Barangaroo
Lend Lease (Millers Point) Pty Ltd
10-Dec-2014

Human Health and Ecological Risk Assessment

Stage 1C Development (ORWN Area), Barangaroo South

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Client: Lend Lease (Millers Point) Pty Ltd

ABN: 15 127 727 502

Prepared by

AECOM Australia Pty Ltd
Level 21, 420 George Street, Sydney NSW 2000, PO Box Q410, QVB Post Office NSW 1230, Australia
T +61 2 8934 0000 F +61 2 8934 0001 www.aecom.com
ABN 20 093 846 925

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Prepared by Gemma Williams, Angela Ruthenberg & Claire Daly

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List of Acronyms

Term	Description
AECOM	AECOM Australia Pty Ltd
AGL	AGL Energy Limited
AHD	Australian Height Datum
ANZECC	Australian and New Zealand Environment and Conservation Council
ASS	Acid Sulphate Soils
The Authority	Barangaroo Delivery Authority
Barangaroo South	Barangaroo Stage 1 Development Precinct
BTEX	Benzene, Toluene, Ethylbenzene and Xylenes
CAD	Computer-aided Design
CIM	Confirmed Impacted Material
CoPC	Chemicals of Potential Concern
CLM	Contaminated Land Management
Crown	Crown Resorts Limited
CSM	Conceptual Site Model
DEC	Department of Environment and Conservation (now NSW EPA)
DECCW	Department of Environment Climate Change and Water (now NSW EPA)
DGI	Data Gap Investigation
DoH	Department of Health
EPA	Environment Protection Authority
ERA	Ecological Risk Assessment
ERM	Environmental Resources Management Australia Pty Ltd
ESA	Environmental Site Assessment
GDS	Groundwater Discharge Study
HHERA	Human Health and Ecological Risk Assessment
HHR	Harbour Heat Rejection
HHRA	Human Health Risk Assessment
ISQG	Interim Sediment Quality Guidelines
LL	Lend Lease (Millers Point) Pty Ltd
m bgl	Metres below ground level
MRL	Minimal Risk Level
MWQC	Marine Water Quality Criteria
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NSW	New South Wales
OCP	Organochlorine pesticides

Term	Description		
OEH	Office of Environment and Heritage (now NSW EPA)		
OPP	Organophosphorous pesticides		
ORWN	Other Remediation Works (North)		
ORWS	Other Remediation Works (South)		
PAH	Polycyclic Aromatic Hydrocarbons		
PCB	Polychlorinated Biphenyls		
PID	Photoionisation Detector		
RAP	Remedial Action Plan		
RSL	Regional Screening Level		
SHTC	Sydney Harbour Trust Commissioners		
SPGWT	Separated Phase Gasworks Waste and Tar		
SSESC	Site-Specific Ecological Screening Criteria		
SSTC	Site-Specific Target Criteria		
SVOC	Semi Volatile Organic Compounds		
TPH	Total Petroleum Hydrocarbons		
TSC	Terrestrial Soil Criteria		
UCL	Upper Confidence Limit		
URS	URS Australia Pty Ltd		
USEPA	United States Environmental Protection Agency		
VENM	Virgin Excavated Natural Material		
VMP	Voluntary Management Proposal		
VOC	Volatile Organic Compounds		
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		

Term	Description		
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 (HHERAs) for selected areas within the Barangaroo Stage 1 Development Precinct (Barangaroo South), 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 (the Authority), as follows:

- **HHERA Voluntary Management Proposal (VMP) Remediation Works Area** (here-in referred to as the *VMP HHERA, AECOM 2012b)* – relates to the NSW Environment Protection Authority (NSW EPA) Remediation Site Declaration Area (Declaration Number 21122) and is designed to develop remediation objectives that will facilitate removal of the NSW EPA Declaration. This area may also be referred to as the "NSW EPA Declaration Area" or "Department of Environment Climate Change and Water (DECCW) Declaration Area" in this or other documents.
- **HHERA Declaration Site (Development Works) Remediation Works Area** (here-in referred to as the *Declaration Site HHERA,* AECOM 2011a) – relates to the same area as the *VMP HHERA* (AECOM, 2012b) but is designed to facilitate the development of remediation objectives as required by the Stage 1 Development of Barangaroo (also referred to as Barangaroo South). The *Declaration Site HHERA* (AECOM, 2011a) was conditionally approved by the NSW EPA (then the Office of Environment and Heritage [OEH]) in its letter dated 11 July 2011.
- **HHERA Addendum Other Remediation Works (South) (ORWS) Area** (here-in referred to as the *ORWS HHERA,* AECOM 2011b) – relates to Blocks 1 to 3 of the Stage 1 Development area, outside the NSW EPA Declaration Area, and is designed to facilitate the development of remediation objectives as required by the Stage 1 Development. The *ORWS HHERA* (AECOM, 2011b) was conditionally approved by the NSW EPA (then the OEH) in its letter dated 11 July 2011.
- **HHERA Other Remediation Works (North) (ORWN) Area** (here-in referred to as the *ORWN HHERA*) – relates to the Stage 1C Development area of Barangaroo South. This *ORWN HHERA* is designed to facilitate the development remediation objectives as required by the Stage 1 Development plans.

This report comprises the HHERA for the **Other Remediation Works North (ORWN) Area**, **Barangaroo** (henceforth referred to as the 'Site'). The Site is also referred to in this and other documents as the Stage 1C Development Area of Barangaroo South. The Site layout and surrounding area is presented in **Figure F2** in **Appendix A**.

In addition to the four documents described above, two supplementary reports have been prepared:

- The *HHERA Harbour Heat Rejection (HHR) System Inlet Area, Barangaroo South* (AECOM, 2012c) was prepared to facilitate the development and construction of the HHR System Inlet Area in the south western portion of the potential Southern Cove. For clarity, the HHR System Inlet Area is not considered to be part of the Site for the purpose of this HHERA; and
- The *Addendum to HHERA, Other Remediation Works (South) Area, Barangaroo* (AECOM, 2013d) was prepared to determine the concentration or concentrations of asbestos in soil that are acceptable to remain within the ORWS Area so that there is no unacceptable risk of harm to human health or any other aspect of the environment based on the proposed development.

It is noted that the footprint of the Site is different to that described as the ORWN Area in the previous *ORWN Area Data Gap Investigation* (DGI) (AECOM, 2010c). This is because the footprint of the ORWN Area has been adjusted since 2010. In particular, the footprint of the Site, relative to the *ORWN DGI* (AECOM, 2010c), no longer includes:

- that part of Barangaroo Block 4 that is outside the NSW EPA Declaration Area – which has been considered by the *NSW EPA Declaration Site 21122 and Block 4 Remedial Action Plan (RAP)* (AECOM, 2013c) (herein referred to as the *VMP / Block 4 RAP*);
- Barangaroo Block 5 and the part of the Public Domain that is west of Block 5 – which will be considered as part of the Barangaroo Central RAP (to be prepared by the Authority); and
- The footprint of the HHR System Inlet – which has been considered by the *Addendum to the ORWS Amended RAP – HHR System Inlet Area, Barangaroo South* (AECOM, 2012c).

The objectives of this HHERA were to:

- develop human health Site-specific target criteria (SSTC) for soil and groundwater for use in defining the remediation end-point for the Site, where the remediation end-point is defined as that required to render the Site suitable for use following redevelopment; and
- assess the risk to ecological receptors that the Site will represent based on the assumption that the remediation works described by the *VMP / Block 4 RAP* (AECOM, 2103c) are undertaken.

This HHERA has been undertaken in accordance with relevant Australian guidance for health and ecological risk assessment including, but not limited to, the *National Environmental Protection (Assessment of Site Contamination) Measure (NEPM) 1999* as amended 2013 (ASC NEPM, 2013).

Available analytical data from relevant published reports were evaluated by AECOM for data quality relevant to use for a risk assessment. 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 are considered to be of an appropriate quality for use in the HHERA.

Human Health Risk Assessment (HHRA)

The HHRA component comprised derivation of SSTC for soil and groundwater based on potential development options for different areas of the Site.

SSTC were derived in accordance with Australian guidelines for risk assessment and derivation of health-based criteria in environmental media. The methodology included 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 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.

Current Site development concepts propose mixed land use comprising hotel (including high density residential with minimal access to soil), commercial / retail (with minimal access to soil), public open space and potential open water (associated with a potential Southern Cove) connected to Darling Harbour. Key components of the proposed development include:

- A mix of residential, commercial, retail, hotel land uses which will comprise of:
  - A basement car park with perimeter soil and groundwater retention systems generally constructed around the future basement and extending to bedrock;
  - Mixed use hotel (including high density residential), commercial and hotel multistorey buildings (greater than two storeys) constructed over the basement;
  - Mixed use commercial and retail buildings (greater than two storeys) built on grade;
  - Public open space, landscaping, roads, pedestrian ways and cycle paths, built on grade.
  - Mixed use commercial and community buildings built on grade (maximum height two storeys).
  - Creation of a waterway (here-in referred to as the potential Southern Cove) connecting with and extending eastward from Darling Harbour, in the southern portion of the Site.

- A proposed integrated resort, to be constructed by Crown Resorts Limited (Crown) within part of the Site and here-in referred to as the Crown Hotel Development, which will comprise of:
  - A basement car park and loading dock;
  - A tower containing hotel rooms, suites and residential apartments. The entire footprint of the tower will be above a basement car park and loading dock; and
  - A podium containing hotel reception, retail and gaming facilities and which will be largely above a basement car park and loading dock but with some limited areas constructed as elevated slab on grade (multi-storey).

While the proposed Crown Hotel Development is largely consistent with the generic proposed development design (as described above), a number of key elements do differ. Specifically:

- All areas outside the proposed basement will be built up, using imported soil, by at least 1m above the existing ground surface;
- The air exchange rate within the buildings will be greater than that typically assumed for a generic commercial building; and
- The configuration of the upper most basement level (level B1) will be different such that: the internal height will be greater; and the finished floor level will be higher.

Based on the above proposed development plans, the broad land use scenarios for which SSTC have been derived are as follows. It is noted that Crown specific land use scenarios have been adopted where the differences between the generic proposed development design and the proposed Crown Hotel Development directly impact the assumptions used to derive the relevant SSTC.

- Lower-most basement car park level below the water table (Scenario 1);
- Upper-most basement car park level, partially above the water table (Scenario 2);
- Crown specific upper-most basement car park level, partially above the water table (Scenario 9);
- Public Domain/recreational area with no concrete/hardstand paving (Scenario 3);
- Crown specific Public Domain/recreational area with no concrete/hardstand paving (Scenario 10);
- Public Domain/recreational area with concrete/hardstand paving (Scenario 4);
- Crown specific Public Domain/recreational area with concrete/hardstand paving (Scenario 11);
- Typical commercial slab on ground construction (maximum height two storeys) (Scenario 5);
- Short term ground-intrusive maintenance (Scenario 6);
- Crown specific short term ground-intrusive maintenance (Scenario 12);
- Hotel or High Density Residential development (over a basement car park) (Scenario 7)
- Crown specific Hotel or High Density Residential development (over a basement car park) (Scenario 13);
- Commercial multistorey development with slab on ground construction (Scenario 8);
- Crown specific commercial multistorey development with elevated slab on ground construction (Scenario 14).

Material and/or soil from the Site which meets relevant criteria may also be re-used to build up the elevation of Public Domain areas within the Site (although it should be noted that the proposed Crown Hotel Development specifically excludes the reuse of material). SSTC derived for relevant generic scenarios (Unpaved Recreation, Paved Recreation, Commercial Slab on Ground (maximum 2 storeys), Intrusive Maintenance and Commercial multistorey development with slab on ground construction) are considered applicable to identification of material suitable for placement within Public Domain areas, depending on the specific location.

It is noted that criteria for the future Headland Park and Barangaroo Central will be developed separately by others.

Odour and Visual Impact Assessment

An odour assessment was included as a component of the HHRA and derivation of the soil and groundwater SSTC based on the proposed future land use scenarios for the Site.

A qualitative assessment of the potential visual and aesthetic considerations of the contamination identified beneath the Site was also undertaken.

Ecological Risk Assessment (ERA)

The point of compliance for the purpose of assessing ecological risk is the down-hydraulic gradient boundary of the Site which is the nearest surface water receptor, Darling Harbour. This approach is consistent with the policies of the NSW EPA, in particular:

- The *Contaminated Land Management (CLM) Act* (1997); and
- The Department of Environment and Conservation (DEC) NSW (now the NSW EPA) *Guidelines for the Assessment and Management of Groundwater Contamination*, March 2007.

The ERA comprised the following key steps:

- Identification of appropriate ecological receptors, including both terrestrial and aquatic ecosystems (including groundwater dependant ecosystems).
- Identification of relevant Marine Water Quality Criteria (MWQC) from a nationally adopted hierarchy of acceptable guidance documents plus consideration of additional international sources based on the protection of the identified nearest surface water receptor, Darling Harbour.
- Identification of non-gasworks CoPC noting that the *VMP Remediation Extent* report (AECOM, 2013b) considered that if the *VMP / Block 4 RAP* (AECOM, 2013c) is implemented, residual gasworks related contamination remaining *in situ* down hydraulic gradient of the Declaration Area will not represent an unacceptable risk to the environment.
- Identification of potential risks associated with the non-gasworks related CoPC based on comparison of concentrations of CoPC (reported both within the Site and at the Site boundary) with the adopted MWQC.
- Assessment of whether (or not) the concentrations of non-gasworks related CoPC within the Site and at the down hydraulic gradient Site boundary represent a risk to Darling Harbour.

Consideration has also been given to protection of future terrestrial plants in open space areas of the Site through adoption of Terrestrial Soil Criteria (TSC) to define material that is appropriate for use as “Suitable Foil” in areas that will be subject to open space use.

Conclusions

Based on the HHRA (**Section 5.0**) and ERA (**Section 7.0**) 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, aesthetic or ecological risks following redevelopment of the Site under the proposed land use scenarios.

Human Health Risks

- **Scenario 6 (Intrusive Maintenance)**: The highest reported concentrations of naphthalene and Total Petroleum Hydrocarbons (TPH) C_{10}-C_{14} fraction in groundwater within the ORWN Area have the potential to result in unacceptable health risks to intrusive maintenance workers.

  The predominant risk driving pathway was identified as dermal contact of intrusive maintenance workers with groundwater. Locations where reported concentrations may result in a potential risk are near the northern edge of the Site, and based on the proposed Crown Hotel Development, the location of these exceedances would be within the proposed Crown Basement. It is considered unlikely that services installed in this area would be constructed at a depth where groundwater contact was probable (that is, the depth to groundwater is approximately 2.5 m (outside of the Crown Hotel Development) and the groundwater is saline which would be corrosive to below ground services). In addition, it is likely that the reported elevated groundwater concentrations are representative of groundwater quality within marine sediments which are present at depths significantly greater than 2.5 m and from which contaminant flux has been shown to be minimal.

Consequently, under the assumed exposure scenarios presented in the HHERA it is considered unlikely that the reported groundwater concentrations in the ORWN would result in an unacceptable health risk for the intrusive maintenance worker. It is also considered that all intrusive maintenance works will be undertaken in accordance with state occupational health and safety requirements and personal protective equipment will be worn.

- **Scenario 8 (Multistorey Commercial Slab on Ground, with Advection)**: The highest reported concentrations of naphthalene in soil and benzene, TPH C_6-C_{10} and TPH >C_{10}-C_{16} in groundwater within the ORWN Area have the potential to result in unacceptable health risks to commercial employees working in a building where advection vapour intrusion processes occur. Locations where reported concentrations may result in a potential risk are near the eastern and northern edges of the Site, and the potential health risk assumes that the future multi-storey commercial slab-on-ground building is on top of these impacted areas. Based on the proposed Crown Hotel Development, the location of these exceedances would be within the proposed Crown Basement and therefore this exposure scenario would not be relevant.

Based on proposed future land use at the Site, there is also potential for intrusive maintenance workers (only) to encounter asbestos in soils during intrusive works. There is currently insufficient data to determine the potential for risks associated with asbestos in soil within the ORWN Area. However, available data collected during excavation of the ORWS Area indicates that there is a significant potential for asbestos containing material to be present. In order to address the potential for future exposures to asbestos at the Site, the current HHERA presents risk based SSTC for asbestos in soils. The future ORWN RAP will be required to consider these SSTCs to minimise the potential for unacceptable risks to intrusive maintenance workers.

Human health risks are not expected to be associated with Scenarios other than 6 and 8. This is because SSTC for these scenarios were not exceeded by reported Site contaminant concentrations, or reported exceedances are not considered to pose a health risk based on consideration of their location, nature and/or extent.

Furthermore is considered that remediation works undertaken in the NSW EPA Declaration Area (including the Block 4 Development Works Area) will result in an overall reduction in groundwater contaminant concentrations within the ORWN Area.

A separate assessment of potential risks to human health from exposure to sediments and surface water within the potential Southern Cove has not been undertaken. This is because , in the event that construction of the potential Southern Cove requires excavation of existing fill, the material at the new surface of the potential Southern Cove will be required to meet the Australian and New Zealand Environment and Conservation Council (ANZECC) 2000 Interim Sediment Quality (High) guidelines (ISQG), which are considered to be suitably protective for recreational exposures for humans and the surface water will be of the same composition and makeup of Darling Harbour. It is also considered that any future design within Southern Cove will prevent direct contact with sediments under normal exposures.

With respect to potential human health risks associated with material which may be reused within the Site, it is expected that material which meets criteria for Scenarios 3 through 6 and Scenario 8 would be suitable for reuse from a human health perspective in areas/locations where respective land use and human exposure assumptions are met. It is understood that the proposed Crown Hotel Development specifically excludes the reuse of material.

Odour Risks

Comparison of Site data to derived odour SSTC indicates one exceedance for 2-methylnaphthalene within the Site, at BH40 at 16.5 m bgl. It is considered that remedial activities at the Site are not likely to extend to this depth. It should be noted, however, observations during intrusive Site investigations have indicated that relatively small scale excavations or intrusive works have potential to result in localised odour issues.

Locations where odour issues may occur are likely to be a result of 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 gasworks waste that cannot be specifically identified and which may contribute to odour); and
- 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 to mitigate risks to human health and excavation of the proposed basement will remove contamination with the potential to generate odour and therefore result in a reduction in the potential for odour generation. It should also be noted that areas of the Site that will not be the subject of remediation or basement excavation and in which potentially odorous material may remain *in situ* will be covered by clean fill (referred to as 'Suitable Fill') and/or concrete paving / hardstand which will further reduce the potential for odour generation (**Figure F14** of **Appendix A**).

Visual Amenity Risks

Limited visual amenity impacts as a result of sheen or tar are expected to occur at the Site. Furthermore, the remediation work described by the future ORWN RAP will make consideration of the potential negative impacts from fill, tar or sheen on visual amenity.

As required by the *ASC NEPM* (2013), all surface soils, including Suitable Fill in areas subject to paved and unpaved recreational land uses (refer to **Section 5.5.6**), must contain 'no visible asbestos'.

Ecological Risks

The *VMP Remediation Extent* report (AECOM, 2013b) considers that if the *VMP / Block 4 RAP* (AECOM, 2013c) is implemented, residual gasworks related contamination remaining *in situ* down hydraulic gradient of the Declaration Area will not represent an unacceptable risk to the environment.

With respect to non-gasworks related contamination, the adopted MWQC were exceeded within groundwater at the Site for copper, zinc, cobalt and nickel within the groundwater wells screened within both the fill and marine sediment.

The concentrations reported for copper, zinc, cobalt and nickel are higher in groundwater wells screened within the marine clays. Notwithstanding, given that there will be negligible contaminant flux from within the marine sediments to Darling Harbour, these concentrations are not considered representative of those that may discharge.

Copper, zinc, cobalt and nickel concentrations reported within groundwater screened within the fill materials are also not considered to present a risk to the environment due to:

- The proposed remedial strategy presented within the *VMP / Block 4 RAP* (AECOM, 2013c) and *VMP Remediation Extent* report (AECOM, 2013b) which includes: (a) historical infrastructure source removal; and, (b) removal of secondary sources of contamination such as Separated Phase Gasworks Waste and Tar (SPGWT) which are both up-gradient sources of contamination on the Site.
- The groundwater retention wall system to be constructed as part of the proposed Block 4 Development Works will limit groundwater movement from up-gradient sources to the Site. It is considered that the up-gradient sources are a significant contributor to the groundwater quality within those wells screened within the fill materials.
- The proposed Stage 1c development is likely to incorporate a basement, similar to that proposed as part of the Block 4 Development Works, contained within a groundwater retention wall which will be keyed into bedrock. While the extent of the basement has not yet been confirmed, it will reduce groundwater migration and potential contaminant flux from that area of the Site that in which the basement is constructed.
- Results of the *Groundwater Discharge Study* (GDS) (AECOM 2010d), which concludes that there is a five-fold mixing and dilution of groundwater within the unconfined aquifer prior to discharge through the tidal prism to Darling Harbour. The current ERA has not adjusted the groundwater concentrations to reflect dilution, and therefore it is considered that concentrations reported within groundwater at the Site will undergo additional dilution prior to discharge to the nearest environmental receptor, Darling Harbour.
- Additional remediation works (as might be required to achieve a greater degree of environment protection), would be impracticable, cost prohibitive and inconsistent with the principles of Ecologically Sustainable Development (ESD). That is, the net cost to the environment of undertaking the additional works would be greater than the environment benefit realised from the additional work at the Site (AECOM, 2013b).

Soil material which may be re-used within the unsaturated zone (depths below 0.5m to a depth of 2m) must demonstrate neutral leachate concentrations which are below the adopted MWQC as outlined in **Table 77**. This requirement is in addition to the requirement that soil concentrations also comply with the relevant human health SSTC (which have not been derived to be protective of the closest down gradient ecological receptor, Darling Harbour, based on the potential for soil leachate to discharge to groundwater). It is noted that the application of the TSC criteria for Suitable Fill within the top 0.5 m is considered to be suitably protective of closest down gradient ecological receptor.

