced-air ventilation expels air to outside of basement via the far-wall ventilation plenum (in accordance with AS 1668.2).
- The lowermost basement floor will be in contact with groundwater and therefore limited groundwater seepage through the basement walls/ floor has been modelled. It is considered that the basement will have water collection devices and engineering controls, such as damp proof barriers and sub-surface sump drainage, to prevent groundwater from wetting the lower basement floor or walls.
- The most conservative exposure scenario is based on the smallest basement dimension that will be independently ventilated (the modelled building area consists of a 900 m$^2$ (30 m x 30 m)). There are variable basement dimension designs which have been supplied to AECOM:
    - multi-storey types with area of some 1000 to 3000 m$^2$; and
    - large single-storey delivery bay basement of some 20 000 m$^2$ (see cross section 2 on SK107A, in Appendix A. This section is indicative only and subject to design development).

- It is considered that based on the proposed building designs that two of the basement walls will have soil adjacent to walls in unsaturated zone and groundwater will seep through 2 of the 4 walls.
- In accordance with Australian Standard (AS) AS1668.2 (Standards Australia, 2002), the basement levels will be maintained at a lower pressure than the overlying occupied areas. This theoretically allows vapour movement by the process of advection (where air porosity is available within soil or concrete).
- The air exchange rate within the basement car park has been assumed to be 4 per hour (in accordance with AS 1668.2).

A diagram showing the assumed ventilation and sealed plenum structure is provided in **Figure 4** in **Appendix A.** It should be noted that LL has recently indicated that some basement structures may be constructed without use of plenum airspaces for ventilation (i.e. the ventilation plenum). While this HHERA has assumed that a ventilation plenum will be present, removal of the plenum will not significantly impact on the vapour modelling and SSTC derivation since the vapour model used assumes that any vapours which enter the basement are mixed throughout the airspace regardless of whether a ventilation plenum is present.

### 5.3.2 Vapour Transport Modelling

In order to estimate the potential concentrations of volatile contaminants within the indoor and outdoor air, two approaches have been adopted.

For scenarios where water seepage is present on walls (relevant for lower and upper basements only in scenario's 1,2 and 7, Section 5.3.4), the estimation of volatile concentrations have been undertaken using USEPA Air Emissions Model for Waste and Wastewater (1994), which includes equations from the USEPA Water 9 model.

The model adopted was based on emission models from impoundments and open tanks which are flowing and is therefore considered to be conservative. The calculation was based on a number of assumptions:

- Volatilisation was considered to be the dominant process and there was no consideration for biodegradation, oxidation/ reduction, hydrolysis, adsorption or photodecomposition processes.
- The volatilisation was estimated from the liquid surface exposed to air.
- The model is based on a liquid and gas phase resistance concept resulting in an overall mass transfer coefficient. For chemicals which are considered to be volatile, the liquid phase resistance model dominated the process.
- The model assumed that chemicals are present within a uniformly mixed solution.
- The model adopted assumed a low windspeed within the basement of 0.03 m/s and a fetch (linear distance of the water) to depth (depth of water) ratio between 0 and 3.25 m/s (which is considered appropriate in a basement scenario where the fetch will likely be greater than the depth). Windspeed in the basement was calculated by dividing the product of the air exchanges per day (96) and the volume of the basement (30 m x 30 m x 2.5 m) by the cross sectional dimension of the basement (30 m x 2.5 m) and converting the units from m/day to m/second.

Further details of the equations and assumptions are presented within **Appendix B**.

In order to estimate the concentration of vapour phase contaminants in indoor air (slab on grade) or outdoor air (i.e. at the point of potentially significant human exposure) that results from given chemical concentration in soil, soil vapour or groundwater, vapour transport modelling was undertaken using methods based on the fundamental theoretical developments of Johnson and Ettinger (1991), as described in the following documents:

- ASTM International, 2002. Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites. E1739 – 95 (reapproved 2002).
- USEPA, 2004a. *User's Guide for Evaluating Subsurface Vapour Intrusion into Buildings.* Office of Emergency and Remedial Response. Revised February 22, 2004.

The above documents were also used as reference sources for vapour transport modelling.

The methodology and algorithms used for vapour modelling are described in more detail in **Appendix B** and the vapour modelling calculations for relevant land use scenarios are included in **Appendix C** to **Appendix I.**

The vapour model methodology predicts the concentration of vapour phase chemical in indoor or outdoor air that may result from a reported concentration in soil or groundwater by estimation of a chemical- and scenario-specific volatilisation factor (VF). The VF incorporates transport and attenuation processes occurring between the soil or groundwater source and the enclosed space or ambient air. The calculation of the VF is dependent on a number of chemical and scenario specific factors such as:

- the volatility of the chemicals;
- the depth to subsurface soil or groundwater contamination;
- the effective porosity of the overlying unsaturated soil zone;
- the presence of surface barriers (e.g. concrete slabs); and
- the extent of dilution and mixing at the surface, based primarily on:
    - building volume and air exchange rates (for indoor air); or
    - wind speed (for outdoor air).

It should be noted that the Johnson and Ettinger (1991) model was designed to be used as a conservative first tier screening model, i.e. to assess whether vapour intrusion risks are possible and therefore whether further investigation or mitigation may be warranted. The model, therefore, incorporates a number of conservative assumptions, including:

- that chemical concentrations in the subsurface source (soil or groundwater) remain constant over the duration of exposure (i.e. a non-depleting source not subject to degradation processes);
- equilibrium partitioning between chemicals in soil and groundwater and chemical vapours in the source zone;
- steady-state vapour and liquid-phase diffusion through the vadose zone;
- no biodegradation or loss of chemical as it diffuses towards the ground surface;
- that all chemical vapours beneath a structure will enter the structure (i.e. vapours will not migrate laterally around a structure); and
- steady, well mixed dispersion of emanating vapours within the enclosed or ambient mixing space.

According to USEPA (2004a), only chemicals with a Henry's Law constant of $1 \times 10^{-5}$ atm-$m^3$/mol or greater are considered sufficiently volatile to warrant consideration with respect to vapour intrusion (**Section 5.1.3**).

### 5.3.3 Soil Vapour Partitioning

Vapour modelling is known to be overly conservative and theoretical indoor air concentrations can be between 10 and 1000 times greater than actual measured values (CCME, 2008b; CRC, 2010; USEPA, 1993; Hartman, 2002; Villeneuve and Fontana (undated) and Shih and Wu, 2005). A number of factors are thought to influence the discrepancy between theoretically modelled soil to air concentrations and actual results such as contaminant soil adsorption, organic carbon, adsorption at the air/ water interface, soil heterogeneity and biodegradation processes.

The UK Environment Agency (2009) has an adopted value of 10 for volatile soil investigation levels to account for this potential discrepancy. The CCME (2008b) has also adopted a correction factor of 10 in the calculation of soil investigation levels in petroleum hydrocarbons (PHC) to account for overestimation in the soil partitioning modelling. The CRC draft health screening levels for petroleum hydrocarbons (E. Friebel and Nadebaum 2010) have also accounted for this partitioning uncertainty and a 10 fold factor has also been adopted. These documents have focussed on petroleum hydrocarbons, which may not be the only compounds for which the overestimation is applicable but are the compounds in which the most research has been conducted.

Therefore to account for this partitioning uncertainty in soil, AECOM has applied a 10 fold partitioning factor in the modelling of human health risks (but not odour) to petroleum related compounds which are sufficiently volatile for vapour intrusion such as TPH ($C_6$-$C_9$ and $C_{10}$-$C_{14}$) and BTEX.

### 5.3.4 Summary of Land Use Scenarios and Associated Conceptual Site Models Considered in the Human Health Risk Assessment

Based on the LL development plans and associated assumptions described above, land use scenarios for which SSTC have been derived are summarised below in **Table 10** and further described in **Section 5.3.5** to **Section 5.3.11**.

**Table 10: Summary of Land Use Scenarios Considered in HHERA**

| Scenario Number | Name and Description | Most Sensitive Human Receptor | General Assumptions |
|---|---|---|---|
| 1 | **Lower Basement**<br>Lower-most basement car park level (below water table), with groundwater seepage through walls and floor (i.e. groundwater seepage may be present at inner surface of outer wall and on floor surface). | Adult or Child Resident<br>Exposed up to 1 hour per day (while en route to and from car), 350 days/year, for 70 years. | Conservative scenario to assess risk if water seeps all the way through walls and floor of lower most basement level.<br>Small layer of groundwater is assumed to be permanently present on some sections of the two walls and floor (within sealed plenum (walls) up to a total of 525m$^2$ across two walls and floor, equivalent to 50% of the surface area) surface area and to act as continuous vapour source. This is considered to be a conservative assumption.<br>Advective flow of vapours is assumed to be negligible (airflow through saturated zone cannot occur due to zero air filled porosity) |
| 2 | **Upper Basement**<br>Upper-most basement car park level, partially above water table. May be used for loading/unloading, or have full time car park attendant present. | Adult Worker<br>Exposed up to 8 hr/day, 240 days/year, for 30 years. | Upper 2 m of walls may have soil directly adjacent to 2 of the 4 walls as a source of vapour.<br>Lower 1 meter of 2 of the 4 walls may have water seepage through into the sealed pleunum wall. It has been conservatively assumed that 25m$^2$ of the two walls will be covered in water seepage (50% of the total wall area).<br>Advective vapour flow considered possible through unsaturated soils (upper 2 m). |

| Scenario Number | Name and Description | Most Sensitive Human Receptor | General Assumptions |
|---|---|---|---|
| 3 | **Unpaved Recreation**<br>Public domain area with no concrete/hardstand paving, but 50 cm of clean fill at surface. | Assumed to be exposed 2 hrs/day, 365 days/year, for 70 years. | Open Space with no Concrete Surface Covering.<br>Assumed that areas are landscaped with at least 50 cm of clean fill overlying contaminated soil.<br>Assume that there is significant oxygen movement through the top 2 m of soil based on the oxygen measurements collected during the soil gas sampling (see **Section 2.9**).<br>Groundwater (GW) depth assumed to be 2 m bgl. |
| 4 | **Paved Recreation**<br>Public Domain area with concrete/hardstand paving. Contaminated soil may be present directly underlying concrete surface cover. | | Open Space with Concrete surface covering.<br>Assume that there is significant oxygen movement through the top 2m of the soil based on the oxygen measurements collected during the soil gas sampling (see **Section 2.9**).<br>Concrete assumed to be minimum 15 cm thick and to have crack fraction of 0.001 (to account for higher cracking possible in surface covering) |
| 5 | **Commercial Slab on Ground**<br>Typical commercial slab on ground scenario for public domain area where basement car park is not present. | Adult worker.<br>Exposed up to 8 hr/day, 240 days/year, for 30 years.<br>Scenario also protective of child who may visit premises on a less frequent basis. | Assumes typical slab on grade commercial premises at ground level. With a maximum of 2 storeys.<br>To account for potential coffee shop, convenience store, restaurant, etc., that could be constructed within the Public Domain. |
| 6 | **Intrusive Maintenance**<br><br>Short term intrusive maintenance scenario, e.g. for maintenance of utility services. | Adult worker<br>8 hrs/day, 15 days/year for 1 year.<br>Water contact may occur due to shallow water – no more than 1 hour per day.<br>Vapour may be derived from pooled GW or from exposed soils in trench. | Post development, short term maintenance work may be required.<br>Assumed not to exceed 3 working weeks per year by same worker. |

| Scenario Number | Name and Description | Most Sensitive Human Receptor | General Assumptions |
|---|---|---|---|
| 7 | **High Density Residential** | Adult or child resident.<br>Assumed to be exposed 24 hrs/day, 350 days/year, for 70 years. | Assuming that the AS 1668.2 car park ventilation rates will be met (approximately 4 exchanges per hour).<br>Assumes that vapours which enter the upper level basement are uniformly mixed and 1/10 of the concentration migrates to the overlying residential property on the ground floor (see **Section 5.3.11**).<br>Within the basement, Upper 2 m of 2 of the 4 walls may have soil directly adjacent to walls as a source of vapour.<br>Lower 1 meter of 2 of the 4 walls may have water seepage through the wall into the sealed plenum. It has been conservatively assumed that 25$m^2$ of the two walls will be covered in water seepage (50% of the total wall area).<br>This scenario would be protective of residential receptors in higher than ground floor premises, where vapour concentrations would be expected to be further diluted than if only mixed within one overlying residential level. |

### 5.3.5 Scenario 1: Lower Basement (Seepage through Walls and Floor)

The CSM for a Lower Basement Level with groundwater seepage through the walls and floor of the basement is depicted in **Figure F 5**.

The following points are relevant to this scenario:

- It is considered unlikely that significant groundwater seepage through basement walls will occur, however this scenario has been modelled to be conservative with consideration of up to 50% of 2 of 4 walls and floor to have water seepage present into the sealed plenum.
- Each basement level has been modelled as separately ventilated airspace. This is more conservative than modelling of mixing of vapours through multiple basement levels, especially for lowermost level.

#### 5.3.5.1 Contaminant Migration Pathways

Contaminant migration pathways relevant to potential human exposure to contaminants within a lower level basement where groundwater seeps through the walls and floor of the basement are summarised below.

**Table 11: Contaminant Migration Pathways - Scenario 1 (Lower Basement)**

| Contaminant Migration Pathways | Relevant to Scenario? | Comments |
|---|---|---|
| Seepage of contaminants in groundwater to basements and volatilisation to indoor air within the basement. | Yes | Lend Lease has provided concept architectural details and has advised that the intent of the building design is to prevent potential for wet walls or pooling of water. Notwithstanding this, AECOM has modelled the potential impact of puddled water.<br>It is conservatively assumed that the groundwater may continuously wet sections of the two walls and floor within the lower basement to a total surface area of 525 $m^2$ which is equivalent to half of the total area of two walls and floor. |
| Volatilisation and vapour migration from soil outside/adjacent the foundation | No | As basement will be below the saturated zone, contaminants dissolved in groundwater will also reflect soil impacts.<br>Note that modelling of vapour from soil outside the wall is therefore not required, since vapour concentration in soil would be equal to that in equilibrium with pore water (groundwater), which is assumed to be present within the basement. |

#### 5.3.5.2 Human Receptors

A range of human receptors may frequent the lower level basement car park at the Site, including commercial workers, customers, tourists and residents within the development.

The most sensitive receptors (i.e. with potential for highest level of exposure to contaminants) are considered to be adults and/or children residing in the high density residential properties at the Site, who could be exposed to car park vapours while walking to and from parked cars on a regular (i.e. daily) basis.

It has been assumed that the lower level basement car park level is not used for loading/unloading and does not have a full time car park attendant and therefore that workers will not be present for extended periods of time. Note that the potential for full time workers to be present in the upper basement level has been considered as Scenario 3.

#### 5.3.5.3 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 medium; and
- an exposure route (e.g. ingestion, inhalation) at the point of exposure.

Where one or more of the above elements is missing, the exposure pathway is considered to be incomplete and there is therefore no risk to the receptor.

Potential pathways via which the above receptors may be exposed to Site-derived contamination are summarised in **Table 12**.

**Table 12: Exposure Pathway Analysis - Scenario 1 (Lower Basement)**

| Exposure Pathway | Complete? | Notes |
|---|---|---|
| **Adult and Child Residents (While Accessing Parked Cars)** | | |
| Incidental ingestion of chemicals in soil | × | Basement construction will preclude direct contact and/or dust generation from soils |
| Dermal absorption of chemicals from soil | × | |
| Inhalation of chemicals in soil-derived airborne particulates | × | |
| Inhalation of soil-derived vapours | × | As basement will be below the saturated zone, primary source of contaminants to basement will be from groundwater. Note that contaminants dissolved in groundwater (to which exposure is being assessed) will also reflect soil impacts. It is also noted that the soil vapour concentration would be equal to that in equilibrium of the pore water (groundwater) which is assumed to seep through the basement. |
| Incidental ingestion of chemicals in groundwater (incidental contact) | (✓) | While water is assumed to seep through basement walls and floor in this scenario, wall seeps will be behind plenum (and not accessible) and receptors are assumed not to have significant direct contact with moist floor (also note that, even though this scenario has conservatively assumed that the basement floor may be partially wetted, it is considered likely that sumps would be installed to prevent accumulation of groundwater on basement floor if necessary and this would preclude significant water contact in basement) |
| Dermal absorption of chemicals in groundwater (incidental contact) | (✓) | |
| Inhalation of groundwater derived vapours | ✓ | Complete and significant pathway if groundwater with volatile contaminants enters basement through walls and/or floor. |

### 5.3.5.4 Exposure Parameters

Human exposure parameters adopted for this scenario are summarised in **Table 13** and were obtained, where available, from recognised Australian and international sources (primarily enHealth, 2004; NEPC, 1999a; USEPA, 1989 and updates to USEPA, 1989). Some parameters have been estimated based on professional judgement and/or site-specific considerations, as noted in **Table 13**.

**Table 13: Exposure Parameters - Scenario 1 (Lower Basement)**

| Parameter (units) | Adopted Value | Source/Reference |
|---|---|---|
| Exposure Time (hours/day) | 1 | Professional judgement for lower level car park area. It is considered that residential (or other) receptors would frequent a basement car park for not more than one hour per day on average. |
| Exposure Frequency (days/year) | 350 | Assumes residents may be away from home up to 2 weeks per year. |
| Exposure Duration (years) | 6 (child)<br>64 (adult) | NEPC (1999a) and enHealth (2004). Assumes residents may be present at the Site for their entire lifetime, assumed to be 70 years. |

The estimation of volatile COPC within the lower basement has been undertaken using USEPA (1994) Water 9 equations as outlined in Section 5.3.2 above. Further details of the vapour transport modelling are also provided in Appendix B.

The geologic, hydrogeologic and building parameters adopted for volatilsation seepage model for Scenario 1 are summarised in **Table 14** below. Chemical-specific properties used in the calculations are included in **Appendix C**

**Table 14: Seepage Modelling Assumptions - Scenario 1 (Lower Basement)**

| Parameter (units) | Adopted Value | Source/Justification |
|---|---|---|
| Volume of Basement | 2250 $m^3$ | Assumes basement area of 30m by 30m and internal height of 2.5m. |
| Volume of Wet Basement | 5.3 $m^3$ | Assumes wet basement area of 15m (width) by 35m (length) and 0.01m (depth) which corresponds to half of the area of the basement anticipated to be wet (i.e. floor and 2 of 4 walls) |
| Enclosed space air exchange rate per day within basement | 96 | AS1668.2 minimum ventilation rate for car park 4 per hour (96 per day). |
| Fetch to Depth Ratio (wet section) | 1500 | Fetch is assumed to be 15m (width) and 0.01m (depth). |
| Concrete Permeability | $8.6x10^{-2}$ m/day | Conservative Value adopted for highly permeable concrete from *Gomes et al* (2003) |
| Windspeed within Basement | 0.03 m/sec | Conservative assumption based on the dimensions of the basement and the assumed air exchange rate (see **Section 5.3.2**) |

### 5.3.6 Scenario 2: Upper Basement

The CSM for an Upper Basement Level is depicted in **Figure F 5**.

The following points are relevant to this scenario:

- The upper most basement level is assumed to extend from the surface to 3 mbgs, such that (assuming an average depth to groundwater of 2 mbgs) water seepage is assumed to occur through the lower 1 m of the wall into the sealed plenum and vapours intruding through the upper 2 m of the wall may be derived from impacted soil, which is assumed to be present directly adjacent the outside of the wall. Refer to **Figure F 5**.
- Each basement level modelled as separately ventilated airspace. This is more conservative than modelling of mixing of vapours through multiple basement levels, especially for the lowermost level.
- It has been assumed that the uppermost basement level (but not lower basement levels) may be occupied by full-time workers, as portions of the upper most basement level may be used for loading/unloading of goods. It is also considered possible that full time car parking attendants may be present in the upper basement level.

- Basement levels between the upper most and the lower most have not been modelled, as basement walls at these levels will be below the water table and the criteria derived for the lower most basement level (Scenario 1) will be suitably protective.
- The potential for advection has been considered in the upper basement (top 2m) for soils present in the unsaturated zone.

#### 5.3.6.1 Contaminant Migration Pathways

Contaminant migration pathways relevant to potential human exposure to contaminants within an upper level basement are summarised below.

**Table 15: Contaminant Migration Pathways - Scenario 2 (Upper Basement)**

| Contaminant Migration Pathways | Relevant to Scenario? | Comments |
|---|---|---|
| Volatilisation to indoor air from groundwater adjacent or within the basement walls | No | Water is assumed to seep through the upper basement walls beneath the water table. See below. |
| Seepage of contaminants in groundwater to basements and volatilisation to indoor air within the basement. | Yes | It is possible that groundwater may seep into the basement areas however it is anticipated that the structure of the basement includes sufficient drainage to limit groundwater accumulation.<br>However to be conservative water has been modelled which seeps through the lower 1m of the basement of two walls into the sealed plenum. The basement dimensions for the upper basement are 25m x 3m x25m. It is considered that greater than half of the area where water can seep (i.e. lower 1m of wall) will be covered in water i.e. 25m$^2$. |
| Volatilisation and vapour migration from soil outside/adjacent the basement walls | Yes | Vapours derived directly from soil are considered to be significant only from 0-2 mbgs (i.e. within unsaturated zone). With advection being noted as the dominant vapour exposure pathway for soils within the unsaturated zone. Below this level (within the saturated zone), diffusion from water seepage is considered to be the dominant vapour pathway. |
| Volatilisation to indoor air from groundwater or soil below basement floor | No | Upper level basement will not have floor overlying contaminated soil and/or groundwater. Note that this has been considered in Scenario 1. The water seepage has only considered migration from two of the four walls beneath the saturated zone. |

#### 5.3.6.2 Human Receptors

The upper level basement car park at the Site may be frequented by a range of human receptors, including commercial workers, customers, tourists and residents within the development. However, in contrast to the lower level basement levels (access to which is assumed to be primarily for travel to and from parked vehicles), the upper level basement level is assumed to also be used for loading/unloading of commercial goods and/or staffed by full-time car park attendants.

The most sensitive receptor in the upper basement level is therefore likely to be an adult worker. Consideration of worker exposure will also be protective of other receptors (e.g. residents, customers, etc) that may also be present in the upper basement level, but for shorter periods of time.

#### 5.3.6.3 Exposure Pathways

Potential pathways via which the above receptors may be exposed to Site-derived contamination are summarised in **Table 16** below.

**Table 16: Exposure Pathway Analysis - Scenario 2 (Upper Basement)**

| Exposure Pathway | Complete? | Notes |
| --- | --- | --- |
| **Adult Worker (Car park attendant and/or workers involved in loading/unloading of commercial goods)** | | |
| Incidental ingestion of chemicals in soil | × | Basement construction will preclude direct contact and/or dust generation from soils |
| Dermal absorption of chemicals from soil | × | |
| Inhalation of chemicals in soil-derived airborne particulates | × | |
| Inhalation of soil-derived vapours | ✓ | Potentially complete and significant pathway. |
| Incidental ingestion of chemicals in groundwater (incidental contact) | × | Groundwater seepage is considered to be unlikely to accumulate on walls based on the building design. However to be conservative sections of basement wall beneath the water table have been considered for water seepage. The basement design allows for a sealed plenum wall which restricts any direct contact with basement walls by receptors. |
| Dermal absorption of chemicals in groundwater (incidental contact) | × | |
| Inhalation of groundwater derived vapours | ✓ | Potentially complete and significant pathway. |

#### 5.3.6.4 Exposure Parameters

Human exposure parameters adopted for Scenario 2 are summarised in **Table 17** below.

**Table 17: Exposure Parameters - Scenario 2 (Upper Basement)**

| Parameter (units) | Adopted Value | Source/Reference |
| --- | --- | --- |
| Exposure Time (hours/day) | 8 | Default for worker (assumes average 8 hour workday) |
| Exposure Frequency (days/year) | 240 | Default for worker (assumes workers are present 5 days/week and 48 weeks/year) |
| Exposure Duration (years) | 30 | NEPC (1999a) and enHealth (2004). |

#### 5.3.6.5 Vapour Transport Modelling

Vapour modelling associated with soil was undertaken using the Johnson and Ettinger (1991) vapour transport model (**Section 5.3.2**). It is noted that both diffusive and advective transport processes were considered in the unsaturated zone adjacent to basement wall.

Vapour modelling associated with groundwater which may be present on the inner walls of the upper basement below the water table was undertaken using the USEPA Water 9 model (**Section 5.3.2**).

Further detail on the vapour transport modelling is provided in Appendix B and the calculations are provided in Appendix D.

The geologic, hydrogeologic and building parameters adopted for vapour intrusion modelling for Scenario 2 are summarised in **Table 18** below.