Multiple lines of evidence have been provided to demonstrate that residual metals contamination reported within groundwater wells screened with the fill materials will not pose a risk to the environment and that the quality of groundwater in fill within the Site will improve over time following the proposed remedial works in the Declaration Area and Block 4. It is therefore considered that the risks to identified environmental receptors at the Site are low and acceptable.

Recommendations

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

1) A RAP should be prepared to determine the extent and need for remediation at the Site based on the following recommendations.

2) Soil and groundwater remaining within the Site should be remediated and/or validated to meet relevant health/odour criteria (SSTC) (**Table T19** and **Table T20** and **Table 70**), as follows:

    a) The specific health/odour SSTC to be met in different Site locations will depend on the land use(s) relevant to the area.

    b) Sediments which occur from 0 to 0.5 m bgl within the potential Southern Cove will meet the ISQG (High) Criteria (**Table 84**).

3) Material reused within the Site should meet relevant health/odour criteria (SSTC) and TSC (**Table T20** and **Table 70** and **Table 85**), as follows:

    c) The specific health/odour SSTC to be met will depend on the exact location of material relative to the proposed land use(s).

    d) Soil re-used in locations above the current ground level should also demonstrate neutral leachate concentrations which are below are below the adopted MWQC.

4) 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:

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

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

    c) Engineering controls must be in place restricting dermal contact by general public and commercial workers (i.e. car park attendants and loading dock workers) to groundwater which may ingress through basement walls.

5) SPGWT should not be present in the immediate vicinity of outer basement walls (to the extent practicable), and basement design and engineering controls should ensure that SPGWT seepage into basements does not occur.

6) Soil to be placed in Headland Park will be required to meet the criteria defined in the separate Headland Park RAP prepared by the Authority.

7) To address potential visual impacts (tar or sheen) to the potential Southern Cove, a suitable cover thickness over any residual tar or visually impacted material should be present in order to ensure that tidal and wave induced movement of sediment does not result in exposed tar at the base of the cove. A suitable cover thickness should be determined in the future ORWN RAP.

8) The ORWN RAP(s) should include consideration of mitigation measures for the appropriate management of asbestos that may be potentially encountered during the remediation works.

9) The future ORWN RAP(s) will describe the validation of groundwater following remediation which will be undertaken by comparison of:

    a) individual groundwater monitoring results with the lowest of the derived SSTC (presented in **Table T19**); and

    b) groundwater monitoring results at the down-hydraulic gradient Site boundary with the MWQC (presented within **Table T21**), to the extent practicable.

10) The future ORWN RAP(s) will describe the validation of soil following remediation (as applicable) which will be undertaken in accordance with the following:

    a) use of systematic sampling patterns;

    b) collection of an appropriate number of samples for estimation of the arithmetic average concentration of contaminant(s) within relevant environmental media and exposure areas; and

    c) estimation of the 95% upper confidence limit (UCL) of the arithmetic average concentration.

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 (HHERAs) for selected areas within the Barangaroo Stage 1 Development Precinct (Barangaroo South), 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 (the Authority), as follows:

- **HHERA Voluntary Management Proposal (VMP) Remediation Works Area** (here-in referred to as the *VMP HHERA, AECOM 2012b)* – relates to the NSW Environment Protection Authority (NSW EPA) Remediation Site Declaration Area (Declaration Number 21122) and is designed to develop remediation objectives that will facilitate removal of the NSW EPA Declaration. This area may also be referred to as the "NSW EPA Declaration Area" or "Department of Environment Climate Change and Water (DECCW) Declaration Area" in this or other documents.
- **HHERA Declaration Site (Development Works) Remediation Works Area** (here-in referred to as the *Declaration Site HHERA*, AECOM, 2011a) – relates to the same area as the *VMP HHERA* (AECOM, 2012b) but is designed to facilitate the development remediation objectives as required by the Stage 1 Development of Barangaroo (also referred to as Barangaroo South). The *Declaration Site HHERA* (AECOM, 2011a) was conditionally approved by the NSW EPA (then the Office of Environment and Heritage [OEH]) in its letter dated 11 July 2011.
- **HHERA Addendum Other Remediation Works (South) (ORWS) Area** (here-in referred to as the *ORWS HHERA*, AECOM, 2011b) – relates to Blocks 1 to 3 of the Stage 1 Development area, outside the NSW EPA Declaration Area, and is designed to facilitate the development of remediation objectives as required by the Stage 1 Development. The *ORWS HHERA* (AECOM, 2011b) was conditionally approved by the NSW EPA (then the OEH) in its letter dated 11 July 2011.
- **HHERA Other Remediation Works (North) (ORWN) Area** (here-in referred to as the *ORWN HHERA*) – relates to the Stage 1C Development area of Barangaroo South. This ORWN HHERA is designed to facilitate the development remediation objectives as required by the Stage 1 Development plans.

This report comprises the HHERA for the **Other Remediation Works North (ORWN), Barangaroo** (henceforth referred to as the 'Site'). The Site is also referred to in this and other documents as the Stage 1C Development Area of Barangaroo South. The Site layout and surrounding area is presented in **Figure F2** in **Appendix A**.

In addition to the four documents described above, two supplementary reports have been prepared:

- The *HHERA Harbour Heat Rejection (HHR) System Inlet Area, Barangaroo South* (AECOM, 2012c) was prepared to facilitate the development and construction of the HHR System Inlet Area in the south western portion of the potential Southern Cove. For clarity, the HHR System Inlet Area is not considered to be part of the Site for the purpose of this HHERA; and
- The *Addendum to HHERA, Other Remediation Works (South) Area, Barangaroo* (AECOM, 2013d) was prepared to determine the concentration or concentrations of asbestos in soil that are acceptable to remain within the ORWS Area so that there is no unacceptable risk of harm to human health or any other aspect of the environment based on the proposed development.

It is noted that the footprint of the Site is different to that described as the ORWN Area in the previous *ORWN Area Data Gap Investigation* (DGI) (AECOM, 2010c). This is because the footprint of the ORWN Area has been adjusted since 2010. In particular, the footprint of the Site, relative to the *ORWN DGI* (AECOM, 2010c), no longer includes:

- that part of Barangaroo Block 4 that is outside the NSW EPA Declaration Area – which has been considered by the *NSW EPA Declaration Site 21122 and Block 4 Remedial Action Plan (RAP)* (AECOM, 2013c) (herein referred to as the *VMP / Block 4 RAP*);
- Barangaroo Block 5 and the part of the Public Domain that is west of Block 5 – which will be considered as part of the Barangaroo Central RAP (to be prepared by the Authority); and
- The footprint of the HHR System Inlet – which has been considered by the *Addendum to the ORWS Amended RAP – HHR System Inlet Area, Barangaroo South* (AECOM, 2012c).

While this report focuses on the ORWN Area (the Site), the following is noted:

- The NSW EPA Declaration Area is east of the Site.
- Part of the Block 4 Development Works Area, which is outside the Declaration Area, is located directly east of the Site, between the Declaration Area and the Site.
- Information relating to the adjacent Block 4 Development Works Area and the Declaration Area has been included within this report to provide a more comprehensive understanding of the Site setting and contamination status.
- The HHR System Inlet Area has been considered separately (AECOM, 2012c), however data collected in this area has also been considered within this report to provide a more comprehensive understanding of the Site setting and contamination status.
- The proposed Crown Hotel Development will occupy only part of the Site (here-in referred to as the Crown Site) as shown on **Figure F2**, **Appendix A**.

This HHERA has been prepared to inform the future ORWN RAP (or RAPs if a staged remediation and development is required), the successful implementation of which is expected to make the Site suitable for the proposed future Stage 1C development.

Discussions with the NSW Department of Health (DoH) and the NSW EPA have been undertaken as part of the HHERA process described above for the Barangaroo precinct. These discussions were undertaken in order to clarify several aspects of the HHERA and to ascertain an agreed approach and methodology.

1.2 Objectives

The specific objectives of the HHERA for the Site were to:

- develop human health Site-specific target criteria (SSTC) for soil and groundwater for use in defining the remediation end-point for the Site, where the remediation end-point is defined as that required to render the Site suitable for use following redevelopment; and
- assess the risk to ecological receptors that the Site will represent based on the assumption that the remediation works described by the *VMP / Block 4 RAP* (AECOM, 2103c) are undertaken.

The remediation end-point is defined as that required to render the Site suitable for use following redevelopment. For the purposes of this HHERA, a ‘suitable for use’ remediation endpoint is considered to be that required to ensure that unacceptable risks to human health or the environment will not occur.

1.3 Assumptions

The following assumptions are implicit in this report:

- The SSTC were developed based on the Site conditions and chemicals of potential concern (CoPC) detected during the Site investigations detailed within this report.
- The SSTC were based on the development concepts and design assumptions provided by LL and Crown to AECOM as outlined in **Section 2.4.1** at the time of completion of this risk assessment.
- Future car-parking basements, if present, will include engineering controls to ensure that contaminated groundwater does not accumulate in the publically accessible car park areas. Further information relating to the potential development design is contained within **Section 2.4.1**.
- The development of SSTCs has not considered the presence of tar, which is required by policy of the EPA (NSW DEC, 2007) to be removed from the Site to the extent practicable. As such, the HHERA has assumed that tar will not be present in 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 in the derivation of SSTC for soils in paved and unpaved areas of the Site, where biodegradation processes are considered to be significant.

- The development of SSTCs has accounted for the presence of mixtures of chemicals at the Site within the same media.
- The development of SSTCs for unpaved areas has assumed that Suitable Fill will be present at the surface at these locations. In particular, a 0.5 m thick layer of Suitable Fill has been assumed for Scenario 3 (as detailed in **Section 5.3.10**) and a 1.0 m thick layer of Suitable Fill has been assumed for Scenario 10 (as detailed in **Section 5.3.17**) For the purpose of this definition 'Suitable Fill' is defined as:
    - Virgin excavated natural material (VENM); or
    - Soil which contains contaminant concentrations below the Terrestrial Soil Criteria (TSC) (refer to **Section 8.0**); and
    - Soil which contains contaminant concentrations below the relevant SSTC (as described by this HHERA).

  With the exception of the definition of VENM, neither the TSC nor the SSTC (for paved or unpaved recreational land use) include a SSTC for asbestos in soil. Therefore, to ensure that Suitable Fill will prevent the exposure of receptors (other than intrusive maintenance workers) to underlying asbestos contamination an asbestos SSTC will also be adopted for Suitable Fill.
- For paved open space (Scenario 4 as detailed in **Section 5.3.11**) areas it is recommended that a minimum of 0.5 m of Suitable Fill be provided directly underneath paved areas. This is to account for the potential that paved areas may in future be unpaved areas. Note that for Scenario 11 (as detailed in **Section 5.3.18**) it has been assumed that 1.0 m of Suitable Fill will be placed directly underneath paved areas. For the purpose 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 benzene, toluene, ethylbenzene and xylenes (BTEX), Total Petroleum Hydrocarbons (TPH) C_6-C_{10} and >C_{10}-C_{16}. These compounds have been selected based on a number of studies which are described further in **Section 5.3.10.5**.
- The remedial works described by the *VMP / Block 4 RAP* (AECOM, 2013c) are completed. Based on the *VMP Remediation Extent* report (AECOM, 2013b), if the remediation works described by the *VMP / Block 4 RAP* (AECOM, 2013c) are completed, it is considered that any residual gasworks contamination that might remain *in situ* within the Site will not represent an unacceptable risk to the environment.

1.4 Framework and Methodology

1.4.1 Human Health Risk Assessment (HHRA)

The human health component of the risk assessment and derivation of SSTC for protection of human health 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, 2012);
- *National Environmental Protection (Assessment of Site Contamination) Measure (NEPM) 1999* as amended 2013. (ASC NEPM, 2013), specifically:
    - *Schedule B4, Guideline on Site-Specific Health Risk Assessment Methodology*.
    - *Schedule B7, Derivation of Health-Based Investigation Levels.*
- *Guidelines for the NSW Site Auditor Scheme (2nd Edition), Appendix VII Human Health Risk Assessment Checklist.* Department of Environment and Conservation, NSW (NSW DEC, 2006).

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

- **Issues Identification**. This includes the identification of the issue to be assessed, the objective of the assessment.
- **Data collection and evaluation**. This includes the acquisition, assessment of the reliability and analysis of information about chemicals present at the Site that may adversely affect human health and identification of those chemicals that will be the focus of the risk assessment. It also involves the development of the conceptual site model (CSM), selection of appropriate Tier 1 screening criteria, undertaking the Tier 1 screen and identification of CoPC to be considered for Tier 2 assessment.
- **Exposure assessment**. This involves identification of exposure parameters for the identified human receptors via identified pathways, identification of Exposure Point Concentrations (EPCs) to be used in the quantitative assessment and quantitative estimation of chemical intakes or exposure-adjusted air concentrations for human receptors and exposure pathways.
- **Toxicity assessment**. This entails hazard identification and does response assessments. Evaluation of both qualitative and quantitative information is undertaken to describe the nature and incidence of adverse effects occurring in humans at different exposure levels.
- **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 (ERA)

The ecological component of the risk assessment for protection of ecological receptors has been undertaken with consideration to the following Australian guidance documents:

- *National Environmental Protection (Assessment of Site Contamination) Measure 1999 as* amended 2013*.* (ASC NEPM, 2013), specifically:
    - *Schedule B5a, Guideline on Ecological Risk Assessment.*
- *Australian and New Zealand Guidelines for Fresh and Marine Water Quality.* Australian and New Zealand Environment and Conservation Council (ANZECC) and Resource Management Council of Australia and New Zealand (ANZECC, 2000).

As required by the NSW EPA, the point of compliance for the purpose of assessing ecological risk is the environment down hydraulic gradient of the Site, which is Darling Harbour. This approach is consistent with the policies of the NSW EPA, in particular:

- The *Contaminated Land Management (CLM) Act* (1997), Section 9;
- The NSW DEC (now the NSW EPA) *Guidelines for the Assessment and Management of Groundwater Contamination*, (DEC, 2007);
- The *ANZECC (2000) Water Quality Guidelines*, section 1; and
- The *ASC NEPM* Schedule B5 (2013) (refer to **Section 8.0**).

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 Site and adjacent areas based on the:
  - ERM, 2007. *Environmental Site Assessment, East Darling Harbour, Sydney, NSW*. June 2007.
  - Coffey, 2009. *Preliminary Environmental Investigation, 30-38 Hickson Road, Millers Point, NSW 2000*. June 2009.
  - ERM, 2008a. *Additional Investigation Works at Barangaroo, Hickson Road, Millers Point, NSW*. July 2008.
  - AECOM, 2010b. *DGI, EPA Declaration Area (Parts of Barangaroo Site and Hickson Road), Hickson Road, Millers Point, NSW*. September 2010.
  - AECOM, 2010c. *DGI, Other Remediation Works (North) Area, Hickson Road, Millers Point, NSW*. October, 2010.
  - AECOM, 2012a. *Supplementary DGI, VMP Area, Millers Point, NSW*, March 2012.
- **Human Health Risk Assessment**:
  - Identification of CoPC for human health, based on comparison of Site data to relevant 'Tier 1' screening criteria 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 CSMs for the post-development status of the Site, including:
    - summarising 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 modelling; and
    - identification of human receptors that may be exposed to Site contaminants following redevelopment and the pathways by which exposure may occur.
  - 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.
  - Characterisation of the nature and potential incidence of adverse health effects to receptors based on comparison of estimated contaminant intake or exposures to relevant toxicity (dose-response) criteria.
  - 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 exceedances and their significance and relevance to future development plans for the Site.

- Consideration of aesthetic risks or issues including odour.
- **Ecological Risk Assessment:**
  - Identification of appropriate ecological receptors, including both terrestrial and aquatic ecosystems.
  - Identification of relevant MWQC from a nationally adopted hierarchy of acceptable guidance documents plus consideration of additional international sources, based on the protection of the nearest surface water receptor, Darling Harbour.
  - Identification of non-gasworks CoPC noting that the *VMP Remediation Extent* report (AECOM, 2013b) considered that if the *VMP / Block 4 RAP* (AECOM, 2013c) is implemented, residual gasworks related contamination remaining *in situ* down hydraulic gradient of the Declaration Area will not represent an unacceptable risk to the environment.
  - Identification of potential risk associated with the non-gasworks related CoPC based on the comparison of the concentration of CoPC (reported both within the Site and at the Site boundary) with the adopted MWQC.
  - Assessment of whether (or not) the concentrations of CoPC within the Site and at the down hydraulic gradient Site boundary represent a risk to Darling Harbour.
- **Reporting and meetings**:
  - preparation of this report; and
  - attendance at meetings and telephone conferences to discuss the results with the Site Auditor, LL, Crown 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 **Table 1** below.

Table 1 Site Identification Details

Item	Description
Site Owner	The Barangaroo Delivery Authority (the Authority)
Client	Lend Lease (Millers Point) Pty Ltd (LL)
Site Address	Hickson Road (Sussex Street), Barangaroo, NSW 2000
Legal Description (Lot and DP)	Part Lot 5 and Part Lot 6 in Deposited Plan 876514
County and Parish	County of Cumberland, Parish of Saint Phillip
Local Government Authority	City of Sydney
Current Zoning	Eastern part of Site: Zone B4 Mixed Use [a] Western part of Site: Zone RE1 Public Recreation
Current Land Use	Unused (note that some parts of the Site are temporarily being used as a staging area for construction works in the ORWS Area). Partial access for public recreation (walking and bike riding) (specifically the Harbour Walk).
Proposed Land Use	Mixed use including hotel (incorporating high density residential with minimal access to soil), commercial / retail (with minimal access to soil), public open space and underground parking. Creation of a waterway (here-in referred to as the potential Southern Cove) connecting with and extending eastward from Darling Harbour, in the southern portion of the Site.
Site Area**	14,459 m^2.
Approximate Average Elevation	2 - 3 m AHD
Site Location	**Figure F1** of **Appendix A**.
Site Layout	**Figure F2** of **Appendix A**.

Notes:** Derived from Computer-aided Design (CAD) plans provided by LL.
AHD – Australian Height Datum
[a] – NSW Department of Planning 2007. Appendix 4. In: *State Environmental Planning Policy (Major Projects) Amendment (Barangaroo), 21 December 2012.*

2.2 Site Description and Current Land Use

The Site covers an irregular shaped area of approximately 1.4 ha (based on LL plans). The location of the Site is presented in **Figure F1** of **Appendix A** and the Site layout is illustrated in **Figure F2** of **Appendix A**.

The Site is open, currently vacant (note that some parts of the Site are temporarily being used as a staging area for construction works in the ORWS Area) and variably paved with concrete and asphalt. The concrete ground surface was observed to be in generally good condition with some cracking noted on the surface of the asphalt.

Access to the Site is limited by the presence of a cyclone wire fence on the eastern side of the broader Barangaroo site. Three gatehouses are present along the fenced area to permit access to Barangaroo, which is controlled by a 24 hour security presence. A harbour walk is variably opened to the public along the western perimeter of the Site adjacent to Darling Harbour. Access to the harbour walk is controlled by timber hoardings.

2.3 Surrounding Land Use

The Site is surrounded by the following land use:

- North: Barangaroo Central, including but not limited to Block 5 and the Block 5 Public Domain (currently open space/concrete hardstand).
- South: Barangaroo Blocks 1 to 3 (also referred to as Stage 1A) (which make up the ORWS Area).
- East: Barangaroo Block 4, including part of the EPA Declaration Area (21122). Hickson Road is present to the east of Block 4.
- West: Darling Harbour.

The location and layout of sub-sites and sampling are presented on **Figure F3** in **Appendix A**.

2.4 Proposed Land Use and Development

The Barangaroo precinct 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 the 'Northern Cove'. A second waterway, here-in referred to as the 'potential Southern Cove', may also be created within Barangaroo South (within part of the Site).

2.4.1 Proposed Future Site Land Use

Based on the proposed development concept for the Site, it is understood that the proposed land use across the Site will comprise mixed land use comprising hotel (including high density residential with minimal access to soil), commercial / retail (with minimal access to soil), public open space and potential open water (associated with the potential Southern Cove) connected to Darling Harbour. Proposed land uses include:

- A mix of residential, commercial, retail, hotel land uses which will comprise of:
  - A basement car park with perimeter soil and groundwater retention systems generally constructed around the future basement and extending to bedrock;
  - Mixed use hotel (including high density residential), commercial and hotel multistorey buildings (greater than two storeys) constructed over the basement;
  - Mixed use commercial and retail buildings (greater than two storeys) built on grade;
  - Public open space, landscaping, roads, pedestrian ways and cycle paths, built on grade.
  - Mixed use commercial and community buildings built on grade (maximum height two storeys).
  - Creation of a waterway (here-in referred to as the potential Southern Cove) connecting with and extending eastward from Darling Harbour, in the southern portion of the Site.
- A proposed integrated resort, to be constructed by Crown within part of the Site (referred to as the Crown Site) and also referred to as the Crown Hotel Development, which will comprise of:
  - A basement car park and loading dock;
  - A tower containing hotel rooms, suites and residential apartments. The entire footprint of the tower will be above a basement car park and loading dock; and
  - A podium containing hotel reception, retail and gaming facilities and which will be largely above a basement car park and loading dock but with some limited areas constructed as elevated slab on grade (multi-storey).

It should be noted that the location and extent of each of the proposed land uses, including the proposed Crown Hotel Development, within the Site have not yet been finalised. Notwithstanding, the proposed land uses – that is a mixture of hotel, commercial and high density residential and public open space – will remain generally consistent with that described by this HHERA.

Design assumptions for the proposed land uses, specifically relating to the basement area and air exchange rates for the proposed basement(s) have been adopted from:

- With respect to Scenarios 1 to 8 (refer to **Section 5.0**) building specific plans supplied by LL in relation to the ORWS basement design in the absence of Site specific information (AECOM 2012g); and
- With respect to Scenarios 9 to 14, information specific to the proposed Crown Hotel Development provided by Crown, as presented in **Appendix JJ**.

2.4.2 Proposed Future Adjacent Land Use

Proposed future adjacent land uses to the Site across the Barangaroo Development Area are described following:

- East: Future land use within Block 4 is expected to include a mixture of high density commercial and residential properties with areas of open space. The proposed development will include the Stage 1B basement car park area (known as the Block 4 Development Works Area) that will extend beyond the NSW EPA Declaration Area to the eastern boundary of the Site. This basement will be constructed within a groundwater retention wall which will limit potential groundwater movement from the east towards the Site. Design plans associated with the Block 4 Development Works Area are provided in the *VMP / Block 4 RAP* (AECOM, 2013c). The *VMP HHERA* (AECOM, 2012b) was prepared to address human health and ecological risks in the Declaration Area as required to enable the NSW EPA Declaration to be revoked. The *Declaration Site (Development Works) HHERA* (AECOM, 2011a) was prepared to address human health risks in the Declaration Area associated with the proposed future Stage 1B development.
- South: The southern boundary of the Site includes the HHR System Inlet area and the ORWS area (also referred to as Stage 1A). Future land use within the HHR System Inlet area will be limited to the seawater intake structures for the HHR system that will provide cooling for the ORWS development (referred to as the HHR System) (AECOM 2012c). Future land use within the ORWS Area is expected to include a mixture of high density commercial and residential properties with areas of open space. The proposed ORWS development will include a basement car park area that will extend to the southern boundary of the Site. The basement will be constructed within a groundwater retention wall which will limit potential groundwater movement from the south towards the Site. The *ORWS HHERA Addendum* (AECOM, 2011b) was prepared to address human health and ecological risks in this area.
- North: Future land use within Barangaroo Central, located to the north of the Site, is expected to include: in the interim, public domain (recreational and open space area); and, in the long term, proposed high density residential and open space land uses (JBS, 2012). A separate HHERA and RAP (prepared for the Authority) has also been prepared for Barangaroo Central to identify potential risks and remediation works required to facilitate the Barangaroo Central development works.

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 receptors) or Darling Harbour (ecological receptors).

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:

- Where basements are constructed as part of the Site development, services will be wholly contained within the basement. 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 would be expected to be generally contained within the upper 1.5 m of the soil profile above the groundwater table. As such there will be no (or limited) exposure of services to contaminated groundwater.
- Services that require passage through the Site to the harbour may be required to penetrate through the basements that may be constructed at the Site. The basement walls will be sealed around these penetrations, effectively eliminating the pathway for migration of vapour or groundwater to sensitive receptors within either the basement or the harbour.
- The SSTCs adopted as part of the remediation goals for the Site will be:
    - protective of intrusive maintenance workers who may construct or maintain the Services within the Site; and
    - representative of 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 history of the Millers Point area in which the Site is located, has been detailed in the publication *Land at Millers Pont Ownership and Usage* (Broomham, 2007). It is understood that the study was commissioned by the former Gasworks owners (Jemena) and focuses on that portion of the Barangaroo South. AECOM considers the information associated with the former gasworks is relevant to understanding the development history of the broader Stage 1 Development area and potential for Site contamination.

The following summarises historic information presented in Broomham (2007) and Environmental Resources Management Australia Pty Ltd (ERM) (2007, 2008). Those historic activities which relate directly to the Site and/or other parts of Barangaroo are specifically noted.

- **1788-1839**: During early colonial times the shoreline was extended and a wharf and a cottage were constructed near the southern boundary of the original subdivision.
- **1839:** The Declaration Area (off-site to the east) was occupied by the Australian Gas Light Company (AGL)] in 1839. The gasworks were extended in 1869 to include a retort house and gasholder 100 feet (approximately 30 metres) in diameter. The gasworks were located at the eastern boundary of Barangaroo and extended across Hickson Road. The remainder of Barangaroo was used for shipping and manufacturing activities.
- **1882**: AGL acquired an additional land on the north side of the gasworks (off-site to the east) and constructed an additional retort house, demolished the first two gas holders and replaced them with a larger 152 feet (approximately 46 metres) diameter gas holder. A tramway system and hydraulic lift was also constructed to transport coke to a depot in Kent Street.
- **1897**: AGL purchased a small piece of land on the northern boundary of the former gasworks site (off-site to the east) to extend the site 40 feet to the north (Broomham, 2007).
- **1899**: A building that housed a carburetted water gas plant was constructed.
- **1908**: Wharf frontages to the north of the gasworks were dredged to make way for the rat-proof sea wall.
- **1912**: The Minister for Public Works of the State of NSW and Sydney Harbour Trust Commissioners (SHTC) owned part of the Declaration Area (part of Lot 3 in DP 876514) between 1912 and 1930. However, it is understood that AGL continued to occupy the gasworks site until 1921 (ERM, 2007 and URS (2001).
- **1918**: Production at the gasworks was terminated at the Declaration Area.
- **1921**: SHTC gained possession of the gasworks site.
- **Mid 1920s**: The following activities occurred at the Declaration Area, in the mid-1920s:
  - Portions of the gasworks (gasholder and purifier beds) were demolished between 1922 and 1925. The former gasholder tanks were backfilled (ERM, 2007 and URS (2001).
  - Hickson Road was constructed through the former gasworks site. At those locations where no rock foundation was identified, a 4-inch (approximately 10 cm) thick foundation of blue metal followed by an 8 inch (approximately 20 cm) thick foundation of concrete was present. A 6-inch (approximately 15 cm) thick foundation of concrete was placed in those locations where a rock foundation was identified;
  - New jetties and cross-wharf sections of new berths required the complete dismantling of the AGL wharf and excavation into a significant part of the former gasworks;
  - The former gasworks was covered with workshops, including blacksmiths, plumbers, carpenters and a motor garage at the northern end; and
  - There was a SHTC depot located on the western side of Hickson Road.
- **Late 1930s**: MSB painted creosote on the wharf piles (located across Barangaroo South) to protect them against insects. Part of the Declaration Area was transferred to MSB after the SHTC was dissolved in 1936;
- **1951**: Five finger wharfs with approximately a dozen east-west oriented narrow warehouse buildings were present on the western edge of Barangaroo South.
- **1960s**: The wharfs were reconstructed across the Site. This included the construction of parallel berths with large cargo-moving areas, demolition and removal of some old wharf structures and formation of new sea walls by sinking caissons filled with concrete.

- **1968**: By 1968 the area behind (east of) the sea wall was in-filled (with unclassified fill) and the area was now a continuous wharf. These works occurred across the western portion of Block 4 and 5.
- **1970s and 1980s**: The wharves across the Barangaroo South site, including the Site, remained utilised for port activities. The 1972 aerial photograph indicated the finger wharfs had been filled in and the Declaration Area comprised a sealed area with two large warehouses, on the northern and western boundary. Southern Cove is still operative.
- **1988**: Southern Cove was filled south of the Site.
- **1995**: The longshore wharves at the Barangaroo South site were leased to Patrick Stevedores No 2 until 2006. The Sydney Ports Corporation (SPC) was also established in 1995.
- **1999:** The SHFA was formed under the Sydney Harbour Foreshore Authority Act 1998 to consolidate the work and functions of City West Development Corporation, Darling Harbour Authority and Sydney Cove Authority. Lots 3 and 5 of DP 876514 were transferred to SHFA in 2007. Wharf 8 Overseas Passenger Terminal constructed within the Site.
- **2007**: The Declaration Area (off-site to the east) is declared an Investigation Area by the NSW EPA.
- **2008**: The wharf west at the Site vacated and warehouses demolished in preparation for development.
- **2009**: The Declaration Area (off-site to the east) is declared a Remediation Site by the NSW EPA.
- **2011**: The Declaration Area (off-site to the east) (excluding Hickson Road) is used as part of the construction site supporting the Barangaroo South Stage 1A basement construction (within the ORWS Area).

Current Site and surrounding land uses are described in **Section 2.2** and **Section 2.3**.

2.6 Previous Investigations

Previous investigations relating to the Site and adjacent areas are summarised in **Table 2** below. Investigations undertaken by AECOM and others over recent years which have included the Site and/or immediately surrounding areas are further described in **Section 2.6.1** to **Section 2.6.14**.

It is noted that the footprint of the Site is different from that described as the ORWN Area in previous documentation (AECOM, 2010c). This is because the footprint of the ORWN Area is no longer considered to include that part of Barangaroo Block 4 that is outside the NSW EPA Declaration Area, any part of Barangaroo Block 5, that part of the Public Domain that is west of Block 5 and the HHR System Inlet Area (refer to **Figure F2**).

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 (PAHs) contamination and identified material required for off-site disposal that would likely require industrial or hazardous waste classification.

Date of Publication	Consultant	Report Title and Key Issues
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 off-site 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	*ESA, 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). Gasworks chemicals were identified in groundwater in the vicinity of the former gas works. Refer to **Section 2.6.1** for further detail regarding the report findings.
June 2009	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. Refer to **Section 2.6.2** for further detail regarding the report findings.
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. Exceedances of assessment criteria for soil were identified for lead, TPH, PAH, 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 monitoring well (MW)204D located within the gas works footprint. Refer to **Section 2.6.3** for further detail regarding the report findings.
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 migration of contamination off 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 and metals exceeding ANZECC (2000) and elevated levels of organochlorine pesticides (OCPs) and TPH C_{10}-C_{36}. Refer to **Section 2.6.4** for further detail regarding the report findings.

Date of Publication	Consultant	Report Title and Key Issues
May 2010	AECOM	*DGI, Other Remediation Works (South) Area Hickson Road, Millers Point NSW* (AECOM, 2010a). The purpose of the DGI was to reduce uncertainties which existed in the data set, to assess the characteristics of soil and groundwater underlying the Site, provide additional data for a quantitative HHERA and facilitate the development of an RAP and Remediation Work Plan (RWP) describing the remediation strategy to be implemented by LL as part of its proposed Stage 1A Development of the Barangaroo Precinct. Refer to **Section 2.6.5** for further detail regarding the report findings.
September 2010	AECOM	*DGI, EPA Declaration Area (Parts of Barangaroo Site and Hickson Road), Millers Point NSW* (AECOM, 2010b). Refer to **Section 2.6.6** for further detail regarding the report findings.
October 2010	AECOM	*DGI, Other Remediation Works (North) Area, Hickson Road, Millers Point NSW* (AECOM, 2010c). Refer to **Section 2.6.7** for further detail regarding the report findings.
November 2010	AECOM	*Groundwater Discharge Study (GDS), Stage 1 Barangaroo Development, Hickson Road, Darling Harbour, NSW* (AECOM, 2010d). Refer to **Section 2.6.8** for further detail regarding report findings.
June 2011	AECOM	*HHERA, Declaration Site (Development Works), Remediation Works Area- Barangaroo* (AECOM 2011a). The purpose of the VMP HHERA was to develop SSTC for human health based on the identified COPC for the proposed development. The proposed development precluded the need for the development of Site-specific ecological screening criteria (SSESC) for the environment. Refer **Section 2.6.9** for further detail regarding the report findings.
March 2012	AECOM	*Supplementary DGI, EPA Declaration Area (Parts of Barangaroo Site and Hickson Road), Millers Point NSW* (AECOM 2012). Refer to **Section 2.6.11** for further detail regarding the report findings.
August 2012	AECOM	*DRAFT HHERA, HHR System Inlet Area, Barangaroo South* (AECOM, 2012c). The purpose of the HHERA was to develop SSTC and SSESC for soil and groundwater for use in defining the remediation end-point for the HHR System Inlet Area. This area is located at the south west of the ORWN Site, between the ORWN and the ORWS Area. Refer to **Section 2.6.12** for further detail regarding the report findings.
AECOM 2012	AECOM	*HHERA-VMP Remediation Works Area (Addressing the NSW EPA Remediation Site Declaration 21122, Millers Point)* (AECOM 2012b). The purpose of the VMP HHERA was to address significant risk of harm issues required for the removal of the EPA declaration no 21122. The HHERA assessed the risk to identified receptors at the Site based on the current landuse. The HHERA addressed risks to human health and the environment. Site specific target concentrations for COPC which were identified to present a potential risk to human health were developed and marine water quality criteria were proposed based on protecting the groundwater ecosystems and those of the nearest downgradient receptor, Darling harbour. Refer to **Section 2.6.10** for further detail regarding the report findings.

Date of Publication	Consultant	Report Title and Key Issues
March 2013	AECOM	*VMP Remediation Extent, VMP Remediation Works Area, (Parts of Barangaroo and Hickson Road), Millers Point, NSW* (AECOM, 2013b). The purpose of the *VMP Remediation Extent* report was to describe the remediation goals based in the assessment of risk in the *VMP HHERA* and development to meet NSW EPA policy requirements that were applicable to remediation of the site to achieve the nominated remediation objectives and describe the extent of remediation required to achieve the remediation goals on which the *VMP / Block 4 RAP* will be based. This report represented a link between the *VMP HHERA* (AECOM, 2012b) and the *VMP / Block 4 RAP* (AECOM, 2013c) and should be read in conjunction with these reports. Refer to **Section 2.6.13** for further detail regarding the report findings.
July 2013	AECOM	*Remedial Action Plan, NSW EPA Declared Remediation Site 21122 and Block 4 (Stage 1B) Development Works, Barangaroo, Millers Point, NSW* (AECOM, 2013c). The purpose of the RAP was to detail the remediation works required to achieve the key remediation objectives of enabling the NSW EPA's declaration of the Declaration Area as a Remediation Site to be revoked and to ensure that Block 4 is remediated to a standard that is suitable for the proposed development in Block 4. Refer to **Section 2.6.14** for further detail regarding the report findings.
August 2013	AECOM	*Addendum to HHERA. Other Remediation Works (South) Area, Barangaroo (AECOM, 2013d).* The purpose of this risk assessment was to assess the type and condition of asbestos identified to be present within the ORWS Area in relation to the potential for unacceptable risks to potential future human receptors. This risk assessment also provided discussion and justification of the most appropriate asbestos SSTC to adopt for future assessment of asbestos in soils. Refer to **Section 2.6.15** for further detail regarding the report findings.

2.6.1 ERM (2007)

ERM was commissioned by Sydney Harbour Foreshore Authority (SHFA) to undertake an ESA which consisted of a Stage 1 Preliminary Site Investigation (PSI) and Stage 2 Detailed Site Investigation for the East Darling Harbour property (Barangaroo).

The PSI component of the investigation reported that the area of investigation was historically used for port/wharf activities and workshops. The AGL gasworks site was also located to the east 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 which required further consideration for the Site were TPH, BTEX, Heavy Metals, PAHs, polychlorinated biphenyl (PCBs), Cyanide, Sulfates, OCPs and organophosphorous pesticides (OPPs).

The DSI made the following conclusions:

- Impacts to soil and groundwater were identified predominantly within the area of the former gasworks infrastructure and the reclaimed areas, with the primary contaminants of concern confirmed as lead, TPH/BTEX and PAH.
- No non-aqueous phase liquids (NAPL) 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.
- The groundwater regime was likely strongly influenced by tidal fluctuation.

- There appeared to be potential for both migration of contamination from the east and migration of contamination into adjacent properties and into Darling Harbour.

The DSI 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 (2009)

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 sandy soils at two locations (Borehole (BH) 3 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 area of investigation.

A summary of the results from within the area of investigation 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 the adopted criteria with the following concentration ranges: Lead (<5 -1320 mg/kg) Arsenic (<5 – 16 mg/kg) Cadmium (<1 – 2 mg/kg) Total Chromium (<2 – 81 mg/kg) Copper (<5 – 228 mg/kg) Mercury (<0.1 – 5.9 mg/kg) Nickel (<2 – 22 mg/kg) Zinc (<5 – 1890 mg/kg)	Arsenic – all results <LOR Cadmium – all results less than LOR with exception of MW09 (1.3 ug/L) Chromium – all results less than LOR with exception of MW20 (2 ug/L) Copper – all results less than LOR with exception of MW17 (2 ug/L) Mercury – all results less than LOR Nickel – results ranged between <10 to 24 ug/L 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 BH117_10-10.5 (10mg/kg) BH117_15-15.5 (244 mg/kg) BH110_23.3-23.8 (46 mg/kg)	All concentrations < LOR with exception of: MW21 – 60 ug/L

Analyte	No. Soil Results	Soil Results	Groundwater Results
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. Results greater than the adopted 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: MW09 – 985 ug/L MW20 – 2870 ug/L 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 adopted criteria. Ethylbenzene, Toluene and Total Xylene were detected in 3 samples at concentrations less than the adopted criteria.	All concentrations < LOR with exception of: 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 adopted criteria (BH117_15-15.5 – 826.3 mg/kg). Benzo(a)pyrene [B(a)P] ranged between <0.5 and 11.4 mg/kg. Three samples exceeded the adopted criteria (BH100 3.0_3.45, BH117_15-15.5 and BH195_10.5).	All concentrations < LOR with exception of: MW21 – Total PAH (25.1 ug/L) and B(a)P (0.7 ug/L) MW18 – Total PAH (8.65 ug/L) and Naphthalene (0.7 ug/L)
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 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 chemicals identified.
- 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.
- A RAP should be developed and following completion of a RAP, a RWP should be developed.

2.6.4 ERM (2008b)

ERM undertook sediment sampling in the area adjacent to Barangaroo in seven transects. The objectives of the sediment screening works were to assess if chemicals have migrated from Barangaroo and accumulated in sediments on the Harbour floor.

The results of the study compared historical data collected on Barangaroo with that collected within the adjacent sediments. The study concluded that the source of elevated chemicals present in the sediment may be from contaminated soil and groundwater identified on Barangaroo.

ERM reported that impacts reported within sediment were in close proximity to free phase hydrocarbons and elevated concentrations of metals, PAHs and TPH C_{10}-C_{36} that were identified in soils at depth at Barangaroo. They also noted that additional sediment assessment works would require an assessment of background sediment concentrations in the wider Harbour area.

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 1A of the Barangaroo South, that is immediately south of the Site (also referred to as the ORWS Area).

The purpose of the DGI was to reduce uncertainties which existed in the available data set, assess 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 a RAP and RWP describing the remediation strategy to be implemented by LL.

The results of the DGI intrusive investigation are briefly summarised as:

- Fill was encountered at the Site overlying natural sands, gravelly sands, clays, weathered and sandstone bedrock. The fill was generally shallower (up to 3 m bgl) in the eastern portion of the Site (near Hickson Road) and trending deeper (up to 19.2 m bgl) towards Darling Harbour.
- Soil impacts appeared to be associated with the historical presence of the former gasworks north of the ORWS Area (located east of 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 chemicals (below soil vapour and ambient air guidelines) in some locations.
- Groundwater was present beneath the ORWS Area 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 Blocks 1, 2 and 3. Groundwater contamination associated with the remaining gasworks infrastructure located to the north of Blocks 1, 2 and 3 did not appear to be migrating into the harbour.

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 asphaltic concrete and concrete ground surface was considered adequate to limit exposure by site users to underlying contamination, future earthworks/remediation/development may complete the exposure pathway.
- *Passive Recreation Land Use at the Public Domain:* The area designated as Public Domain was 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 presented a low risk to human health in its current condition.
- *Environment:* The DGI identified potential risks to the down hydraulic 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 for future development.
- Additional assessment of the materials should be undertaken in accordance with the RAP in the event that materials may be encountered during the excavation and remediation works that are different to those found during the DGI and/or previous investigations.
- An Acid Sulphate Soil (ASS) Management Plan may be required for the management of Potential Acid Sulphate 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 EPA Declaration Area 21122 (also known as the former Millers Point gasworks), at Hickson Road, Millers Point. This area is also designated as the “VMP Remediation Works Area”.

The purpose of the DGI was to reduce uncertainties which existed in the available data set, assess the characteristics of soil and groundwater underlying the Site, provide the additional data required for a quantitative HHERA. The HHERA would assist in the development of a RAP and RWP.

The NSW EPA 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 NSW EPA Declaration Area.

The results of this DGI intrusive investigation as they apply to the Site are discussed in further detail in **Section 3.0** of this report.

In summary, the DGI identified elevated concentrations of chemicals in soil and groundwater exceeding the adopted 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.

The DGI recommended completion of the following:

- HHERAs addressing remediation of the NSW EPA Declaration Area in order to address the significant contamination, the NSW EPA Declaration removal and for the proposed future land use;
- RAPs detailing options for remediation and/or management and recommended preferred strategy to facilitate removal of the NSW EPA Declaration and render the area suitable for their intended land use;
- RWPs 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; and
- An ASS Management Plan may be required for the management of PASS during future excavation works.

2.6.7 AECOM (2010c)

AECOM was engaged by LL to undertake a DGI of the area then defined as the Barangaroo ORWN Area. At the time of the investigation, the ORWN Area was defined as that portion of the Block 4 and the proposed Southern Cove (including associated Public Domain areas) outside the NSW EPA Declaration Area. As described by **Section 2.1**, the ORWN Area (or Site) referred to by this document is limited to the Block 4 Public Domain and proposed Southern Cove areas only (excluding the HHR System Inlet Area) (refer to **Figure F2** of **Appendix A**).

The purpose of the DGI was to reduce uncertainties which existed in the available data set, assess the characteristics of soil and groundwater underlying the site, provide the additional data required for a quantitative HHERA. The HHERA would assist in the development of a RAP and RWP.