**Table 18: Vapour Modelling Assumptions - Scenario 2 (Upper Basement)**

| Parameter (units) | Adopted Value | Source/Justification |
|---|---|---|
| **Vadose Zone and Hydrogeologic Parameters – Soil to Indoor Air** | | |
| Depth to soil contamination (cm) | 0.001 | Negligible distance – assumes soil is directly adjacent building foundation. |
| Fraction of organic carbon in soil source (unitless) | 0.002 | USEPA (2004a) defaults for coarse sand/gravel |
| Soil bulk density ($g/cm^3$) | 1.66 | |
| Total porosity in soil source zone (for soil model) (unitless) | 0.375 | |
| Air filled porosity in soil source zone (unitless) | 0.321 | |
| Water filled porosity in soil source zone (unitless) | 0.054 | |
| Vapour phase source partitioning adjustment (unitless) | 10 | A factor of 10 has been applied to soil-to-vapour partitioning equation associated with BTEX, TPH $C_6$-$C_9$, $C_{10}$-$C_{14}$, to reflect the differences observed between theoretical estimates of partitioning and field measurements (see CCME, 2008b and Friebel and Nadebaum, 2010, CRC, 2010). |
| **Building Parameters – Soil to Indoor Air** | | |
| Ratio of enclosed space volume to infiltration area (cm) | 1,875 | Assumes basement area of 25 m by 25 m and internal height of 3 m, based on dimensions for smallest separately ventilated upper basement, as shown on plans provided by LL (northern-most B1 level; see cross-section 2 on SK107A in **Appendix A).** Note that this diagram is indicative only and subject to design development. Infiltration area for soil assumed to comprise the upper 2 m of two of the four walls (100 $m^2$), since plenum ventilation system will result in vapours from one wall being forced into the building and vapours from opposite wall being forced out of the building. In addition, vapours may also enter basement through one additional wall. Enclosed volume assumed to be 25 m by 25 m by 3 m = 1875 $m^3$. It has been assumed that no independently ventilated basement structure will have more than two of four walls adjacent to residual contamination (i.e. entire basement excavation area is large and only some sections of basement walls will face towards soil and groundwater). |
| Enclosed space foundation/wall thickness (cm) | 15 | Conservative default; note that LL plans specify outer diaphragm walls of 600 mm thickness, but shorter thickness has been assumed as a conservative measure. |
| Advective vapour flow rate | Calculated | Calculated based on foundation dimensions, pressure differential and vapour permeability |
| Soil vapour permeability ($cm^2$) | $1 \times 10^{-7}$ | USEPA, 2004a default for sand/gravel. |
| Indoor-outdoor pressure differential ($g/cm\text{-}s^2$) | 40 | USEPA, 2004a conservative default. |
| Enclosed space air exchange rate ($s^{-1}$) | 0.001 | AS1668.2 minimum ventilation rate for car park (4 per hour). |

| Parameter (units) | Adopted Value | Source/Justification |
|---|---|---|
| Areal fraction of cracks in foundations/walls | 0.0002 | USEPA (2004a) default value for basements. |
| Total porosity in foundation/wall cracks | 0.375 | Assumes foundation/wall cracks filled with sand (values are USEPA, 2004a defaults for coarse sand). |
| Air filled porosity in foundation/wall cracks | 0.321 | |
| Water filled porosity in foundation/wall cracks | 0.054 | |

#### 5.3.6.6 Estimation of Volatile Emissions from Seepage Water within Basement

The estimation of potential volatile emissions associated with groundwater within a basement from water which has seeped through either basement walls and/or floors has been undertaken and previously described in **Section 5.3.2**.

The geologic, hydrogeologic and building parameters adopted for volatilisation seepage model for Scenario 2 are summarised in **Table 19** below. Chemical-specific properties used in the calculations are included in **Appendix D**.

**Table 19: Seepage Modelling Assumptions - Scenario 2 (Upper Basement)**

| Parameter (units) | Adopted Value | Source/Justification |
|---|---|---|
| Volume of Basement | 1875 $m^3$ | Assumes basement area of 25 m by 25 m and internal height of 3 m. |
| Volume of Wet Basement | 0.25 $m^3$ | Assumes wet basement area of half the total area anticipated to be wet (5 m (length) by 5 m (width) and 0.01m (depth). |
| Enclosed space air exchange rate per day within basement | 96 | AS1668.2 minimum ventilation rate for car park 4 per hour (96 per day). |
| Fetch to Depth Ratio (wet section) | 500 | Fetch is assumed to be 5 m (width) and 0.01m (depth). |
| Concrete Permeability | $8.6 \times 10^{-2}$ m/day | Conservative Value adopted for highly permeable concrete from *Gomes et al* (2003) |
| Windspeed within Basement | 0.03 m/sec | Conservative assumption based on dimensions of the basement and the assumed air exchange rate (see **Section 5.3.2**) |

### 5.3.7 Scenario 3: Unpaved Recreation

The unpaved recreation scenario is assumed to represent areas of the site which, following development, may be used for public open space and which may not have a concrete surface covering present.

Unpaved open space (Scenario 3) areas of the Site will be covered in a minimum of 0.5 m of suitable fill. Suitable fill of greater than 0.5 m thickness is recommended in areas where deeper rooting trees will be planted. For the purposes of unpaved open space (Scenario 3), suitable fill is defined as either:

- virgin excavated natural material (VENM); or
- soil which contains contaminant concentrations below the terrestrial soil criteria (developed for the maintenance of plant health and human health (refer to **Section 7.3** and **Table 46**).

#### 5.3.7.1 Contaminant Migration Pathways

Contaminant migration pathways relevant to potential human exposure to contaminants within unpaved recreation/open space areas are summarised below.

**Table 20: Contaminant Migration Pathways - Scenario 3 (Unpaved Recreation)**

| Contaminant Migration Pathways | Relevant to Scenario? | Comments |
|---|---|---|
| Volatilisation from soil and vapour migration to outdoor air | Yes | While significant accumulation of vapours in outdoor air is considered unlikely, it is possible that soil or groundwater derived vapours may be dispersed in outdoor air within public open space/recreation areas at the Site. However it is considered that there would be significant biodegradation processes occurring within the surface soils based on the measured oxygen concentrations within the soil profile being >5% (**Section 2.9**). To account for the potential for degradation processes to be occurring, a 10 fold factor has been applied to the modelled soil vapour concentrations taken from Davis et al (2009). |
| Volatilisation from groundwater and vapour migration to outdoor air | Yes | |
| Migration of outdoor air/vapours to indoor airspaces | Potentially | Significant levels of soil or groundwater derived contaminants in outdoor air are not expected to reach indoor air spaces due to significant mixing and degradation processes which would occur. |

### 5.3.7.2 Human Receptors

It is considered that adults and children may frequent the outdoor unpaved areas of the site for periods up to 2 hours per day, 365 days per year.

### 5.3.7.3 Exposure Pathways

Potential pathways via which the above receptors may be exposed to Site-derived contamination are summarised in **Table 21** below.

**Table 21: Exposure Pathway Analysis - Scenario 3 (Unpaved Recreation)**

| Exposure Pathway | Complete? | Notes |
|---|---|---|
| **Adult and Child Residents** | | |
| Incidental ingestion of chemicals in soil | × | Unpaved recreation areas assumed to be covered/landscaped with minimum 50 cm suitable fill as defined in **Section 5.3.7** above |
| Dermal absorption of chemicals from soil | × | |
| Inhalation of chemicals in soil-derived airborne particulates | × | |
| Inhalation of soil-derived vapours | ✓ | Potentially complete and significant pathway. |
| Incidental ingestion of chemicals in groundwater (incidental contact) | × | Groundwater present at average 2 mbgs and assumed not to be contacted by Site receptors. |
| Dermal absorption of chemicals in groundwater (incidental contact) | × | |
| Inhalation of groundwater derived vapours | ✓ | Potentially complete and significant pathway. |

### 5.3.7.4 Exposure Parameters

Human exposure parameters adopted for Scenario 3 are summarised in **Table 22** below.

**Table 22: Exposure Parameters - Scenario 3 (Unpaved Recreation)**

| Parameter (units) | Adopted Value | Source/Reference |
|---|---|---|
| Exposure Time (hours/day) | 2 | Professional judgement, conservative assumption. |
| Exposure Frequency (days/year) | 365 | Conservative assumption. |
| Exposure Duration (years) | 6 (child)<br>64 (adult) | NEPC (1999a) and enHealth (2004). Assumes recreational users may frequent the outdoor unpaved areas of the site for their entire lifetime, assumed to be 70 years. |

#### 5.3.7.5 Vapour Transport Modelling

Soil and groundwater vapour modelling was undertaken using the Johnson and Ettinger (1991) vapour transport model as summarised in **Section 5.3.2** and described in more detail in **Appendix B**. The vapour modelling calculations for Scenario 4 are included in **Appendix E**.

The CRC draft health screening levels for petroleum hydrocarbons (Friebel and Nadebaum 2010) have also accounted for biodegradation and adjustments between 10 and 100 fold are applicable to derived criteria when evidence of oxygen >5% and or certain site conditions are met. CCME (2008b) has also reported that not accounting for biodegradation could result in the risks being overestimated 10 to 1000 times.

Polycyclic aromatic hydrocarbons such as acenaphthene, acenaphthylene, phenanthrene and pyrene and compounds such as dibenzofuran are known to have half lives in soil and groundwater which range from 4 weeks to 5 years (Howard et al, 1991)[2] and relatively shorter half lives in air ranging from 1 hour to 24 hours. The relatively rapid half life in air is predominately due to biodegradation and hydrolysis.

AECOM has measured oxygen from a range of depths (1.6-2.5 mbgs) from beneath the Site between 4.2% and 17.6%, indicating that the conditions currently and in the future for unpaved and paved areas of the site will be influenced by the presence of oxygen. It is noted that future conditions are likely to have a higher level of oxygen present due to the nature of the fill material to be brought onto the site (i.e. less compacted than the current natural material). AECOM considers that the current slab conditions are a conservative representation of potential future paved areas of the site. The presence of oxygen beneath the site and within the soil indicates that the conditions are favourable for biodegradation processes.

It is considered appropriate that a 10 fold factor is applied to the modelled soil concentrations at the Barangaroo site to account for biodegradation processes, as measured oxygen within the sub-surface at the site was greater than 5%.

The geologic, hydrogeologic and building parameters adopted for vapour intrusion modelling for Scenario 4 are summarised in **Table 23** below.

[2] Handbook of Environmental Degradation Rates, Philip H Howard, Robert S Boethling, William F Jarvis, William M Meylan, Edward M Michalenko, Lewis Publishers, 1991, CRC Press LLC.

**Table 23: Vapour Modelling Assumptions - Scenario 3 (Unpaved Recreation)**

| Parameter (units) | Adopted Value | Source/Justification |
|---|---|---|
| **Vadose Zone and Hydrogeologic Parameters – Soil to Outdoor Air** | | |
| Depth to soil contamination (cm) | 50 | Unpaved recreation areas assumed to be covered/landscaped with minimum 50 cm suitable fill as defined in **Section 5.3.7** above |
| Fraction of organic carbon in soil source (unitless) | 0.002 | USEPA (2004a) defaults for coarse sand/gravel |
| Soil bulk density ($g/cm^3$) | 1.66 | |
| Total porosity in soil source zone (for soil model) (unitless) | 0.375 | |
| Air filled porosity in soil source zone (unitless) | 0.321 | |
| Water filled porosity in soil source zone (unitless) | 0.054 | |
| Vapour phase source partitioning adjustment (unitless) | 10 | A factor of 10 has been applied to soil-to-vapour partitioning equation associated with BTEX, TPH $C_6$-$C_9$, $C_{10}$-$C_{14}$, to reflect the differences observed between theoretical estimates of partitioning and field measurements (see CCME, 2008b and Friebel and Nadebaum, 2010, CRC, 2010). |
| Biodegradation adjustment factor (unitless) | 10 | Adjustment for assumed presence of oxygen (and associated biodegradation of vapours) in unpaved areas. Factor of 10 is considered conservative as it is at lower end of ranges suggested by Davis et al. (2009) and CCME (2008b). |
| **Vadose Zone and Hydrogeologic Parameters – Groundwater to Outdoor Air** | | |
| Depth to groundwater contamination (cm) | 200 | Based on reported average depth to groundwater of 2 m.<br>Capillary zone thickness is USEPA (2004a) default value for sand aquifer.<br>Vadose zone thickness calculated as depth to water less capillary zone thickness. The default capillary zone thickness for sand (USEPA, 2004a) has been adopted after review of borelogs for bores drilled in locations where this scenario is likely to be applied. It was determined that the predominant soil type in these areas was sand, silty sand, clayey sand and gravelly sand. As the presence of other soil types with sand is likely to increase the capillary zone thickness it was considered conservative to assume the capillary zone thickness of sand as this soil type displays the lowest capillary thickness. |
| Vadose zone thickness (cm) | 183 | |
| Thickness of capillary zone (cm) | 17 | |
| Total porosity in vadose zone (unitless) | 0.375 | USEPA (2004a) defaults for sand (residual impacted soil and imported fill conservatively assumed to be sandy) |
| Air filled porosity in vadose zone (unitless) | 0.321 | |
| Water filled porosity in vadose zone (unitless) | 0.054 | |
| Total porosity in capillary zone (unitless) | 0.375 | USEPA (2004a) default for sand (considered conservative for mixed soil/fill types reported at site). |

| Parameter (units) | Adopted Value | Source/Justification |
|---|---|---|
| Air filled porosity in capillary zone (unitless) | 0.122 | |
| Water filled porosity in capillary zone (unitless) | 0.253 | |
| **Outdoor/Ambient Air Characteristics** | | |
| Wind speed (cm/s) | 378 | Average annual 9 am and 3 pm wind speeds measured at observatory point in Sydney (BOM, 2010). |
| Width of source area parallel to wind (cm) | 4500 | Conservative default – assumed receptor is downwind of 45 m source zone and all vapours from that zone reach receptor. |
| Ambient air mixing zone height (cm) | 200 | Conservative default – assumes all emitted vapours are mixed within two metres of ground surface. |

### 5.3.8 Scenario 4: Paved Recreation

The paved recreation scenario is assumed to represent areas of the site which, following development, may be used for public open space and which will have hardstand/concrete surface covering.

It is noted that the development of SSTCs for paved recreation has been based on the presence of a concrete/ hardstand cover to a minimum thickness of 10cm. The SSTCs for soil have been developed to be placed directly below this cover. It is however noted that in the future areas where paving is present may be unpaved, so it is recommended that at least half a meter (0.5m) of suitable fill be placed below areas of the Site that will be paved. Suitable fill is defined as either:

- virgin excavated natural material (VENM); or
- soil which contains contaminant concentrations below the terrestrial soil criteria (developed for the maintenance of plant health and human health (refer to **Section 7.3** and **Table 46**).

It is noted that there is little change in the developed SSTCs for paved recreation whether the material is placed beneath paving (i.e. 10cm depth) or if the material is placed below a 50cm "suitable material" buffer. It is also noted that the soils placed within the unsaturated zone in public open space will be dominated by the lowest derived human health SSTC from Scenario 3, 4, 5 and 6.

#### 5.3.8.1 Contaminant Migration Pathways

Contaminant migration pathways relevant to potential human exposure to contaminants within paved recreation/open space areas are summarised below.

**Table 24: Contaminant Migration Pathways - Scenario 4 (Paved Recreation)**

| Contaminant Migration Pathways | Relevant to Scenario? | Comments |
|---|---|---|
| Volatilisation from soil and vapour migration to outdoor air | Yes | While significant accumulation of vapours in outdoor air is considered unlikely, it is possible that soil or groundwater derived vapours may be dispersed in outdoor air within public open space/recreation areas at the Site. |
| Volatilisation from groundwater and vapour migration to outdoor air | Yes | |
| Migration of outdoor air/vapours to indoor airspaces | Potentially | Significant levels of soil or groundwater derived contaminants in outdoor air are not expected to reach indoor air spaces due to significant mixing and degradation processes which would occur, |

#### 5.3.8.2 Human Receptors

It is considered that adults and children may frequent the outdoor unpaved areas of the site for periods up to 2 hours per day, 365 days per year.

#### 5.3.8.3 Exposure Pathways

Potential pathways via which the above receptors may be exposed to Site-derived contamination are summarised in **Table 25** below.

**Table 25: Exposure Pathway Analysis - Scenario 4 (Paved Recreation)**

| Exposure Pathway | Complete? | Notes |
|---|---|---|
| **Adult and Child Residents** | | |
| Incidental ingestion of chemicals in soil | × | Paved recreation areas assumed to be covered with concrete or other hardstand, which would preclude direct contact and/or generation of dust from contaminated soil. |
| Dermal absorption of chemicals from soil | × | |
| Inhalation of chemicals in soil-derived airborne particulates | × | |
| Inhalation of soil-derived vapours | ✓ | Potentially complete and significant pathway. |
| Incidental ingestion of chemicals in groundwater (incidental contact) | × | Groundwater present at average 2 mbgs and assumed not to be contacted by Site receptors. |
| Dermal absorption of chemicals in groundwater (incidental contact) | × | |
| Inhalation of groundwater derived vapours | ✓ | Potentially complete and significant pathway. |

#### 5.3.8.4 Exposure Parameters

Human exposure parameters adopted for Scenario 4 are summarised in **Table 26** below.

**Table 26: Exposure Parameters - Scenario 4 (Paved Recreation)**

| Parameter (units) | Adopted Value | Source/Reference |
|---|---|---|
| Exposure Time (hours/day) | 2 | Professional judgement, conservative assumption. |
| Exposure Frequency (days/year) | 365 | Conservative assumption. |
| Exposure Duration (years) | 6 (child)<br>64 (adult) | NEPC (1999a) and enHealth (2004). Assumes recreational users may frequent the outdoor unpaved areas of the site for their entire lifetime, assumed to be 70 years. |

#### 5.3.8.5 Vapour Transport Modelling

Soil and groundwater vapour transport modelling was undertaken using the Johnson and Ettinger (1991) vapour transport models summarised in **Section 5.3.2** and described in more detail in **Appendix B**. The vapour modelling calculations for Scenario 5 are included in **Appendix F**.

The geologic, hydrogeologic and building parameters adopted for vapour intrusion modelling for Scenario 4 are summarised in **Table 27** below. The vapour transport modelling for paved recreation has also considered the potential for biodegradation as discussed in **Section 5.3.7.5** above.

**Table 27: Vapour Modelling Assumptions - Scenario 4 (Paved Recreation)**

| Parameter (units) | Adopted Value | Source/Justification |
|---|---|---|
| **Vadose Zone and Hydrogeologic Parameters – Soil to Outdoor Air** | | |
| Depth to soil contamination (cm) | 0.01 | Negligible value – assumes soil contamination may be present directly beneath concrete/hardstand at Site. It should be noted that it is recommended that at least a half a meter of suitable material (**Section 5.3.8**) be placed above the remediated/ validated soils beneath the proposed paved areas of the Site to account for changes to outdoor use in the future and to allow for biodegradation processes within the surficial soils. It is noted that the derived SSTC are saturation limited whether a 0.01 or 50cm depth is assumed. |
| Fraction of organic carbon in soil source (unitless) | 0.002 | USEPA (2004a) defaults for coarse sand/gravel |
| Soil bulk density ($g/cm^3$) | 1.66 | |
| Total porosity in soil source zone (for soil model) (unitless) | 0.375 | |
| Air filled porosity in soil source zone (unitless) | 0.321 | |
| Water filled porosity in soil source zone (unitless) | 0.054 | |
| Vapour phase source partitioning adjustment (unitless) | 10 | A factor of 10 has been applied to soil-to-vapour partitioning equation associated with BTEX, TPH $C_6$-$C_9$, $C_{10}$-$C_{14}$, to reflect the differences observed between theoretical estimates of partitioning and field measurements (see CCME, 2008b and Friebel and Nadebaum, 2010, CRC, 2010). |
| Biodegradation adjustment factor (unitless) | 10 | Adjustment for assumed presence of oxygen (and associated biodegradation of vapours) in unpaved areas. Factor of 10 is considered conservative as it is at lower end of ranges suggested by Davis et al. (2009) and CCME (2008b). |
| **Vadose Zone and Hydrogeologic Parameters – Groundwater to Outdoor Air** | | |
| Depth to groundwater contamination (cm) | 200 | Based on reported average depth to groundwater of 2 m, allowing for USEPA (2004a) default capillary zone thickness for sand aquifer and for concrete surface covering. Vadose zone thickness calculated as depth to water less capillary zone thickness less concrete thickness. The default capillary zone thickness for sand (USEPA, 2004a) has been adopted after review of borelogs for bores drilled in locations where this scenario is likely to be applied. It was determined that the predominant soil type in these areas was sand, silty sand, clayey sand and gravelly sand. As the presence of other soil types with sand is likely to increase the capillary zone thickness is was considered conservative to assume the capillary zone thickness of sand as this soil type displays the lowest capillary thickness. |
| Vadose zone thickness (cm) | 173 | |
| Thickness of capillary zone (cm) | 17 | |
| Total porosity in vadose zone (unitless) | 0.375 | USEPA (2004a) defaults for sand (residual impacted soil and imported fill conservatively assumed to be sandy) |

| Parameter (units) | Adopted Value | Source/Justification |
|---|---|---|
| Air filled porosity in vadose zone (unitless) | 0.321 | |
| Water filled porosity in vadose zone (unitless) | 0.054 | |
| Total porosity in capillary zone (unitless) | 0.375 | USEPA (2004a) default for sand (considered conservative for mixed soil/fill types reported at site). |
| Air filled porosity in capillary zone (unitless) | 0.122 | |
| Water filled porosity in capillary zone (unitless) | 0.253 | |
| **Concrete Surface Cover Characteristics** | | |
| Concrete thickness (cm) | 10 | Conservative assumption. Concrete thickness considered likely to be greater than 10 cm. |
| Areal crack fraction (unitless) | 0.01 | Conservative assumption to account for potential cracks in concrete cover. Note that 0.01 (1%) cracks is equivalent to the presence of a one metre long 1 cm crack within every square meter of concrete. |
| Total porosity in concrete cracks | 0.375 | Assumes cracks in concrete surface cover are filled with sand (values are USEPA, 2004a defaults for coarse sand). |
| Air filled porosity in concrete cracks | 0.321 | |
| Water filled porosity in concrete cracks | 0.054 | |
| **Outdoor/Ambient Air Characteristics** | | |
| Wind speed (cm/s) | 378 | Average annual 9 am and 3 pm wind speeds measured at observatory point in Sydney (BOM, 2010). |
| Width of source area parallel to wind (cm) | 4500 | Conservative default – assumed receptor is downwind of 45 m source zone and all vapours from that zone reach receptor. |
| Ambient air mixing zone height | 200 | Conservative default – assumes all emitted vapours are mixed within two metres of ground surface. |

### 5.3.9 Scenario 5: Commercial Slab on Ground

The commercial slab on ground scenario has been considered to account for the possible presence of mixed retail and commercial premises (e.g. cafes or small shops) of one or two storey's (only) in the Public Domain of the final development, i.e. overlying areas where basements will not be present.

Therefore it is considered that diffusion will be the dominant vapour intrusion pathway, with advection considerations being negligible.

#### 5.3.9.1 Contaminant Migration Pathways

Contaminant migration pathways relevant to potential human exposure to contaminants within commercial slab on ground premises are summarised below.

**Table 28: Contaminant Migration Pathways – Scenario 5 (Commercial Slab on Ground)**

| Contaminant Migration Pathways | Relevant to Scenario? | Comments |
|---|---|---|
| Volatilisation from soil and vapour migration to indoor air | Yes | It is possible that soil or groundwater derived vapours may accumulate within indoor airspaces overlying contaminated soil or groundwater. |
| Volatilisation from groundwater and vapour migration to indoor air | Yes | |

#### 5.3.9.2 Human Receptors

The most highly exposed receptor within mixed retail/commercial premises at the Site would be a full-time worker. Consideration of a potential full-time worker will also be protective of other receptors (e.g. customers, visitors, part-time workers) who may also be present in retail premises but for shorter periods of time.

#### 5.3.9.3 Exposure Pathways

Potential pathways via which the above receptors may be exposed to Site-derived contamination are summarised in Table 29 below.

**Table 29 Exposure Pathway Analysis - Scenario 5 (Commercial Slab on Ground)**

| Exposure Pathway | Complete? | Notes |
|---|---|---|
| **Adult and Child Residents** | | |
| Incidental ingestion of chemicals in soil | × | Recreation areas around retail premises assumed to be covered with concrete hardstand or landscaped with clean fill, which would preclude direct contact and/or generation of dust from contaminated soil. |
| Dermal absorption of chemicals from soil | × | |
| Inhalation of chemicals in soil-derived airborne particulates | × | |
| Inhalation of soil-derived vapours | ✓ | Potentially complete and significant pathway. |
| Incidental ingestion of chemicals in groundwater (incidental contact) | × | Groundwater present at average 2 mbgs and assumed not to be contacted by Site receptors. |
| Dermal absorption of chemicals in groundwater (incidental contact) | × | |
| Inhalation of groundwater derived vapours | ✓ | Potentially complete and significant pathway. |

Human exposure parameters adopted for Scenario 5 are summarised in **Table 30** below.

**Table 30: Exposure Parameters - Scenario 5 (Commercial Slab on Ground)**

| Parameter (units) | Adopted Value | Source/Reference |
|---|---|---|
| Exposure Time (hours/day) | 8 | Default for worker (assumes average 8 hour workday) |
| Exposure Frequency (days/year) | 240 | Default for worker (assumes workers are present 5 days/week and 48 weeks/year) |
| Exposure Duration (years) | 30 | NEPC (1999a) and enHealth (2004). |

#### 5.3.9.4 Vapour Transport Modelling

Soil and groundwater vapour transport modelling was undertaken using the Johnson and Ettinger vapour transport models summarised in **Section 5.3.2** and described in more detail in **Appendix B**. The vapour modelling calculations for Scenario 5 are included in **Appendix G**.

The geologic, hydrogeologic and building parameters adopted for vapour intrusion modelling for Scenario 5 are summarised in **Table 31** below.

**Table 31: Vapour Modelling Assumptions - Scenario 5 (Commercial Slab on Ground)**

| Parameter (units) | Adopted Value | Source/Justification |
|---|---|---|
| **Vadose Zone and Hydrogeologic Parameters – Soil to Indoor Air** | | |
| Depth to soil contamination (cm) | 0.001 | Negligible distance – assumes soil is directly adjacent building foundation. |
| Fraction of organic carbon in soil source (unitless) | 0.002 | USEPA (2004a) defaults for coarse sand/gravel |
| Soil bulk density ($g/cm^3$) | 1.66 | |
| Total porosity in soil source zone (for soil model) (unitless) | 0.375 | |
| Air filled porosity in soil source zone (unitless) | 0.321 | |
| Water filled porosity in soil source zone (unitless) | 0.054 | |
| Vapour phase source partitioning adjustment (unitless) | 10 | A factor of 10 has been applied to soil-to-vapour partitioning equation associated with BTEX, TPH $C_6$-$C_9$, $C_{10}$-$C_{14}$ to reflect the differences observed between theoretical estimates of partitioning and field measurements (see CCME, 2008b and Friebel and Nadebaum, 2010, CRC, 2010). |
| **Vadose Zone and Hydrogeologic Parameters – Groundwater to Indoor Air** | | |
| Depth to groundwater contamination (cm) | 200 | Based on reported average depth to groundwater of 2 m.<br>Capillary zone thickness is USEPA (2004a) default value for sand aquifer.<br>Vadose zone thickness calculated as depth to water less capillary zone thickness.<br>The default capillary zone thickness for sand (USEPA, 2004a) has been adopted after review of borelogs for bores drilled in locations where this scenario is likely to be applied. It was determined that the predominant soil type in these areas was sand, silty sand, clayey sand and gravelly sand. As the presence of other soil types with sand is likely to increase the capillary zone thickness is was considered conservative to assume the capillary zone thickness of sand as this soil type displays the lowest capillary thickness. |
| Vadose zone thickness (cm) | 183 | |
| Thickness of capillary zone (cm) | 17 | |
| Total porosity in vadose zone (unitless) | 0.375 | USEPA (2004a) defaults for sand (residual impacted soil and imported fill conservatively assumed to be sandy) |
| Air filled porosity in vadose zone (unitless) | 0.321 | |
| Water filled porosity in vadose zone (unitless) | 0.054 | |

| Parameter (units) | Adopted Value | Source/Justification |
|---|---|---|
| Total porosity in capillary zone (unitless) | 0.375 | USEPA (2004a) default for sand (considered conservative for mixed soil/fill types reported at site). |
| Air filled porosity in capillary zone (unitless) | 0.122 | |
| Water filled porosity in capillary zone (unitless) | 0.253 | |
| **Building Parameters** | | |
| Ratio of enclosed space volume to infiltration area (cm) | 300 | Assumes ceiling height of 3 m within commercial/retail premises. |
| Enclosed space foundation/wall thickness (cm) | 15 | ASTM (2002) default – considered conservative for commercial/retail premises. |
| Enclosed space air exchange rate ($s^{-1}$) | $5.6x10^{-4}$ | 2 exchanges per hour have been assumed for commercial buildings |
| Areal fraction of cracks in foundations/walls | 0.00038 | USEPA (2004a) default value for slab on ground. |
| Total porosity in foundation/wall cracks | 0.375 | Assumes foundation/wall cracks filled with sand (values are USEPA, 2004a defaults for coarse sand). |
| Air filled porosity in foundation/wall cracks | 0.321 | |
| Water filled porosity in foundation/wall cracks | 0.054 | |
| Convective vapour flow rate | 0.001 | Assumes vapour advection from subslab to indoor air is negligible. This is considered reasonable given the generally warm climate through most of the year (such that significant stack effects due to heating are unlikely) and that retail premises in the development would likely be well ventilated during operation due to frequent entry and exit of patrons. Coffee shops and similar premises would also likely operate with open doors during much of the year, be erected as a slab on ground (not above basement carparks) and have a maximum of two storey's above ground level. |

### 5.3.10 Scenario 6: Intrusive Maintenance

The intrusive maintenance scenario has been considered to account for potential future intrusive maintenance activities which may be undertaken following redevelopment of the Site. It should be noted that modelling of exposure and risks to intrusive receptors is associated with a high degree of uncertainty, as it is not possible to accurately predict the nature and extent of intrusive works which may occur at the site in the future. The intrusive worker considered in this assessment was assumed to only occasionally and/or intermittently conduct intrusive works at the site (e.g. as required to maintain underground services), but is not assumed to undertake longer term intrusive works, such as construction or redevelopment of the site. Potential risks to a worker involved in extended periods of intrusive works at the site would need to be considered and managed in the future should such activities occur.

It is also noted that risks to construction and/or remediation workers during the planned remediation and redevelopment of the Site have been considered in a separate study reported under separate cover.

#### 5.3.10.1 Contaminant Migration Pathways

Contaminant migration pathways relevant to potential human exposure to contaminants by intrusive maintenance workers are summarised below.

**Table 32: Contaminant Migration Pathways – Scenario 6 (Intrusive Maintenance)**

| Contaminant Migration Pathways | Relevant to Scenario? | Comments |
|---|---|---|
| Volatilisation from soil and vapour migration to within trenches/excavations | Yes | It is possible that soil or groundwater derived vapours may accumulate within trench airspaces overlying contaminated soil or groundwater. |
| Seepage of groundwater to within trenches or excavations | Yes | Due to the shallow nature of and tidal influence on groundwater levels at the Site, groundwater may seep into maintenance trenches or other excavations. |
| Volatilisation from groundwater (within trench) to trench air | Yes | Vapours derived from groundwater which has seeped into a trench may volatilise to outdoor/trench air. |
| Volatilisation from subsurface groundwater and vapour migration to within trenches/excavations | No | While this contaminant migration pathway may be relevant for a shallow trench scenario (less than 1 mbgs), the more conservative scenario where groundwater is assumed to enter the trench has been modelled for this scenario. |

#### 5.3.10.2 Human Receptors

The most highly exposed receptor for the intrusive maintenance scenario is a short term maintenance worker involved in maintenance/excavation activities. This level of exposure is considered to be protective of a casual observer, or banksman, above the trench.

#### 5.3.10.3 Exposure Pathways

Potential pathways via which the above receptors may be exposed to Site-derived contamination are summarised in **Table 33** below.

**Table 33: Exposure Pathway Analysis - Scenario 6 (Intrusive Maintenance)**

| Exposure Pathway | Complete? | Notes |
|---|---|---|
| **Adult Intrusive Worker** | | |
| Incidental ingestion of chemicals in soil | ✓ | Workers may come into contact with soil exposed as a result of excavation activities. |
| Dermal absorption of chemicals from soil | ✓ | |
| Inhalation of chemicals in soil-derived airborne particulates (within trench) | ✓ | Airborne dust may be generated from exposed soils within trench. |
| Inhalation of soil-derived vapours | ✓ | Chemicals may volatilise from exposed soils within trench and accumulate within the trench airspace. |
| Incidental ingestion of chemicals in groundwater (incidental contact) | ✓ | Workers may come into contact with shallow groundwater which has seeped into trench extending below the water table. |
| Dermal absorption of chemicals in groundwater (incidental contact) | ✓ | |
| Inhalation of groundwater derived vapours | ✓ | Groundwater derived vapours are assumed to volatilise from groundwater which has seeped into trench. |

#### 5.3.10.4 Exposure Parameters

Human exposure parameters adopted for Scenario 6 are summarised in **Table 34** below.

**Table 34: Exposure Parameters - Scenario 6 (Intrusive Maintenance)**

| Parameter (units) | Adopted Value | Source/Reference |
|---|---|---|
| Body weight (kg) | 70 | USEPA (1989). Note that enHealth (2004) and NEPC (1999a) recommended value of 64 kg has not been adopted as it is based on reported body weights in developing countries and is not considered representative of body weights for the Australian population. |
| Exposure Frequency (days/year) | 15 | Professional judgement – allows for up to 3 working weeks of maintenance at the Site to be undertaken by the same maintenance worker. |
| Exposure Duration (years) | 1 | Assumes maintenance work at the Site will be undertaken by different workers from year to year (i.e. it is not considered likely that the same worker would return to undertake maintenance work over consecutive years, based on the intermittent and random nature of maintenance work that would be expected at the Site). |
| Exposure Time for Inhalation (hours/day) | 8 | Conservatively assumes worker may work within trench for entire workday (8 hours/day). |
| Incidental Soil Ingestion Rate (mg/day) | 330 | USEPA (2002) recommended value for construction workers. |
| Exposed Skin Surface Area for Soil Contact ($cm^2$/day) | 3,600 | Assumes that workers will wear long pants and that head, forearms and hands may be in contact with soil. Based on 50$^{th}$ percentile skin surface area for males (from Table 6-2 within USEPA, 1997). |
| Soil to Skin Adherence Factor ($mg/cm^2$) | 1.5 | Dermal adherence factor US EPA (2009 update) Exposure Factor Handbook. Range for construction worker was from 1.4-1.6, average value has been adopted. |
| Exposed Skin Surface Area for Groundwater Contact | 3,870 | Assumes that lower legs and feet may be wetted while workers stand in pooled water within trench. Based on 50$^{th}$ percentile skin surface area for males (from Table 6-2 within USEPA, 1997). |
| Exposure Time for Water Contact (hours/day) | 1 | Professional judgement; assumes that worker would not be wading/standing in water for more than one hour per day (on average) during maintenance works. |
| Incidental Water Ingestion Rate (L/day) | 0.005 | Professional judgement. Value is five times higher than that recommended by EPHC (2006) for indirect/incidental ingestion via contact with plants and lawns during irrigation and 50 times higher than that specified for incidental ingestion due to exposure to sprays during irrigation. |

#### 5.3.10.5 Chemical-Specific Factors for Dermal Exposure Assessment

Dermal absorption factors (DAF; for estimation of chemical absorption from soil during dermal contact) and dermal permeability constants ($K_p$; for estimation of chemical absorption from water during dermal contact) were obtained, where available from RAIS (University of Tennessee, 2010). Where DAFs were not published by RAIS, default values for chemical groups were adopted based on USEPA (2004b) and/or USEPA (1995) recommendations (i.e. 10% for semi-volatile chemicals, 1% for metals/inorganics and insignificant for volatiles).

$K_p$ values for TPH fractions were estimated from log $K_{ow}$ values reported by TPHCWG (1997b) for specific compounds within each TPH fraction (see Table 3 within TPHCWG, 1997b). The geometric mean of log $K_{ow}$ values for compounds relevant to each TPH fraction was first calculated and the $K_p$ for that fraction was estimated using the following empirical predictive correlation recommended by USEPA (2004b):

$$\log K_p = -2.80 + 0.66 * \log K_{ow} - 0.0056 * MW$$

Where:

$K_p$ = Dermal permeability coefficient (cm/hr)

$K_{ow}$ = Octanol/water partition coefficient (unitless)

MW = Molecular weight (g/mole).

The log $K_{ow}$ values reported by TPHCWG (1997b) for specific chemicals within TPH mixtures were estimated using the commercially available software program ClogP, rather than empirically derived and TPHCWG (1997b) noted that estimates of log $K_{ow}$ greater than 6 are likely to be overestimated and the log K values used for estimation of $K_p$ in this assessment were therefore capped at a value of 6 (i.e. the log $K_{ow}$ of fractions for which the geometric mean was greater than 6 were assumed to be 6).

Molecular weights for TPH mixtures used to estimate $K_p$ values were fraction weighted averages of values recommended by TPHCWG (1997b) for differently grouped TPH fractions.

The DAF and $K_p$ values adopted for this assessment are included in **Table T5.**

#### 5.3.10.6 Vapour Transport Modelling

Volatilisation factors for vapour migration from surface soil to trench air were estimated based on the Jury et al (1983) method, as recommended by ASTM (2002). The vapour modelling calculations for Scenario 6 are included in **Appendix H**.

Volatilisation factors for vapour migration from groundwater present within an excavation to trench air were conservatively modelled as mass limited based on the following equation:

$$VF_{w,exc} = \frac{Q_{water}}{U_{air} W \delta_{air}}$$

Where:

$VF_{w.exc}$ = Volatilisation factor from water pooled within a trench to trench air (mg/m$^3$ per mg/L)

$Q_{water}$ = flow rate of water into trench (cm$^3$/s)

$U_{air}$ = ambient air velocity within the trench (cm/s)

W = width of source zone area (cm)

$\delta_{air}$ = air mixing zone height (cm)

$Q_{water}$ was calculated using the following equation:

$$Q_{water} = V_{gw} D_{gw} W_{trench}$$

Where:

$V_{gw}$ = groundwater seepage velocity (cm/sec)

$D_{gw}$ = depth of groundwater in trench (cm)

$W_{trench}$ = width of trench (cm)

The parameters required for the intrusive maintenance scenario vapour modelling for Scenario 6 are summarised in **Table 35** below.

**Table 35: Vapour Modelling Assumptions - Scenario 6 (Intrusive Maintenance)**

| Parameter (units) | Adopted Value | Source/Justification |
|---|---|---|
| **Vadose Zone/Soil Parameters – Soil to Trench Air** | | |
| Fraction of organic carbon in soil source (unitless) | 0.002 | USEPA (2004a) defaults for coarse sand/gravel |
| Soil bulk density ($g/cm^3$) | 1.66 | |
| Total porosity in soil source zone (for soil model) (unitless) | 0.375 | |
| Air filled porosity in soil source zone (unitless) | 0.321 | |
| Water filled porosity in soil source zone (unitless) | 0.054 | |
| Vapour phase source partitioning adjustment (unitless) | 10 | A factor of 10 has been applied to soil-to-vapour partitioning equation associated with BTEX, TPH $C_6$-$C_9$, $C_{10}$-$C_{14}$ to reflect the differences observed between theoretical estimates of partitioning and field measurements (see CCME, 2008b and Friebel and Nadebaum, 2010, CRC, 2010). |
| **Groundwater Parameters – Groundwater to Trench Air** | | |
| Groundwater seepage velocity into trench (cm/sec) | $1.5 \times 10^{-4}$ | Conservative estimate of maximum expected velocity for a sandy or gravelly aquifer (50 ft/day = 13 m/day) |
| Depth of groundwater in trench (cm) | 50 | For surface excavation, assumes trench may extend to 2 mbgs and that average groundwater level over the excavation period is 1.5 mbgs. This is considered conservative given that average depth to groundwater over tidal cycle is reported be approximately 2 mbgs. |
| Dimension of trench perpendicular to groundwater flow (cm) | 200 | The width of the source parallel to the wind is the dimensions of the length of the source in the direction of windflow. As the trench is assumed to be affected by tidal inflow and may theoretically be wet along all walls and the floor of the trench, the source area parallel to the wind has been conservatively assumed to include 200 cm along two walls and the floor of the trench (200 x 300 cm). This is defined separately from the dimension of the trench perpendicular to groundwater flow which has been set at 200 cm.<br>It should be noted that due to the extensive development works (basement carparks and retention walls) intrusive maintenance workers would only be anticipated to come into contact with groundwater in the area of Hicksons Road. |

| Parameter (units) | Adopted Value | Source/Justification |
|---|---|---|
| **Outdoor/Ambient Air Characteristics** | | |
| Wind speed (cm/s) | 37.8 | Average annual 9am and 3pm wind speeds measured at observatory point in Sydney (BOM, 2010), reduced by factor of 10 to account for reduced wind circulation within a trench. |
| Width of source area parallel to wind (cm) | 600 | Assumes trench is up to 200cm long and up to 200 cm deep. |
| Ambient air mixing zone height | 200 | Conservative default – assumes all emitted vapours are mixed within two metre deep trench. |

#### 5.3.10.7 Particulate Emission Factors

The respirable dust ($PM_{10}$) concentrations in trench air were estimated assuming a particulate emission factor (PEF) of $3.6 \times 10^7$ $m^3$/kg. This PEF is the USEPA (2002) default for construction (dozing and grading) activities. It is noted that this PEF is applicable to large scale construction projects and is therefore considered to be conservative for assessment of smaller scale short term maintenance/trench scenarios.

### 5.3.11 Scenario 7: High Density Residential

The CSM for the High Density Residential Scenario is similar to that for Scenario 2 (Upper Basement Level depicted in **Figure F 5**), with the exception that vapours which enter the lower basement were assumed to be mixed through both the basement level and an overlying residential premise in which adult and child residential receptors are present.

The following points are relevant to this scenario:

- The upper most basement level is assumed to extend from the surface to 3 mbgs, such that (assuming an average depth to groundwater of 2 mbgs) groundwater seepage into the sealed plenum will occur in the lower 1 m of the wall equal to 50% of two of the four walls. Vapours intruding through the upper 2 m of the wall may be derived from impacted soil, which is assumed to be present directly adjacent the outside of the wall. This is illustrated by **Figure F 5**.
- It has been assumed that the residential premises on the ground floor overlying a basement may be occupied by adult and child residents on a full time basis.
- Vapours which enter the upper basement level (derived from soil and groundwater) are assumed to be separately mixed throughout the basement into the first floor. The estimate of vapour concentrations within the first floor are assumed to be 1/10 of the modelled concentrations within the basement and into the first and subsequent floors in accordance with the following:
  - Chan et al (2010) studied TCE exposure of occupants on the first floor of a house with a basement. Attenuation of TCE concentrations from the basement to the first floor was approximately 15.6 times, with outside temperatures greater than 15 degrees Celsius and approximately 6.8 times, when the temperature was between 6 and 4 degrees Celsius.
  - In a study between Olson et al (2001), using sulphur hexafluoride it was noted that the concentration difference between the basement and first floor ranged from 10 to 80 times (with the higher concentration being present within the basement).
  - Fang et al (1995) modelled a 12 storey residential apartment consisting of 4 apartments, lift wells and common hall areas. There were two simulations modelled- one without and with exhaust fans.
    - The study without an exhaust fan and 0m/s windspeed (with a 10 degree difference between indoor and outdoor air) showed an attenuation factor of 0.07 between the basement and average overall apartments within the 12 stories (it is noted that there was an attenuation factor of 0.1 noted between the basement and 12$^{th}$ floor (due to stack effects) with attenuation factors being further reduced in the presence of higher windspeeds and temperature differences.
    - In buildings with exhaust fans (considered representative of the building design for Barangaroo, with a 10 degree indoor and outdoor air temperature difference and 0 m/s windspeed), the

attenuation between the basement and average over all apartments was observed to be 0.03 and 0.1 for the basement and 12th floor.

- Dodson et at (2007) conducted a study on 1-2 storey residential homes with garages and basements and showed that the median, basements contributed only 10-20% of the estimated indoor air concentrations of chemicals such as BTEX. It is anticipated that these studies are likely to have been conducted on buildings which do not have the level of engineering controls which are proposed for the Barangaroo development and are therefore overly conservative for adoption of vapour modelling associated with Scenario 7.

It is noted that the basement will be designed at a negative pressure in accordance with Australian Standards further reducing potential migration of volatile chemicals from the basement.

AECOM have adopted an attenuation factor of 0.1 (which is considered to be conservative as it is representative of residential apartments which are subjected to stack effects).

#### 5.3.11.1 Contaminant Migration Pathways

Contaminant migration pathways relevant to potential human exposure to contaminants within a residential property overlying a basement car park are summarised below.

**Table 36: Contaminant Migration Pathways - Scenario 7 (High Density Residential)**

| Contaminant Migration Pathways | Relevant to Scenario? | Comments |
|---|---|---|
| Volatilisation to indoor air from groundwater adjacent or within the basement walls. | No | Water is assumed to seep through the upper basement walls beneath the water table. See below. |
| Seepage of contaminants in groundwater to basements and volatilisation to indoor air within the basement. | Yes | It is possible that groundwater may seep into the basement areas however it is anticipated that the structure of the basement includes sufficient drainage to limit groundwater accumulation.<br>Therefore to be conservative water has been modelled which seeps through the lower 1m of the basement of two walls into the sealed plenum. The basement dimensions for the upper basement are 25m x 3m x25m. It is considered that half of the area in which groundwater can filtrate (lower 1m of wall) will be covered in water i.e. $25m^2$. |
| Volatilisation and vapour migration from soil outside/adjacent the basement walls. | Yes | Vapours derived directly from soil are considered to be significant only from 0-2 mbgs (i.e. within unsaturated zone). With advection being noted as the dominant vapour exposure pathway for soils within the unsaturated zone. Below this level (within the saturated zone), diffusion from water seepage is considered to be the dominant vapour pathway. |
| Volatilisation to indoor air from groundwater or soil below basement floor. | No | Upper level basement will not have floor overlying contaminated soil and/or groundwater. Note that this has been considered in Scenarios 1. The water seepage has only considered migration from two of the four walls. |

#### 5.3.11.2 Human Receptors

The most highly exposed receptor for this scenario would be a permanent adult or child resident living in ground floor residential properties. Consideration of residential receptors will also be protective of other receptors (e.g. visitors) who may also be present in residential properties but for shorter periods of time.

#### 5.3.11.3 Exposure Pathways

Potential pathways via which the above receptors may be exposed to Site-derived contamination are summarised in **Table 37** below.

**Table 37: Exposure Pathway Analysis - Scenario 7 (High Density Residential)**

| Exposure Pathway | Complete? | Notes |
|---|---|---|
| **Adult and Child Residents** | | |
| Incidental ingestion of chemicals in soil | × | Basement construction will preclude direct contact and/or dust generation from soils |
| Dermal absorption of chemicals from soil | × | |
| Inhalation of chemicals in soil-derived airborne particulates | × | |
| Inhalation of soil-derived vapours | ✓ | Potentially complete and significant pathway. |
| Incidental ingestion of chemicals in groundwater (incidental contact) | × | Residents will not be exposed to subsurface groundwater. |
| Dermal absorption of chemicals in groundwater (incidental contact) | × | |
| Inhalation of groundwater derived vapours | ✓ | Potentially complete and significant pathway. |

#### 5.3.11.4 Exposure Parameters

Human exposure parameters adopted for Scenario 7 are summarised in **Table 38** below.

**Table 38: Exposure Parameters - Scenario 7 (High Density Residential)**

| Parameter (units) | Adopted Value | Source/Reference |
|---|---|---|
| Exposure Time (hours/day) | 24 | Conservatively assumes residents may be present inside residential properties at the Site for the entire day. |
| Exposure Frequency (days/year) | 350 | Assumes residents may be away from home up to 2 weeks per year. |
| Exposure Duration (years) | 6 (child)<br>64 (adult) | NEPC (1999a) and enHealth (2004). Assumes residents may be present at the Site for their entire lifetime, assumed to be 70 years. |

#### 5.3.11.5 Vapour Transport Modelling

Vapour modelling associated with soil was undertaken using the Johnson and Ettinger (1991) vapour transport model (Section 5.3.2). It is noted that both diffusive and advective transport processes were considered in the unsaturated zone adjacent to basement wall.

Vapour modelling associated with groundwater which may be present on the inner walls of the upper basement below the water table was undertaken using the USEPA Water 9 model (Section 5.3.2).

Further detail on the vapour transport modelling is provided in Appendix B and the calculations are provided in Appendix I.

The geologic, hydrogeologic and building parameters adopted for vapour intrusion modelling for Scenario 7 are summarised in **Table 39** below.