The results of the investigation conducted by AECOM across the subject area indicated the following:

- Encountered fill depths ranged from 10.0 to 23.5 m bgl. Fill materials were generally shallower in the eastern portion of the Site closest to the Declaration Area and deeper in the western portion of the Site closest to Darling Harbour. The thickness of fill material generally increased from east to west across the Site.
- Natural soils encountered across the Site comprised silty sands, gravelly sands, clays, weathered sandstone and sand with components of clay. Sandstone bedrock was encountered across the Site with encountered depths ranging from 10.0 m bgl to 25.0 m bgl. Bedrock was generally shallower in the eastern portion of the Site closest to Darling Harbour and deeper in the western portion of the Site closest to Darling Harbour.
- The reported chemical concentrations were generally consistent with those identified during previous reports encompassing the Site and surrounding areas, and variably exceeded the adopted investigation criteria.
- The maximum concentrations of chemicals were generally located in proximity to and down hydraulic gradient from the former gasworks infrastructure in the NSW EPA Declaration Area.
- A reported concentration of naphthalene above the adopted soil vapour screening guidelines was detected in the single soil vapour well within the Site located down-gradient of the former gasworks, 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 1.82 to 2.98 m bgl and was observed to be subject to tidal influence.

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 are considered to be associated with the footprint of the former gasworks within the NSW EPA Declaration Area. Monitoring wells screened entirely within the top 10 m of the aquifer generally reported TPH, PAH and BTEX concentrations less than the laboratory LOR.

2.6.8 AECOM (2010d)

To further understand the potential groundwater discharge from the Site to the receptor, Darling Harbour, AECOM undertook a 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.
- Provide an updated conceptual model for this portion of Barangaroo, to inform the ERA 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 existed 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 was therefore considered to be 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 contributing 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 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 (2011a)

AECOM was engaged by LL to undertake a HHERA for the proposed development within the Declaration Site (Stage 1B).

The objective of the HHERA was to develop SSTC and SSESC (if relevant) for soil and groundwater for use in defining the remediation end-point for the Site.

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

- lower-most basement car park level below the water table (Scenario 1);
- upper-most basement car park level, partially above the water table (Scenario 2);
- unpaved public domain / open space (Scenario 3);
- paved public domain / open space (Scenario 4);
- typical commercial slab on ground construction (Scenario 5);
- short term ground-intrusive maintenance (Scenario 6), and
- typical residential residence with basement construction (Scenario 7).

The development of SSESCs were not considered to be warranted as the proposed development comprises of the entire Site being 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.

Human Health

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.

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.

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.

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.

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.

Odour Risks

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

- gasworks waste is inherently odorous material;
- it is possible that some odorous material could remain at the Site following remediation; and

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

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

2.6.10 AECOM (2012a)

AECOM was engaged by LL to undertake a Supplementary VMP DGI for areas adjacent to the western and southern boundaries of the NSW EPA Declaration Area.

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 Declaration Area and to assess whether these impacts will require remediation to facilitate removal of the NSW EPA Declaration. The objectives of the investigation were to:

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

The scope of work undertaken included:

- Advancing a total of 14 boreholes (BH400 to BH413) to bedrock generally west of the Declaration Area.
- Conversion of one borehole into a groundwater monitoring well (BH401/MW401) and five boreholes into bundled piezometers (BH405/IT03, BH410/IT04, BH411/IT05, BH412/IT06 and BH413/IT07) (refer to **Figure F3** in **Appendix A**).
- Groundwater sampling of four existing monitoring wells (MW62, MW68, MW69 and MW210) and six newly installed monitoring wells (MW410, IT03, IT04, IT05, IT06 and IT07).
- Analysis of selected soil and groundwater samples for the following contaminants of concern by National Association of Testing Authorities (NATA) accredited laboratories.
- The following analysis were undertaken:
  - Leachability (Toxicity Characteristic Leaching Procedure [TCLP] and Australian Standard Leaching Procedure [ASLP]) analysis of selected soil samples collected from BH400 to BH413.
  - Analysis of selected soil samples for phenols.
  - Groundwater sampling of groundwater from five additional monitoring wells (MW198, MW200, MW204S, MW209 and MW08).
  - Standard laboratory analysis of additional groundwater samples from the five additional monitoring wells.
  - Laboratory analysis following laboratory double filtering of selected groundwater samples (filtrate analysis).
  - Laboratory analysis of residue on filter papers from all filtrate samples for PAHs and phenols.

The Supplementary VMP DGI made the following findings:

- Tar impacted soil was identified at and below the fill and natural soil interface in boreholes BH400 to BH406.
- Concentrations of chemicals including lead, TPH, BTEX, and PAHs were reported at each location (BH400 to BH413), with the exception of BH412.
- Observations of contamination and photoionisation detector (PID) readings were consistent with analytical results.

- Asbestos fibre bundles were identified in fill materials BH405 and BH401. Potential asbestos containing material such as fibre cement fragments were not observed in any sample collected.
- Concentrations of chemicals were reported in existing and newly installed monitoring wells, with the highest concentrations within the VMP Site.

2.6.11 AECOM (2012b)

AECOM was engaged by LL to undertake a HHERA to address significant risk of harm issues required for the removal of the NSW EPA declaration 21122.

The objectives of the HHERA were to:

- assess the risk to human health and the environment that the Site represents in its current form; and
- develop SSTC for soil and groundwater for use in defining the remediation end-point for the Site, where this end-point is defined as removal of the NSW EPA Declaration relating to the Site.

The risk assessment was based on the current Site usage which is considered to comprise of limited use with the majority of the Site being vacant paved open space areas.

The current Site use is vacant paved open space. The risk assessment has focussed on potential human health exposure scenarios which are considered to be relevant under the current zoning of the Site and uses which are allowed without planning consent. As such, the broad land use scenarios for which SSTC have been derived are:

- paved open space; and
- short term ground-intrusive maintenance.

The focus of the VMP HHERA was on the chemicals specified within the NSW EPA Declaration, specifically:

- PAHs;
- BTEX;
- TPH;
- Ammonia;
- Phenol; and
- Cyanide.

Human Health Risks

Unacceptable human health risks have been identified for the following scenario and remediation is required to make the Site fit for its current land use. The following specific issue was identified:

- Scenario 2 (Intrusive Maintenance): The highest reported soil and groundwater concentrations of benzene, carcinogenic PAHs, fluoranthene, naphthalene, phenanthrene, pyrene , TPH C_{10}-C_{14}, TPH C_{15}-C_{28} and TPH C_{29}-C_{36} have the potential to result in adverse health risks to short-term intrusive maintenance workers who come into direct contact with soil and groundwater during trenching activities. Locations in Hickson Road where free tar has been reported are of particular significance, based on the potential for direct contact and indirect groundwater-derived vapour exposures.

Odour Risks

No exceedances of theoretical odour-based SSTC for Scenarios 1 and 2 have been reported in soil and groundwater, however:

- gasworks waste is inherently odorous material; and
- it is possible that some odorous material could remain at the Site following remediation.

<u>Visual Amenity Issues/Risks</u>

Visual amenity issues are not considered significant on the Site under current land use scenarios.

Ecological Risks

Exceedances of the MWQC have been identified in groundwater within the Site and at the Site boundary, indicating the potential for an unacceptable risk to the environment. Remediation is required to minimise the risk of adverse impact to the environment.

It is noted that the analytical composition of CoPC within the Site are: (a) consistent with those expected in association with historic gasworks; and, (b) similar in composition to those reported in areas down hydraulic gradient of the Site (ORWN), suggesting that impacted groundwater is migrating off Site.

2.6.12 AECOM (2012c)

The objective of HHR HHERA was to develop SSESC (soil and groundwater concentrations) and, if applicable, human health based SSTC, that remediation would have to achieve to allow construction of the HHR System Inlet. The SSESCs and SSTCs are concentrations that would not give rise to unacceptable risks to both human health and the environment, respectively, under the specified land use.

There is limited soil investigation data (specifically two locations BH01 and BH39) within the HHR System Inlet Area. Further, there is no groundwater investigation data from within the HHR System Inlet Area. Therefore, the following conclusions are necessarily based on consideration of soil and groundwater conditions reported in areas adjacent to the HHR System Inlet Area (specifically within the proposed Southern Cove) as well as from within the HHR System Inlet Area (where they are available).

Ecological Risks

Limited unacceptable ecological risks have been identified. The following specific issues were identified:

- There were limited exceedances of the derived soil SSESC reported within the HHR System Inlet Area and its surrounds. An exception to this is BH01, located within the HHR System Inlet Area, where heavy metal concentrations (As, Zn and Cu) exceeding the soil SSESC (both upgradient of the tidal prism and within the tidal prism) were reported between 2 m bgl and 25 m bgl.
- PAH and Phenol impacts within soils exceeding the derived soil SSESCs were reported in areas near to the HHR System Inlet Area typically at depths greater than 12 m bgl. It is considered that the majority of these impacts are representative of historical contamination residing at the base of the fill and on top of the marine clays (considered to be natural material).
- Comparison of the limited groundwater monitoring results reported from locations near the HHR System Inlet Area with the derived SSESC (upgradient of the tidal prism and within tidal prism) were all within an order magnitude of the derived SSESC. The exception was 2,4 dimethylphenol, which marginally exceeded the order of magnitude within the tidal prism SSESC at MW40.

A number of assumptions with respect to dilution attenuation factors have been applied to the SSESC derived for the Site. It is considered that these assumptions are conservative, and if further data are collected which demonstrates that the dilution is greater or less than that assumed the SSESCs will require revision.

Human Health Risks

There are no identified complete human exposure pathways within the proposed HHR System Inlet Area that are considered to warrant derivation of SSTCs.

Comparison of the SSESC derived for the protection of ecological receptors derived at the HHR System Inlet Area with the SSTC derived for the protection of human health in the EPA Declaration Area shows that the derived SSESCs are protective of human health risks associated with the HHR System Inlet Area.

Visual Amenity Issues / Risks

Based on current conditions within the HHR System Inlet Area and the proposed development, visual amenity issues are considered unlikely to be a significant on the HHR System Inlet Area.

2.6.13 AECOM (2013b)

This *VMP Remediation Extent* report (AECOM, 2013b) was prepared to describe:

- The remediation goals, based on the assessment of risk in the *VMP HHERA* (AECOM, 2012b), that are applicable to remediation of the Declaration Area; and
- The extent of remediation required to achieve the remediation goals and thereby enable removal of the NSW EPA Declaration.

As such, the *VMP Remediation Extent* report represents a link between the *VMP HHERA* (AECOM, 2012b) and the *VMP / Block 4 RAP* (AECOM, 2013c).

Remediation Goals

The remediation goals developed by the *VMP Remediation Extent* report (AECOM, 2013b) for the protection of human health and the environment based on the recommendations of the *VMP HHERA* (AECOM, 2012b) were:

- As a primary goal, removal / remediation of Separated Phase Gasworks Waste and Tar (SPGWT) to the extent practicable as required by the NSW DEC (2007) *Guidelines for the Assessment and Management of Groundwater Contamination*; and
- As a secondary goal, removal/remediation of soil, to the extent practicable:
  - That is representative of Confirmed Impacted Material (CIM), which is defined as:
    - Unsaturated soil concentrations exceeding the soil SSTCs; and/or
    - Unsaturated or saturated soil concentrations that is considered to be the source of groundwater concentrations exceeding the groundwater SSTCs in fill material; and
  - Such that that groundwater quality within fill material leaving the Declaration Area (measured in fill material at the down hydraulic boundary) approaches the MWQC (as detailed in Section 3.4 of the *VMP Remediation Extent* report (AECOM, 2013b).

Remediation Extent

The extent of remediation required in the unsaturated and saturated zones was presented on Figure F14 and Figure F15 of the *VMP Remediation Extent* report (AECOM, 2013b), respectively.

The lateral extent of remediation was determined based on consideration of:

- The presence of historic gasworks infrastructure and the distribution of SPGWT and CIM within the respective Site areas; and
- The extent of remediation that can be practicably accomplished for the protection of the environment based on:
  - The standard of remediation that can be practically achieved by the remediation technologies that are most likely to be implemented;
  - Regulatory policy requirements including:
    - source removal, removal of NAPL to the extent practicable, and clean-up to the extent practicable as contemplated by the NSW DEC (2007) *Guidelines for the Assessment and Management of Groundwater Contamination*
    - The principles of ESD as required by Section 9 of the *CLM Act* (1997); and
    - The principles of the *Waste Avoidance and Resource Recovery Act* (2001).

The standard of remediation to be accomplished in the Declaration Area was defined to equal the higher of:

- Removal of SPGWT to the extent practicable, for the protection of human health and the environment;
- Removal/remediation of soil and groundwater concentrations present within fill material exceeding the relevant SSTCs, to the extent practicable; and
- Removal/remediation of contaminated fill materials such that the contaminant mass is reduced, on average, by 90% within the extent of remediation (calculated based on the estimated mass of naphthalene and TPH C_{10} - C_{14}).

The vertical extent of remediation was broadly defined as remediation to the depth of the underlying natural bedrock to a maximum depth of 10 m below ground level (bgl). The vertical extent of remediation is based on consideration of:

- locations where SPGWT has been reported;
- locations where exceedances of the groundwater SSTC and unsaturated soil SSTC have been reported;
- the footprint of historical gasworks structures and infrastructure; and
- the depth to bedrock (noting that the depth to bedrock steadily increases to the west beyond the 10 m bgl rock contour).

It was also noted that SPGWT and CIM have been reported in the natural marine sediments both within the Declaration Area and in some hydraulically down gradient areas to the west of the Declaration Area. However, the negligible contaminant flux from these natural materials is not considered to pose a significant risk to human health or the environment. As such, the proposed extent of remediation works excludes remediation of natural marine sediments which are present below a depth of 10 m bgl.

2.6.14 AECOM (2013c)

The conclusions of the *VMP / Block 4 RAP* (AECOM, 2013c) are presented below.

Remediation Extent - VMP Remediation Works

The proposed remediation extent is detailed in **Section 2.6.13** above.

Remediation Extent - Block 4 Development Remediation Works

The Block 4 Development Works remediation criteria (as developed by the *Declaration Site HHERA* (AECOM, 2011a) and *Declaration Site HHERA Letter* (AECOM, 2012f), to be achieved within the Block 4 basement area requires that remediation should be undertaken as follows:

- As a primary goal, removal/remediation of SPGWT to the extent practicable, for the protection of human heath; and
- As a secondary goal, removal/remediation of identified CIM, to the extent practicable based on remediation of soil contamination that is considered to be the source of groundwater concentrations exceeding the relevant groundwater SSTC.

The extent of remediation required to facilitate the Block 4 Development Works as recommended by the *Declaration Site HHERA* (AECOM, 2011a) is presented in Figure F12 of the *VMP / Block 4 RAP* (AECOM, 2013c).

It is noted that the proposed design for the Block 4 Development includes construction of a basement groundwater retention wall system around the perimeter of Block 4 that will extend to and be keyed into bedrock. In consideration of this, the development of remediation criteria for Block 4 (within the retention wall system) for ecological protection is therefore not required for the Block 4 Development Remediation Works.

Preferred Remediation Option

The preferred remediation option for each of Block 4, Block 5 and Hickson Road (as appropriate) is summarised as follows:

- Block 4 VMP Remediation Works - excavation of contaminated materials as required to facilitate removal of the NSW EPA Declaration from Block 4, followed by on-site treatment (where required) and off-site landfill disposal;
- Block 4 Development Remediation Works - excavation of contaminated materials as required to make the site suitable for the proposed future land use including construction of the basement groundwater retention wall system;

- Block 5 and Hickson Road (within the Declaration Area) VMP Remediation Works:
  - Completion of a S-ISCO® and SEPR™ Proving Phase and Pilot Trial to demonstrate the effectiveness of the treatment processes and enable optimisation of the full scale treatment process; and
  - If the Proving Phase and Pilot Trial are successful - Option 1:
    - Full scale S-ISCO® and SEPR™ treatment of the SPGWT and CIM in accordance with the Remediation objectives; or
  - If the Proving Phase and Pilot Trial are unsuccessful - Option 2:
    - Excavation of required contaminated materials, followed by on-site treatment (where required) and off-site landfill disposal.

It is noted that, any remediation of SPGWT and/or CIM undertaken as part of the bulk excavation and Block 4 Development Works is considered VMP Remediation Works to the extent that it would have been required in any event to remove the NSW EPA Declaration.

2.6.15 AECOM (2013d)

The conclusions of the *Addendum to HHERA, Other Remediation Works (South) Area* (AECOM, 2013d) are presented below.

Data Reviewed from the ORWS Area

Asbestos data from a total of 10 investigations undertaken within the ORWS area was reviewed as part of the Addendum HHERA for the ORWS Area (AECOM, 2013d). These investigations were undertaken by AECOM, Noel Arnold and Associates (NAA), and Sydney Environmental and Soil Laboratory (SESL). The methodology used to collect this data was a combination of laboratory analysis of samples from bore holes, test pits and excavated materials (removed as part of basement excavations), and visual inspection of excavated material by experienced personnel (NAA and SESL). Greater than 1000 samples were analysed and visually inspected during the asbestos assessments undertaken within the ORWS Area. Though the data was not collected for the purpose of characterising the nature and extent of asbestos contamination within the ORWS Area, the volume of data was considered adequate to provide an understanding of the condition of asbestos which was encountered in the subsurface.

Condition of Asbestos within the ORWS Area

Limited information is available describing the condition of asbestos identified in the ORWS Area. AECOM requested further information from NAA regarding the condition of the bonded ACM fragments identified at the Site. NAA confirmed that if material was considered to be friable in nature it was noted in the Asbestos Finds Log (which has not been reviewed by AECOM) or the relevant Stockpile Verification Certificate.

Observations recorded by NAA indicated that ACM fragments observed to be present in soils ranged in condition from poor to good (or sound) with a number of fragments identified to be weathered. Any material noted to be in poor condition was “due to the incomplete nature of the fragment and the exposed edges” (NAA email correspondence dated 25 July 2013). Photographs of ACM fragments made available to AECOM and correspondence with NAA indicated that the majority of the ACM fragments, though in poor condition, were not identified to be friable or likely to be able to be crushed by hand (AECOM hygienist email correspondence dated 26 July 2013). However further inspection would be required to confirm this.

NAA noted that there were a “few” instances where ACM was visually identified to be composed of friable material (i.e. no field test were conducted to confirm the friable nature of this material), such as fibrous gaskets, fibrous backing paper and woven rope. It is considered that there is limited potential for these items to result in generation of asbestos fibres, and these ‘potentially friable’ materials were not reported to be widespread.

It should be noted that SESL did not report on the condition of bonded ACM it identified at the Site. Therefore, no reference has been made to the condition of asbestos in samples collected by SESL within this HHERA.

It is noted that bonded ACM in soils, such as asbestos-cement, vinyl-asbestos floor tiles and compressed asbestos gaskets, do not liberate measurable ‘respirable’ airborne asbestos fibres when subjected to excavators, front end loaders, tracked vehicles, hand digging and sieving (AS4964-2004). The *ASC NEPM* (2013) states that bonded ACM is not a human health risk but bonded ACM may represent a health risk where it is identified to be damaged such that it has become friable. Based on the information available to AECOM it is our understanding that the bonded ACM fragments observed at the Site were sometimes described to be in poor and weathered condition but were not degraded such that they were friable in nature. AECOM therefore assumes that the majority of bonded ACM at the Site is unlikely to result in generation of asbestos fibres. This assumption is further confirmed by the results of the air monitoring conducted by NAA

Adoption of Site Specific Target Criteria (SSTC) for Asbestos

Health risks as a result of the presence of asbestos in soil are extremely difficult to predict because there has been no relationship established between concentrations reported in soils and potential resultant airborne concentrations (enHealth, 2005; QDoH, 1993; Swartjes and Tromp, 2008). It is also widely accepted that asbestos in soil, that is buried and left undisturbed does not pose a risk to human health and therefore there is no justification for setting an 'acceptable' level in soils which are to remain in-situ. Where there is potential for disturbance of soils that contain bonded ACM, AF or FA, human exposures need to be assessed and managed on a Site specific basis.

Swartjes and Tromp (2008) reported that only highly asbestos contaminated soils have the potential to result in air concentrations above the maximum permissible risk level of 100,000 fibre equivalents/m3 of air. While less contaminated soils rarely exceed the negligible risk level of 1,000 fibre equivalents/m3 of air. This information emphasises the limited potential for surface soil impacts to result in detectable airborne asbestos fibre concentrations.

The future land use scenarios identified within the ORWS area (AECOM, 2013d) are such that the only receptor that may potentially be exposed to bonded ACM in soils under future conditions within the ORWS Area are intrusive maintenance workers. All other receptors are not considered likely to be exposed as a result of the future conditions proposed for the ORWS Area. Intrusive maintenance workers are considered to be present for eight (8) hours per day, for a maximum of 15 days per year over a one year period. These receptors are not considered likely to be present for longer periods of time because it is assumed that the same worker would not conduct intrusive works over more than 15 days per year. Due to the number and variety of underground services likely to be present beneath the Site it is unlikely that the same worker would conduct works over a longer period, or over multiple years.

The assumed exposure duration for intrusive maintenance workers is considered to be consistent with an acute exposure (in the event that airborne asbestos fibres are generated during works). The available information pertaining to health risks as a result of exposure to asbestos fibres indicates that acute exposures are unlikely to result in health effects. The enHealth (2005) guidance states that an isolated exposure to asbestos fibres is 'extremely unlikely' to result in development of asbestos related disease because fibre concentrations in air are unlikely to be sufficient to increase the cumulative lifetime exposure of the receptor.

The asbestos reported to be present within soils within the ORWS is predominately bonded ACM and therefore the potential for fibre generation would be as a result of physical disturbance of bonded ACM. It is considered that the historical sampling conducted at the ORWS is representative of the worst case scenario for the generation of AF from the physical disturbance of bonded ACM (AECOM, 2013d). That is, the soil that was subject to the sampling regime was subject to excavation, stockpiling and mechanical reworking. Where a description of the condition of the bonded ACM was provided, it was described as being in poor to weathered condition (although it is understood that a description was not provided for bonded ACM that was considered to be in good condition). There were no asbestos fibres detected as part of the air quality monitoring program undertaken during the aforementioned physical disturbance of the bonded ACM. Therefore, the likelihood of the generation of asbestos fibres to air from the bonded ACM identified at the Site is considered to be low based on the current condition.