**Table 39: Vapour Modelling Assumptions - Scenario 7 (High Density Residential)**

| Parameter (units) | Adopted Value | Source/Justification |
|---|---|---|
| **Vadose Zone and Hydrogeologic Parameters – Soil to Indoor Air** | | |
| Depth to soil contamination (cm) | 0.001 | Negligible distance – assumes soil is directly adjacent building foundation. |
| Fraction of organic carbon in soil source (unitless) | 0.002 | USEPA (2004a) defaults for coarse sand/gravel |
| Soil bulk density ($g/cm^3$) | 1.66 | |
| Total porosity in soil source zone (for soil model) (unitless) | 0.375 | |
| Air filled porosity in soil source zone (unitless) | 0.321 | |
| Water filled porosity in soil source zone (unitless) | 0.054 | |
| Vapour phase source partitioning adjustment (unitless) | 10 | A factor of 10 has been applied to soil-to-vapour partitioning equation associated with BTEX, TPH $C_6$-$C_9$, $C_{10}$-$C_{14}$ to reflect the differences observed between theoretical estimates of partitioning and field measurements (see CCME, 2008b and Friebel and Nadebaum, 2010, CRC, 2010). |
| Air filled porosity in vadose and capillary zones (unitless) | 1 | |
| Water filled porosity in vadose and capillary zones (unitless) | 0 | |
| **Building Parameters – Soil to Indoor Air** | | |
| Ratio of enclosed space volume to infiltration area (cm) | 1875 | Assumes basement area of 25 m by 25 m and internal height of 3 m, based on dimensions for smallest separately ventilated upper basement, as shown on plans provided by LL (northern-most B1 level; see cross-section 2 on SK107A in **Appendix A** . Note that this diagram is indicative only and subject to design development. Infiltration area for soil assumed to comprise the upper 2 m of two of the four walls (100 $m^2$), since plenum ventilation system will result in vapours from one wall being forced into the building and vapours from opposite wall being forced out of the building. In addition, vapours may also enter basement through one additional wall. Enclosed volume assumed to be 25 m by 25 m by 3 m = 1875 $m^3$. It has been assumed that no independently ventilated basement structure will have more than two of four walls adjacent to residual contamination (i.e. entire basement excavation area is large and only some sections of basement walls will face towards soil and groundwater). |
| Enclosed space foundation/wall thickness (cm) | 60 | Based on LL plans which specify outer diaphragm walls of 600 mm thickness. |
| Advective vapour flow rate | Calculated | Calculated based on foundation dimensions, pressure differential and vapour permeability |
| Soil vapour permeability ($cm^2$) | $1 \times 10^{-7}$ | USEPA, 2004a default for sand/gravel. |

| Parameter (units) | Adopted Value | Source/Justification |
|---|---|---|
| Indoor-outdoor pressure differential (g/cm-s$^2$) | 40 | USEPA, 2004a conservative default. |
| Indoor Attenuation Factor (Unitless) | 1/10 | Conservative assumption that vapour concentrations in the first floor are 1/10 of those estimated to be present within the basement, See discussion in **Section 5.3.11**above. |
| **Building Parameters – Groundwater to Indoor Air** | | |
| Indoor Attenuation Factor (Unitless) | 1/10 | Conservative assumption that vapour concentrations in the first floor are 1/10 of those estimated to be present within the basement, See discussion in **Section 5.3.11** above. |
| **Building Parameters –Soil Models** | | |
| Enclosed space air exchange rate (s$^{-1}$) | 0.001 | AS1668.2 minimum ventilation rate for car park (4 per hour). |
| Areal fraction of cracks in foundations/walls | 0.0002 | USEPA (2004a) default value for basements. |
| Total porosity in foundation/wall cracks | 0.375 | Assumes foundation/wall cracks filled with sand (values are USEPA, 2004a defaults for coarse sand). |
| Air filled porosity in foundation/wall cracks | 0.321 | |
| Water filled porosity in foundation/wall cracks | 0.054 | |

The geologic, hydrogeologic and building parameters adopted for volatilisation seepage model for Scenario 7 are summarised in **Table 40** below. Chemical-specific properties used in the calculations are included in **Appendix I**.

**Table 40: Seepage Modelling Assumptions - Scenario 7 (High Density Residential)**

| Parameter (units) | Adopted Value | Source/Justification |
|---|---|---|
| Volume of Basement | 1875 m$^3$ | Assumes basement area of 25 m by 25 m and internal height of 3m. |
| Volume of Wet Basement | 0.25 m$^3$ | Assumes wet basement area of 5m (length by 5 m (width) and 0.01m (depth). |
| Enclosed space air exchange rate per day within basement | 96 | AS1668.2 minimum ventilation rate for car park 4 per hour (96 per day). |
| Fetch to Depth Ratio (wet section) | 500 | Fetch is assumed to be 5m (width) and 0.01m (depth). |
| Concrete Permeability | 8.6x10$^{-2}$ m/day | Conservative Value adopted for highly permeable concrete from *Gomes et al* (2003) |
| Windspeed within Residence | 0.03 m/sec | Conservative assumption based on dimensions of the basement and the air exchange rate (see **Section 5.3.2**). |

#### 5.3.12 Beneficial Re-Use of Soil in other areas of Barangaroo South

It is understood that material and/or soil from the Site which meets relevant SSTC may also be re-used to build up the elevation of Public Domain areas within Barangaroo South (including in particular the adjacent OWRN area).

While specific locations and development plans for areas where this may occur are not available, it is considered possible that material to be re-used may either be above or below the water table, may have variable levels of fill material overlying it and/or may have overlying concrete slabs and/or commercial/retail facilities overlying.

The CSMs and SSTC derived for Scenarios 3 to 6 above (Unpaved Recreation, Paved Recreation, Commercial Slab on Ground and Intrusive Maintenance) are therefore considered to be broadly applicable to the beneficial re-use of material within the Public domain. It is noted that any material placed within open space areas within the top 0.5m must meet the terrestrial soil criteria (TSC) outlined in **Table 46**.

While slight refinement/modification of SSTC for re-use scenarios would result from consideration of more specific design and landscaping details, the Scenario 3 to 6 SSTC are likely to be appropriate to provide an initial estimate of human health based SSTC for re-use, provided that the exposure and vapour modelling assumptions described above are met within the specific re-use areas.

## 5.4 Acceptable Risk Levels

### 5.4.1 CoPC Assessed on the Basis of Threshold Toxicity Criteria

As described in **Section** 5.2.5**,** to allow for the presence of mixtures of chemicals at locations across the Site, non-carcinogenic and/or non-genotoxic CoPC have been assigned proportional hazard indices. This differs from the standard approach (enHealth, 2004) which allocates a target hazard quotient of 1 for each individual chemical and specifies that in setting risk-based environmental health criteria exposure to a substance should not exceed the ADI.

The target hazard quotient (outlined in **Section 5.2.5**) were applied in each exposure scenario (1-7) and allow for collocation of contaminants in soil and groundwater.

### 5.4.2 CoPC Assessed on the Basis of Non-Threshold Toxicity Criteria

For CoPC considered to be genotoxic carcinogens and assessed on the basis of non-threshold toxicity criteria, an incremental cancer risk of $1 \times 10^{-5}$ has been adopted as the acceptable cancer risk threshold for each individual chemical, based on the following considerations:

- The Victorian State Environment Protection Policy (Air Quality Management) adopts an incremental lifetime cancer risk of $1 \times 10^{-5}$ for screening individual chemicals in air.
- The NSW OEH has typically adopted an incremental lifetime cancer risk of $1 \times 10^{-5}$ for assessing acceptability of site contamination.
- EPA Victoria (EPAV) has advised auditors that where more than one carcinogenic chemical is present at a site, the cumulative cancer risks for all chemicals should not exceed $1 \times 10^{-5}$.
- NHMRC (2004) Australian Drinking Water Guidelines nominate a negligible level of risk as 1 in 1,000,000 ($1 \times 10^{-6}$) for development of drinking water guideline values.
- WHO (2006) Guidelines for Drinking Water Quality adopt a target cancer risk of $1 \times 10^{-5}$ for development of drinking water guidelines.
- USEPA adopts an incremental lifetime cancer risk of $1 \times 10^{-6}$ for development of Regional Screening Levels (USEPA, 2009a; formerly known as Preliminary Remediation Goals; PRGs) for individual chemicals and advises that the cumulative risk (including all chemicals) should not exceed 1 in 10,000 ($1 \times 10^{-4}$).

As described in **Section 5.2.4** carcinogenic PAHs (CPAH) were assessed combined (as TEF equivalents) rather than individually. This approach was taken to allow for the collocation of CPAH across the Site.

## 5.5 Estimation of Site-Specific Target Criteria

SSTC were estimated for specific environmental media (e.g. soil or water) and receptors, with consideration for each pathway relevant to the receptor and medium. For example, the intrusive maintenance worker (Scenario 7) was assumed to be exposed to chemicals in soil via incidental ingestion, dermal absorption, inhalation of particulates and inhalation of soil-derived vapours.

In order to estimate SSTC, a chemical-specific factor which incorporates all exposure and toxicity parameters other than the soil or groundwater concentration is first calculated. For simplicity, these factors are referred to as intake-toxicity factors (ITF). The ITFs are based on equations used for forward estimation of exposure and risk (equations as per USEPA, 1989, 2004b and 2009b guidance), but have been algebraically rearranged to express a numerical value which, if multiplied by the chemical concentration relevant to the pathway, would result in a risk estimate.

For chemicals assessed on the basis of threshold effects, ITFs are estimated as follows:

**Incidental Ingestion of Soil**

$$ITF_{ing,s} = \frac{IngR_s * EF * ED * CF}{365 \frac{days}{year} * AT * BW} * \frac{1}{RfD}$$

Where:

| | | |
|---|---|---|
| $ITF_{ing,s}$ | = | Intake-Toxicity Factor for Soil Ingestion (kg/mg) |
| $IngR_s$ | = | Soil Ingestion Rate (mg/day) |
| EF | = | Exposure Frequency (days/year) |
| ED | = | Exposure Duration (years) |
| CF | = | Unit conversion factor (kg/$10^6$ mg) |
| AT | = | Averaging Time (years) |
| | = | 70 years for non-threshold carcinogens |
| | = | ED for chemicals assessed based on threshold effects |
| BW | = | Body weight (kg) |
| RfD | = | Oral Reference Dose (mg/kg/day) |

**Dermal Contact with Soil**

$$ITF_{der,ss} = \frac{AH * SA * AF * EF * ED * CF}{365 \frac{days}{year} * AT * BW} * \frac{1}{RfD}$$

Where:

| | | |
|---|---|---|
| $ITF_{der,s}$ | = | Intake-Toxicity Factor for Dermal Contact with Soil (kg/mg) |
| AH | = | Soil Adherence Factor (mg/cm$^2$/day) |
| SA | = | Skin Surface Avalable for Contact (cm$^2$) |
| AF | = | Dermal Absorption Factor (chemical-specific; unitless) |

and other parameters are as defined earlier.

**Inhalation of Soil-Derived Particulates**

$$ITF_{inh,part} = \frac{ET * EF * ED}{PEF * AT * 365\frac{days}{year} * 24\frac{hours}{day}} * \frac{1}{RfC}$$

Where:

$ITF_{inh,part}$ = Intake-Toxicity Factor for Particulate Inhalation (kg/mg)

ET = Exposure Time (hours/day)

RfC = Reference or Tolerable Concentration in Air (mg/m$^3$)

PEF = Particulate Emission Factor (m$^3$/kg)

and other parameters are as defined earlier.

**Inhalation of Soil-Derived Vapours**

$$ITF_{inh,vap,s} = \frac{VF_s * ET * EF * ED}{AT * 365\frac{days}{year} * 24\frac{hours}{day}} * \frac{1}{RfC}$$

Where:

$ITF_{inh,vap,s}$ = Intake-Toxicity Factor for Inhalation of Soil-Derived Vapours (kg/mg)

$VF_s$ = Volatilisation Factor for Soil to Air (mg/m$^3$ per mg/kg)

and other parameters are as defined earlier.

**Incidental Ingestion of Water**

$$ITF_{ing,w} = \frac{IngR_w * EF * ED}{365\frac{days}{year} * AT * BW} * \frac{1}{RfD}$$

Where:

$ITF_{ing,w}$= Intake-Toxicity Factor for Water Ingestion (L/mg)

$IngR_s$ = Water Ingestion Rate (L/day)

and other parameters are as defined earlier.

**Dermal Contact with Water**

$$ITF_{der,w} = \frac{k_p * SA * ET * EF * ED * CF_w}{365\frac{days}{year} * AT * BW} * \frac{1}{RfD}$$

Where:

$ITF_{der,w}$ = Intake-Toxicity Factor for Dermal Water Contact (L/mg)

$k_p$ = Dermal Permeability Constant for Water Contact (cm/hr)

$CF_w$ = Unit Conversion Factor (L/10$^3$ cm$^3$)

and other parameters are as defined earlier.

**Inhalation of Groundwater-Derived Vapours**

$$ITF_{inh,vap,gw} = \frac{VF_{gw} * ET * EF * ED}{AT * 365 \frac{days}{year} * 24 \frac{hours}{day}} * \frac{1}{RfC}$$

Where:

$ITF_{inh,vap,gw}$ = Intake-Toxicity Factor for Inhalation of Groundwater-Derived Vapours (L/mg)

$VF_{gw}$ = Volatilisation Factor for Groundwater to Air (mg/m$^3$ per mg/L)

and other parameters are as defined earlier.

For genotoxic carcinogens assessed on the basis of non-threshold effects, the 1/RfD term in the above equations is replaced with the Cancer Slope Factor (for dermal and ingestion pathways), or the 1/RfC term is replaced by the Inhalation Unit Risk (IUR) multiplied by a conversion factor of 1000 µg/mg.

SSTC were then estimated as:

$$SSTC = \frac{THQ}{\sum_{i=1}^{n} ITF_i}$$

or

$$SSTC = \frac{TCR}{\sum_{i=1}^{n} ITF_i}$$

Where:

THQ = Target Hazard Quotient (applied on a chemical by chemical basis)

TCR = Target Cancer Risk (applied on a chemical by chemical basis)

$ITF_i$ = ITF for Exposure Pathway *i* of *n* pathways relevant to exposure medium and receptor.

Where SSTC are derived for scenarios where receptor exposure is assumed to occur only via the vapour inhalation pathway, if the calculated soil SSTC was greater than the soil concentration at which dissolved pore water and vapour phases become saturated ($C_{sat}$). The soil SSTC then corresponds to an estimated pore vapour concentration greater than the chemical component saturated vapour concentration limit and the specific target risk level cannot be physically achieved in the defined scenario, even where phase separated hydrocarbon (PSH) is present (USEPA, 2004a). In these cases, the SSTC is denoted as ## (see **Section 5.5.1** for details). Theoretical $C_{sat}$ values for each CoPC are included in **Appendix C** to **Appendix I.**

Similarly, where the estimated groundwater SSTC was greater than the theoretical pure component aqueous solubility, the SSTC corresponds to an estimated source vapour concentration greater than the saturated vapour concentration limit and the specified target risk level cannot be achieved, even where PSH is present (USEPA, 2004a). In these cases the groundwater SSTC is denoted as "##". Pure component aqueous solubilities for each CoPC are included in **Appendix C** to **Appendix I**.

However, in cases where receptor exposure may occur through a combination of vapour and direct contact or dust inhalation pathways, the SSTC cannot be saturation or solubility limited for the non-vapour exposure pathways. Therefore, in order to avoid unnecessarily low SSTC where a portion of chemical exposure is solubility or saturation limited, but where the remainder of exposure is not, SSTC were checked for sensitivity to saturation or solubility limiting of vapour exposure and revised (where necessary) using the following procedure:

a) Forward risk was estimated across all exposure pathways relevant to medium (for each chemical) using the SSTC as input concentration but incorporating solubility or saturation limit for risk estimation of vapour pathways (i.e. using minimum of SSTC or saturation/solubility limit as input concentration).

b) If the estimated forward risk was equal to the target risk level used for SSTC estimation, vapour pathways are not saturation or solubility limited and no SSTC revision is necessary.

c) If forward risk was less than target risk level adopted for SSTC derivation, saturation or solubility limited risk was calculated for vapour pathways, using the following equation:

$$Risk_{vap} = \sum_{i=1}^{n} ITF_{vap,i} * C_{sat/sol}$$

Where:

| | | |
|---|---|---|
| $Risk_{vap}$ | = | Saturation or solubility limited risk due to vapour pathways (unitless) |
| $ITF_{vap,I}$ | = | ITF for Vapour Exposure Pathway *i* of *n* vapour exposure pathways relevant to exposure medium and receptor. |
| $C_{sat/sol}$ | = | $C_{sat}$ (for soil exposure pathways) or aqueous solubility limit (for groundwater pathways). |

d) $Risk_{vap}$ was subtracted from the target risk level, and this value ($Risk_{non\text{-}vap}$) was used as target risk for estimation of revised SSTC, using the following equation:

$$SSTC_{rev} = \frac{Risk_{non-vap}}{\sum_{i=1}^{n} ITF_{non-vap,i}}$$

Where:

| | | |
|---|---|---|
| $SSTC_{rev}$ | = | SSTC revised for saturation/solubility limiting of vapour risk components |
| $Risk_{non\text{-}vap}$ | = | Target risk for SSTC less saturation/solubility limited risk component (i.e. residual target risk which can be allocated to non-vapour pathways) |
| $ITF_{non\text{-}vap,I}$ | = | ITF for Non-Vapour Exposure Pathway *i* of *n* Non-Vapour Exposure Pathways Relevant to Exposure Medium and Receptor. |

The spreadsheet-based calculations of SSTC are detailed in **Appendix C** to **Appendix I** and **Appendix K to Appendix Q** for **Scenarios 1 to 7**, respectively.

### 5.5.1 Saturation and Solubility Considerations in SSTC Derivation

The SSTC is represents an acceptable chemical concentration in soil or groundwater based on the chemical properties of a pure or surrogate chemical.

Comparison of derived SSTCs against maximum Site data indicates exceedences of numerous orders of magnitude above theoretical saturation/ solubility limits (**Table 41** and **Table 42**) and indicates the use of derived SSTCs (which have not been limited by saturation or solubility) for some chemicals is an overconservative estimate. The derived SSTC presented within Tables 38 and 39 for some compounds are likely to be equal to separated phase concentrations within soil and groundwater. The calculated SSTC therefore indicate that from a human health perspective, separated phase or grossly impacted material does not present a health risk for a number of scenarios.

In addition to meeting the derived SSTC for the Site, the removal of separated phase/ grossly impacted material to the extent practicable is an important remediation objective for the Site. It is therefore considered that SSTC presented for human health for remediation purposes need to support this objective.

To address this and establish reasonable and realistic SSTCs for soil and groundwater given the presence of chemical mixtures across the Site, the following steps were undertaken:

a) Risk and odour SSTCs were derived for soil and groundwater and compared to saturation /solubility limits and maximum Site concentrations.

b) Where derived SSTC's were greater than 10 times the theoretical saturation/ solubility limits the SSTC were considered to be approaching separated phase/ grossly impacted material and these concentrations have been removed as they do not meet the remediation objectives for the Site. In these instances no SSTC was proposed.

c) Where SSTCs are not saturation or solubility limited, or are within 10 times the saturation/ solubility limits the SSTC was adopted.

d) Although the derived TPH soil and groundwater SSTCs for fractions $C_6$-$C_9$ and $C_{10}$-$C_{14}$ are over 10 times the saturation/ solubility limits, the derived SSTC has been adopted (with the exception of soil, where the derived SSTCs were adopted to concentrations equal to the maximum concentrations present at the Site, TPH $C_6$-$C_9$ 7,500 mg/kg, $C_{10}$-$C_{14}$ 70,000 mg/kg and $C_{15+}$ 130,000 mg/kg). TPH fractions are a heterogeneous mixture of potentially hundreds of compounds and the derivation of an SSTC based on the theoretical chemical properties for these fractions is considered to be associated with a high degree of inaccuracy. Moreover, the maximum Site concentrations indicated that the derived SSTCs were reasonable and achievable as remediation objectives for the Site for a number of scenarios.

e) SSTCs for carcinogenic PAHs were determined as a "total cPAH" based off the SSTC derived for benzo(a)pyrene. It is noted that The soil SSTC is dominated by the use of the Knafla dermal slope factor.

The SSTCs derived for soil and groundwater for each scenario based on this approach are presented in **Table 41** and **Table 42**.

**Table 41: Comparison of Derived and Proposed Groundwater SSTC**

| Chemical | Solubility Limits (mg/L) | Groundwater Health and /or Odour Target Criteria (SSTC) (lowest of health and odour based) (mg/L) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Scenario 1- Upper Basement | | Scenario 2 - Upper Basement | | Scenario 3 - Unpaved Recreation | | Scenario 4 - Paved Recreation | | Scenario 5 - Commercial Slab on Ground) | | Scenario 6 - Intrusive Maintenance | | Scenario 7 - High Density Residential | |
| | | Derived | Proposed | Derived | Proposed | Derived | Proposed | Derived | Proposed | Derived | Proposed | Derived | Proposed | Derived | Proposed |
| Acenaphthene | 3.9 | 610 | ## | 1,900 | ## | 720,000 | ## | 7,000,000 | ## | 20,700 | ## | 61 | ## | 4,280 | ## |
| Acenaphthylene | 16 | 300 | ## | 910 | ## | 1,230,000 | ## | 12,600,000 | ## | 38,000 | ## | 57 | 57 | 2,090 | ## |
| Ammonia | 482,000 | 2,400 | 2,400 | 6,800 | 6,800 | 2,400,000 | 2,400,000 | 28,800,000 | ## | 87,000 | 87,000 | 15,300 | 15,000 | 15,600 | 16,000 |
| Aniline | ***36,000*** | ***1,400,000*** | ## | ***3,800,000*** | ## | ***1,570,000,000*** | ## | ***36,000,000,000*** | ## | ***110,000,000*** | ## | 977 | 980 | ***8,760,000*** | ## |
| Anthracene | 0.043 | 17 | ## | 50 | ## | 11,700,000 | ## | 147,000,000 | ## | 440,000 | ## | 184 | ## | 114 | ## |
| Arsenic, Inorganic | | - | - | - | - | - | - | - | - | - | - | 384 | 380 | - | - |
| Barium | | - | - | - | - | - | - | - | - | - | - | 565 | 570 | - | - |
| Benz(a)anthracene | 0.0094 | - | - | - | - | - | - | - | - | - | - | (See cPAH) | | - | - |
| Benzene | 1,790 | 21 | 21 | 95 | 95 | 621 | 620 | 5,300 | 5,300 | 22 | 22 | 3.4 | 3.4 | 150 | 150 |
| Benzo(a)pyrene | 0.00162 | - | - | - | - | - | - | - | - | - | - | (See cPAH) | | - | - |
| Benzo(b)fluoranthene | 0.0015 | - | - | - | - | - | - | - | - | - | - | (See cPAH) | | - | - |
| Benzo(g,h,i)perylene | 0.00026 | - | - | - | - | - | - | - | - | - | - | (See cPAH) | | - | - |
| Benzo(k)fluoranthene | 0.0008 | | - | - | - | - | - | - | - | - | - | (See cPAH) | | - | - |
| Bis(2-ethylhexyl)phalate | 0.27 | - | - | - | - | - | - | - | - | - | - | 9.7 | ## | - | - |
| Cadmium | | - | - | - | - | - | - | - | - | - | - | 14.5 | 15 | - | - |
| Chromium(III) | 1,690,000 | - | - | - | - | - | - | - | - | - | - | 8,400 | 8,400 | - | - |
| Chromium(VI) | 1,690,000 | - | - | - | - | - | - | - | - | - | - | 7.6 | 7.6 | - | - |

| Chemical | Solubility Limits (mg/L) | Groundwater Health and /or Odour Target Criteria (SSTC) (lowest of health and odour based) (mg/L) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Scenario 1- Upper Basement | | Scenario 2 - Upper Basement | | Scenario 3 - Unpaved Recreation | | Scenario 4 - Paved Recreation | | Scenario 5 - Commercial Slab on Ground) | | Scenario 6 - Intrusive Maintenance | | Scenario 7 - High Density Residential | |
| | | Derived | Proposed | Derived | Proposed | Derived | Proposed | Derived | Proposed | Derived | Proposed | Derived | Proposed | Derived | Proposed |
| Chrysene | 0.002 | - | - | - | - | - | - | - | - | - | - | (See cPAH) | | - | - |
| Cobalt | | - | - | - | - | - | - | - | - | - | - | 260 | 260 | - | - |
| Copper | | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Dibenz(a,h)anthracene | 0.0025 | - | - | - | - | - | - | - | - | - | - | (See cPAH) | | - | - |
| Dibenzofuran | 3.1 | 1,100 | ## | 3,200 | ## | 3,870,000 | ## | 37,000,000 | ## | 110,000 | ## | 267 | ## | 7,350 | ## |
| Dimethylphenol, 2,4- | 7,870 | - | - | - | - | - | - | - | - | - | - | 722 | 720 | - | - |
| Ethylbenzene | 169 | 4,000 | ## | 13,000 | ## | 112,000 | ## | 950,000 | ## | 2,800 | ## | 211 | 210 | 29,400 | ## |
| Fluoranthene | 0.26 | - | - | - | - | - | - | - | - | - | - | 11 | ## | - | - |
| Fluorene | 1.69 | 48 | ## | 140 | ## | 936,000 | ## | 10,000,000 | ## | 30,000 | ## | 32 | ## | 325 | ## |
| Indeno(1,2,3-cd)pyrene | 0.00019 | - | - | - | - | - | - | - | - | - | - | (See cPAH) | | - | - |
| Lead and Compounds | | - | - | - | - | - | - | - | - | - | - | 1,110 | 1,100 | - | - |
| Manganese | | - | - | - | - | - | - | - | - | - | - | 2,390 | 2,400 | - | - |
| Methylphenol, 2- | 180 | - | - | - | - | - | - | - | - | - | - | 4900 | 4900 | - | - |
| Methylnaphthalene, 2- | 24.6 | ***38*** | 38 | 120 | 120 | ***75400*** | ## | ***671000*** | ## | ***1960*** | ## | 38 | 38 | ***270*** | ## |
| Methylphenol, 3&4 | ***22,700*** | ***1,000*** | ***1,000*** | ***2,700*** | ***2,700*** | ***1,160,000*** | ## | ***29,000,000*** | ## | ***89,000*** | ***89,000*** | ***273*** | ***270*** | ***6,200*** | ***6,200*** |
| Naphthalene | 31 | 0.92 | 0.92 | 2.9 | 2.9 | 3,950 | ## | 35,000 | ## | 103 | 100 | 29 | 30 | 6.6 | 6.6 |
| Nickel | | - | - | - | - | - | - | - | - | - | - | 350 | 350 | - | - |
| Phenanthrene | 1.15 | 22 | ## | 64 | ## | 3,250,000 | ## | 43,000,000 | ## | 130,000 | ## | 36 | ## | 1450 | ## |
| Phenol | ***82,800*** | ***310,000*** | ***310,000*** | ***830,000*** | ## | ***309,000,000*** | ## | ***7,900,000,000*** | ## | ***24,700,000*** | ## | 23,400 | 23,000 | ***1,900,000*** | ## |
| Pyrene | 0.14 | 11 | ## | 29 | ## | 4,700,000 | ## | 93,000,000 | ## | 290,000 | ## | 13 | ## | 67 | ## |

| Chemical | Solubility Limits (mg/L) | Groundwater Health and /or Odour Target Criteria (SSTC) (lowest of health and odour based) (mg/L) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Scenario 1- Upper Basement | | Scenario 2 - Upper Basement | | Scenario 3 - Unpaved Recreation | | Scenario 4 - Paved Recreation | | Scenario 5 - Commercial Slab on Ground) | | Scenario 6 - Intrusive Maintenance | | Scenario 7 - High Density Residential | |
| | | Derived | Proposed | Derived | Proposed | Derived | Proposed | Derived | Proposed | Derived | Proposed | Derived | Proposed | Derived | Proposed |
| Styrene | 310 | 3,300 | ## | 10,000 | ## | 246,000 | ## | 2,100,000 | ## | 6,100 | ## | 88 | 88 | 2,3800 | ## |
| Toluene | 526 | 160,000 | ## | 49,500 | ## | 449,000 | ## | 3,800,000 | ## | 11,000 | ## | 756 | 760 | 113,000 | ## |
| TPH $C_6$-$C_9$ aliphatic ($) | 11.9 | 28,000 | 28,000 | 90,000 | 90,000 | 3,4600 | 3,500 | 29,000 | 29,000 | 86 | 86 | 1,390 | 1,400 | 205,000 | 210,000 |
| TPH $C_{10}$-$C_{14}$ aliphatic ($) | 0.1 | 7.7 | 7.7 | 14.5 | 15 | 13,552 | 14,000 | 120,000 | 120,000 | 338 | 340 | 21 | 21 | 33.8 | 34 |
| TPH $C_{10}$-$C_{14}$ aromatic ($) | 25.3 | | | | | | | | | | | | | | |
| TPH $C_{15}$-$C_{28}$ aliphatic | 0.0001 | - | - | - | - | - | - | - | - | - | - | 222 | 220 | - | - |
| TPH $C_{15}$-$C_{28}$ aromatic | 1.1 | | | | | | | | | | | | | | |
| TPH $C_{29}$-$C_{36}$ aliphatic | 0.000003 | - | - | - | - | - | - | - | - | - | - | 249 | 250 | - | - |
| TPH $C_{29}$-$C_{36}$ aromatic | 0.0066 | | | | | | | | | | | | | | |
| Trimethylbenzene, 1,2,4- | 57 | 87 | 87 | 278 | 280 | 3,460 | ## | 30,000 | ## | 86 | 86 | 1550 | ## | 636 | ## |
| Vanadium | | - | - | - | - | - | - | - | - | - | - | 960 | 960 | - | - |
| Xylenes (total) ($) | 1.1 | 6,50 | ## | 2,200 | ## | 23,200 | ## | 200,000 | ## | 576 | ## | 407 | ## | 4,980 | ## |
| CPAH#[1] | | - | - | - | - | - | - | - | - | - | - | 0.01 | # | - | - |

> Sol = SSTC exceeds aqueous solubility limit; maximum vapour phase concentration of chemical cannot result in unacceptable risk level.
## = an SSTC has not been determined for remediation purposes as the derived level is at least 10 times greater than saturation/ solubility limits
# [1]= the solubility limits for individual carcinogenic PAHs are in the order of $10^{-3}$ to $10^{-4}$ mg/L and are assumed to represent the solubility of the CPAH group. The derived SSTC for CPAH is 0.01 mg/L and is considered to be well over the solubility limits and has therefore not been adopted.
CPAH = carcinogenic PAHs and includes: benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h) anthracene and indeno (1,2,3-cd)pyrene (see text for details)
Derived SSTL is solubility limited but within 10 x solubility of chemical, hence SSTC has been adopted.
***Italics= odour SSTC (were lower than human health SSTC)***
$ = SSTC is greater than 10 times the saturation/ solubility limit and has been adopted on the following basis: **TPH fractions:** SSTC has been adopted as it is not considered appropriate to exclude this complex and chemically diverse group of chemicals based on the solubility/ saturation characteristics of an analytical surrogate.

**Key Assumptions:**

- The derivation of SSTCs has been based on plans and design assumptions provided by Lend Lease.
- The development of SSTCs has assumed that tar will be removed from the immediate vicinity of outer basement walls to the extent practicable, and basement design and engineering controls should ensure that tar seepage into basements does not occur.
- There are significant biodegradation processes occurring within sub-surface soils based on measured oxygen concentrations beneath the sub-surface. To account for these biodegradation processes, a 10 fold factor (Davis 2009) has been adopted for site specific target criteria for soil for the paved and unpaved areas of the Site, where biodegradation processes are considered to be significant.
- Risks associated with mixtures of chemicals have been modelled by applying proportional risks as follows: BTEX (HI 0.25 each), PAH (HI 0.2), TPH (HI 0.25 total for aliphatic and aromatic per fraction), all other chemicals HI = 1.
- The lower and upper basements have been modelled using a water seepage model adopted from Water 9 (USEPA, 1994).
- In the lower and upper basements a windspeed of 0.03 m/sec within the basements (scenario 1,2 and 7) has been modelled
- Chemicals are assumed to be volatile if Henry's Law constant is greater than 1 x $10^{-5}$ atm-$m^3$/mole (USEPA,2004)
- The air exchange rate within the basement car park has been assumed to be 4 per hour (in accordance with AS 1668.2).
- In basement scenarios (1, 2 and 7) it has been assumed that no more than two walls will be in contact with contaminated soil / groundwater (with Scenario 1 also considering exposures to the floor). Based on building plans provided by LL, it has been assumed that basement areas will be compartmentalised with each compartment adjacent to basement areas leaving a maximum of 2 exposed walls.
- The basement groundwater retention wall system will comprise a secant pile wall, extending to and keyed into bedrock, with a reinforced concrete basement wall, constructed on the inside. A sealed plenum constructed immediately inside the reinforced concrete basement wall will include: (a) passive ventilation to the atmosphere; and (b) dish drains that will drain any seepage.

**Table 42: Comparison of Derived and Proposed Soil SSTC**

| Chemical | Saturation Limits (mg/kg) ** | Soil Health and /or Odour Target Criteria (SSTC) (lowest of health and odour based) (mg/kg) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Scenario 2 - Upper Basement | | Scenario 3 - Unpaved Recreation | | Scenario 4 - Paved Recreation | | Scenario 5 - Commercial Slab on Ground | | Scenario 6 - Intrusive Maintenance Worker | | Scenario 7 – High Density Residential | |
| | | Derived | Proposed | Derived | Proposed | Derived | Proposed | Derived | Proposed | Derived | Proposed | Derived | Proposed |
| Acenaphthene | 39 | 22,200 | ## | 695,000 | ## | 63,800,000 | ## | 206,000 | ## | 19.800 | ## | 53,300 | ## |
| Acenaphthylene | 163 | 35,800 | ## | 1,260,000 | ## | 115,000,000 | ## | 374,000 | ## | 19,800 | ## | 85,900 | ## |
| Anthracene | 1.42 | 1,190,000 | ## | 48,600,000 | ## | 4,440,000,000 | ## | 14,400,000 | ## | 99,000 | ## | 2,870,000 | ## |
| Arsenic, Inorganic | | - | - | - | - | - | - | - | - | - | - | - | - |
| Benz(a)anthracene | 3.33 | - | - | - | - | - | - | - | - | (see CPAH) | | - | - |
| Benzene | 659 | 15.3 | 15 | 188 | 190 | 17,200 | ## | 80.7 | 81 | 376 | 380 | 25.6 | 26 |
| Benzo(a)pyrene | 1.90 | - | - | - | - | - | - | - | - | (see CPAH) | | - | - |
| Benzo(b)fluoranthene | 1.80 | - | - | - | - | - | - | - | - | (see CPAH) | | - | - |
| Benzo(k)fluoranthene | 0.94 | - | - | - | - | - | - | - | - | (see CPAH) | | - | - |
| Benzo(g,h,i)perylene | 1.01 | - | - | - | - | - | - | - | - | (see CPAH) | | - | - |
| Chromium(III), Insol. Salts | | - | - | - | - | - | - | - | - | 180,000 | 180,000 | - | - |
| Chromium(VI) | | - | - | - | - | - | - | - | - | 954 | 950 | - | - |
| Chrysene | 0.7 | - | - | - | - | - | - | - | - | (see CPAH) | | - | - |
| Copper | | - | - | - | - | - | - | - | - | - | - | - | - |
| Dibenz(a,h)anthracene | 9.51 | - | - | - | - | - | - | - | - | (see CPAH) | | - | - |
| Dibenzofuran | 57 | 174,000 | ## | 6,730,000 | ## | 616,000,000 | ## | 2,000,000 | ## | 310,000 | ## | 418,000 | ## |
| Ethylbenzene | 167 | ***602*** | ***600*** | 90,700 | ## | 829,000,000 | ## | 26,900 | ## | 125,000 | ## | ***1,500*** | ***1,500*** |

| Chemical | Saturation Limits (mg/kg) ** | Soil Health and /or Odour Target Criteria (SSTC) (lowest of health and odour based) (mg/kg) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Scenario 2 - Upper Basement | | Scenario 3 - Unpaved Recreation | | Scenario 4 - Paved Recreation | | Scenario 5 - Commercial Slab on Ground | | Scenario 6 - Intrusive Maintenance Worker | | Scenario 7 – High Density Residential | |
| | | Derived | Proposed | Derived | Proposed | Derived | Proposed | Derived | Proposed | Derived | Proposed | Derived | Proposed |
| Fluoranthene | 29 | - | - | - | - | - | - | - | - | 13,200 | ## | - | - |
| Fluorene | 31 | 51,400 | ## | 1,850,000 | ## | 170,000,000 | ## | 550,000 | ## | 13,200 | ## | 124,000 | ## |
| Indeno(1,2,3-cd)pyrene | 74 | - | - | - | - | - | - | - | - | (see CPAH) | | - | |
| Lead | | - | - | - | - | - | - | - | - | 15,300 | 15,000 | - | |
| Methylnaphthalene, 2- | 123 | ***1,080*** | ***1,100*** | ***32,600*** | ## | ***2,980,000*** | ## | ***9,700*** | ## | 41,000 | ## | ***2,460*** | ## |
| Methylphenol, 3&4 | 14,400 | ***8,800*** | ***8,800*** | ***190,000*** | ## | 17,300,000 | ## | ***56,300*** | ***56,000*** | ***5,410*** | ***5,400*** | ***21,100*** | ***21,000*** |
| Naphthalene | 96 | 40.8 | 41 | 1,070 | ## | 97,800 | ## | 318 | 320 | 4,330 | ## | 98 | 98 |
| Phenanthrene | 38 | 319,000 | ## | 14,700,000 | ## | 1,340,000,000 | ## | 4,350,000 | ## | 19,900 | ## | 767,000 | ## |
| Pyrene | 14 | 1,840,000 | ## | 105,000,000 | ## | 9,600,000,000 | ## | 31,000,000 | ## | 9,900 | ## | 4,430,000 | ## |
| Toluene | 291 | ***6,040*** | ## | 204,000 | ## | 11,300,000 | ## | 60,700 | ## | 286,000 | ## | 1,4500 | ## |
| TPH C06-C09 aliphatic ($) | 221 | 3,360 | 3,400 | 53,200 | ## | 4,870,000 | ## | 15,800 | ## | 3,220,000 | ## | 8,060 | ## |
| TPH C10-C14 aliphatic ($) | 111 | 13,000 | 13,000 | 205,000 | ## | 18,900,000 | ## | 61,200 | 61,000 | 89.1000 | 90,000 | 31,200 | 31,000 |
| TPH C10-C14 aromatic ($) | 154 | | | | | | | | | | | | |
| TPH C15-C28 aliphatic | 70 | - | - | - | - | - | - | - | - | 496,300 | ## | - | - |
| TPH C15-C28 aromatic | 80 | | | | | | | | | | | | |
| TPH C29-C36 aliphatic | 3.2 | - | - | - | - | - | - | - | - | 496,300 | ## | - | - |
| TPH C29-C36 aromatic | 1.7 | | | | | | | | | | | | |
| Trimethylbenzene, 1,2,4- | 75 | 14.3 | 14 | 370 | 370 | 34,200 | ## | 111 | 110 | 16,000,000 | ## | 34 | 34 |
| Vanadium | | - | - | - | - | - | - | - | - | 22,000 | 22,000 | - | |

| Chemical | Saturation Limits (mg/kg) ** | Soil Health and /or Odour Target Criteria (SSTC) (lowest of health and odour based) (mg/kg) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Scenario 2 - Upper Basement | | Scenario 3 - Unpaved Recreation | | Scenario 4 - Paved Recreation | | Scenario 5 - Commercial Slab on Ground | | Scenario 6 - Intrusive Maintenance Worker | | Scenario 7 – High Density Residential | |
| | | Derived | Proposed | Derived | Proposed | Derived | Proposed | Derived | Proposed | Derived | Proposed | Derived | Proposed |
| Xylenes (total) | 8.90 | 856 | ## | 16,000 | ## | 1,470,000 | ## | 4,760 | ## | 230,000 | ## | 2,060 | ## |
| Zinc | | - | - | - | - | - | - | - | - | | - | - | - |
| CPAH | | | | | | | | | | 67.2 | 67 | | |

>Sat = SSTC exceeds soil saturation concentration; maximum vapour phase concentration of chemical cannot result in unacceptable risk level.
## = an SSTC has not been determined for remediation purposes as the derived level is at least 10 times greater than saturation/ solubility limits
CPAH = carcinogenic PAHs and includes: benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h) anthracene and indeno (1,2,3-cd)pyrene (see text for details)
Derived SSTL is solubility limited but within 10 x solubility of chemical, hence SSTC has been adopted.
***Italics= odour SSTC (where lower than human health SSTC)***
$ = SSTC is greater than 10 times the saturation/ solubility limit and has been adopted on the following basis: **TPH fractions:** SSTC has been adopted as it is not considered appropriate to exclude this complex and chemically diverse group of chemicals based on the solubility/ saturation characteristics of an analytical surrogate up to the maximum observed concentrations on site of TPH $C_6$-$C_9$ 7,500 mg/kg, $C_{10}$-$C_{14}$ 70,000 mg/kg and $C_{15+}$ 130,000 mg/kg.

**Key Assumptions:**

- The derivation of SSTCs has been based on plans and design assumptions provided by Lend Lease
- The development of SSTCs has assumed that tar will be removed from the immediate vicinity of outer basement walls to the extent practicable, and basement design and engineering controls should ensure that tar seepage into basements does not occur
- There are significant biodegradation processes occurring within sub-surface soils based on measured oxygen concentrations beneath the sub-surface. To account for these biodegradation processes, a 10 fold factor (Davis 2009) has been adopted for site specific target criteria for soil for the paved and unpaved areas of the Site, where biodegradation processes are considered to be significant.
- The current theoretical estimation of soil concentrations within indoor and outdoor air is based on partitioning modelling which has been demonstrated to overestimate concentrations between 10-1,000 fold. To account for this conservatism, an adjustment factor of 10 has been applied. In all scenarios a soil partitioning factor of 10 has been applied to BTEX, TPH (fractions $C_6$-$C_9$ and $C_{10}$-$C_{14}$ to account for the overconservative nature of vapour modelling associated with these chemicals (CCME, 2008b. CRC 2010)
- Risks associated with mixtures of chemicals have been modelled by applying proportional risks as follows: BTEX (HI 0.25 each), PAH (HI 0.2), TPH (HI 0.25 total for aliphatic and aromatic per fraction), all other chemicals HI = 1Chemicals are assumed to be volatile if Henry's Law constant is greater than 1 x $10^{-5}$ atm-$m^3$/mole (USEPA,2004)
- The air exchange rate within the basement car park has been assumed to be 4 per hour (in accordance with AS 1668.2).
- In the unpaved recreation scenarios (Scenario 3 and Scenario 4) it has been assumes that the upper 0.5 m of soil is composed of “suitable fill” as defined by Section 5.3.7.

## 5.6 Risk Characterisation

### 5.6.1 Comparison of SSTC to Site Concentrations

#### 5.6.1.1 Soil

SSTC for soil are compared to reported CoPC concentrations in Site soil samples in **Table T6** to **Table T11**, for Scenarios 2 to 7, respectively (note that soil SSTC were not derived for Scenario 1 as this scenario relates to exposure to groundwater derived contaminants only). The tables also compare SSTC reduced by a factor of five to reported soil concentrations, to allow a preliminary assessment where chemical concentrations are approaching the SSTC.

The nature and extent of soil SSTC exceedences are detailed in **Table T6** to **Table T11** are summarised in **Table 43** below and in **Figure F 8** to **Figure F 11**. Note that only scenarios with relevant exceedences, scenarios 2, 5, and 7 are illustrated in figures and only locations which have been shown to exceed the SSTC or approaching within five times the SSTC are identified in the tables. The exceedences shown in Table 43 below are representative of soil concentrations within the unsaturated zone.

**Table 43: Summary of Soil SSTC Exceedences**

| Scenario | Chemicals Exceeding SSTC | Locations/ Depths of Key Concern | Notes |
|---|---|---|---|
| 1 – Lower Basement | Not applicable; soil exposure pathways not complete for these scenarios. | | |
| 2 – Upper Basement | Benzene<br>1,2,4-Trimethylbenzene<br>Naphthalene<br>TPH $C_{10}$-$C_{14}$ | BH087/1.5-1.95<br>BH200/1<br>BH204/1<br>BH204D/1.5<br>BH54/1.0-1.4<br>BH55/1.0-1.2<br>BH59/1.9-2.0<br>BH64/1-1.2 | Maximum reported concentration for benzene in the unsaturated zone (61 mg/kg) exceeds SSTC of 15.3 mg/kg.<br>Maximum reported concentration for 1,2,4-Trimethylbenzene in the unsaturated zone (16.4 mg/kg) exceeds the SSTC of 14 mg/kg.<br>Maximum reported concentration for naphthalene in the unsaturated zone (8410 mg/kg) exceeds the SSTC of 408 mg/kg.<br>Impacts not reported in soils above water table have not been considered as they are not relevant to Scenario 2.<br>Soil emplaced adjacent upper level basements should meet SSTC for this scenario.<br>Cumulative effects not expected as other chemicals are greater than one order of magnitude below SSTC and/or SSTC are saturation limited. |

| Scenario | Chemicals Exceeding SSTC | Locations/ Depths of Key Concern | Notes |
|---|---|---|---|
| 3 – Unpaved Recreation | No exceedences reported in the unsaturated zone | See notes – not expected to be of concern. | Conservative vapour modelling accounting for biodegradation indicates that the majority of chemicals are saturation limited. There were no exceedences of soil reported within the unsaturated zone (0.0-2mbgs). Soil vapour data for naphthalene indicated concentrations within the vadose zone up to 383 µg/m$^3$, which exceeded the soil vapour screening criterion of 37 µg/m$^3$ adopted in the DGIs by approximately ten times. However, Johnson and Ettinger modelling based on the maximum reported soil vapour concentration at the Site (which was measured in a heavily impacted area within the Site) and Scenario 3 vapour modelling parameters yields an estimated naphthalene concentration in outdoor air being saturated limited , i.e. more than two orders of magnitude below the naphthalene reference concentration.<br>Note that vadose zone soil vapour concentrations are not expected to be exceeding those reported at the Site to date, as most heavily impacted gasworks impacted fill material will be excavated, treated and/or stabilised. |
| 4 – Paved Recreation | No exceedences reported in the unsaturated zone | None | There were no exceedences of the derived SSTC for soil as they were generally saturation limited for CoPCs at the site (SSTC derived for TPH $C_{10}$-$C_{14}$ and TPH $C_{15}$-$C_{28}$ were not saturation limited, however reported site concentrations did not exceed the calculated SSTCs) based on conservative Johnson and Ettinger modelling with biodegradation taken into account. |
| 5 – Commercial Slab on Ground | Naphthalene | BH087/1.5-1.95<br>BH204S/1<br>BH204D/1.5<br>BH54/1.0-1.4<br>BH55/1.0-1.2<br>BH59/1.9-2 | There were three exceedences of the derived SSTC in the unsaturated zone for naphthalene (8 410 mg/kg; 6 370 mg/kg; and 4 510 respectively) and derived SSTC of 3 200 mg/kg.<br>Most exceedences were reported below depth of water table (with the exception of those listed in the current table) and therefore not of concern in current location.<br>All locations where concentrations exceed SSTC are within Site, which will be excavated for basement installation.<br>Soil removed from these areas and re-used beneath commercial slab on ground/retail buildings should meet SSTC for this scenario. |

| Scenario | Chemicals Exceeding SSTC | Locations/ Depths of Key Concern | Notes |
|---|---|---|---|
| 6 – Intrusive Maintenance | cPAH | BH073_1.5-1.95<br>BH075_0.3-0.5<br>BH087_1.5-1.95<br>BH141_1.5-1.95<br>BH200_1<br>BH204S_1<br>BH204D_1.5<br>BH49_1.5-1.7<br>BH54_1-1.5<br>BH55_1-1.2<br>BH59_1.9-2<br>BH1_1<br>BH058_1.5-1.95<br>BH062_1.5-1.95<br>BH145_0.3-0.5<br>BH64_1-1.2<br>SV09_0.2-0.4<br>BH53_1.1-1.5 | There were two exceedences of the total carcinogenic PAH criteria within Hickson Rd at BH1 and BH53. BH058, BH64, BH062 and SV09 are all located within the PDA area of Block 5 but are not expected to be excavated for basement construction.<br>All locations where concentrations exceed SSTC are within Site, which will be excavated for basement installation. |
| 7 – High Density Residential | Benzene<br>Naphthalene<br>TPH $C_{10}$-$C_{14}$ | BH087/1.5-1.95<br>BH204/1.0<br>BH204D/1.5<br>BH54/1.0-1.4<br>BH55/1.0-1.2<br>BH59/1.9-2 | Maximum reported concentration for benzene in the unsaturated zone (61 mg/kg) exceeds SSTC of 26 mg/kg.<br>Maximum reported concentration for naphthalene in the unsaturated zone (8410 mg/kg) exceeds the SSTC of 980 mg/kg<br>Impacts in soils below water table have not been considered relevant to the current scenario.<br>Soil emplaced adjacent upper level basements should meet SSTC for this scenario.<br>Cumulative effects not expected as other chemicals are greater than one order of magnitude below SSTC and/or SSTC are saturation limited. |

#### 5.6.1.2 Groundwater

SSTC for groundwater are compared to reported CoPC concentrations in Site groundwater samples in **Table T12** to **Table T18** for Scenarios 1 to 7, respectively. The tables also compare SSTC reduced by a factor of five to reported groundwater concentrations, to allow a preliminary assessment of chemical concentrations which are approaching the derived SSTC.

The nature and extent of groundwater SSTC exceedences detailed in **Table T12** to **Table T18** are summarised in **Table 44** below. Exceedences of SSTC for Scenarios 1, 5, 6 and 7 are shown in **Figure F 12** to **Figure F 16**. Note that only scenarios with relevant exceedences, scenarios 1, 5, 6 and 7, are illustrated in figures.