Intrusive Maintenance Exposure Scenario

Based on the *ASC NEPM* (2013) and to account for the potential for that bonded ACM present at the Site may degrade over time and generate asbestos fibres as a result of future physical disturbance by intrusive maintenance works, the asbestos SSTC adopted for the Intrusive Maintenance Exposure Scenario is:

- 0.05 % w/w asbestos in soil – taken from the *ASC NEPM* (2013) guideline for protection of commercial / industrial receptors from bonded ACM in soil.

The *ASC NEPM* (2013) guideline for protection of commercial/industrial receptors is considered appropriate based on the fact that intrusive maintenance workers are likely to be the only receptors who may contact potentially asbestos containing materials under proposed future land use scenarios. The guideline of 0.02% w/w (for recreational users) has not been adopted as recreational receptors as not considered likely to contact soils at the Site under proposed future land use conditions.

Suitable Fill

The *ASC NEPM* (2013) states that surface soils must be free of “visible asbestos” under all land use scenarios. Surface soils are interpreted by the *ASC NEPM* (2013) to be the top 0.1 and 0.3m of soil.

Therefore, based on the *ASC NEPM* (2013) the asbestos SSTC adopted for Suitable Fill is:

- No visible asbestos.

It is noted that the ORWS HHERA (AECOM, 2011b) has specified that 0.5 m of Suitable Fill must be placed within all paved and unpaved recreation land use areas. While the requirement of the *ASC NEPM* (2013) is that the top 0.3m of soil be visually free from asbestos, it is not considered practicable to have a separate criteria for the lower 0.2 m of Suitable Fill. It has therefore been determined that the same asbestos SSTC should be adopted for all Suitable Fill placed within all paved and unpaved recreation land use areas.

2.7 Geology

2.7.1 Regional Geology

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

As described by **Section 2.5**, historical information indicates 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 were infilled in several stages between the 1960’s and 1980’s with various types of material. The former Southern Cove was located on the south side of the current Site and is understood to have been filled in 1988.

Various intrusive and geotechnical investigations have been undertaken within Barangaroo South and surrounding area. The *Barangaroo Stage 1 Development Geotechnical Report (*Coffey, 2010) described the following sub surface units present across Barangaroo:

- Fill: heterogeneous fill consisting of mainly of crushed sandstone with inclusions of brick, concrete, timber, glass and slag. The fill becomes progressively deeper from east to west and the base of the fill has been interpreted as highly irregular.
- Estuarine sediments: Dark grey to black silty and sandy clays containing shells and organic material were typically observed across the southern and eastern portion of the Barangaroo South. Organic peaty clay layers were also present in areas. The estuarine sediments were identified at two distinct horizons at 4 to 6 m bgl and 11 to 14 m bgl with thicknesses of 1 to 2 m.
- Alluvial sediments: firm silty sands, clayey sands and stiff sandy clay sourced from weathered sandstone were identified at depths of 5 m bgl in the east and greater than 16 m bgl in the west with thickness ranging from 3 to 10 m.
- Residual soil: hard silty clay and sandy clay encountered at depths greater than 13 m bgl in some locations with thicknesses of up to 1.5 m.
- Sandstone: extremely low strength and extremely highly weathered sandstone grading to high strength sandstone generally encountered shallow in the east and slopes down to the west.
- Dolerite Dyke (The Pittman Dyke): a near vertical extremely weathered dyke consisting of very stiff to hard pale grey/white kaolinitic clay runs east-west through the northern portion of the Barangaroo South development at depths from 5 to 14 m bgl.

2.7.2 Site Geology

Based on the boreholes completed during previous environmental investigations, the following is known about the subsurface:

- Fill: A layer of heterogeneous fill consisting of predominantly crushed sandstone and clay containing demolition rubble (mainly bricks, timber and concrete) was encountered across the Site. The fill layer was generally shallowest in the north east portion of the Site (12-13 m bgl) and deepest in the western portion of the Site (20 to 25 m bgl).

- Natural soil/sediments: estuarine sediments including sand with shells, soft sandy clay and organic dark grey silty clay were encountered below the fill in many of the boreholes completed. Residual weathered sandstone soil consisting of stiff sandy clay and dense clayey sand underlay the estuarine sediments in some locations. It is noted in some locations fill directly overlies sandstone bedrock and no natural soil or sediment was present.
- Bedrock: sandstone bedrock was encountered at depths ranging from 19 to 25 m bgl. The depth to sandstone bedrock was highly variable across the Site, with apparent deeper troughs running east to west. It is noted that the dolerite dyke is located in the southern to central portion of the Site.

Observations of tar contamination in the investigations were mainly identified at the interface of fill and natural soil/sediment and directly above bedrock.

2.8 Hydrogeology

The *ORWN DGI* (AECOM, 2010a) reported the following findings:

- Groundwater was present as an unconfined, shallow aquifer within the fill materials and the underlying natural sediments. Groundwater was also likely to occur as a deeper bedrock aquifer within the underlying sandstone bedrock. Groundwater within the bedrock would occur as a fractured bedrock aquifer, potentially confined by an overlying clay unit in some areas of the ORWN Area.
- The highest reported groundwater contaminant concentrations were generally encountered within wells screened deeper within the aquifer, across the base of the fill and natural sediments and immediately overlying bedrock.
- Due to the proximity of the Site to Darling Harbour, the depth to groundwater was shallow (between 1.8 to 2.9 m bgl) and the overall direction of groundwater flow was expected to be towards Darling Harbour. Groundwater at the Site was tidally influenced, resulting in the fluctuation of groundwater levels within the fill materials and natural sediments.
- Although the results of the tidal assessment indicated the Site was tidally influenced, the low dissolved oxygen concentrations reported across the Site suggested there was limited flushing of groundwater and associated contamination occurring.
- Based on the results reported in *ORWN DGI* (AECOM, 2010a) there appeared to be an efficient hydraulic connection between the saturated fill material and Darling Harbour indicating a significant exchange of water during tidal cycles. However groundwater flux in the underlying natural material was determined to be negligible.
- The hydraulic conductivities and laboratory permeability's reported for the Site were considered to be variable due to the heterogeneous nature and distribution of fill materials. This variability in conductivity results in inconsistent lag times for tidal influence across the Site and creates a tortuous flow path for groundwater and associated contamination.

A search of the NSW Department of Natural Resources (DNR) groundwater bore data base was reported in ERM (ERM, 2007) and indicated that there were 32 registered groundwater bores within a 4 km radius of the Site. Groundwater bore information indicated that the bores were registered for either recreation, irrigation or monitoring purposes. It is noted that, in the opinion of AECOM, the current dataset and CSM indicate that the shallow subsurface trenches are unlikely to act as preferential pathways for contaminant migration as the contamination is present at depths below the likely depth of the service trenches.

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

2.9 Soil Vapour

AECOM (2010a, 2010b and 2010c) conducted sampling of soil vapour from across Barangaroo (six locations) at depths ranging from 0.6 m bgl to 1.7 m bgl, the majority of these locations (five locations) were outside the Site. The soil vapour wells were installed using permanent soil gas implants and the construction details of each soil vapour well are 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 United States Environmental Protection Agency (USEPA) TO-14 method utilising the USEPA

TO-15 analyte list. The results collected indicated exceedances of the adopted ambient air guidelines (converted Agency for Toxic Substances and Disease Registry (ATSDR) 2005 minimal risk level (MRL)) for naphthalene at locations SV05 and SV11 located within the NSW EPA Declaration Area and SV08 located within the ORWN Area (the Site) and SV01 and SV02 located within the ORWS Area.

Prior to sampling, the oxygen measurements within the subsurface ranged from 4.2% to 17.6%, indicating that oxygen is present within the upper soil profiles 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, used for recording the in-situ parameters, 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. *ESA, East Darling Harbour, Sydney, NSW*. June 2007.
- Coffey, 2009. *Preliminary Environmental Investigation, 30-38 Hickson Road, Millers Point*, NSW 2000. June 2009.
- ERM, 2008a. *Additional Investigation Works at Barangaroo, Hickson Road, Millers Point, NSW*. July 2008.
- AECOM, 2010b. *DGI, EPA Declaration Area (Parts of Barangaroo Site and Hickson Road), Hickson Road, Millers Point, NSW*. September 2010.
- AECOM, 2010c. *DGI, Other Remediation Works (North) Area, Hickson Road, Millers Point, NSW*. October, 2010.
- AECOM, 2012a. *Supplementary DGI, VMP Area, Millers Point, NSW*, March 2012.

The quality and quantity of the analytical data collected as part of the above investigations are 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 comprised the review of the analytical procedure compliance and an assessment of the precision, accuracy, representativeness, completeness and comparability 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 EPA Auditor Guidelines, Appendix VII* (2006), AS4482.1 (*Guide to the sampling and investigation of potentially contaminated soil. Part 1: Non-volatile and semi-volatile compounds*) and the United States Environment Protection Agency (USEPA, 1992) *Guidance for Data Useability in Risk Assessment.*

Table 4 Data Confirmation

Considerations	Coffey (2009)	ERM (2007)	ERM (2008a)	AECOM (2010b)	AECOM (2010c)	AECOM (2012a)
Data Quality Objectives (precision, accuracy, representativeness, completeness and comparability).	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 DEC (2006), ANZECC and National Environment Protection Council (NEPC).	The QA/QC program implemented as part of the AECOM DGIs (AECOM 2010b, 2010c, 2012a) 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 wells 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, included a suitable concentration range of chemicals including assessment at or near maximum soil chemical 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		The strategy for a supplementary DGI was to inform the risk assessment process with respect to the nature and extent of contaminant discharge from the Site to Darling Harbour. 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; and, include selection of a suitable concentration range of chemicals, including assessment at or near maximum soil chemical concentrations for the Site. The data set is considered adequate for graphical and statistical analysis.
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.	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 Group (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.		Analyses of primary and intra-laboratory duplicate soil and groundwater samples were undertaken by ALS Environmental. Triplicate samples were analysed by MGT Labmark. Laboratories. 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 (DQI) 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 DQI was considered adequate.		Collection rate of QA samples as listed under DQI was considered adequate.

Considerations	Coffey (2009)	ERM (2007)	ERM (2008a)	AECOM (2010b)	AECOM (2010c)	AECOM (2012a)
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, OPP, phenols, asbestos, 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])	Metals (As, Cu, Cr, Cd, Hg, Pb, Ni, Zn), CN, sulphates, TPH, BTEX, PAH, phenols. PCBs, OCP/OPP, asbestos	Metals (As, Cu, Cr, Cd, Hg, Pb, Ni, Zn), CN, sulphates, TPH, BTEX, PAH, phenols, PCBs, asbestos	Metals (As, Cu, Cr, Cd, Hg, Pb, Ni, Zn), sulphates, CN, ammonia, TPH, BTEX, PAH, phenols. PCBs, OCPs, asbestos, volatile organic compounds (VOCs), semi volatile organic compounds (SVOCs), ASS		Metals (As, Cu, Cr, Cd, Hg, Pb, Ni, Zn), sulphates, CN, ammonia, TPH, BTEX, PAH, phenols. PCBs, OCPs, asbestos, VOCs, SVOCs, ASS
Data Validation	Data validation procedure employed is summarised in Section 10 and *Appendix G* of Coffey (2009) 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 (2008a). 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, 2012a) field and laboratory QA/QC data indicated that the reported analytical results are representative of soil, soil vapour and groundwater conditions at the sample locations and that the overall quality of the analytical data produced is acceptably reliable for the purpose of the DGI.		
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 reported detectable levels exceed the Groundwater Investigation Levels (GILs) such that these compounds have been further evaluated based on detected concentrations. 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 laboratory results, and has been earmarked as needing further investigation. The ERM dataset was reported to have been reviewed by an independent expert on behalf of Sydney Harbour Foreshore Authority (SHFA), including data quality. Preceding the DGIs, AECOM randomly assessed and verified a portion of the ERM data including data from ERM (2008a) by cross-checking the ESDAT result database against survey data obtained from LL. AECOM accepts the ERM dataset based on the limited review and the review of SHFA's independent expert.	Some holding times, RPD results 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. Laboratory LORs for some VOCs (1,3-butadiene, trichloroethylene , 1,2-dichloroethane, hexachlorobenzene and 1,2-dibromomethane) were greater than the adopted air and soil screening criteria but these were not considered to be site contaminants and results would not significantly affect the dataset interpretation. 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. A number of CN compounds in 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.	Some field RPDs, laboratory duplicate RPDs, laboratory control sample recoveries, matrix spike recoveries and surrogate recoveries outside the AECOM DQIs and rinsate blank detections. There were some holding time exceedances for additional laboratory leachate testing requested after the initial analysis was completed.	It is noted that there were high RPDs reported between the primary sample IT04M and the triplicate sample QC645 for both organic and inorganic chemicals. It is considered that the result for the triplicate sample is an anomaly due to the fact that it (a) has no chemical resemblance to the primary sample and field duplicate sample QC644 and (b) based on field observations taken at the time of sampling. It is likely to either be attributed to a sample mix up either in the laboratory or field as the differences observed are greater than those expected due to different analytical procedures. Therefore the results of QC645, whilst presented will not be adopted as being representative of the sample location.

Based on the assessment presented in **Table 4**, there are no significant potential impacts to the overall Data Quality Indicators (DQIs) (precision, accuracy, representativeness, completeness and comparability) 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 complies with the reporting quality protocols, addresses identified existing data gaps and confirms the general characteristics of soil, fill, soil vapour and groundwater underlying the Site sufficiently to allow for development of a Site specific HHERA.

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

3.3 Data Representativeness and Completeness

3.3.1 Soil Investigation Data

The ERM (2007) *ESA, East Darling Harbour, Sydney, NSW*, comprised the following scope of work:

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

The ERM (2008a) *Additional Investigation Works at Barangaroo, Hickson Road, Millers Point, NSW,* 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 potential Site contaminants.
- Rock coring in 13 targeted boreholes within the former gasworks area, to maximum depth of 22.5 m bgl and analysis for potential Site contaminants.
- Installation of 13 new monitoring wells, gauging, sampling and analysis for potential Site contaminants.
- Gauging and sampling of the 13 new monitoring wells and 23 existing monitoring wells for a range of potential Site contaminants.

AECOM notes that only a proportion of the sampling locations investigated by ERM were situated across the Site. Rock coring was undertaken where the potential for impact into bedrock was considered high, this being within the former gasworks area (outside the Site).

The Coffey (2009) *Preliminary Environmental Investigation 30-38 Hickson Road Millers Point NSW* was undertaken at the segment of Hickson Road (between numbers 30 to 38), Millers Point, NSW, located east of the Site. The scope of work from this investigation that relates to Hickson Road included:

- Advancement of 15 boreholes, ranging from 6 to 12 m in depth, sampling and analysis for potential site contaminants.
- Conversion of 6 boreholes into new monitoring wells, gauging, sampling and analysis for potential site contaminants (AECOM notes that one monitoring well (MW1) was dry and not sampled).

The Coffey sampling locations were targeted to assess specific potential areas of concern such as historical gas holder and tar wells and presence of site wide fill and to provide general coverage of accessible areas within the subject area. None of the sampling locations were located within the Site.

The DGI intrusive investigations undertaken by AECOM were designed to acquire targeted data to address potential data gaps at a number of locations across the Site and surrounding areas:

- *DGI ORWS* (AECOM, 2010a);
  - advancement and sampling of a total of 35 boreholes across the area of investigation;
  - installation and sampling of four soil vapour wells;
  - conversion of seven boreholes to groundwater monitoring wells, which were subsequently sampled;
  - monitoring of groundwater including completion of rising head tests and tidal fluctuation monitoring within selected groundwater monitoring wells.

- *DGI NSW EPA Declaration Area / Block 4 Development Works Area* (AECOM, 2010b);
    - advancement and sampling of a total of 25 boreholes across the area of investigation;
    - conversion of nine boreholes to groundwater monitoring wells and sampling and analysis of groundwater from these wells;
    - installation and sampling of seven soil vapour wells; and
    - monitoring of groundwater including completion of rising head tests and tidal fluctuation monitoring within selected groundwater monitoring wells.
- *ORWN DGI* (AECOM, 2010c);
    - advancement and sampling of a total of 13 boreholes across the Site;
    - conversion of five boreholes to groundwater monitoring wells, which were subsequently sampled;
    - sampling of existing wells installed by ERM;
    - sampling of two nested intertidal wells and one stilling well installed as part of the intertidal assessment;
    - installation and sampling of one soil vapour well;
    - advancement and sampling of an additional five boreholes and one converted groundwater monitoring well outside the Site boundary to the northwest of the Site; and
    - monitoring of groundwater including completion of rising head tests and tidal fluctuation monitoring within selected groundwater monitoring wells.
- *Supplementary DGI* (AECOM, 2012a);
    - advancement and sampling of a total of 14 boreholes across the area of investigation;
    - Conversion of one borehole into a groundwater monitoring well, which was subsequently sampled along with pre-existing wells; and
    - Conversion of five boreholes into bundled piezometers, which were subsequently sampled.

The AECOM investigation locations were selected on a judgemental (targeted) basis to attempt to fill data gaps and to target known or suspected areas of contamination with the aim of capturing worse-case soil, groundwater and soil vapour concentrations.

The spatial coverage of soil and groundwater investigation locations within the Site (see **Figure F3** in **Appendix A**) is considered generally sufficient to characterise the nature and extent of contamination within the Site. The available soil analytical results for the Site includes samples collected from a total of 23 borehole locations across a range of depths at each borehole location. While it is noted that the overall sampling pattern was not entirely grid-based (due to the difficulty in drilling experienced during field works), if a grid-based sampling pattern is assumed, the total number of borehole locations is expected to detect circular hot spots of diameter greater than 15 m^2 with 95% confidence (based on calculation approaches in *Appendix D* of *AS4482.1-2005*; Standards Australia, 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 (these locations generally occur to the east of the Site boundary).

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 bedrock (>16 m bgl) underlying the Site is not known with certainty.

3.3.2 Groundwater Investigation Data

The available groundwater monitoring data include a network of 12 groundwater monitoring locations, four of which (IT1, IT2, IT04 and IT05) were nested bores screened within three different depth intervals (i.e. a total of 20 groundwater monitoring points). Of the available monitoring bores, the screened intervals included, 12 wells screened entirely in fill material, four wells screened entirely in natural soils (sands and clays overlying sandstone bedrock), and four wells screened across the fill/natural interface. **Table 5** details the groundwater screening depths and lithologies.

The spatial coverage of the groundwater monitoring wells has been targeted to locations down hydraulic gradient of source areas within the adjacent Declaration Area to provide spatial coverage of the Site. However, it should be noted that no wells were screened either wholly or partially within bedrock. There is, therefore, some uncertainty as to contaminant concentrations within bedrock underlying the Site.

Table 5 Summary of Groundwater Screening Depths and Lithologies for wells considered in this HHERA

Bore ID/Location Code	Approximate Screen Interval (m bgl)	Screened Lithology	Report
BH40/MW40	14.3 – 20.4	FILL / NATURAL	AECOM (2010c)
BH56/MW56	17.5 – 21	NATURAL	
BH60/MW60	13.5 – 22	FILL / NATURAL	
IT1 Shallow: Mid: Deep:	 1.8 – 2.8 7.9 – 8.9 16.6 – 17.6	 FILL FILL NATURAL	AECOM (2010d)
IT2 Shallow: Mid: Deep:	 2.3 – 3.3 7.7 – 8.7 16.5 – 17.5	 FILL FILL FILL / NATURAL	
BH053/MW11	3 – 9	FILL	
BH076/MW14	3 – 9	FILL	ERM (2007)
BH116/MW22	3 – 9	FILL	
BH129/MW24 (located north of the Site boundary).	2.3 – 6.9	FILL	
MW212	1.3 – 16.7	FILL	ERM (2008a)
BH410 / IT04 Shallow: Mid: Deep:	 2 – 3 16.5 – 17.5 30.5 – 32.2	 FILL FILL / NATURAL NATURAL	AECOM (2012a)
BH411 / IT05 Shallow: Mid: Deep:	 2 – 3 13.5 – 14.5 26 – 27	 FILL FILL NATURAL	

3.4 Data Gaps

Some observed data gaps which may impact this HHERA have been identified based on review of the available report and data, these are summarised in **Table 6**. The manner in which data gaps have been addressed in the HHERA is also summarised.

Table 6 Summary of Identified Data Gaps

Identified Data Gap or Issue	Potential Significance to HHERA	Manner in Which Addressed in HHERA
Limited soil and groundwater sampling locations.	The lack of a defined sampling grid (associated with the difficulty in drilling and installation of groundwater wells experienced during the fieldworks) may result in the exclusion of impacts identified at the Site.	The HHERA used data collected across the entire Barangaroo South area to determine the CoPC which would be considered, this included the NSW EPA Declaration Area where significant historic impacts have been identified in soil and groundwater. The development of SSTC has therefore not been limited by the impacts observed only at sampling locations within the Site boundary.
Soil vapour data collected only from surficial soil depths due to shallow and tidally influenced water table at Site.	Soil vapour data is not necessarily representative of soil or groundwater-derived vapour concentrations which may enter basement structures at depth following redevelopment.	For deep basement structures below the depth of water table, groundwater is considered to be the primary source of vapours and soil vapour data is not needed. Soil vapour data was considered suitable for assessment of public open space/ recreational scenarios and used as secondary line of evidence for interpretation of soil SSTC derived for these scenarios. For other scenarios where soil vapour concentrations may be relevant (commercial slab on ground and shallow basement levels with soil potentially adjacent to basement walls), SSTC have been conservatively derived for bulk soil concentrations assuming equilibrium partitioning between soil and vapour phases.
Groundwater sampling locations are not located immediately adjacent to the down hydraulic gradient Site boundary. Further, groundwater monitoring wells are variably screened in the fill and/or in the underlying natural material. Depending on the location of the groundwater monitoring wells, and the timing of the sampling activities relative to the tide, the groundwater sampled in the wells may not be representative of groundwater quality leaving the Site.	Available on-Site groundwater data may not be representative of the groundwater conditions at the Site boundary (considered to be the point of discharge for the ERA).	No adjustment of groundwater concentrations for potential dilution of groundwater concentrations prior to discharge has been undertaken within this HHERA. Consequently, groundwater concentrations both at the Site boundary and across the Site have been directly compared to the MWQC to assess risk to the environment (which is conservative).

<table>
<tr><th>Identified Data Gap or Issue</th><th>Potential Significance to HHERA</th><th>Manner in Which Addressed in HHERA</th></tr>
<tr><td>Vertical extent of SPGWT (as described in Section 4.2.1) within fractured bedrock underlying the Site is not known with certainty (due to practical constraints).</td><td rowspan="2">This data gap does not impact the ability to derive SSTC for gasworks contaminants, but should be considered in overall remedial planning for the Site.
Contaminant flux modelling undertaken in support of the VMP Remediation Extent report (AECOM, 2013b) has demonstrated that there is negligible contaminant flux from the bedrock and marine sediment to either the overlying fill and Darling Harbour.</td><td rowspan="2">Vertical distribution of CoPC is noted as an uncertainty; potential for impacts to be present needs to be considered as part of the remedial planning for the Site because tar impacts need to be removed to the extent practicable.</td></tr>
<tr><td>Contaminant concentrations in groundwater within the deeper bedrock aquifer have not been investigated in all areas.</td></tr>
<tr><td>Limited asbestos sampling has been conducted at the Site. Based on validation sampling conducted within the ORWS area it is expected that there is potential for significant asbestos impacts to be present within the sub-surface.</td><td>Asbestos fibres have not been detected in samples collected from the ORWN area. However samples collected from within the ORWS area during basement excavations indicated that asbestos containing material (ACM) was present within soils, but there was limited detection of asbestos fibres.</td><td>The available data from within the ORWS area has been used to assess the potential condition of asbestos containing material within the ORWN area. This approach is considered appropriate as potential asbestos within the ORWN area is likely to have been subject to similar environmental conditions as that detected in the ORWS area.</td></tr>
</table>

4.0 Nature and Extent of Contamination

4.1 Contamination Sources

The NSW EPA Declaration Area to the east (up hydraulic gradient) of the Site largely corresponds with the inferred footprint of the former Millers Point gasworks footprint. This Declaration Area includes part of the Barangaroo South and Hickson Road. The Block 4 Development Works Area, includes part of the Declaration Area but extends beyond the western boundary of the Declaration Area. The Site (ORWN Area) extends west from the western boundary of the Block 4 Development Works Area to Darling Harbour (see **Figure F3**).

Buried gasworks infrastructure is understood to remain beneath the NSW EPA Declaration Area. URS (2001) estimated the footprint of the former gasworks to encompass approximately 5,420 m^2 and comprised the following structures:

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

Other historical structures associated with the former gasworks site include 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, 2009).

The former gasworks is recognised as a key source of contaminants at Barangaroo (i.e. NA&A, 1996; ERM, 2007; Coffey, 2009; ERM, 2008a; AECOM, 2010a; 2010b; 2010c). This and other CoPC sources on and near the Site have been identified by historical studies, as summarised in **Table 7.**

Table 7 Summary of Potential Contamination Sources on Site [a]

Description of Potentially Contaminating Activity	CoPC	Comments
Former gasworks up-gradient of the Site	Metals, TPH, BTEX, PAHs, phenols, sulphate, cyanide, ammonia.	Associated with gasworks waste. Gasworks contamination is likely to be concentrated in the vicinity gasworks infrastructure up hydraulic gradient of 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 historically for reclamation of land from Darling Harbour in the former 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 and 2010c)
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
PASS – potential acid sulphate soils

It should also be noted that the area east of Barangaroo South and the NSW EPA Declaration Area (i.e. to the east of Hickson Road) was historically occupied by a mixture of commercial, industrial and residential facilities, which may currently or could have historically also been sources of contamination. Potential contaminants are likely to include those summarised above.

Assessment and remediation of contamination extending outside the Site will be addressed as follows:

- East of the Site:
  - Potential health and ecological risks associated with soil and groundwater contamination identified to the east of the Site, within the NSW EPA Declaration Area and Block 4, have been addressed as part of the risk assessments:
    - the *VMP HHERA* (AECOM, 2012b) in relation to removal of the NSW EPA Declaration; and,
    - the *Declaration Site (Development Works) Remediation Works HHERA* (AECOM, 2011a) in relation to the proposed future development.
  - Contamination identified to the east of the Site will be managed in accordance with the *VMP / Block 4 RAP* (AECOM, 2013c);
- South of the Site:
  - Potential health and ecological risks associated with existing soil and groundwater contamination identified south of the Site, in the ORWS Area, have been addressed as part of the risk assessments relating to the ORWS Area (AECOM, 2011b) and the HHR System Inlet Area (AECOM, 2012c).
  - Contamination identified to the south of the Site will be managed as part of the *ORWS Area RAP* (AECOM, 2011c) and the *Addendum to the ORWS Area RAP* (AECOM, 2012g).
- North of the Site:
  - Potential health and ecological risks associated with existing soil and groundwater contamination identified north of the Site, in Barangaroo Central, will be addressed as part of the risk assessments relating to those areas (prepared for the Authority); and
  - Contamination identified north of the Site will be managed as part of the RAP for Barangaroo Central (prepared for the Authority).

4.2 Impacted Media

4.2.1 Soil

Field Observations

Based on a review of the borehole logs related to the soil sampling works conducted within the Site, field observations from the sampled fill materials indicate that the material is generally non-odorous and with no visible signs of staining. This was supported by the screening of soil samples using a PID which recorded very low (<10 ppm) or zero VOC concentrations. The key exceptions were the fill material sampled and analysed from (refer to **Figure F3**):

- BH053 – faint hydrogen sulphide odour (3.0 m – 3.28 m);
- BH054 – slight to moderate hydrocarbon odour (2.5 - 3.0 m);
- BH212 – black staining (1.5 m – 1.6 m), black staining and slight hydrocarbon odour (1.85 m – 2.00 m), trace black staining (2.5 m – 6.0m), trace black staining 7.2 m – 7.7 m), black staining on brick fragment (12.0 m – 12.2 m), black staining on brick and sandstone (15.45 m – 15.9 m);
- BH40 – chemical odour noted in marine sediments from 16 to 19.2 m, black stained veins of tar with sheen at 16.5;
- BH46 – very strong chemical odour noted in marine sediments from 19.0 m;
- BH47 – slight hydrocarbon odour noted in fill material from 4.0 to 16.0 m and within marine sediments at 16.0 m;
- BH56 – tar odour noted (7.0 m – 8.5 m);

- BH60 – strong tar odour and lumps of tar noted in marine sediments at 16.0 m. Slight tar odour to 23.5 m;
- BH72 – slight chemical odour noted in marine sediments (16.0 – 17.0 m);
- IT1 – slight tar odour (>5.0 m);
- IT2 – slight hydrocarbon odour (2.7 m – 3.5 m); and
- BH410 – hydrocarbon odour noted in marine sediments at 17.0 m.

A review of the borehole logs and analytical data from the Site indicates that impacted natural materials, likely to be attributable to the former gas works site (located to the east), are predominantly located within the marine sediments where there is negligible contaminant flux (refer to **Section 2.6.8**). Due to the depth of the marine sediments, these impacts are present at depths ranging between approximately 14.3 m bgl (BH40) and 23.5 m bgl (BH39). Consequently, given the depth, they are unlikely to have aesthetic impacts on the proposed Southern Cove surface waters.

Total Concentrations

The results of the soil total concentration analysis are presented in **Table T1** of **Appendix B**.

PAHs (including B(a)P and naphthalene) and heavy metals (arsenic, chromium, cobalt and lead) in soil were reported at concentrations above the adopted site investigation criteria across the Site. In particular, elevated concentrations have been reported within the marine sediments in the vicinity of BH60, BH72 and BH191.

TPH C_6-C_9 was reported in soil at concentrations that exceeded the adopted site investigation criteria at one sample location (BH60), within the marine sediments. Heavy end TPH fractions (TPH C_{15}-C_{28} and TPH C_{29}-C_{36}) were reported in soil at concentrations that exceeded the adopted site investigation criteria more broadly across the northern portion of the Site in both the fill and marine sediments.

BTEX were typically reported in soil at concentrations below the laboratory LOR and/or the adopted site investigation criteria. The only exceptions were BH40, BH60, and BH191, where benzene concentrations were reported in marine sediments above the site investigation criteria at depths greater than 16m bgl.

Concentrations of phenols and SVOC were typically reported below the laboratory LOR.

Separated Phase Gasworks Waste and Tar (SPGWT)

For the purposes of this report, SPGWT refers to:

- Tar Containing Materials (TCM), as per the definition described below:
  - Greater than 10% visible coal tar (where coal tar is a phase separated hydrocarbon by-product from coal gasification); and/or
  - Contaminant concentrations exceeding the following limits:
    - PAHs - 2,000 mg/kg; or
    - Benzo(a)Pyrene (B(a)P) - 150 mg/kg.
- Dense Non Aqueous Phase Liquids (DNAPLs).

The above TCM definition was originally proposed by AECOM and adopted by LL/the Authority to define TCM within Barangaroo South, particularly in the context of material that is unsuitable for beneficial reuse (in conjunction with the site-specific risk based criteria).

It is noted that the term SPGWT has not been used in the previous site investigation reports where such materials were variably referred to as tar, coal tar and other similar terms.

SPGWT was identified within the marine sediments at BH60/MW60 only within the Site.

Asbestos

A total of five samples (collected from locations where buried fill and rubble were identified) were analysed for asbestos during the *ORWN DGI* (AECOM, 2010c). No asbestos was detected in the samples analysed. A single result (AECOM BH48_11.5-11.7) (located east of the Site) reported the presence of unidentified mineral fibres. The corresponding bore log notes for this sample recorded 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 *ORWN DGI* (AECOM, 2010c).

ERM (2008a) previously analysed a total of 39 samples across Barangaroo (including 1 location (BH191) within the Site) and detected chrysotile and amosite asbestos in a single location (BH203_1.5) (which was not located within the Site).

As mentioned in **Section 2.6.13**, greater than 1000 samples were analysed and/or visually inspected for the presence of ACM as part of Stage 1A basement excavations works in the adjacent ORWS Area. ACM was identified to be widespread within excavated material within the ORWS Area (AECOM, 2013d) therefore it is assumed that there is signficiant potential for bonded ACM to be present within fill materials within the Site.

Soil Leachability

Twenty five selected soil samples from Barangaroo South were nominated for TCLP analysis during the *ORWN DGI* (AECOM, 2010c) for the purpose of preliminary waste classification in accordance with the NSW DECC (2009) guidelines. Of these samples, six were located within the Site. Based on the total and TCLP results (where analysed), the reported results exceeded the DECC (2009) "General Solid Waste" criteria at one location within the Site (BH191_16.5).

A total of 39 selected soil samples were also subject to Australian Standard Leachability Procedure (ASLP) during the *Declaration Area DGI* (AECOM, 2010b) and *ORWN DGI* (AECOM, 2010c). The results of the ASLP analysis are presented in **Table T23** of **Appendix B**. Samples were selected to be representative of chemical impact based on field observations including odour, colour/staining and PID readings.

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.

Further analyses in consideration of the potential mobility of the above CoPCs included ultra-trace (low level) PAH, phenols, BTEX, inorganics and metals ASLP analysis of selected soil samples as part of the *Supplementary VMP DGI* (AECOM, 2012a). The results of this analysis are provided in **Table T23** of **Appendix B**. The additional analyses were undertaken on soil samples taken from locations selected to be representative of significant contamination identified from previous field observations (based on PID readings, visual observations and odour). That is, 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 under laboratory ASLP conditions.

Notwithstanding these results, the *VMP Remediation Extent* report (AECOM, 2013b) demonstrated that if the remediation works described by the *VMP / Block 4 RAP* (AECOM, 2013b) are completed, the residual gasworks related contamination that will remain *in situ* down hydraulic gradient of the Declaration Area will not represent an unacceptable risk to the environment.

With respect to the potential for non-gasworks related contamination that might leach under ASLP conditions, the following are considered relevant:

- The Site is subject to tidal movements from Darling Harbour. In particular, they are inundated by seawater twice a day, which saturates the upper portions of the fill material at the Site, and over time it is likely to have reduced potential for leaching of soils within the Site.
- The proposed Development Works in Block 4 incorporates a basement contained within a groundwater retention wall which will be keyed into bedrock on the Site boundary. This will reduce groundwater migration and potential contaminant flux from areas up-hydraulic gradient from the Site.
- Soil will be remediated on the Site to meet the proposed SSTC based on the most sensitive land use. In the event that the proposed Southern Cove is created by excavation of existing fill materials, soil in the base of the proposed Southern Cove (from 0 to 0.5 m bgl) will meet the ANZECC Interim Sediment Quality (High) Guidelines (ISQG) (**Section 7.10**).
- The proposed Stage 1C development is likely to incorporate a basement, similar to that proposed as part of the Block 4 Development Works, contained within a groundwater retention wall which will be keyed into bedrock. While the extent of the basement has not yet been confirmed, it will reduce groundwater migration and potential contaminant flux from that area of the Site that in which the basement is constructed.

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, 2005 MRL) at two locations within the NSW EPA Declaration Area, one location within the Site and two locations within the ORWS area.

Oxygen measurements taken from 11 locations within Barangaroo South, from depths of 0.6 to 1.7 m bgl, 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 (which was observed to be of varying quality) to support biodegradation processes.

Soil vapour results have not been presented within this report as these results are not considered necessary to derive the SSTC for the Site.

4.2.3 Groundwater

Groundwater is present beneath the Site within the fill materials and underlying natural material. Groundwater was encountered at the Site at depths ranging from 1.823 to 2.975 m bgl (AECOM, 2010c).

The groundwater level gauging within the Site produced variable results (as expected based on tidal fluctuation), with no distinct flow direction ascertained. The reported variability is related to tidal fluctuations, the nature and distribution of fill materials and the presence of subsurface structures (including the caisson wall associated with the historic southern cove).

Dissolved phase concentrations of PAH (including naphthalene), heavy metals (in particular, arsenic, cobalt, manganese and nickel), benzene and ethylbenzene in groundwater were reported above the adopted site investigation criteria across the Site.

Concentrations of toluene, xylene, VOC (1,2,4-trimethylbenzene and styrene) and SVOC (bis(2-ethylhexyl)phthalate and dibenzofuran), exceeding the adopted site investigation criteria have also been observed at limited locations and largely within the northern portion of the Site.

Phenols were typically reported below the laboratory LOR and/or adopted site investigation criteria, with the exception of one groundwater sample (MW60) which reported a concentration of 2,4-dimethyphenol above the adopted site investigation criteria.

It should be noted that the most significant groundwater contamination was reported from wells screened deeper within the aquifer, specifically across the base of the fill and within the marine sediments immediately overlying bedrock.

Groundwater results are presented in **Table T2** of **Appendix B**.

4.2.4 Considerations for Contaminant Mobility

Soil

The AECOM (2010b) investigation reported SPGWT in a number of locations within the former gasworks area (east of the Site), indicating these locations were source areas for contamination.

The location where SPGWT was observed within the Site is presented in **Figure F12** of **Appendix A**. In particular, black lumps of tar/dark brown tarry substance, strong tar odour and black staining were noted within the marine sediments between depths of 16 to 18.4 m bgl at BH60/BH191.

Black stained veins of tar with a sheen and a strong chemical odour were also noted within the marine sediments at BH40/MW40 (from 16.5 to 19.0 m bgl), however this impact was not considered to be representative of SPGWT as defined in **Section 4.2.1**.

Maximum concentrations of CoPC were generally located within close proximity to and to a lesser extent, down hydraulic gradient (west), of the former gasworks footprint within the NSW EPA Declaration Area. These results support that some lateral migration of gasworks related contamination has occurred.

The above observations support a CSM in which gasworks related impacts are generally located in fill material and marine sediments within the Declaration Area and have migrated to a limited extent onto the Site. The SPGWT observed in BH60/BH191 is considered likely to be the results of a different contamination mechanism to the migration of gasworks contamination from the Declaration Area. In particular, the dumping of gasworks wastes as part of fill materials which, over time, has migrated into the marine sediments.

As described by the *VMP Remediation Extent* report (AECOM, 2013b), previous investigations (AECOM, 2010d) and contaminant flux mass modelling have indicated there is negligible flux of contamination from marine sediments either into the overlying fill or into Darling Harbour (refer also to **Section 4.2.5**).

Soil Leachability

ASLP analysis reported by AECOM (2010a), AECOM (2010b) and AECOM (2010c) further indicated there is potential for mobility of key CoPC from soil sources, at concentrations which exceed the adopted groundwater screening criteria (refer to **Section 7.6**). The analysis 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, 2012a) provided further evidence 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 ASLP results are shown in **Table T23** of **Appendix B**. Sample locations are shown on **Figure F3** of **Appendix A**. The results indicate that:

- cyanide was not detected above the LOR in leachate;
- high molecular weight PAHs and some phenols exhibited very limited if any leachability;
- ammonia exhibited limited leachability;
- 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
- overall, some metals, low molecular weight PAHs and some phenols exhibited potential mobility via leaching to groundwater.

As noted in **Section 4.2.1**, the consideration of the potential for soil to leach within the Site has not been considered within this assessment, as it is considered that contribution from soil leaching will be negligible following proposed remediation at the Site and within up-gradient source areas (i.e. within the Declaration Area and Block 4 Developments Works Area).

Groundwater

Dissolved phase contamination associated with the former gasworks, was reported by AECOM (2010b) as being present across the Declaration Area. Significant concentrations of arsenic, lead, cadmium, 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.

Additional analyses were undertaken by AECOM, in consideration of contaminant mobility in groundwater, as part of the *Supplementary VMP DGI* (AECOM, 2012a). The additional analysis included:

- Standard (Limit of Reporting) PAH and phenol analysis of unfiltered groundwater samples (herein referred to as unfiltered results);
- Ultra-trace (low level) PAH and phenol analysis of twice laboratory filtered (using 0.45µm filter paper) groundwater samples (herein referred to as “Filtered” results). The laboratory LOR for all ultra-trace analysis was less than the adopted Marine Water Quality Criteria (MWQC) outlined in **Section 7.6**;
- 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 F3** of **Appendix A** and are referred to as *AECOM Supplementary VMP DGI Intertidal Well Location*. The results are discussed further in **Section 7.7.2**.

The potential for groundwater discharge to Darling Harbour and the extent to which tidal fluctuations may influence groundwater migration was investigated as part of the *GDS* (AECOM, 2010d) which has been outlined in **Section 2.6.8** and detailed in **Section 7.4.1**. From this study it was noted that whilst contaminants sorbed onto colloids may be transported in the saturated zone, the inundation of seawater twice a day with the incoming tide will reduce the overall seaward movement of contamination. That is, the migration of groundwater from the conate zone, located up hydraulic gradient of the Tidal Prism, is slowed by each flooding tide. In consideration of this, and the lack of leachability of high molecular weight PAHs reported by the *Supplementary VMP DGI* (AECOM, 2012a), only contaminants which are present within the dissolved phase will be considered as CoPC for the purposes of assessing ecological risk. As such, AECOM has not considered high molecular weight PAHs as CoPC, as they are not present within the dissolved phase groundwater at the Site and are more likely to be impeded from migration off-site by the fill soils.

Separated Phase Gasworks Waste and Tar SPGWT)

AECOM notes that Section 3.5.1 of the NSW DEC (2007) Guidelines for the Assessment and Management of Groundwater Contamination requires that "*Where light NAPLs (LNAPLs) or dense NAPLs (DNAPLs) are present in the subsurface they must be removed or treated as much as practicable*".

AECOM (2010b) considered the migration of SPGWT (as described in **Section 4.2.1**), which includes Tar Containing Materials (TCM), and Dense Non Aqueous Phase Liquids (DNAPLs) to occur 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.

Figure F12 of **Appendix A** shows the locations where SPGWT has been identified (in the form of DNAPL, TCM or sheen) across both the Site and the areas of Barangaroo considered to be hydraulically up-gradient of the Site. Within the Site boundaries, SPGWT has previously been identified within the marine sediments at BH60/MW60 only.

4.2.5 Consideration of Contamination at Depth within Natural Marine Sediments

Groundwater Discharge Study

The *GDS* (AECOM 2010d) was prepared to inform the *VMP HHERA* (AECOM, 2012b) with respect to the interaction of groundwater from Barangaroo South (including the Site) with Darling Harbour and the potential for contaminant mass flux due to mixing of seawater prior to discharge.

Relative to that occurring from the fill sequence, groundwater discharge volumes and therefore contaminant mass flux from the marine sediments was considered to be negligible from a hydrogeological perspective. Groundwater discharge occurring via the basal Hawkesbury Sandstone was not considered significant in the context of contaminant flux due to very low values of permeability reported for this formation in the literature.

A complete summary of the *GDS* (AECOM, 2010d) is presented in **Section 7.4.1**.

Contaminant Mass Flux Study

AECOM undertook a Contaminant Mass Flux Study to assess the significance of contaminant mass flux and discharge in the natural soil, marine sediments and groundwater underlying the Site. The study is presented as part of the *VMP Remediation Extent Report* (AECOM, 2013b) and concluded that:

- Lithology and hydraulic conductivity data indicate that groundwater flow in the underlying natural soil and marine sediments is very low and in the order 0.4 metres per year, with contaminant velocities likely to be at least an order of magnitude lower due to attenuation (sorption, biological degradation, etc.);
- The effect of the twice daily tide provides changes in hydraulic head that further reduce the migration of groundwater and hence the contaminants;
- Mass discharge modelling indicates that both the mass and impact from the natural soil and marine sediments underlying the Site to the receiving water are insignificant and could not be measured due to the low expected concentrations; and
- The lines of evidence assessed indicate that there is not a significant flux and discharge of contamination from the natural soil and marine sediments underlying the Site into Darling Harbour.