**Table 44: Summary of Groundwater SSTC Exceedences**

| Scenario | Chemicals Exceeding SSTC | Locations/ Depths of Key Concern | Notes |
|---|---|---|---|
| 1 – Lower Basement | Benzene<br>2-Methylnaphthylene<br>Naphthalene<br>TPH $C_{10}$-$C_{14}$ | BH69<br>BH046/MW08<br>BH60/MW60<br>BH087/MW15<br>BH200/MW200<br>BH204D/MW204D<br>BH204S/MW204S<br>BH205/MW205<br>BH206/MW206<br>BH209/MW209<br>BH54/MW54<br>MW10<br>MW15<br>MW3<br>MW7<br>MW210 | Potential risks have been identified based on modelling assumptions used in this scenario. The modelling was conducted based on the assumption that intermittent groundwater seepage (covering a maximum area of 525$m^2$) on two of the walls and floor.<br>This assumption has been considered to be the most conservative of the basement models and has been considered most relevant to construction at the Site. However it should be noted that proposed installation of the groundwater retention wall system is likely to prevent this scenario from occurring at the Site. |
| 2 – Upper Basement | Naphthalene<br>TPH $C_{10}$-$C_{14}$ | BH046/MW08<br>BH60/MW60<br>BH087/MW15<br>BH200/MW200<br>BH204D/MW204D<br>BH204S/MW204S<br>BH205/MW205<br>BH206/MW206<br>BH54/MW54<br>MW10<br>MW15<br>MW7 | Potential risks have been identified based on modelling assumptions used in this scenario. The modelling was conducted based on the assumption that groundwater seepage (covering a maximum area of 45 $m^2$) will be present on two of the walls and floor.<br>Although it has been assumed that groundwater seepage may occur in the lower portion of the wall, it should be noted that proposed installation of the groundwater retention wall system is likely to prevent this scenario from occurring at the Site. |
| 3 – Unpaved Recreation | None | None | |
| 4 – Paved Recreation | None | None | |
| 5 – Commercial Slab on Ground | Benzene<br>Naphthalene<br>TPH $C_{10}$-$C_{14}$ | BH204D/MW204D<br>BH205/MW205<br>MW15<br>MW7<br>MW10 | Exceedences reported only in locations with highest chemical concentrations, which are located in areas which will be excavated for basements or along Hicksons road, and over which slab on ground premises are not expected to be constructed.<br>Source removal in these areas considered likely to reduce groundwater concentrations below those which are conservatively predicted to pose potential vapour risk to commercial/retail slab on grade premises. |

| Scenario | Chemicals Exceeding SSTC | Locations/ Depths of Key Concern | Notes |
|---|---|---|---|
| 6 – Intrusive Maintenance | Benzene<br>2-Methylnaphthalene<br>Naphthalene<br>TPH $C_{10}$-$C_{14}$<br>TPH $C_{15}$-$C_{28}$<br>TPH $C_{29}$-$C_{36}$ | IT2<br>BH046/MW08<br>BH60/MW60<br>BH087/MW15<br>BH200/MW200<br>BH204D/MW204D<br>BH204S/MW204S<br>BH205/MW205<br>BH206/MW206<br>BH209/MW209<br>BH54/MW54<br>BH61/MW61<br>BH210/MW210<br>MW3<br>MW7<br>MW10<br>MW15 | SSTC are driven primarily by dermal water contact pathway.<br>The majority of the locations where exceedences have been reported are expected to be inaccessible to future intrusive maintenance because of the presence of basements.<br>Exceedence locations in Hickson Road (MW7, MW10, BH15/MW15) are those where free tar has been reported. It is expected that free tar will be removed to the extent practicable and thus will not be a direct contact issue in the future. |
| 7 – High Density Residential | Naphthalene<br>TPH $C_{10}$-$C_{14}$ | BH046/MW08<br>BH087/MW15<br>BH200/MW200<br>BH204D/MW204D<br>BH204S/MW204S<br>BH205/MW205<br>BH206/MW206<br>BH54/MW54<br>MW10<br>MW15<br>MW7 | The highest reported groundwater concentration of naphthalene of 283 mg/L exceeds the calculated SSTC of 6.6 mg/L, while the maximum reported concentration of TPH $C_{10}$-$C_{14}$ 1 730 mg/L exceeds the SSTC of 98 mg/L.<br>The majority of locations where these exceedences are reported (especially the highest reported concentrations) will be excavated for basement installation.<br>It is expected that removal of free tar from the site will contribute to a reduction on groundwater concentrations.<br>It is also expected that installation of the groundwater retention wall system will reduce the potential for this scenario to occur. |

### 5.6.2 Conclusions

Based on the comparison of reported soil and groundwater concentrations to human health-based SSTC for potential future land use scenarios at the Site, human health risks are generally not expected at the Site following redevelopment, with the exception of the following locations and/or situations:

1) **Scenario 1 (Lower Basement):** The highest reported groundwater concentrations of benzene, 2-methylnaphthalene, naphthalene and TPH $C_{10}$-$C_{14}$ have the potential to result in unacceptable health risks from inhalation of vapours in the basement airspace. However it is expected that installation of the groundwater retention wall system will prevent impacted groundwater from contacting basement walls.

2) **Scenario 2 (Upper Basement)):** The highest reported concentrations of benzene, 1,2,4-trimethylbenzene, naphthalene and TPH $C_{10}$-$C_{14}$ in soil and naphthalene and TPH $C_{10}$-$C_{14}$ in groundwater have the potential to result in unacceptable health risks from inhalation of vapours in indoor airspaces. The highest reported concentrations of benzene in soil have the potential to cause unacceptable human health risks due to vapour intrusion from soils in the unsaturated zone.

3) **Scenario 5 (Commercial Slab on Ground)**: The highest reported concentrations of benzene, naphthalene and TPH $C_{10}$-$C_{14}$ in groundwater, and naphthalene in soils at the Site have the potential to result in unacceptable health risks due to vapour intrusion. The locations of unacceptable concentrations of naphthalene in soil are such that unacceptable risks are not possible under the current LL development design as the soil in this area will be excavated for basement installation and thus commercial slab on ground construction will not be present above these locations. Similarly unacceptable chemical

concentrations in groundwater have been reported at locations where commercial slab on ground development is unlikely to occur.

4) **Scenario 6 (Intrusive Maintenance)**: The highest reported groundwater concentrations of benzene, 2-methylnaphthalene, naphthalene, TPH $C_{10}$-$C_{14}$, TPH $C_{15}$-$C_{28}$, and TPH $C_{29}$-$C_{36}$ and soil concentrations of cPAHs have potential to result in adverse health risks to short-term intrusive maintenance workers if workers come into direct contact with groundwater and soil. The locations where exceedences of SSTC have been reported for groundwater fall within Hickson Road (BH61/MW61, MW3, MW7, MW10 and BH15/MW15), the Block 4 portion of the Site (MW200, MW204S, MW204D, MW205, BH54/MW54, BH210/MW210, BH87/MW15) , the Public Domain area of Blocks 4 and 5 (IT2, BH046/MW08, BH60/MW60), and the Southern Cove portion of the Site (MW206, MW209). Given that the locations within Block 4 and Southern Cove will not be accessible following redevelopment, exceedences in these locations are not expected to be associated with risks to intrusive workers. Exceedence locations in Hickson Road correspond to those where free tar has been reported within bores during the most recent DGI (AECOM, 2010 b). Risks to intrusive workers in these locations are therefore considered possible, although it is expected that free tar within Hickson Road, particularly at depths which may be contacted during intrusive maintenance and/or construction works within the road, will be removed and/or remediated and that groundwater concentrations following remediation will likely be below SSTC for Scenario 6. It is also noted that direct contact with groundwater (as was conservatively assumed for the purposes of this HHRA) is considered unlikely to occur for extended periods of time as the majority of services within Hickson Road are likely to be above the water table. Exceedances of the adopted SSTCs for soils for the sum of cPAHs are noted to be within Hickson Rd and Block 5. All other exceedances were reported in areas of the Site where basement excavations are proposed to occur.

5) **Scenario 7 (High Density Residential):** The highest reported soil concentrations of benzene, naphthalene and TPH $C_{10}$-$C_{14}$ and highest reported concentrations of naphthalene and TPH $C_{10}$-$C_{14}$ in groundwater, have the potential to result in adverse health risks to residential receptors in high density residential buildings at the Site. The majority of locations where soil and groundwater exceedences were reported are within the area of block 4 where current LL development plans include basement excavations. It is therefore expected that the highest reported concentrations of chemical contaminants in soils at the site will be excavated during basement construction. It is expected also that the remediation of the site will result in reduced chemical concentrations in groundwater at the Site.

With respect to potential human health risks associated with material which may be reused within the Public Domain, it is expected that material which meets criteria for Scenarios 3 through 6 would be suitable for reuse from a human health perspective in areas/locations where respective land use and human exposure assumptions are met.

Criteria for the suitability of materials for placement in public domain areas of Headland Park will be developed by others.

# 6.0 Aesthetic Impacts

## 6.1 Odour

It has been AECOM's experience that the chemical contaminants generally associated with gasworks sites are highly odours and thus it is expected that odours are likely to be emitted during remediation of the Site. It is for this reason that the current HHERA has attempted to provide an indication of the chemicals likely to be present at the site at concentrations that have the potential to be odorous. In an attempt to aid the remediation process, odour-based SSTC ($SSTC_{odour}$) have been derived, these SSTC provide an indication of the chemicals likely to create odours in indoor and outdoor spaces following remediation.

The derivation of these odour-based SSTC ($SSTC_{odour}$) was undertaken using the risk modelling spreadsheets for Scenarios 1 to 7 described in **Section 5.0**, but with the following modifications:

- Threshold toxicity (dose-response) values were replaced with relevant chemical-specific odour threshold values, where available. Odour thresholds were adopted from Agency for Toxic Substances and Disease Registry (ATSDR) toxicological profiles for specific chemicals or chemical groups, or from the IRIS database (USEPA, 2010). Adopted odour threshold values and their sources are summarised in **Table T19**. These odour thresholds have been considered to be most relevant to the current HHERA as they have been reviewed by ATSDR and IRIS and found to be acceptable, this approach is in line with recommended sources published by enHealth (2004) and NEPC (1999). It should be noted that each chemical may have a broad range of published odour threshold values, some of which may be lower than those adopted in the current HHERA. Odour values are very subjective and are based on the sensitivity of the people used in the study, hence there is a large variability in values which may be adopted. It is considered that there is not a high degree of precision and accuracy within the currently available odour values which are published. This is because odour thresholds are based a threshold at which some members of the population may be able to detect the odour under certain conditions. In reality the thresholds at the population is able to detect odours are highly dependent on weather conditions such as wind speed and temperature and sensitivity of the individual. In consideration of variability in the available odour thresholds, a number of other conservative assumptions have been adopted during the calculation of odour based SSTC, such as the removal of the 10 fold soil partitioning factor that was adopted during the calculation of the health based $SSTC_{odour}$ (see below). The $SSTC_{odour}$ have also been developed based on 24 hour a day and 365 days a year exposure which is over conservative (see below). The conservative assumptions adopted by AECOM are considered to remove any uncertainty that might be associated with the selected odour thresholds used in the development of the $SSTC_{odour}$. AECOM considers that the adopted odour values are therefore appropriate.
- Non-threshold toxicity values were not considered, as they are not relevant to odour generation.
- As the olfactory capacity of humans is highly variable, and to ensure the derived odour SSTCs are suitably protective AECOM have conservatively removed the 10 fold soil partitioning factor applied in the derivation of risk based SSTCs (see Section 5.3.2).
- Both volatile and semi volatile COPC were included in the vapour emission modelling. This was undertaken as conservative measure since key odour drivers within gasworks waste are typically phenolic compounds which are classified by USEPA (2004a) as not sufficiently volatile to warrant inclusion into vapour intrusion modelling, but are considered to potentially contribute to odour generation, particularly for intrusive scenarios.
- Receptor exposure time and frequency were set to 24 hours/day and 365 days/year, respectively. This was undertaken as a conservative measure to ensure that odour-based SSTC were based on estimates of average air concentrations within indoor or outdoor air, rather than exposure adjusted air concentrations.
- To date there is limited information available with regards to the effects of chemical mixtures on odour levels, none of this information specifically addresses odorous gasworks related contaminants. Odour emissions from chemical mixtures are dependent upon a number of factors such as the ratio of chemicals present, environmental factors and the specific combination of chemicals. In an attempt to account for the mixtures likely to be present at the Site the mixtures approach adopted during derivation of risk based SSTCs has also been adopted for calculation of odour based SSTCs. This approach has been outlined in **Section 5.2.5.**

- The modelling assumptions for each Scenario as detailed within Section 5.3 have been applied to the derivation of $SSTC_{odour}$, with the exceptions noted above.

The estimated $SSTC_{odour}$ are detailed in **Appendix K** to **Appendix Q** and compared to reported soil and groundwater concentrations at the Site in **Table T6** to **Table T11** (for soil) and **Table T12** to **Table T18** (for groundwater).

The nature and extent of $SSTC_{odour}$ exceedences are summarised in **Table 45** below.

**Table 45: Summary of Exceedences of Odour-Based SSTC**

| Scenario | Soil | | Groundwater | |
|---|---|---|---|---|
| | Chemicals | Locations | Chemicals | Locations |
| 1 – Lower Basement A | 2-methylnaphthalene | MW10 | 2-methylnaphthalene, naphthalene | MW205, MW15 |
| 2 – Upper Basement | None | NA | None | NA |
| 3 – Unpaved Recreation | None | NA | None | NA |
| 4 – Paved Recreation | None | NA | None | NA |
| 5 – Commercial Slab on Ground | None | NA | None | NA |
| 6 – Intrusive Maintenance | None | NA | m&p-cresol | MW7 |
| 7 – High Density Residential | None | NA | None | NA |

Note that while comparison of Site data to the above odour SSTC indicates minimal exceedences, even during intrusive works, observations during intrusive Site investigations have indicated that relatively small scale excavations or intrusive works have potential to result in localised odour issues.

The prediction of minimal locations where odour issues may occur is likely to result from one or more of the following:

- Compounds not specifically identified in analytical suites may contribute to odour (i.e. there are many hydrocarbon compounds within mixtures of gas works waste that cannot be specifically identified and which may contribute to odour).
- Cumulative effects from chemical mixtures may result in odours even where concentrations of individual compounds are below relevant odour thresholds.

It is expected that remediation of the site based on derived human health criteria will result in significantly reduced *in-situ* chemical concentrations and thus odour generation will be significantly reduced. It should also be noted that the development of the Site should prevent odours in future as a large portion of soils at the Site will be removed as part of construction of basement car parks and the remaining areas of the site where soils will remain in place will have clean fill and paving placed on the surface (**Appendix A).**

## 6.2 Visual Amenity

### 6.2.1 Fill Material

It is noted that observations during previous intrusive works have indicated the presence of highly variable fill material at the Site, including gravel, sand, bricks, timber, slag and steel. Black staining, tar and surface sheen were also noted in the footprint of the former Retort House and Purifying Beds. These materials have the potential to impact visual amenity at the Site if exposed, however it has been assumed based on the development plans for the Site that soil or fill materials remaining and/or reused within the development would be overlain by either concrete or landscaping materials to avoid adverse impacts to visual amenity.

#### 6.2.2 Tar Seepage into Basements

As noted in **Section 3.4**, the vertical extent of gasworks derived material (e.g. tar) within fractured bedrock underlying the Site is not known with certainty. This material may cause visual amenity impacts within basements excavated into bedrock if:

- bedrock faces are not sealed with suitable thickness of shotcrete (or similar); and
- tar is present within the bedrock in which the basements are excavated.

However, as noted above in **Section 5.3**, for the purposes of SSTC derivation it has been assumed that exposed sandstone walls within basements will be covered with a minimum of 100 mm of shotcrete, and that this shotcrete is of sufficient strength/density to prevent tar seepage into the concrete and/or basement interior. Visual amenity issues due to tar seeps within basements are therefore not expected. It is expected that free tar will be removed to the extent practicable during remediation works proposed at the Site.

It should be noted that visual, health and/or odour risks are considered to be of potential concern if tar seepage into basement structures occurs, and engineering controls should therefore ensure that this does not occur.

#### 6.2.3 Potential Sheen Impacts to Surface Water Bodies

Sheen has been reported in a number of groundwater monitoring wells, primarily within the Site in close proximity to locations in which free tar has been reported in groundwater monitoring bores and/or in which tar was noted in borehole logs (**Figure F 18**). These observations suggest that under the current hydrogeologic regime, although DNAPL is present within the former gasworks footprint, the sheen impacts to groundwater are not laterally extensive and groundwater with CoPC concentrations high enough to cause sheen is unlikely to extend as far as Darling Harbour.

Locations where tar and/or sheen have been reported during previous investigations include the following (**Figure F 18**):

- Within eastern section of Southern Cove (i.e. within the Site):
- Within the Site footprint: Sheen reported in BH209 and tar in BH206/MW206. BH206 was screened between 7 mbgs and 8 mbgs and BH209 was screened between approximately 1.8 and 8.6 mbgs.
    - Outside, but within close proximity to, the Southern Cove footprint: tar has been reported in MW205, MW204D, BH10 and sheen in BH87/MW15. It is expected that these impacts will be at least partially excavated as part of the basement excavations.
- Within western section of Southern Cove (i.e. outside the Site, within ORWN):
    - Within the Southern Cove footprint: Tar reported in BH40/MW40 at depth greater than 16.5 m.
    - Outside, but within close proximity to, the Southern Cove footprint: tar reported in BH48 at 14-17 m and sheen reported in BH47 at 5-7 m.

Following redevelopment of the Site, the hydrogeological regime within the Site will be modified by the following key changes (refer also to **Section 2.4**):

- The eastern end of the Southern Cove, where the Southern Cove is within the Site, will effectively be concrete lined as a result of the cap park basements to be constructed below it.
- A basement groundwater retention wall system, extending to and keyed into bedrock, will be constructed at the outer edges of Block 4 (in which basement car parks are proposed as part of the redevelopment) and Block 5. The groundwater retention wall system will effectively isolate the basements and any underlying fill from the surrounding ground conditions.
- A shallow canal may be constructed parallel to and slightly west of Hickson Road, connecting the eastern end of Southern Cove to the northern edge of Block 4. The design of the feature is still to be finalised, but AECOM understands that the canal would be concrete lined and therefore have no hydraulic connectivity of groundwater to the canal.

Based on the above, visual impacts due to either sheen or tar are considered to be unlikely within that portion of the Southern Cove which will be within the Site.

The design of the western portion of the Southern Cove (outside the Site and within the ORWN area) has not yet been finalised. An assessment of the risk to visual amenity from tar or sheen in the western Southern Cove (i.e. within the ORWN area) will be made as part of the ORWN HHERA. The scope of remediation work described by the ORWN RAP will be designed to ensure that negative impacts to visual amenity from tar or sheen do not eventuate.

# 7.0 Ecological Risk Assessment

The ecological risk assessment component of this project has comprised consideration of the derivation of site-specific screening criteria (SSESC) for soil, neutral leachate and groundwater based on protection of the environment following development of the Site.

Consideration has also been given to protection of future terrestrial ecosystems (principally plants in landscaped and unpaved areas of the site) through derivation of Terrestrial Soil Criteria (TSC) to define material that is appropriate for use as "suitable fill" in the upper 0.5 m of areas that will be subject to unpaved recreation land-use.

## 7.1 Background

### 7.1.1 Terrestrial Habitat

The Barangaroo area is currently comprised of paved open space with minimal terrestrial organisms. The Site and surrounding terrestrial area have been extensively developed, contain minimal natural vegetation and do not contain threatened or vulnerable terrestrial species, populations, communities or significant habitats (NSW DOP, 2007). Terrestrial habitat at the Site is considered to have a low level of environmental sensitivity.

Furthermore, it has been assumed that potential adverse impacts to future terrestrial ecological receptors (e.g. vegetation and urban wildlife which may inhabit landscaped/vegetated areas) following redevelopment will not occur, as the Site surface will:

- have paved or built structures on the surface; and/or
- be covered with a minimum of 0.5 m of suitable fill in landscaped / unpaved areas (refer to **Section 7.3**).

Therefore, with the exception of consideration of the proposed planting of trees at the Site (refer to **Section 7.3**), risks to terrestrial ecological receptors have not been considered further in this assessment.

### 7.1.2 Aquatic Habitat

Existing Site conditions have been considered along with the proposed development plans at the Site to characterise potential issues for the aquatic habitat. This characterisation is considered to be important for ensuring that there are no unacceptable risks to the ecology of the harbour, in line with the NSW DECCW (OEH) (2010) water quality objectives.

The closest aquatic ecological receptor/receiving environment is Darling Harbour located to the west of the Site, beyond the ORWN area. Darling Harbour and the adjacent Sydney Harbour are highly urbanised estuaries. Sydney Harbour is used for a mixture of purposes including recreational purposes such as boating, swimming and fishing and for commercial purposes including cargo and passenger transport. The area of Darling Harbour adjacent to the Site currently serves as a passenger terminal for cruise vessels.

***Surface Water***

Surface water quality adjacent the Site has not been extensively investigated to AECOM's knowledge. Analytical results for a sample of surface water collected from a stilling well adjacent the Site as part of the groundwater discharge study (AECOM, 2010d) did not indicate the presence of metals above ANZECC (2000) trigger values for marine water. PAHs or other hydrocarbons were not reported above laboratory detection limits.

***Sediment***

Surface sediments within Sydney Harbour have been reported to contain elevated levels of heavy metals, pesticides and PAHs (Irvine and Birch, 1998; Birch and Taylor, 1999; Birch and Taylor, 2000; McReady et al, 2000), presumably as a result of the urbanised and industrial history of the surrounding area, including the former gasworks.

Based on observations of the benthic sedimentary environment adjacent to the Site (as reported by ERM, 2008b), the benthic sedimentary habitat near the Site contains anthropogenic debris including chains, bricks, steel and old fencing. Sandstone rock armour was observed on the surface of the harbour floor within 10 m of the wharf edge and minimal shell fragments or organic matter were reported in the upper 1.2 m of sediment.

Worley Parsons (2010) reported that a diverse range of benthic marine organisms were identified in sediments adjacent to Barangaroo and other Harbour study sites and that soft sediment habitat is available throughout

Darling Harbour. The report also commented on: the high level of boating activity and lack of suitable aquatic feeding and nesting habitat at Barangaroo; the low likelihood that any species of threatened fauna utilise this area; and, the relative absence of known top marine fauna such as fish and sharks.

However, the fact that a range of benthic marine organisms were identified in sediments from the Barangaroo area and that soft sediment habitat is present, means that improvement of the waterway consistent with the management goals for the catchment (see **Section 7.1.3**) is practical and that remediation is an important component of ecological improvement over time.

### 7.1.3 Management Objectives for Darling Harbour

Guidance from the NSW Department of Environment Climate Change and Water (NSW DECCW (2010) indicates that although Darling Harbour area is classified as a waterway affected by urban development, the applicable water quality objectives are:

- protection of aquatic ecosystems;
- protection of visual amenity; and
- achievement of secondary contact recreation and primary contact recreation quality goals over a period of some five years.

These publicly available objectives are considered to reflect community expectations about the harbour.

The aim of the DECCW (OEH) guidance is to make aquatic ecosystems as healthy as possible. It notes that, although a return to natural aquatic ecosystems may be impractical in the short term, an improvement in ecological health is desirable and necessary.

The NSW DECCW (OEH) (2010) guidance identifies water quality trigger values as numeric criteria which if exceeded may indicate potential for harm to occur to the marine environment. The default trigger values provided in ANZECC (2000) are described in the DECCW guidance as conservative and precautionary. If these are not exceeded a very low risk of damage can be assumed to apply. If they are exceeded, further investigation of the pollutant concerned is ‘triggered’ requiring a site-specific investigation and decision tree approach. NSW DECCW (OEH) (DEC 2007) stated that concentrations of potential contaminants of concern in groundwater at a site should be compared, in the first instance, against existing generic criteria, if available, which protect environmental values such as the quality of ecosystems (identified as provided in ANZECC 2000).

AECOM considers that the following overall remediation goals are consistent with the OEH objectives and community expectations for ecological management of Darling Harbour:

- to reduce impacts to Darling Harbour, the nearest sensitive environmental receptor, to a level in keeping with the status ‘slightly to moderately disturbed’; and
- that the concentrations of Site contaminants reaching the receptor do not exceed:
  - ANZECC (2000) 95% species protection marine trigger values;
  - ANZECC (2000) 99% species protection marine trigger values for potentially bioaccumulative contaminants; or
  - other appropriate guideline values which provide a similar level of ecological protection to the ANZECC (2000) trigger values.

## 7.2 Risk Characterisation

Key features of the proposed future development of the Site, as they relate to the ecological risk assessment, are described in **Section 2.4** and **Appendix A**. With the exception of Hickson Road, it is proposed that the entire Site (specifically those portions of Block 4 and Block 5 that are within the Site) be encapsulated by a basement groundwater retention wall system that will extend to and be keyed into bedrock and will ensure that groundwater will no longer be able to migrate from the east of the Site into Darling Harbour. In consideration of the effective removal of the hydraulic connection between the Site and Darling Harbour, the assessment of ecological risk for the Site is not required for ecological protection.

Furthermore, the basement groundwater retention wall system will effectively cut off direct migration from Hickson Road to Darling Harbour, requiring groundwater from Hickson Road to migrate to the north or south around the perimeter of the Stage 1 Development. In consideration of the distance between Hickson Road and Darling

Harbour, the assessment of ecological risk for the areas of the Site within Hickson Road is not considered to be required for ecological protection.

Ecological risk assessment will therefore be undertaken on a site-specific basis in those areas of Barangaroo South that will be in hydraulic connection with Darling Harbour following the development. That is, site-specific ecological risk assessments, including the derivation of site-specific SSESCs will be completed as part of the HHERAs to be prepared in relation to ORWN and ORWS (Addendum).

## 7.3 Protection of Future Plantings

The human health risk assessment has assumed that open space areas of the Barangaroo Stage 1 development will be covered in a minimum of 0.5 m of suitable fill (refer to Section 5.3.7). It is proposed that the potential for phytotoxicity to trees and other vegetation planted within the suitable fill cover as part of the future development will be addressed by:

- derivation of Terrestrial Soil Criteria (TSC) that will both maintain soil and plant health and be protective of human health under the proposed land use; and
- increasing the depth of suitable fill in specific areas as required to accommodate the current and future potential planting of different species and sizes at th e Site.