Supplementary Contaminant Mass Flux Study

AECOM also undertook a supplementary Contaminant Mass Flux study which is similarly presented as part of the *VMP Remediation Extent Report* (AECOM, 2013b). The objective of the supplementary study was to assess: (a) the decrease in contaminant flux that could be expected to result from the proposed VMP remediation extent; and (b) potential impacts to water quality in Darling Harbour from the contamination that will, as an outcome of the proposed VMP remediation extent, remain *in situ* in fill material and marine sediment within the NSW Declaration Area, Block 4 (down hydraulic gradient of the Declaration Area) and the Site.

The study concluded:

- A significant (between 250% and 380%) improvement in contaminant mass flux would be expected to be realised by the proposed VMP remediation extent;
- Less than 1% of the calculated contaminant mass flux to Darling Harbour from residual contamination remaining after the proposed remediation extent would be expected to be associated with contamination within the marine sediment;
- Groundwater quality in fill discharging to Darling Harbour would be expected to improve over time; and
- Groundwater quality estimated from the contaminant mass flux from contamination that will remain *in situ* (both on Site and off Site) following the proposed remediation for the protection of human health entering Darling Harbour was less than the MWQC.

4.2.6 Consideration of Co-occurrence of Chemicals in Soil and Groundwater

There is potential for chemicals to be present in soil and groundwater at the same location at the Site. In particular, co-occurrence of CoPC with similar toxicological mechanisms for humans or the environment in both soil and groundwater may be expected to exhibit additive or other effects. These effects are discussed in the relevant guidance documents adopted for this HHERA. The derivation of SSTCs for soil and groundwater at the Site is considered to be sufficiently conservative such that should a mixture of contaminants be present in both soil and groundwater at any one location, human health is unlikely to be adversely impacted.

5.0 Human Health Risk Assessment

The HHRA comprised derivation of SSTC for soil and groundwater that are protective of future Site users, based on potential development options for different areas of the Site.

SSTC were derived in general accordance with *ASC NEPM* (2013) and enHealth (2012) 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 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 migration modelling where relevant to the CSM.
- Identification of acceptable risk levels for derivation of the SSTC.
- Derivation of soil and groundwater 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.

Based on the proposed development concepts, 14 potential exposure scenarios were considered within this HHERA.

- Scenarios 1 to 8 are based on generic land uses and were generally based on building specific plans supplied by LL in relation to the ORWS basement design (AECOM 2012g);
- Scenario 9 to 14 are based on information that is specific to the proposed Crown Hotel Development provided by Crown (presented in **Appendix JJ**).

A detailed description of these exposure scenarios is provided in **Section 5.3.7**. The exposure scenarios are:

- Scenario 1 – Lower Basement (which includes consideration of a commercial worker undertaking works within loading dock areas potentially within the lower basement areas of the Site and residential receptors utilising car parking)
- Scenario 2 – Upper Basement (which includes consideration of a commercial worker undertaking works within loading dock areas potentially within the lower basement areas of the Site and residential receptors utilising car parking)
- Scenario 3 – Unpaved Recreation
- Scenario 4 – Paved Recreation
- Scenario 5 – Commercial Slab on Grade (to a maximum of 2 storeys)
- Scenario 6 – Intrusive Maintenance Work (with potential to contact groundwater)
- Scenario 7 – High Density Residential (overlying a basement)
- Scenario 8 – Multistorey Commercial Slab on Grade (with advection)
- Scenario 9 – Crown specific Upper Basement (which includes consideration of a commercial worker undertaking works within loading dock areas potentially within the upper basement areas of the Site and residential receptors utilising car parking)
- Scenario 10 – Crown specific Unpaved Recreation
- Scenario 11 – Crown specific Paved Recreation
- Scenario 12 – Intrusive Maintenance Work (without potential to contact groundwater)
- Scenario 13 – Crown specific High Density Residential (overlying a basement)
- Scenario 14 – Crown specific Multistorey Commercial elevated Slab on Grade (with advection): which is applicable to those parts of the proposed Crown podium that will not be constructed over the proposed Crown basement.

It is noted that while the proposed Crown Hotel Development is largely consistent with the generic proposed development design, a number of key elements do differ. Specifically:

- All areas outside the proposed basement will be built up, using imported soil, by at least 1m above the existing ground surface (this difference is reflected in Scenarios 9 to 14);
- The air exchange rate within the buildings will be greater than that typically assumed for a generic commercial building (this difference is reflected in Scenario 14); and
- The configuration of the upper most basement level (level B1) will be different such that: the internal height will be greater; and the finished floor level will be higher (this difference is reflected in Scenarios 9 and 13).

It is noted that Scenario 1 – the lower most basement – is unaffected by these design differences and is therefore applicable to both the generic basement design and the proposed Crown Hotel Development basement design.

No additional exposure scenarios have been identified based on AECOM's current understanding of the potential future land uses (including the proposed Crown Hotel Development).

The potential Southern Cove, if constructed, will be located on the southern boundary of the Site. Further consideration and assessment of potential risks to human health associated with the potential Southern Cove has not been undertaken because:

- If excavation of existing fill material is required to facilitate construction of the proposed Southern Cove, soil at the new surface of the potential Southern Cove (0 to 0.5 m bgl) will be required to meet the ANZECC (2000) ISQG (**Section 7.10**). Whilst contact with sediments is considered to be unlikely, it is considered that these guideline values are suitably protective for human exposures to sediments within the Cove.
- Water quality within the proposed Cove will be of the same as Darling Harbour.
- Groundwater discharging to the potential Southern Cove will be required to meet the lowest of the proposed human health SSTC and the adopted MWQC (as outlined in **Section 7.6**).
- The potential Southern Cove is likely to be limited in its lateral extent such that its construction will not require excavation of existing fill materials. That is, construction of the potential Southern Cove is likely to be limited to removal of the existing suspended concrete slab that was constructed at the western edge of the reclaimed historic Southern Cove. In this event, the depth of water at the edge of the potential Southern Cove would be such that contact with sediments is extremely unlikely.
- Exposures will be limited and are likely to be short and infrequent in duration. It is considered that if the surface water quality is similar to that of the existing Darling Harbour, then there are no increased risks to human health from contact with surface water within the potential Southern Cove.

The algorithms used for vapour modelling and for the estimation of risk and derivation of SSTCs are detailed in **Appendix C**. The model spreadsheets used for SSTC derivation are provided in **Appendix D** to **Appendix K** and **Appendix X** to **Appendix CC**.

In addition to health risks, chemical contaminants associated with gasworks sites are generally odorous and thus it is expected that odours may be emitted during remediation of the Site. Therefore, in order to aid the remediation process, odour-based SSTC ($SSTC_{odour}$) have been derived, which will provide an indication of the chemicals likely to create odours in indoor and outdoor spaces following remediation. The process for estimation of $SSTC_{odour}$ is described further in **Section 6.1**. The model spreadsheets used for $SSTC_{odour}$ derivation are provided in **Appendix M** to **Appendix T** and **Appendix DD** to **Appendix II**.

5.1 Chemicals of Potential Concern

For the purposes of the HHRA, CoPC are considered to be those chemicals which are known or suspected to be present at concentrations which may warrant inclusion in the HHRA. 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 available dataset for the Barangaroo South including that part of Hickson Road that is within the NSW EPA Declaration Area.

The CoPC selection process for the purpose of the HHRA 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 selected based on the following hierarchy:

- *ASC NEPM* (2013): Schedule B1. Soil Health Investigation Levels (HILs), specifically:
  - HIL B (high-density residential);
- *Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE) Technical Report No.10 - Health Screening Levels (HSLs) for Petroleum Hydrocarbons in Soil and Groundwater* (Friebel, E. and Nadebaum, P., 2011): Soil HSLs, specifically:
  - HSL A&B – vapour intrusion (Sand: 0->1m) for residential (adjusted to be applicable to gasworks sites, see below).
  - HSL B – direct contact for high-density residential (adjusted to be applicable to gasworks sites, see below).
- USEPA (May 2013) - *Regional Screening Levels (RSLs) – Residential Soil.*

Where no screening value is presented in the above referenced guidelines the laboratory limit of reporting was adopted as a suitable screening value.

AECOM has reviewed the derivation calculations of the HSLs presented as *Tables F1-F17* in *Appendix F, Part 1* of the *CRC CARE Technical Report No. 10* (Friebel, E. and Nadebaum, P., 2011) to allow for adoption of the HSL (infinite) values for BTEX and naphthalene for use at non-petroleum sites. For screening purposes, these values were rounded in accordance with *ASC NEPM* (2013), Schedule B1. It is noted that the infinite HSLs may be above the theoretical saturation/solubility limits. Direct contact HSLs were not limited based on saturation/solubility limits, therefore the direct contact HSLs for BTEX and naphthalene are considered to be appropriate for non-petroleum sites.

In accordance with the guidance set out in *CRC CARE Technical Report No. 10* (Friebel, E. and Nadebaum, P., 2011), the HSL (infinite) values derived for the 13 Total Petroleum Hydrocarbon Criteria Working Group (TPHCWG) fractions can either be collapsed to the smaller fractions based on appropriate weighting factors for the fuel type, or in the absence of sufficient data to identify appropriate weighting factors, the most conservative of the TPH CWG fractions within *ASC NEPM* (2013) fractions may be adopted. AECOM reviewed a technical paper *Comparative assessment of coal tars obtained from 10 former manufactured gas plant sites in the Eastern United States* (Brown et al, 2006), in order to determine potentially appropriate weightings which may be applied to TPH fractions reported at the Site. This document presented data relating to the speciation of fractions in ten separate coal tar samples and states '*the aromatic fraction accounted for 88-99% of the sum of the aliphatic and aromatic fractions*'. As there is currently limited data relating to the weightings of fractions for non-petroleum sources (such as gasworks waste), and based on the data presented in Brown *et al* (2006), AECOM has adopted the most conservative aromatic HSL (infinite) values derived for the TPH CWG fractions to obtain HSLs relevant for comparison with data from gasworks derived contamination in environmental media.

Available historical soil analytical data are summarised and compared to the adopted screening criteria in **Table T1** of **Appendix B**.

CoPC for Soil were retained or excluded from the risk assessment as follows:

- Chemicals which were not reported above laboratory LORs in any samples were excluded as CoPC.
- Chemicals for which the maximum reported concentration did not exceed the adopted screening criterion 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 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 LOR, but for which no screening criterion was available, were further evaluated on a case by case basis to assess whether the frequency of detection and reported concentrations warranted further consideration.

Asbestos

As described by **Section 4.2.1** it was initially expected that the presence of asbestos at the Site was likely to be limited. However, data from excavation of the Stage 1A basement in the ORWS Area indicates that there is significant potential for bonded asbestos containing material (ACM) to be present within the Site.

The Stage 1A basement encompasses Blocks 1 to 3 and is located south of the Site. As outlined in the *ORWS Addendum HHERA* (AECOM, 2013), significant amounts of bonded ACM fragments were encountered as part of the Stage 1A basement excavation and removed in accordance with an Asbestos Management Plan. Airborne asbestos fibres were not been encountered in air quality monitoring undertaken as part of the Stage 1A excavation works.

While the available data pertaining to asbestos within the ORWN area is limited, based on the findings within the adjacent ORWS Area, it is reasonable to anticipate that bonded ACM may also be present within fill at the Site. It is therefore considered appropriate to include asbestos (specifically bonded ACM) as a CoPC for the Site.

Chemicals included in the CoPC for Soil

Based on the comparison of site data to adopted health-based screening criteria (for residential use of land) (see **Table T1** of **Appendix B**), the following CoPC have been identified in soil:

- Petroleum Hydrocarbon Groups
  - BTEX;
  - TPH (as C_6-C_{10}, >C_{10}-C_{16}, >C_{16}-C_{34} and >C_{34}-C_{40} fractions);
  - PAHs:
    - 1-methylnaphthalene;
    - 2-methylnaphthalene;
    - Acenaphthylene;
    - Fluoranthene;
    - Naphthalene;
    - Pyrene; and
    - Carcinogenic PAHs (CPAH), which include:
      - Benz(a)anthracene;
      - Benzo(a)pyrene;
      - Benzo(b)fluoranthene;
      - Benzo(k)fluoranthene;
      - Benzo(g,h,i)perylene;
      - Chrysene;
      - Dibenz(a,h)anthracene; and
      - Indeno(1,2,3-c,d)pyrene.
- Other Organics
  - 2,4-dimethylphenol;
  - Total Cresols;
  - Dibenzofuran;
  - 1,2,4-trimethylbenzene;
- Metals and/or Inorganic Compounds
  - Lead.
- Asbestos (bonded ACM)

5.1.2 Chemicals excluded from the CoPC in Soil

Carbazole was reported at 21 locations above the laboratory LOR. However, review of these locations 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 carbazole, and given its co-location, further consideration is not warranted.

2-Picoline was only reported in 3 locations across the Site and thus it was not considered to be a significant contaminant. Review 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. Finally, AECOM is not aware of any suitably published peer reviewed toxicity data relevant for use in modelling exposures. Therefore, further consideration of 2-Picoline as a CoPC is not considered warranted.

Iron was present above the adopted screening criteria in five of 90 samples analysed and therefore it was not considered to be a significant contaminant.

Total cyanide was detected above the adopted screening criteria (USEPA, 2013). However, *ASC NEPM* (2013) discusses that the most dominant species of cyanide present in soil and groundwater at former gasworks sites are the relatively nontoxic strong metal-cyanide complexes (primarily the iron-complexed species). Studies referenced by *ASC NEPM* (2013) have demonstrated that free cyanide is generally not detectable in soils or groundwater collected from former gasworks sites; this is also the case at the current Site. The presence of iron in soil and groundwater at the Site indicates that it is highly likely that the majority of the cyanide present at the Site would be bonded to iron forming comparatively, non-toxic complexes. Therefore cyanide is not considered further as a CoPC.

Ammonia was detected in four of 22 samples analysed and therefore was not considered to be a significant contaminant. It is noted that ammonia is considered a CoPC in groundwater.

Sulphate has not been considered further in this assessment as it is not considered to be sufficiently toxic, as discussed in NHMRC (2011), and is not considered to be volatile in accordance with *ASC NEPM* (2013).

The following chemicals were reported at a concentration only marginally above (generally within two to three times) the LOR and were therefore excluded as soil CoPC:

- 3-methylnaphthalene;
- 1-naphthylamine;
- Benzo(e)perylene;
- Perylene;
- p-isopropyltoluene;
- a-BHC;
- Endosulfan sulphate;
- Pirimphos-ethyl;
- 3,3-dichlorobenzidine;
- 4-(dimethylamino)azobenzene;
- 4-aminobiphenyl.

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

- Laboratory LORs were elevated as a result of matrix effects associated with high TPH concentrations. This was 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 LORs.

- Standard laboratory LORs exceeded relevant screening criteria (generally applicable to selected OCP, OPPs and non-standard PAHs (e.g. 7,12-dimethylbenz(a)anthracene, 2-(acetylamino)fluorene). These chemicals have not been considered quantitatively in this assessment because:
  - OCPs and OPPs - are not expected to be significant CoPC at the Site based on site history information (i.e. extensive pesticide use has not been reported);
  - Non-standard PAHs - while there is a potential for PAHs other than the primary 16 to be present at the Site, it is considered likely that they would be present at much lower concentrations than the 16 key PAHs. Where analysed, PAHs other than the 16 key PAHs were not reported above detection limits, even in material heavily impacted by PAHs. Therefore, it is considered that: detection of the 16 key PAHs (which are the most common and well-studied PAHs) at high concentrations would drive potential human health risks; and remediation of the Site for the 16 key PAHs is likely to adequately address potential risks posed by non-standard PAHs should they be present.

5.1.3 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 abstractive 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.

There are limited soil vapour screening values available within Australia guidance documents. The *CRC CARE Technical Report No. 10* (Friebel, E. and Nadebaum, P., 2011) HSLs for soil vapour were considered as potential screening criteria; however they were not adopted due to the depth to groundwater being less than 2 m for some receptors.

Therefore groundwater investigation criteria for potable water use (i.e. the most conservative of available human health based guideline values) have been adopted 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). Therefore, this screening is appropriate for the purposes of identifying potential CoPC at the Site as they are protective of multiple direct contact exposure pathways.

The screening criteria adopted for CoPC selection in groundwater were selected based on following hierarchy:

- National Health and Medical Research Council (NHMRC, 2011), *Australian Drinking Water Guidelines (ADWG)*.
- World Health Organization (WHO, 2011), *Guidelines for Drinking-water Quality 4th Edition.*
- USEPA (May 2013) - *RSLs – Tap Water.*
- Where no screening value is presented in the above referenced guidelines (e.g. TPH fractions) the laboratory LOR has been adopted as a suitable screening value.

Available historical groundwater analytical data are summarised and compared to the adopted screening criteria in **Table T2** of **Appendix B**.

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

- Chemicals which were not reported above laboratory LOR in any samples were excluded as CoPC.
- Chemicals for which the maximum reported concentration did not exceed the adopted investigation criterion 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 which were reported above laboratory LOR, but for which no investigation criterion 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.
- Chemicals which were reported in one or more samples above the adopted investigation criteria were selected as CoPC and further considered in the quantitative risk assessment.

Chemicals included in the CoPC for groundwater

Based on the comparison of site data to adopted health-based screening criteria (see **Table T2** of **Appendix B**), the following CoPC have been identified in groundwater:

- Petroleum Hydrocarbon Groups
  - BTEX;
  - TPH (as C_6-C_{10}, >C_{10}-C_{16}, >C_{16}-C_{34} and >C_{34}-C_{40} fractions);
  - PAHs:
    - 1-methylnaphthalene;
    - 2-methylnaphthalene;
    - Acenaphthene;
    - Acenaphthylene;
    - Anthracene;
    - Fluoranthene;
    - Fluorene;
    - Naphthalene;
    - Phenanthrene;
    - Pyrene; and
    - Carcinogenic PAHs (CPAH), which include:

      Benz(a)anthracene;

      Benzo(a)pyrene;

      Benzo(b)fluoranthene;

      Benzo(k)fluoranthene;

      Benzo(g,h,i)perylene;

      Chrysene;

      Dibenz(a,h)anthracene; and

      Indeno(1,2,3-c,d)pyrene.
- Other Organics
  - 2,4-dimethylphenol;
  - Total Cresols;
  - Phenol;
  - Aniline;
  - Bis(2-ethylhexyl)phthalate;
  - Dibenzofuran;
  - 1,2,4-trimethylbenzene;
  - 1,3,5-trimethylbenzene; and
  - Styrene.

- Metals and/or Inorganic Compounds
    - Arsenic;
    - Barium;
    - Cadmium;
    - Cobalt;
    - Lead;
    - Manganese;
    - Nickel; and
    - Ammonia.

5.1.4 Chemicals excluded from the CoPC in Groundwater

3-methylcholanthrene was only detected in one sample of 82 analysed and thus it was not considered to be a significant contaminant. Further assessment of the location at which 3-methylcholanthrene was reported indicated 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.

1-napthylamine has not been further assessed as AECOM is not aware of any published toxicological data relevant for use in modelling exposures. 1-naphthylamine was only reported in a single location (MW200) across the Site. This location reported significant concentrations of TPH, PAHs and BTEX and it is therefore considered appropriate to assume that remediation of the Site for these TPH, PAHs and BTEX is likely to result in reduction or removal of 1-naphthylamine from the Site.

2,6-dichlorophenol was only detected in one sample of 172 analysed and thus it was not considered to be a significant contaminant. This location (MW08) reported significant concentrations of TPH, PAHs and BTEX and it is therefore considered appropriate to assume that remediation of the Site for these TPH, PAHs and BTEX is likely to result in reduction or removal of 1-naphthylamine from the Site.

2-picoline has not been further assessed 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 four samples 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.

There is limited toxicological data for modelling exposures to carbozole. Review of the 24 locations at which carbazole 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.

The following compounds were reported above the screening criteria and/or were above laboratory LOR 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 exceedance; and
    - the fact that concentrations in the majority of samples were below the adopted screening criterion.
- Benzo(e)pyrene was detected in two samples of 40 analysed at concentrations (0.3 µg/L in both samples) only marginally above the laboratory LOR (0.1 µg/L). Consideration of other PAHs in this assessment is likely to account for this compound.
- Perylene was detected in two samples out of 40 analysed at concentrations (0.1 µg/L and 0.2 µg/L) marginally above or equal to the laboratory LOR (0.1 µg/L). Consideration of other PAHs in this assessment is likely to account for this compound.
- P-isopropyltoluene was detected in one sample out of 81 analysed at a concentration (1 µg/L) equal to the laboratory LOR (1 µg/L).

No drinking water guideline values are available for calcium, magnesium, potassium and sodium 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.

Chromium was reported in one sample above the adopted drinking water guideline (reported at 102 µg/L compared to drinking water guideline value of 50 µg/L), but has not been included as a CoPC based on the fact that concentrations in the majority of samples were below the adopted screening criterion.

Iron was reported above the adopted screening criteria in seven of 29 filtered samples analysed and therefore it was not considered to be a significant contaminant.

Total cyanide was detected above the adopted drinking water guideline, however, *ASC NEPM* (2013) discusses that the most dominant species of cyanide present in soil and groundwater at former gasworks sites are the relatively nontoxic strong metal-cyanide complexes (primarily the iron-complexed species). The studies have demonstrated that free cyanide is generally not detectable in soils or groundwater collected from former gasworks sites; this is also the case at the current Site. The presence of significant concentrations of iron in soil and groundwater at the Site indicates that it is highly likely that the majority of the cyanide present at the Site would be bonded to iron forming comparatively, non-toxic complexes. Therefore cyanide is not considered further as a CoPC.