### 7.3.1 Generic Guidelines for Phytotoxicity

The development of screening criteria for phytotoxicity has been dealt with in various ways by different jurisdictions in Australia and internationally; however, some jurisdictional approaches are utilised more commonly in typical phytotoxicity practice. AECOM has considered and adapted existing Australian and international information on phytotoxicity to develop a set of TSC that are appropriately protective of plantings at Barnagaroo. The reviewed generic guidance, and the contribution to the derivation of the TSC, is summarised below:

- CCME (1999a, 1999b, 1999c, 1999d, 2008a and 2008b) soil quality guidelines have been derived over a number of years for the protection of soil invertebrates and plants based on direct contact exposures. These are published in a series of scientific support documents for individual chemicals and for chemical groups such as PAHs.
- DEC (2006) developed provisional phytotoxicity based investigation levels. These values were proposed by DEC to be used in urban redevelopment scenarios of pH 6-8 and sandy loam soils. DEC (2006) indicates that these levels are not appropriate for assessing fill material.
- US EPA Region III (1995) BTAG Screening Levels are ecotoxicology-based screening benchmark values to be used for the evaluation of sampling data at Superfund sites and not for determining target criteria as the values were based on several toxicological end points.
- NMHSPE/Netherlands Ministry for Housing, Spatial Planning and the Environment (2000) developed target intervention values calculated for ecotoxicological effects i.e. concentrations in soil which cause negative effects to 50% of potentially present species. Soil was determined to have 10% organic matter and 25% clay.
- NEPM (1999d), interim EILs were developed for generic use in urban environments until more preferable regional guidelines were developed. These interim guidelines were developed based on consideration of phytotoxicity (copper, chromium and lead) ANZECC B values and soil survey data from four Australian capital cities.
- The NEPM (Draft, 2010) EILs have been developed based on consideration of a species sensitivity distribution model derived specifically for Australian soil conditions which included factors for phytotoxicity, as well as a review of CCME (2008) guidance on petroleum hydrocarbons in soil. The NEPM schedule B(5a) notes that EILs are only to be applied to soil to a depth of 2m BGL, and the species protection level for urban residential/public open space has been set at 80%.
- USEPA (2007) Ecological Soil Screening Levels (eco SSLs). The USEPA indicates that: (a) the Eco SSLs are screening ecotoxicity values derived to avoid underestimating risk; and, (b) a requirement for cleanup based solely on Eco-SSL values would not be technically defensible. AECOM also considers that protection of plants and soil invertebrates historically has not been a major focus of USEPA risk assessment guidance, and is a low priority relative to the protection of mammalian and avian receptors.

- USEPA Region V (2003) Ecological Screening Levels (August), are values based on exposure to a single species, a masked shrew. The masked shrew was selected as it almost exclusively feeds on invertebrates. Other toxicological sources are largely unknown. The values are recommended by USEPA (2003) to be used for screening only.
- NSWEPA (1994) Service Station Site guidelines - These are considered to be intervention values (protecting 50% of species) and maximum permissible concentrations (protects 95%). The value for Benzene is based on the document ANZECC/NHMRC, *Australian and New Zealand Guidelines for the Assessment and Management of Contaminated Sites* (1992). The guideline provided in ANZECC/NHMRC (1992) has been derived based on consideration of threshold levels for phytotoxicity and uptake of contaminants which may impair the growth or reproduction of plants, or cause unacceptable residue levels. The toluene, ethylbenzene and xylenes guideline values are based on guidance from Netherlands. The toluene value is a maximum permissible concentration to protect organisms in soil. The Ethylbenzene value is a maximum permissible concentration value derived from aquatic ecotoxicological data. The Xylene value is a maximum permissible concentration.

Of all the reviewed guidelines, AECOM considers that the Canadian (CCME) soil quality guidelines place greatest emphasis on defining soil toxicity thresholds specifically for the protection of soil ecological integrity and the ability of soil to support plants and soil invertebrates. Therefore, AECOM has favoured these guidelines in addition to Australian-based guidelines from NSWEPA (1994) and the draft NEPM (2010).

The use of CCME Soil quality Guidelines (SQG) for Commercial/Industrial land use, specifically the course textured soil criterion, is considered appropriate for Barangaroo South because the criterion is derived for application to direct contact plant growth and protection. Complementary CCME SQG derived for other land uses, including for example agricultural and parkland, take into account additional factors such as cattle feeding which are considered less relevant in the Barangaroo South tree planting context.

### 7.3.2 Terrestrial Soil Criteria

Terrestrial Soil Criteria (TSC) have been developed to define material that is appropriate for use as “suitable fill” placed in the upper 0.5 m of open space areas.

The derived TSC must be protective of both human health and plants. In consideration of this, AECOM has derived the TSC from the lower of the following generic guideline values for the protection of plants (refer to Section 7.3.1 above) and human health:

- Canadian Council of Environment Ministers Soil Quality Guidelines (CCME SQG) for Commercial/Industrial Land Use – Course textured soil;
- DRAFT NEPM (2010) EILs for Public Open Space;
- NEPM (1999d) Schedule B(1), Guideline on the Investigation Levels for Soil and Groundwater, Interim Urban EILs;
- DRAFT NEPM (2010) HIL C for Developed Open Space/Recreational Land Use; and
- NSW EPA (1994) Guidelines for Assessing Service Station Sites.

The terrestrial soil criteria are presented in **Table 46**.

**Table 46: Terrestrial Soil Criteria**

| Key Chemical | Criteria for Protection of Plants and Soil (mg/kg) | Grouped Criteria (mg/kg) | Data Sources/Notes |
|---|---|---|---|
| **Metals and Inorganics** | | | |
| Arsenic[a] | 20 | | NEPM (1999) - Interim Urban |
| Cadmium | 3 | | NEPM (1999) - Interim Urban |
| Chromium | 190 | | NEPM (draft, 2010) EILs - Public open space – aged |
| Copper[a] | 60 | | NEPM (draft, 2010) EILs - Public open space – aged |
| Lead[a] | 1100 | | NEPM (draft, 2010) EILs - Public open space – aged |
| Mercury | 1 | | NEPM (1999) - Interim Urban |
| Nickel | 30 | | NEPM (draft, 2010) EILs - Public open space – aged |
| Zinc[a] | 200 | | NEPM (1999) - Interim Urban |
| cyanide (if free) | 8 | | CCME (1999b) coarse soil |
| Ammonia | 1 | | Calculated based on irrigation guideline of 5 mg/L as N (based on protection of plants) and leachability calculation[b] |
| **Petroleum Hydrocarbons** | | | |
| TPH $C_6 – C_9$ | 210 | | CCME (1999b) coarse soil |
| TPH $C_{10} – C_{14}$[a] | 150 | | CCME (1999b) coarse soil |
| TPH $C_{15} – C_{28}$ | - | **300** | CCME (1999b) coarse soil |
| TPH $C_{29} – C_{36}$ | - | | |
| Benzene | 1 | | NSW EPA (1994) |
| Toluene | 1.4 | | NSW EPA (1994) |
| Ethylbenzene | 3.1 | | NSW EPA (1994) |
| Xylenes | 14 | | NSW EPA (1994) |
| **Low MWT PAHs** | | **sum - 50[b]** | [a:] CCME (1999b)<br>[b:] Total PAHs (excluding carcinogenic PAHs), from USEPA Eco SSLs of 48mg/kg rounded to 50mg/kg |
| Acenaphthene[a] | | | |
| Acenaphthylene[a] | | | |
| Anthracene | | | |
| Fluorene[a] | | | |
| Phenanthrene | | | |
| Naphthalene[a] | 22 | | |
| **High MWT PAHs** | | | |
| benzo[a]anthracene | | TEF – 4[c] | [C]: Criteria of 4 for total TEF carcinogenic PAHs based on benzo(a)pyrene and applied using the following TEFs from CCME (2008b) :<br>- benzo[a]anthracene, 0.1<br>- benzo[a]pyrene, 1<br>- benzo[b]fluoranthene, 0.1<br>- benzo[k]fluoranthene, 0.1<br>- benzo[ghi]perylene, 0.01 |
| benzo[a]pyrene | | | |
| benzo[b]fluoranthene | | | |
| benzo[k]fluoranthene | | | |
| benzo[ghi]perylene | | | |
| Chrysene | | | |
| dibenz[ah]anthracene | | | |

| Key Chemical | Criteria for Protection of Plants and Soil (mg/kg) | Grouped Criteria (mg/kg) | Data Sources/Notes |
|---|---|---|---|
| indeno[1,2,3 cd] pyrene | | | - chrysene, 0.01<br>- dibenz[ah]anthracene, 1<br>- indeno[123cd]pyrene, 0.1 |
| Fluoranthene[a] | | Sum – 18[d] | [d]:Total for flouranthene and pyrene based on USEPA Eco SSL (June, 2007) |
| Pyrene | | | |
| **Phenols** | | | |
| Phenol | 3.8 | | CCME (1999d) coarse soil |
| 2,4dimethylphenol | 3.8 | | CCME (1999d) coarse soil |
| 2-methylphenol | 3.8 | | CCME (1999d) coarse soil |
| 3&4-methylphenol | 3.8 | | CCME (1999d) coarse soil |

Notes:

[a] Where the TSC are greater than the derived leachability based soil SSESC the relevant soil SSESC will be adopted.
[b] Guideline based on ANZECC (2000) for Nitrogen and Ammonia Methodology and Leachability Calculation as per Appendix D utilising Koc for Ammonia of 14 L/Kg (ATSDR 2011) and Foc 0.01 (AECOM 2011) with resulting Kd of 0.14 L/Kg.  It is noted that 20 mg/kg for Ammonia (as N) is the standard laboratory LOR.

AECOM considers that the TSCs presented in **Table 46** are appropriate for use for the definition of suitable soil to be placed in the 0.5 m cover layer in unpaved open space areas at Barangaroo. The TSCs are considered to be:

- consistent with development of a sustainable remediation scope of work;
- protective of human health for parks, playgrounds, playing fields and secondary schools; and
- protective of terrestrial ecosystems.

## 7.4 Conclusions

Consideration was given to development of site-specific ecological screening criteria (SSESC) for the protection of the environment.  Darling Harbour was identified as the nearest sensitive environmental receptor to the Site.

With the exception of Hickson Road, the proposed design includes encapsulation of the entire Site by a basement groundwater retention wall system that will extend to and be keyed into bedrock and will ensure that groundwater will no longer be able to migrate from the east of the Site into Darling Harbour.  The development of SSESCs for the areas of Site within the retention wall system is therefore not required for ecological protection.  Furthermore, the basement groundwater retention wall system will effectively cut off direct groundwater migration from Hickson Road to Darling Harbour, requiring groundwater from Hickson Road to migrate to the north or south around the perimeter of the Stage 1 Development.  Therefore, in consideration of the distance between Hickson Road and Darling Harbour, the development of SSESCs for Hickson Road is not considered to be required for ecological protection.

For areas of the Barangaroo development which lie between the basement groundwater retention wall system and Darling Harbour, SSESC will be derived in HHERAs for those specific areas (in particular ORWN, ORWS (as an Addendum to this HHERA), and for the VMP area relevant to existing Site configuration).

# 8.0 Uncertainties

## 8.1 Human Health

Risk assessments and development of health risk-based soil and groundwater criteria involve 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 have therefore been selected to be conservative in nature, in order to evaluate an assumed reasonable maximum exposure scenario and provide a deliberate margin of safety.

A more detailed discussion of some of the uncertainties associated with different components of the risk assessment process is provided in the following sections.

### 8.1.1 Sampling and Analysis

Data collected from the site have been based on the knowledge of the site history and hydrogeological conditions. The laboratory analytical schedule has also been selected based on a knowledge of former site activities and hence has focussed on chemicals which were known or expected to be present at, or to have been formerly used at, the site. There is the potential for chemicals to be present on the site which have not been characterised based on omission from site history records.

Overall, the data utilised in this risk assessment are considered to be representative of environmental conditions at the site at the time of sampling.

The identification of CoPC in groundwater has considered use of current guidelines that are based on the more conservative endpoint of drinking water. While the guidelines adopted do not specifically address vapour migration and intrusion issues, the guidelines are designed to be protective of all uses and exposure pathways (including volatilisation). The approach adopted, however, is considered appropriate for the identification of key chemicals that warrant more detailed assessment.

### 8.1.2 Human Exposure Parameters

Risk assessments require the adoption of several assumptions in order to assess potential human exposure. This risk assessment includes assumptions about general characteristics and patterns of human exposure relevant to the site and surrounding areas. The assumptions used are conservative and developed to provide an estimate of reasonable maximum exposures rather than the actual exposures. This approach tends to overestimate the risks.

It is also noted that a number of the exposure guideline values derived from enHealth (2004) and NEPC (1999a) tend to be conservative as they are designed to be protective of the most highly exposed members of the population and their use may lead to an overestimation of risk for the majority of receptors.

### 8.1.3 Vapour Transport Modelling

The assumptions adopted for vapour transport modelling are generally considered to be conservative and likely to overestimate actual vapour concentrations at the Site. The use of a model requires the simplification of many complex processes in the subsurface as well as the potential for entry and dispersion within a building. To address this simplification, the vapour models available (as adopted in this HHERA) are considered to be conservative such that uncertainties are addressed through the overestimation of actual concentrations.

It should be noted that the vapour model used is designed to be a first tier screening tool (Johnson and Ettinger, 1991 and USEPA Air Emissions for Waste and Wastewater 1994) and is considered likely to overestimate air concentrations (and associated risks) due to the incorporation of a number of conservative assumptions, including the following:

- Chemical concentrations in soil and groundwater were assumed to remain constant over the duration of exposure (i.e. it was assumed that the source was non-depleting and not subject to natural biodegradation processes).
- Equilibrium partitioning between chemicals in soil or groundwater and chemical vapours in the source zone was assumed.
- Steady-state vapour and liquid-phase diffusion through the vadose zone was assumed.

- No biodegradation or loss of chemical during diffusion towards the ground surface with slab on grade or basement structure is considered. Biodegradation effects have been considered for paved and unpaved areas of the site.
- Steady, well mixed dispersion of emanating vapours within the enclosed or within surface water body (for seepage) or ambient mixing space is assumed.
- Volatilisation was considered to be the dominant process and oxidation/reduction, hydrolysis and adsorption processes were not considered.

Overall, the vapour model is expected to provide an over-estimation of the actual vapour exposure concentrations. Further, where Site-specific input parameters were not available, conservative estimates for some input parameters were used which may lead to an over-estimation of risk.

#### 8.1.3.1 Approach to Potential Wet Basement Uncertainties

The estimation of potential vapour concentrations within a basement where groundwater migration has occurred and intermittent wet walls and floor are present (Scenario 1) was undertaken using the USEPA (1994) Air Emission Model for Waste and Wastewater. The model is based on a liquid and gas phase resistance model which calculates an overall mass transfer coefficient. The transport of water through the concrete was dominated by the water permeability through concrete. The values adopted in the modelling were based on high permeability concrete (*Gomes et al*).

The assumptions adopted for the basement modelling were purposefully conservative, given the uncertainties associated with application of the models to a wet basement and are considered to represent an upper bound estimate of the extent of vapour intrusion which may occur, based on the following:

- For scenario 1, 2 of the 4 walls and the basement floor were considered to be subject to water seepage. A conservative assumption of 50% of the total area of the two floors and floor were subject to water seepage. .
- For scenario 2 and 7, 2 of the four walls below the water table are considered to be subject to water seepage. A conservative assumption of 50% of the total area of the upper basement which is covered in water (i.e. 1m x 25m x 2= 50m$^2$ of total area which could be wet below the water table). To be conservative, 25m$^2$ has been assumed to be subject to water seepage.
- For all scenarios where water is considered to seep into the basement, it has been assumed that the water flow is continuous, which is unlikely to be the case during seasonal variations. It is also considered that the current basement and engineering controls will restrict the migration of water seepage into the lower basement

It is however important to recognise that it is difficult to predict the nature and extent of groundwater infiltration through basement walls which may occur. As such, the following is recommended:

- In accordance with AS 1668.2 (Standards Australia, 2002), basement car park levels will be maintained at exchange rates of 4 per hour (which has been considered within the modelling presented within this report).
- A further recommended precautionary basement design provision is placement of sump rooms at farthest distance available from lift wells.
- Groundwater will not pool within basement floors and walls, as this would be considered unacceptable from a strata management point of view.
- The concrete in the lower basements has been assumed to be at a minimum grade 40 (based on AS3735 requirements) where contact with groundwater is considered likely to occur. It is also noted that the current design plans have a plenum and sump drains which will mitigate migration of water into publically accessible areas.

Each element of the above engineering controls is consistent with standard design and is compatible with normal building management requirements.

It is also noted that refined building design plans supplied by LL since completion of the HHERA modelling indicate that the current building and basement design incorporates features which are likely to further reduce the potential for vapour intrusion into buildings (relative to the building aspects assumed and modelled in the HHERA) thereby providing a further margin of safety with respect to potential uncertainties.

#### 8.1.3.2 Advective Flow

The vapour modelling has assumed that building underpressurisation within subsurface car parks may lead to advective flow of vapours from vadose zone soils to indoor air.

Advective flow has not been considered for scenario 1 where the presence of saturated groundwater on basement walls and floor results in zero air filled porosity precludes advective air/vapour flow into portions of the basement below the water table.

Advective flow was considered for scenario 2 and scenario 7 (through the unsaturated zone soil).

In the case of slab on ground premises (Scenario 6), building underpressurisation is considered unlikely given the warm climate and expected well ventilated nature of cafes or shops which are expected to be constructed (i.e. 1-2 storeys high). However, if the nature of future slab on ground buildings is expected to result in significant underpressurisation of the building airspace relative to the subsurface vadose zone may occur, the SSTC for these buildings may need to be reconsidered and/or buildings should be engineered and ventilated in such a manner that vapour intrusion is mitigated. Care should also be taken to minimise preferential vapour flow pathways into these buildings, e.g. around utility service entrance points, etc.

### 8.1.4 Basement Air Exchange Rate

The approach to the assessment of air exchange rates within proposed basement carparking at the site has been to adopt the minimum AS 1668.2 standard of 4 per hour.

With respect to scenario 1 (seepage of water into 2 walls and floor) it is noted that if the total air exchanges are halved to a total of 48 per day (i.e. 2 per hour), the calculated SSTC decrease by half for chemicals which are not solubility limited.

It is considered that if the building is maintained in accordance with AS 1668.2, the approach taken to the risk assessment is appropriate.

### 8.1.5 Toxicity Assessment

In general, the available scientific information is insufficient to provide a thorough understanding of all of the potential toxic properties of chemicals to which humans may be exposed. It is necessary, therefore, to extrapolate these properties from data obtained under other conditions of exposure and involving experimental laboratory animals.

This may introduce two primary types of uncertainties into the risk assessment, as follows:

- those related to extrapolating from one species to another; and
- those related to extrapolating from the high exposure doses, usually used in experimental animal studies, to the lower doses usually estimated for human exposure situations.

The majority of the toxicological knowledge of chemicals comes from experiments with laboratory animals, although there may be interspecies differences in chemical absorption, metabolism, excretion and toxic response. There may also be uncertainties concerning the relevance of animal studies using exposure routes that differ from human exposure routes. In addition, the frequent necessity to extrapolate results of short-term or sub-chronic animal studies to humans exposed over a lifetime has inherent uncertainty.

In order to adjust for these uncertainties, ADIs and RfDs incorporate safety factors that may vary from 10 to 1000.

Further, the USEPA assumes that humans are as sensitive to carcinogens as the most sensitive animal species. The policy decision, while designed to minimise the potential for underestimating risk, introduces the potential to overestimate carcinogenic risk. Conversely, it also does not allow for the possibility that humans may be more sensitive than the most sensitive animal species. The model used by the USEPA to determine slope factors is a linearised multistage model, which provides a conservative estimate of cancer risk at low doses and is likely to overestimate the actual slope factor. It is assumed in this approach that a genotoxic mechanism applies, however, most carcinogens do not actually cause cancer by this mechanism.

The result is that the use of slope factors has the general effect of overestimating the incremental cancer risks.

The approach for evaluating risks to mixtures of chemicals assesses dose additively and does not account for potential synergism, antagonism or differences in target organ specificity and mechanism of action. In general, the additive approach has the effect of overestimating the risks. This is because chemicals that have no additive effects are included together as well as chemicals that may have additive effects.

Uncertainties in deriving toxicity values for TPH fractions also incorporate a number of uncertainties and assumptions including:

- the composition of the TPH fractions present at the Site may vary from the surrogate chemical or chemical mixture upon which adopted toxicity criteria are based; and
- the composition of the TPH fractions present at the Site may change with weathering in the environment.

#### 8.1.5.1 Dermal Toxicity of PAHs

The assessment of dermal toxicity associated with exposure to carcinogenic PAHs in soil has been assessed using the Knafla et al (2005) dermal cancer slope factor of 25 mg/kg. This factor was not adopted in the assessment of exposure risks associated with dermal contact to groundwater as the development plans for the Site are assumed to limit the possibility of exposure to intrusive maintenance workers (i.e. extensive basement carpark developments, the installation of a retention wall surrounding and paved areas leaves only a small area of the Site 'open' to intrusive maintenance works). It is also expected that excavations and trenches will not readily fill with water over a day of maintenance.

If the Knafla et al (2005) dermal slope factor is adopted for benzo(a)pyrene and for other carcinogenic PAHs in groundwater , it will reduce the SSTC by 60-fold, as shown in **Table 47.**

**Table 47: Sensitivity Analysis – Dermal Slope Factor for Carcinogenic PAHs (Scenario 6 only)**

| Carcinogenic PAH | Groundwater SSTC (mg/L) | |
|---|---|---|
| | Based on NHMRC (2004) CSF | Based on Knafla et al (2006) CSF |
| CPAH/ Benzo(a)pyrene | 1 | 0.0173 |

Derivation of a groundwater SSTC for BaP using the Knafla dermal slope factor generates an SSTC of 0. 0173 mg/L in contrast to the SSTC of 1 mg/L derived using the NHMRC (2004) cancer slope factor (see **Appendix R** for modelling details). While the difference in SSTCs is significant (a 60 fold reduction), it is considered unnecessary conservative considering the limited proportion of the Site where intrusive maintenance works could be undertaken.

#### 8.1.5.2 Potential Background Exposure to CoPC

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, 2004; NEPC, 1999a). As background intakes have not been accounted for in the derivation of human health based SSTC for this HHERA, background concentrations of volatile CoPC (where available) have been compared to RfCs adopted for assessment of threshold inhalation health effects in **Table 48** below. Only background air concentrations of CoPC have been evaluated, since the primary exposure pathway of concern for the human health based SSTC derived in this HHERA is the vapour inhalation pathway.

**Table 48: Comparison of Urban Background Concentrations of CoPC to Adopted RfCs**

| Chemical | RfC mg/m$^3$ | Lowest reported background Level mg/m$^3$ | Highest reported background Level mg/m$^3$ | Source |
|---|---|---|---|---|
| Acenaphthene | 0.21 | < 0.0000045 | <0.001 | DEC (2004) [1] |
| Acenaphthylene | 0.21 | < 0.0000045 | <0.001 | DEC (2004) [1] |
| Ammonia | 0.0695 | 0.0013 | <0.02 | ATSDR (2004) |
| Anthracene | 3.5 | < 0.0000045 | <0.001 | DEC (2004) [1] |
| Benzene | 0.0096 | 0.004 | 0.4 | DEH (2003) [2] |
| Ethylbenzene | 22 | 0.004 | <0.001 | DEH (2003) [2] |
| Fluoranthene | 0.14 | < 0.0000045 | <0.001 | DEC (2004) [1] |
| Fluorene | 0.14 | < 0.0000045 | <0.001 | DEC (2004) [1] |

| Chemical | RfC mg/m$^3$ | Lowest reported background Level mg/m$^3$ | Highest reported background Level mg/m$^3$ | Source |
|---|---|---|---|---|
| 2-Methylnaphthalene | 0.14 | 0.0015 | 0.01 | ATSDR (2005) |
| Naphthalene | 0.003 | < 0.0000045 | <0.001 | DEC (2004) [1] |
| Phenanthrene | 0.21 | < 0.0000045 | <0.001 | DEC (2004) [1] |
| Pyrene | 0.105 | < 0.0000045 | <0.001 | DEC (2004) [1] |
| Styrene | 0.26 | 0.021 | 0.08 | Hawas (2002) |
| Toluene | 0.38 | 0.025 | 0.07 | DEH (2003) [2] |
| Xylenes | 0.87 | 0.023 | 0.03 | DEH (2003) [2] |

[1] Value is for total PAHs but has conservatively been adopted for individual PAHs.

[2] Mean personal exposure level for winter and summer for four urban cities in Australia.

The comparison in the above table indicates that typical background concentrations of CoPC assessed on the basis of threshold inhalation toxicity criteria and for which background air data are available, are generally less than 10% of the respective RfCs, with the exception of benzene. While background concentrations of some other compounds approached 10% of their respective RfCs (e.g. styrene, toluene), the background contributions are considered to be negligible in comparison to the overall uncertainty associated with the derivation of the RfCs themselves (considered to be at least an order of magnitude) and it is therefore not considered warranted to correct for them.

In the case of benzene, mean urban background air concentrations reported by DEH (2003) were approximately 40% of the adopted RfC. Accounting for background exposure would therefore result in inhalation-based SSTC for threshold effects which are approximately 40% lower than those derived in this HHERA. However, adjustment for background would have no effect on the adopted human health SSTC for benzene, since benzene SSTC were driven by non-threshold, rather than threshold, health effects.

Based on the above, background correction of RfC used in the derivation of human health based SSTC for this HHERA is not considered necessary, as correction would have negligible effect on the derived SSTC.

### 8.1.6 Sensitivity Analysis

**Table 49: Sensitivity of Modelling Input Parameters**

| Parameter | Range of Values | Value Adopted in Risk Assessment | Effect on derived SSTC | Outcome in Risk Assessment |
|---|---|---|---|---|
| Depth to Groundwater | 1.38 to 2.92 mbgs | 2.0 mbgs | Value will increase with increased depth | Value adopted is likely to be representative of the average depth to groundwater across the site |
| Geology | A range of geological conditions have been encountered on the Site which are predominantly sand, gravel and some clay | Sand < 12% fines | Value will increase with increased clay content | Assumption of sand across the site with <12% fines is conservative |
| Soil Bulk Density | Sand- range 1.5-1.7 g/cm3 | 1.66 g/cm3 | Value will increase with decreased bulk density | Conservative assumption with higher of the range adopted resulting in a lower SSTC |

| Parameter | Range of Values | Value Adopted in Risk Assessment | Effect on derived SSTC | Outcome in Risk Assessment |
|---|---|---|---|---|
| Air Exchange Rate in Basement | Range of values from 2 to 4 air exchanges per hour | 4 | Value will decrease if lower air exchange rate is adopted. | Considered that higher exchange rate is justified in accordance with AS1668.2 |
| Areal fraction of cracks in foundation/ walls | Range of values from 0.01-0.0004 | 0.0002 for basement and 0.00038 for slab on grade | Value will decrease with a larger area fraction of cracks | Considered that adopted values are representative of a basement and slab on ground under normal conditions. Buildings are all new in construction; hence the quality of the slab is anticipated to be sound. |
| Advection Rate cm3/sec | Average default is 1L/min- 10L/min with default of 5L/min equal to 83 cm3/sec | Calculated values adopted average value of 175 cm3/sec | Value will increase with a higher advection rate | Conservative assumptions have been adopted for where advection is considered to be relevant. |
| Biodegradation Adjustment | For the paved and unpaved scenario biodegradation range of 10-100 fold factors | 10 fold factor | Value will increase with a higher biodegradation rate | Conservative assumption to account for actual biodegradation rates are unknown. Oxygen measurements within the soil support the evidence of biodegradation |
| Soil Partitioning Equation Adjustment | Adjustment due to the conservative nature of the predicted values. Over prediction has been shown to range from 10 to 1000 times | 10 fold factor applied to BTEX, TPH $C_6$-$C_9$, $C_{10-14}$, naphthalene, 1,2,4-trimethylbenzene | Value will increase with a higher biodegradation rate | Conservative assumption to account for over-estimation for derived soil SSTC. |
| Concrete water permeability | Range of values from high impermeability $8.6 \times 10^{-6}$ m/day to high permeability $8.6 \times 10^{-2}$ m/day | $8.6 \times 10^{-2}$ m/day (high permeability) | Value will decrease with lower permeability rate | Conservative assumption to account for more permeable concrete |

| Parameter | Range of Values | Value Adopted in Risk Assessment | Effect on derived SSTC | Outcome in Risk Assessment |
|---|---|---|---|---|
| Modelling of vapour emissions from groundwater. | Water may seep through entire three of the four walls for the proposed basement within the PDA remediation works area. | Model has assumed that 2 of the 4 walls have water seepage (50%) for the upper basement and 2 of the 4 walls and floor for the lower basement. | If the area of infiltration is increased, the SSTC will increase. | It is considered that the assumptions presented within the risk assessment are conservative and are representative of unrealistic scenarios where 50% of 2 of the 4 wall areas (and floor for lower basement) are continuously covered in water. |

### 8.1.7 Overall

The quantification of risks to human health and derivation of SSTC presented in this report has considered a range of issues that are associated with uncertainties inherent in the site-specific data, toxicological data and assumptions adopted. A number of these uncertainties and issues that warrant consideration in the interpretation of the risk estimates have been identified.

In addition to these uncertainties, a number of exposure and vapour model parameter values are selected to represent a variable range of physiological, behavioural, chemical and physical conditions. These variables are considered to be better represented as a distribution rather than a single point value. The outcome of the assessment can therefore be affected by the variability associated with key parameters (most sensitive values). However, it should be highlighted that the assessment presented in this report has adopted conservative or reasonable upper-bound values for these variables in most cases. The compounding effect of utilising multiple reasonable upper limits for quantitative parameters in the assessment is expected to give rise to an overestimation of actual exposure and associated health risk.

# 9.0 Summary of SSTC

## 9.1 Summary of SSTC for Groundwater

Presented in **Table 50** below is a summary of the SSTC for groundwater for the Site.

**Table 50: Summary of Groundwater SSTC**

| Chemical | Groundwater Health and/or Odour Criteria (SSTC)(lowest of health and odour based) (mg/L) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Scenario 1 – Lower Basement | Scenario 2 - Upper Basement | Scenario 3 - Unpaved Recreation | Scenario 4 - Paved Recreation | Scenario 5 - Commercial Slab on Ground | Scenario 6 - Intrusive Maintenance | Scenario 7 - High Density Residential |
| Acenaphthene | - | | - | - | - | - | - |
| Acenaphthylene | - | - | - | - | - | 57 | - |
| Ammonia | 2,400 | 6,800 | 2,400,000 | - | 87,000 | 15,000 | 16,000 |
| Aniline | - | - | - | - | - | 980 | - |
| Anthracene | - | - | - | - | - | - | - |
| Arsenic, Inorganic | - | - | - | - | - | 380 | - |
| Barium | - | - | - | - | - | 570 | - |
| Benz(a)anthracene | - | - | - | - | - | - | - |
| Benzene | 21 | 95 | 620 | 5,300 | 22 | 3.4 | 150 |
| Benzo(a)pyrene | - | - | - | - | - | - | - |
| Benzo(b)fluoranthene | - | - | - | - | - | - | - |
| Benzo(g,h,i)perylene | - | - | - | - | - | - | - |
| Benzo(k)fluoranthene | - | - | - | - | - | - | - |
| Bis(2-ethylhexyl)phalate | - | - | - | - | - | - | - |
| Cadmium | - | - | - | - | - | 15 | - |
| Chromium(III) | - | - | - | - | - | 8400 | - |

| Chemical | Groundwater Health and/or Odour Criteria (SSTC)(lowest of health and odour based) (mg/L) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Scenario 1 – Lower Basement | Scenario 2 - Upper Basement | Scenario 3 - Unpaved Recreation | Scenario 4 - Paved Recreation | Scenario 5 - Commercial Slab on Ground | Scenario 6 - Intrusive Maintenance | Scenario 7 - High Density Residential |
| Chromium(VI) | - | - | - | - | - | 7.6 | - |
| Chrysene | - | - | - | - | - | - | - |
| Cobalt | - | - | - | - | - | 260 | - |
| Copper | - | - | - | - | - | - | - |
| Dibenz(a,h)anthracene | - | - | - | - | - | - | - |
| Dibenzofuran | - | - | - | - | - | - | - |
| Dimethylphenol, 2,4- | - | - | - | - | - | 720 | - |
| Ethylbenzene | - | - | - | - | - | 210 | - |
| Fluoranthene | - | - | - | - | - | - | - |
| Fluorene | - | - | - | - | - | - | - |
| Indeno(1,2,3-cd)pyrene | - | - | - | - | - | - | - |
| Lead and Compounds | - | - | - | - | - | 1,100 | - |
| Manganese | - | - | - | - | - | 2,400 | - |
| Methylnaphthalene, 2- | **38** | **120** | - | - | - | 38 | - |
| Methylphenol, 3&4 | **1,000** | **2,700** | - | - | **89,000** | **270** | **6,200** |
| Naphthalene | 0.92 | 2.9 | - | - | 100 | 30 | 6.6 |
| Nickel | - | - | - | - | - | 350 | - |
| Phenanthrene | - | - | - | - | - | - | - |
| Phenol | **310,000** | - | - | - | - | 23,000 | - |
| Pyrene | - | - | - | - | - | - | - |
| Styrene | - | - | - | - | - | 88 | - |

| Chemical | Groundwater Health and/or Odour Criteria (SSTC)(lowest of health and odour based) (mg/L) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Scenario 1 – Lower Basement | Scenario 2 - Upper Basement | Scenario 3 - Unpaved Recreation | Scenario 4 - Paved Recreation | Scenario 5 - Commercial Slab on Ground | Scenario 6 - Intrusive Maintenance | Scenario 7 - High Density Residential |
| Toluene | - | - | - | - | - | 760 | - |
| TPH $C_6$-$C_9$ aliphatic | 28,000 | 90,000 | 3,500 | 29,000 | 86 | 1,400 | 210,000 |
| TPH $C_{10}$-$C_{14}$ aliphatic/ aromatic | 7.7 | 15 | 14,000 | 120,000 | 340 | 21 | 34 |
| TPH $C_{15}$-$C_{28}$ aliphatic/ aromatic | - | - | - | - | - | 220 | - |
| TPH $C_{29}$-$C_{36}$ aliphatic/ aromatic | - | - | - | - | - | 250 | - |
| Trimethylbenzene 1,2,4- | 87 | 280 | - | - | 86 | - | - |
| Vanadium | - | - | - | - | - | 960 | - |
| Xylenes (total) | - | - | - | - | - | - | - |
| Zinc | - | - | - | - | - | - | - |
| CPAH | - | - | - | - | - | - | - |

"-" No value derived; chemical is either not volatile, or concentration derived is in excess of solubility limits and therefore not relevant to exposure scenario. See Section 5.1.3.
CPAH = carcinogenic PAHs and includes: benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h) anthracene and indeno (1,2,3-cd)pyrene (see report for details)
***Bold = odour SSTC***

**Key Assumptions:**

- The derivation of SSTCs has been based on plans and design assumptions provided by Lend Lease.
- The development of SSTCs has assumed that tar will be removed from the immediate vicinity of outer basement walls to the extent practicable, and basement design and engineering controls should ensure that tar seepage into basements does not occur.
- There are significant biodegradation processes occurring within sub-surface soils based on measured oxygen concentrations beneath the sub-surface. To account for these biodegradation processes, a 10 fold factor (Davis 2009) has been adopted for site specific target criteria for soil for the paved and unpaved areas of the Site, where biodegradation processes are considered to be significant.
- Risks associated with mixtures of chemicals have been modelled by applying proportional risks as follows: BTEX (HI 0.25 each), PAH (HI 0.2), TPH (HI 0.25 total for aliphatic and aromatic per fraction), all other chemicals HI = 1.
- The lower and upper basements have been modelled using a water seepage model adopted from Water 9 (USEPA, 1994).

- In the lower and upper basements a windspeed of 0.03 m/sec within the basements (scenario 1,2 and 7) has been modelled
- Chemicals are assumed to be volatile if Henry's Law constant is greater than 1 x $10^{-5}$ atm-$m^3$/mole (USEPA,2004)
- The air exchange rate within the basement car park has been assumed to be 4 per hour (in accordance with AS 1668.2).
- In basement scenarios (1, 2 and 7) it has been assumed that no more than two walls will be in contact with contaminated soil / groundwater (with Scenario 1 also considering exposures to the floor). Based on building plans provided by LL, it has been assumed that basement areas will be compartmentalised with each compartment adjacent to basement areas leaving a maximum of 2 exposed walls.
- The basement groundwater retention wall system will comprise a secant pile wall, extending to and keyed into bedrock, with a reinforced concrete basement wall, constructed on the inside. A sealed plenum constructed immediately inside the reinforced concrete basement wall will include: (a) passive ventilation to the atmosphere; and (b) dish drains that will drain any seepage.

## 9.2 Summary of SSTC for Soil

Presented in **Table 51** below are a summary of the derived SSTC for the Site.

**Table 51: Summary of Soil SSTC**

| Chemical | Soil Health and/or Odour Target Criteria (SSTC)(lowest of health and odour based) (mg/kg) | | | | | |
|---|---|---|---|---|---|---|
| | Scenario 2 - Upper Basement | Scenario 3 - Unpaved Recreation | Scenario 4 - Paved Recreation | Scenario 5 - Commercial Slab on Ground | Scenario 6 - Intrusive Maintenance | Scenario 7 - High Density Residential |
| Acenaphthene | - | - | - | - | - | - |
| Acenaphthylene | - | - | - | - | - | - |
| Anthracene | - | - | - | - | - | - |
| Arsenic, Inorganic | - | - | - | - | - | - |
| Benz(a)anthracene | - | - | - | - | - | - |
| Benzene | 15 | 190 | - | 81 | 380 | 26 |
| Benzo(a)pyrene | - | - | - | - | - | - |
| Benzo(b)fluoranthene | - | - | - | - | - | - |
| Benzo(g,h,i)perylene | - | - | - | - | - | - |
| Benzo(k)fluoranthene | - | - | - | - | - | - |
| Chromium(III), Insoluble Salts | - | - | - | - | 180,000 | - |
| Chromium(VI) | - | - | - | - | 950 | - |
| Chrysene | - | - | - | - | - | - |
| Copper | - | - | - | - | - | - |
| Dibenz(a,h)anthracene | - | - | - | - | - | - |
| Dibenzofuran | - | - | - | - | - | - |
| Ethylbenzene | **600** | - | - | - | - | **1,500** |

| Chemical | Soil Health and/or Odour Target Criteria (SSTC)(lowest of health and odour based) (mg/kg) | | | | | |
|---|---|---|---|---|---|---|
| | Scenario 2 - Upper Basement | Scenario 3 - Unpaved Recreation | Scenario 4 - Paved Recreation | Scenario 5 - Commercial Slab on Ground | Scenario 6 - Intrusive Maintenance | Scenario 7 - High Density Residential |
| Fluoranthene | - | - | - | - | - | - |
| Fluorene | - | - | - | - | - | - |
| Indeno(1,2,3-cd)pyrene | - | - | - | - | - | - |
| Lead | - | - | - | - | 15,000 | - |
| Methylnaphthalene, 2- | **1100** | - | - | - | - | - |
| Methylphenol, 3&4 | **8,800** | - | - | **56,000** | **5,400** | **21,000** |
| Naphthalene | 41 | - | - | 320 | - | 98 |
| Phenanthrene | - | - | - | - | - | - |
| Pyrene | - | - | - | - | - | - |
| Toluene | - | - | - | - | - | - |
| TPH $C_6$-$C_9$ aliphatic | 3,400 | - | - | - | - | - |
| TPH $C_{10}$-$C_{14}$ aliphatic/ aromatic | 13,000 | - | - | 61,000 | 90,000 | 31,000 |
| TPH $C_{15}$-$C_{28}$ aliphatic/ aromatic | - | - | - | - | - | - |
| TPH $C_{29}$-$C_{36}$ aliphatic/ aromatic | - | - | - | - | - | - |
| Trimethylbenzene, 1,2,4- | 14 | 370 | - | 110 | - | 34 |
| Vanadium | - | - | - | - | 22,000- | - |
| Xylenes (total) | - | - | - | - | - | - |
| Zinc | - | - | - | - | - | - |
| CPAH | - | - | - | - | 67 | - |

"-" No value derived, chemical is either not volatile or concentration derived is in excess of saturation limits and therefore not relevant to exposure scenario. See Section 5.1.3

CPAH= carcinogenic PAHs and includes: benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h) anthracene and indeno (1,2,3-cd)pyrene (see report for details)
***Bold = odour SSTC***

**Key Assumptions:**

- The derivation of SSTCs has been based on plans and design assumptions provided by Lend Lease
- The development of SSTCs has assumed that tar will be removed from the immediate vicinity of outer basement walls to the extent practicable, and basement design and engineering controls should ensure that tar seepage into basements does not occur
- There are significant biodegradation processes occurring within sub-surface soils based on measured oxygen concentrations beneath the sub-surface. To account for these biodegradation processes, a 10 fold factor (Davis 2009) has been adopted for site specific target criteria for soil for the paved and unpaved areas of the Site, where biodegradation processes are considered to be significant.
- The current theoretical estimation of soil concentrations within indoor and outdoor air is based on partitioning modelling which has been demonstrated to overestimate concentrations between 10-1,000 fold. To account for this conservatism, an adjustment factor of 10 has been applied. In all scenarios a soil partitioning factor of 10 has been applied to BTEX, TPH (fractions $C_6$-$C_9$ and $C_{10}$-$C_{14}$ to account for the overconservative nature of vapour modelling associated with these chemicals (CCME, 2008b. CRC 2010)
- Risks associated with mixtures of chemicals have been modelled by applying proportional risks as follows: BTEX (HI 0.25 each), PAH (HI 0.2), TPH (HI 0.25 total for aliphatic and aromatic per fraction), all other chemicals HI = 1.
- Chemicals are assumed to be volatile if Henry's Law constant is greater than 1 x $10^{-5}$ atm-$m^3$/mole (USEPA,2004)
- The air exchange rate within the basement car park has been assumed to be 4 per hour (in accordance with AS 1668.2).
- In the unpaved recreation scenarios (Scenario 3 and Scenario 4) it has been assumes that the upper 0.5 m of soil is composed of “suitable fill” as defined by Section 5.3.7.

# 10.0 Conclusions and Recommendations

## 10.1 Conclusions

The health and odour based target criteria (SSTC) derived for the Site are summarised in Section 9 and presented within **Table T20** and **Table T21**.

Based on comparison of derived health/odour criteria (SSTC) to available Site data and with consideration of the uncertainties and limitations of available data and information, the following conclusions are provided with respect to potential for human health, odour or aesthetic risks following redevelopment of the Site. As described above, the derivation of SSESC for ecological protection was not required in consideration of the proposed development design.

**Human Health Risks**

a) Potentially unacceptable human health risks have been identified under a number of redevelopment scenarios and remediation is required to make the Site fit for the proposed land uses. The following specific issues were identified:

   1) **Scenario 1 (Lower Basement):** The highest reported groundwater concentrations of benzene, 2-methylnaphthalene, naphthalene and TPH $C_{10}$-$C_{14}$ have the potential to result in unacceptable health risks from inhalation of vapours in the basement airspace.

   2) **Scenario 2 (Upper Basement):** The highest reported concentrations of benzene, 1,2,4-trimethylbenzene, naphthalene and TPH $C_{10}$-$C_{14}$ in soil and naphthalene and TPH $C_{10}$-$C_{14}$ groundwater have the potential to result in unacceptable health risks from inhalation of vapours in indoor airspaces.

   3) **Scenario 5 (Commercial Slab on Ground)**: The highest reported groundwater concentrations of naphthalene in soil and benzene, naphthalene and TPH $C_{10}$-$C_{14}$ in groundwater at the Site, have the potential to result in unacceptable health risks due to vapour intrusion. The unacceptable concentrations of naphthalene in soils were only observed where basements are intended and thus commercial slab on ground construction will not be present above these locations thus naphthalene in soil is not likely to be a concern in this scenario. It is considered likely that remediation of soils at the Site will result in a reduction in groundwater chemical concentrations; installation of the groundwater retention wall system will also reduce the likelihood of chemical contaminants in groundwater being present beneath commercial slab on ground buildings.

   4) **Scenario 6 (Intrusive Maintenance)**: The highest reported groundwater concentrations of benzene, 2-methylnaphthalene, naphthalene, TPH $C_{10}$-$C_{14}$, TPH $C_{15}$-$C_{28}$ and TPH $C_{10}$-$C_{36}$ fractions and soil concentrations of carcinogenic polycyclic aromatic compounds (cPAHs) have the potential to result in adverse health risks to short-term intrusive maintenance workers, if workers come into direct contact with impacted soil or groundwater.

   5) **Scenario 7 (High Density Residential)**: The highest reported soil concentrations of benzene, naphthalene and TPH $C_{10}$-$C_{14}$ and groundwater concentrations of naphthalene and TPH $C_{10}$-$C_{14}$ have the potential to result in unacceptable health risks due to vapour intrusion. It should be noted that the majority of location where exceedences of calculated SSTC were reported were within areas that LL development plans current indicate that basement construction will occur. Thus contaminated soil and groundwater is unlikely to be present in areas where residential buildings are planned to be constructed at the Site.

b) Unacceptable human health risks are not expected to be associated with Scenario 3 (Unpaved Recreation) and Scenario 4 (Paved Recreation) as SSTC for these scenario were not exceeded by reported Site concentrations, or the nature, extent and/or location of the exceedences were insignificant. The exposure duration for human health receptors for paved and unpaved areas of the Site are significantly less in duration than those considered in Scenario 2, 5 and 7.

c) The majority of soil/fill material from the Site is considered (based on human health considerations) to be suitable for beneficial reuse in the public domain (outside the Site) provided that the reused material meets human health based SSTC for public open space, commercial slab on ground or intrusive maintenance scenarios, as relevant to the specific location of reuse. Note that because the public domain areas will likely be in hydraulic connection with Darling Harbour, reused material should also meet ecological based SSESC derived by the applicable site-specific ecological risk assessment for the proposed beneficial reuse location.

d) The above conclusions are based on the exposure assumptions and vapour migration models described in this report. The exposure and modelling assumptions were selected to be conservative in order to account for potential uncertainties and provide a deliberate margin of safety. Recent building plans, supplied by LL, indicate that the current basement design is likely to provide significantly greater reduction in the potential for vapour intrusion than that modelled in this HHERA; thereby providing a further margin of safety.

**Odour Risks**

e) Minimal exceedences of theoretical (modelled) odour-based SSTC have been reported in soil and groundwater, however:

    2) gasworks waste is inherently odorous material;

    4) it is possible that some odorous material could remain at the Site following remediation; and

    5) the extent to which odorous vapours may enter basement structures is difficult to predict and/or model.

f) Large scale source removal / remediation, as is proposed as part of the development, would be expected to significantly reduce the risk of future odours.

**Visual Amenity Issues/Risks**

g) Visual amenity issues are not considered likely to arise on the remainder of the Site, given the proposed future land uses and development plans.

## 10.2 Recommendations

Based on the above conclusions, and with consideration of the uncertainties and limitations of available data and information, the following recommendations are provided:

a) Basement design plans must include engineering controls to ensure that contaminated groundwater does not accumulate in compartments which are ventilated to basement airspaces since potentially adverse health risks and odours have been estimated to arise from low concentrations of volatile groundwater contaminants if water enters basements. The following is also recommended:

    1) Basement levels should be maintained at a lower pressure than occupied areas above in accordance with AS 1668.2 (Standards Australia, 2002).

    2) Sump rooms should be placed as far as possible from lift wells.

    3) Air exchange rates within the basement areas should be maintained at a minimum of the Australian Standard 4 per hour.

b) Tar should be removed from the immediate vicinity of outer basement walls to the extent practicable, and basement design and engineering controls should ensure that tar seepage into basements does not occur.

c) Soil and groundwater remaining within the Site should be remediated to meet relevant health/odour criteria (SSTC) (**Table T20** and **Table T21**).The specific health/odour SSTC to be met in different Site locations will depend on the land use(s) relevant to the area. In the case where more than one Scenario is applicable to the area, the most conservative (i.e. the lowest value) of the applicable SSTCs will be adopted as the remediation goal.

d) Shallow groundwater within Hickson Road, if present at depths which may be directly contacted by intrusive workers, should meet SSTC for Scenario 6.

e) Unpaved open space (Scenario 3) areas will be covered in a minimum of 0.5 m of suitable fill. Suitable fill of greater than 0.5 m thickness is recommended in areas where deeper rooting trees will be planted. For the purposes of unpaved open space (Scenario 3), suitable fill is defined as either:

    1) virgin excavated natural material (VENM); or

    2) soil which contains contaminant concentrations below the terrestrial soil criteria (developed for the maintenance of plant health and human health (refer to **Section 7.3** and **Table 46**).

f) It is recommended that paved open space (Scenario 4) areas will be covered in a minimum of 0.5 m of suitable fill (directly under the pavement). This is to account for the potential that paved areas may in the future be unpaved areas. Therefore for the purposes of definition, suitable fill will be defined as for unpaved open space areas (see above).

g) Validation of soil and groundwater following remediation should be undertaken using appropriate statistical methodologies to ensure that the arithmetic average concentration of contaminants are below relevant screening criteria, in accordance with NSW EPA (1995) guidance. The validation process should therefore include:

   1) use of systematic sampling patterns;

   2) collection of an appropriate number of samples for estimation of the arithmetic average concentration of contaminant(s) within relevant environmental media and land use areas (land use areas should be determined based on specific development plans with consideration to areas of soil and groundwater from which vapours may enter a given basement structure and/or from which CoPC may enter surface water bodies);

   3) estimation of the 95% upper confidence limit (UCL) of the arithmetic average concentration within relevant environmental media and exposure areas;

h) The human health-based SSTC have accounted for potential exposures to mixtures of chemicals.

i) Soil sourced from the Site for proposed beneficial reuse in Public Domain areas of ORWN or ORWS should meet relevant health/odour criteria (SSTC) and site-specific ecological screening criteria (SSESC) developed in the HHERAs for those beneficial reuse locations. The risk based acceptance criteria for material that might be placed in the future Headland Park will be developed separately by others.

j) The RAP should include consideration of mitigation measures for the appropriate management of:

   1) asbestos that may be potentially encountered during the remediation works; and

   2) odours that may accumulate in the basements following construction (while this is considered very unlikely, it is recommended that it be considered as part of the contingency measures included within the RAP in recognition of the uncertainties inherent in assessment of odour).

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