Sulphate was reported above the adopted screening criteria (NHMRC, 2011), however this guideline value is based on taste rather than health effects. NHMRC states that '*sulphate is one of the least toxic anions*' and therefore sulphate has not been considered further in this assessment.

It should be noted that a number of chemicals were not reported in groundwater at concentrations above the laboratory LOR, but the laboratory LORs achieved in one or more samples exceeded relevant screening criteria. This applied to a number of amino aliphatics, anilines, chlorinated and halogenated hydrocarbons, explosives, pesticides and PCBs (see **Table T2** of **Appendix B**). While this introduces some uncertainty as to the presence (or not) of these compounds at concentrations above the selected health-based screening criteria, these compounds were not included in the HHRA since they are not associated with historical Site activities.

Soil moisture (and groundwater) is most likely to bond asbestos fibres to soil rather than mobilise them and to minimise the risk of fibres being liberated from bonded ACM (even if it is disturbed). Therefore it is considered unlikely that asbestos fibres would be present within groundwater at detectable concentrations. No further consideration of asbestos in groundwater has been made in the current HHERA.

5.1.5 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. Therefore, consideration of which CoPC were sufficiently volatile to migrate into indoor and outdoor air was made and CoPC that were not sufficiently volatile were not included in inhalation exposure pathways.

For vapour pathways, a CoPC was considered to be sufficiently volatile if its Henry's law constant is greater than 1×10^{-5} atm-m^3/mol and the vapour pressure is greater than 1 mm Hg at room temperature (*ASC NEPM* (2013): Schedule B2) with the exception of naphthalene which was considered sufficiently volatile.

Therefore, with the exception of exposure scenarios that consider direct contact pathways between receptors and soil and groundwater, the following CoPC have been selected for assessment of risk associated with vapour intrusion as they are considered to be sufficiently volatile for intrusion into indoor and outdoor air:

- Ammonia;
- Benzene;
- Ethylbenzene;
- Naphthalene;
- Styrene;
- Toluene;
- TPH C_6-C_{10};
- TPH >C_{10}-C_{16};
- 1,2,4-trimethylbenzene;
- 1,3,5-trimethylbenzene; and
- Xylenes.

5.1.6 Summary of Selected CoPC in Soil and Groundwater

Table 8 summarises the CoPC selected in soil and groundwater based on the approach detailed in **Section 5.1.1** to **Section 5.1.5.**

Table 8 Selected CoPC in Soil and Groundwater

CoPC	Soil	Groundwater	Volatile / Not Volatile [a]
Acenaphthene	×	✓	Not Volatile
Acenaphthylene	✓	✓	Not Volatile
Ammonia	×	✓	Volatile
Aniline	×	✓	Not Volatile
Anthracene	×	✓	Not Volatile
Arsenic, inorganic	×	✓	Not Volatile
Barium	×	✓	Not Volatile
Benz(a)anthracene	✓	✓	Not Volatile
Benzene	✓	✓	Volatile
Benzo(a)pyrene	✓	✓	Not Volatile
Benzo(b)fluoranthene	✓	✓	Not Volatile
Benzo(g,h,i)perylene	✓	✓	Not Volatile
Benzo(k)fluoranthene	✓	✓	Not Volatile
Bis(2-ethylhexyl)phthalate	×	✓	Not Volatile
Cadmium	×	✓	Not Volatile
Chrysene	✓	✓	Not Volatile
Cobalt	×	✓	Not Volatile
Total Cresols	✓	✓	Not Volatile
Dibenz(a,h)anthracene	✓	✓	Not Volatile
Dibenzofuran	✓	✓	Not Volatile
Dimephylphenol, 2,4-	✓	✓	Not Volatile
Ethylbenzene	✓	✓	Volatile
Fluoranthene	✓	✓	Not Volatile
Fluorene	×	✓	Not Volatile
Indeno(1,2,3-cd)pyrene	✓	✓	Not Volatile
Lead	✓	✓	Not Volatile
Manganese	×	✓	Not Volatile
Methylnaphthalene, 1-	✓	✓	Not Volatile
Methylnaphthalene, 2-	✓	✓	Not Volatile
Naphthalene	✓	✓	Volatile
Nickel	×	✓	Not Volatile
Phenanthrene	×	✓	Not Volatile
Phenol	×	✓	Not Volatile
Pyrene	✓	✓	Not Volatile

CoPC	Soil	Groundwater	Volatile / Not Volatile [a]
Styrene	×	✓	Volatile
Toluene	✓	✓	Volatile
TPH $C_6 – C_{10}$	✓	✓	Volatile
TPH $>C_{10} – C_{16}$	✓	✓	Volatile
TPH $>C_{16} – C_{34}$	✓	✓	Not Volatile
TPH $>C_{34} – C_{40}$	✓	✓	Not Volatile
Trimethylbenzene, 1,2,4-	✓	✓	Volatile
Trimethylbenzene, 1,3,5-	×	✓	Volatile
Xylenes (total)	✓	✓	Volatile
Total	27	43	

Notes: ✓ Selected as a CoPC
× Not selected as a CoPC
a. Determination if whether a CoPC is volatile or not volatile is described in **Section 5.1.5**.

5.1.7 Lead

The *ASC NEPM* (2013) discusses assessment of lead using a blood lead model. A blood lead model was not adopted as part of this assessment as the soil HILs presented in the NEPM (NEPC, 1999) prior to its amendment in 2013 are consistent with the soil HILs presented in the *ASC NEPM* (2013), which incorporates use of the blood lead model. Therefore, it is considered unlikely that there would be a significant difference between SSTCs for lead calculated with or without the blood lead model.

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 selection of appropriate toxicity criteria from a hierarchy of sources, in accordance with *ASC NEPM* (2013) and enHealth (2012) 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 CoPC (listed in **Section 5.1** above) are provided in **Appendix L**.

Asbestos

Asbestos is a naturally occurring fibrous mineral that was mined for commercial use due to its physical properties such as its high tensile strength and its resistance to fire, heat, electrical and chemical damage (ATSDR, 2001). Asbestos fibres also do not dissolve in water or evaporate, they have no detectable odour or taste and individual fibres are not visible to the naked eye (ATSDR, 2001). The two most common types of asbestos are, amphibole asbestos (which are broken further into three types: crocidolite, tremolite, and amosite) and serpentine (or chrysotile) asbestos (enHealth, 2005). Amphibole asbestos fibres considered more hazardous than serpentine / chrysotile asbestos fibres.

Asbestos containing materials (ACM) were first manufactured in Australia in the 1920's and were commonly used between the 1940's and 1980's. Up to 90% of the asbestos mined or imported into Australia was used for the manufacture of residential and commercial building products (*ASC NEPM,* 2013). The most common types of asbestos that were used commercially in Australia are chrysotile (white), amosite (brown or grey) and crocidolite (blue).

Soil may be contaminated with asbestos by the weathering of natural asbestos deposits, or by land based disposal of waste asbestos materials (ATSDR, 2001). Asbestos is therefore usually encountered in fill materials at sites where no natural source of asbestos is present. There are no known natural sources of asbestos at

Barangaroo. However, significant filling and reclamation activities have occurred at the Site in the past, which has resulted in placement of large quantities of fill (AECOM, 2011c). The composition of fill material has been described in **Section 2.7.2** above.

It has been noted that all forms of asbestos are hazardous and have the potential to cause cancer as a result of inhalation of individual respirable size fibres (ATSDR, 2001). As asbestos fibres are not soluble and do not pose a risk as a result of dermal exposure, inhalation is the predominant route of exposure in relation to potential health risks arising from exposure to asbestos. When asbestos fibres are bonded within other materials the potential for inhalation of fibres is significantly decreased. Therefore, loose asbestos fibres represent a potential risk to human health, whereas risks to human health from bonded ACM, such as asbestos cement sheeting, is considered to be negligible. However, bonded ACM may present a risk to human health through weathering/disturbance where there is the potential for asbestos fibres to be released.

The potential for exposure to respirable asbestos fibres to result in lung cancer and mesothelioma has been extensively studied and it has been concluded that asbestos fibres have the capacity to result in cancer (specifically lung cancer and mesothelioma) (WA, DoH, 2009; ATSDR, 2001). However, the potential for exposure to inhalable asbestos fibres in air to result in cancer has been found to be heavily dependent upon the following factors (ATSDR, 2001; enHealth, 2005):

- The level and the duration of exposure;
- The time since exposure occurred;
- The age at which exposure occurred;
- The tobacco-smoking history of the exposed person; and
- The type and size distribution of the asbestos fibres.

The most important of these factors has been found to be the type and size distribution of the asbestos fibres to which receptors are exposed.

The physical properties of asbestos fibres play an important role in the ability of the fibre to be deposited in the lungs. Each particle must first pass through the nose which will remove the larger airborne fibres, then the trachea and bronchioles which are lined with cilia and mucous membranes which are likely to filter out additional fibres. The body's natural mechanisms will generally act to reduce the potential for fibre deposition within the lungs (enHealth, 2005). If lung deposition does occur there is still potential for these fibres to be cleared from the lungs by macrophages.

Respirable airborne fibres are considered to be those of 5 – 100 µm in length, with a diameter less than 1.5 – 2 µm. Studies of the carcinogenic potential of fibres have shown that the most highly carcinogenic fibres are those of a length greater than 8 µm and diameter less than 0.25 µm (enHealth, 2005). The Dutch Health Council has classified amphibole and chrysotile fibre carcinogenic potency based on length, with amphibole fibres found to have a generally higher carcinogenic potency than chrysotile fibres (Swartjes and Tromp, 2008; enHealth, 2005). The Dutch Health Council classification indicates that fibres of a length greater than 5 µm as having a greater carcinogenic potency than fibres less than 5 µm in length (Swartjes and Tromp, 2008).

When asbestos is bonded within other material the potential for exposure and thus lung cancer is significantly reduced. The type of asbestos and the condition of ACM in the environment is also therefore a very important factor in determining the potential for exposure.

Information pertaining to asbestos in soils within the ORWS Area (refer to **Section 4.2.1**) indicated that ACM was in poor to weathered condition but that it was not friable (this is defined as ACM being in a condition such that it can be broken or crumbled by hand pressure). It is therefore assumed that the most common form of asbestos likely to be present at the Site is bonded ACM which is unlikely to be friable, and that asbestos fibres are unlikely to be present in detectable concentrations.

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. Exceedance of the threshold level does not imply that adverse effects will occur, as there are a number of uncertainties and safety factors incorporated into the threshold value adopted, rather that exposure needs to be further evaluated.

The toxicity values adopted for the CoPC in this risk assessment are discussed in toxicological profiles provided in **Appendix L** and summarised in **Table T3** of **Appendix B**. Values have been obtained (where available) from the following information sources (listed in order of preference, as per *ASC NEPM* (2013) and enHealth, 2012 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 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 $(\mu g/m^3)^{-1}$) is used to estimate the probability of an individual developing cancer at some point in a lifetime as a result of a specific exposure.

As described in **Appendix L**, of the CoPC identified at the Site the following are considered to be genotoxic carcinogens, generally have published IURs and/or CSFs, and therefore, have been assessed based on non-threshold toxicity criteria where available:

- Aniline;
- Benzene;
- 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.

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 accordance with *ASC NEPM* (2013) CPAHs have been assessed using toxicity equivalent factors.

Adopted non-threshold toxicity criteria and the source of the adopted values are summarised in **Table T3** of **Appendix B**.

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 daily intake 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 soil, groundwater or both media, AECOM has adopted the following approach to allocate proportional risks to chemicals present on Site:

1) Benzene, toluene, ethylbenzene and xylene were assigned a hazard index of 0.25 each.
2) TPH fractions C_6-C_{10}, >C_{10}-C_{16}, >C_{16}-C_{34}, >C_{34}-C_{40}) were assigned a hazard index of 0.25 each.
3) All non carcinogenic PAHs were assigned a hazard index of 0.2.
4) 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 T3** of **Appendix B**.

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 HHRA in Australia (*ASC NEPM*, 2013) given that dermal dose-response factors are generally not published by regulatory agencies endorsed by the *ASC NEPM* (2013) 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 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 $(mg/kg/day)^{-1}$, which is 50 times higher than the adopted oral slope factor (from NHMRC, 2011) 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 HHRA, 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 et al. (2006) dermal slope factor value for the assessment of exposure to soils. It is considered that the slope factor should not be applied to the groundwater SSTC derivation as discussed in **Section 9.1.4**.

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 AECOM's knowledge for dibenzofuran.

Screening for dibenzofuran in soil and groundwater identified eight soil (BH42_3.2-3.3, BH48_14.5-14.7, BH53_4.0-4.4, BH55_2.2-2.4, BH59_3.4-3.5, BH70_16.0-16.2, BH403_10-10.4 and BH403_15-15.4) and 14 groundwater (IT1 (3 samples), MW6, MW15, MW40, MW54, MW60, MW61, MW69, MW200, MW205, MW204S, MW206) locations where dibenzofuran was reported above adopted screening criteria across Barangaroo. Dibenzofuran is not considered to be volatile in accordance with the definition of volatility presented in *ASC NEPM* (2013) based on a Henry's law constant greater than $1x10^{-5}$ atm-m^3/mol and vapour pressure greater than 1 mm Hg.

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 PAHs.
- 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 (identified in **Section 5.2.4**) (0.06 mg/kg/day and 0.21 mg/m^3, respectively) has therefore been adopted for dibenzofuran (see toxicity profile for PAHs in **Appendix L**).

A RfD for dibenzofuran has been published in the USEPA (2013) RSLs (the USEPA adopted the provisional peer reviewed toxicity value [PPRTV] of 1×10^{-3} mg/kg/day) and from this a RfC has been determined via route to route extrapolation (RTR) (as published in the USEPA (2013)). 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 mg/m^3 is lower than that used in this 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, significant concentrations of TPH, PAH and BTEX were also reported. 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 Areas

5.3.1 Description of Assumed Generic Development

Based on the building specific plans supplied by LL in relation to the ORWS basement design with the exception of the Crown Site specific information, it is understood that the potential generic land use across the Site would include mixed land use comprising residential (with minimal access to soil), commercial / retail (with minimal access to soil), public open space and potential open water (associated with a proposed Southern Cove) connected to Darling Harbour.

Key components of the generic land uses are expected to include:

- A basement car park with perimeter soil and groundwater retention systems generally constructed around a future basement and extending to bedrock;
- Mixed use hotel (including high density residential), commercial and hotel multistorey buildings (greater than two storeys) constructed over the basement;
- Mixed use commercial and retail buildings (greater than two storeys) built on grade;
- Public open space, landscaping, roads, pedestrian ways and cycle paths, built on grade.
- Mixed use commercial and community buildings built on grade (maximum height two storeys).
- Creation of a waterway (the potential Southern Cove) connecting with and extending eastward from Darling Harbour, in the southern portion of the Site. Incidental access to the open water from the Site may be accommodated by the final development (for example through the provision of step seats leading to the

edge of the water). However, the potential for recreational access to sediment by the general public is considered very unlikely given the depth of water that will be present within the potential Southern Cove

- Potential areas of open water in water features constructed over basement car parks (if constructed).
- Reuse of material from the Site or other areas of Barangaroo South to build up the elevation of the ORWN public domain (refer to **Figure F14**).

It should be noted that the location and extent of each of the potential generic land uses within the Site has not yet been finalised. Notwithstanding, the proposed land uses will likely remain consistent with those described by this HHERA.

5.3.2 Description of Proposed Crown Hotel Development

Based on the current development concept for the Site, it is understood that Crown intends to construct a Hotel Development within part of the Site (the Crown Site). The proposed land use associated with the Crown Hotel Development will include mixed land use comprising hotel (including high density residential with minimal access to soil), commercial / retail (with minimal access to soil) and public open space.

Key components of the proposed Crown Hotel Development are expected to include:

- An underground basement intended to provide car parking and loading facilities associated with the Crown Hotel Development;
- A tower containing hotel rooms, suites and residential apartments. The entire footprint of the tower will be above a basement;
- A multistorey podium containing hotel reception, retail and gaming facilities. The podium will be largely above a basement but with some limited areas constructed as elevated slab on grade;
- Terrace areas containing restaurant and bar facilities largely constructed as elevated slab on grade;
- Public open space, landscaping, roads, pedestrian ways and cycle paths, largely built on grade (more than 1m above existing surface level); and
- Raising of the finished surface level in areas of the Crown Site that are outside the proposed basement by the import of Suitable Fill by a minimum of 1m above the current ground level.

While the proposed Crown Hotel Development is largely consistent with the generic proposed development design (refer to **Section 5.2.7**), a number of key elements do differ. Specifically:

- All areas outside the proposed basement will be built up, using imported soil, by at least 1m above the existing ground surface;
- The air exchange rate within the buildings will be at least 5 air changes per hour (**Appendix JJ**), which is greater than that typically assumed for a generic commercial building (2 air changes per hour); and
- The configuration of the upper most basement level (level B1) will be different such that: the internal height will be greater (5 m verses the generic assumption of 4.5m); and the finished floor level will be higher (-2 m AHD verses the generic assumption of –2.5 m AHD) (see **Appendix JJ**).

The Crown Hotel Development plans are subject to final detailed design and development, however will remain generally consistent with that described by this HHERA.

5.3.3 Assumed Generic Basement Design

As noted in **Section 5.3.1**, it is expected that a portion of the Site will be excavated and a basement car park constructed. As described by **Section 5.3.2**, it is likely that the basement constructed will be part of the proposed Crown Hotel Development. The design of the proposed Crown Hotel Development basement is described by **Section 5.3.4**.

Notwithstanding, in the absence of a final basement design for the Site, the general design adopted for the NSW EPA Declaration Area has been used, as per the diagrams presented in *Appendix A* of the *Declaration Site HHERA* (AECOM, 2011a) and the revised design and basement use discussed in the *Assessment of the Implications of the Revised Basement Design letter* (AECOM, 2012f).

Based on these design plans, a basement groundwater retention wall system will be installed that has been designed to prevent groundwater from migrating from within the basement footprint. In addition, the following assumed performance specification for the basement construction has been adopted (for Scenarios 1, 2 and 7):

- Outer basement walls are anticipated to comprise of 600mm thick reinforced concrete diaphragm walls

  It should be noted that the risk assessment has conservatively assumed basement walls and floor construction to be approximately 150 mm thick.
- The concrete walls are of sufficient strength/density to prevent tar seepage into the concrete.
- A physical barrier will be provided within the basement to prevent contact of people within the basement with groundwater seepage that may occur through the basement wall.
- There may be two ventilation plenums constructed per basement floor, one fed by an intake and one which is vented by exhaust, both above ground level (in accordance with Australian Standard AS 1668.2). Alternative ventilation designs may also be adopted.
- The lowermost basement floor will be in contact with groundwater but the basement will have water collection devices and engineering controls, such as damp proof barriers to minimise the potential of groundwater wetting the lower basement floor or walls.
- The smallest occupiable basement dimension that will be independently ventilated and accessible to general building users is an area of 2500 m^2 based on a dimension of (50 m x 50 m).
- Where basement walls are exposed to groundwater, it is assumed that groundwater will seep through an area equivalent to half of 2 (out of the total 4) basement walls. In the lower basement, it is assumed that in addition to the walls, groundwater will also seep through half of the basement floor footprint.
- The basement will be mechanically vented in accordance with *Australian Standard AS 1668.2* (Standards Australia, 2002).
- In accordance with *Australian Standard AS1668.2* (Standards Australia, 2002), the basement levels will be maintained at a lower pressure than the overlying occupied areas.
- The air exchange rate within the basement car park has been assumed to be an average of 3.5 air exchanges per hour. This air exchange rate is based on the proposed approach to the basement car park ventilation for the Crown basement (AECOM, 2014) (refer to **Appendix JJ**). It is understood that it is consistent with the Australian Standard AS 1668.2 and accounts for periods of decreased ventilation when vehicle movement in the basement is minimal (AECOM, 2012h).
- The hydraulic conductivity of the basement walls has been calculated based on the LL performance specification for the ORWS Basement which requires that groundwater ingress not exceed 0.75 L/min across the entire basement wall area. The hydraulic conductivity of the concrete is required to determine the potential volume of water which can physically move through the basement walls into the basement for use in the USEPA Water Model (refer to **Section 5.3.5**). The hydraulic conductivity was calculated, based on Darcy's Law which considers flow through porous media, to be 2.04×10^{-5} m/day. The calculation of hydraulic conductivity has been based on the design of the ORWS basement and is based on the approach presented in the letter titled *HHERA - Other Remediation Works (South) Area, Barangaroo. Assessment of the Implications of the Finalised Basement Design* (AECOM, 2012h). It is noted that the hydraulic conductivity of the basement walls to be constructed as part of the Crown Hotel Development (refer to **Section 5.3.4**).

A diagram showing the assumed ventilation and physical barrier is provided in *Figure 4*, *Appendix A* of the *Declaration Site HHERA* (AECOM, 2011a).

5.3.4 Proposed Crown Basement Details

As noted in **Section 5.3.2**, the proposed Crown Hotel Development includes excavation of a portion of the Crown Site for construction of a basement carpark and loading dock.

Based on design plans provided by Crown (refer to **Appendix JJ**) the basement to be constructed as part of the proposed Crown Hotel Development is assumed to:

- Extend over a footprint equal to or greater than the footprint of the proposed hotel tower.
- Extend to a depth below the groundwater table (that is will be constructed within both the saturated and unsaturated soil).

- Be constructed with a basement groundwater retention wall system that will extend around the perimeter of that part of the Site occupied by the basement and will be designed to prevent groundwater from migrating from within the basement footprint.

Based on the Crown design plans, the following assumed performance specification for the basement to be constructed as part of the Proposed Crown Basement has been adopted (for Scenarios 9 and 13):

- Outer basement walls are anticipated to comprise 800 mm to 1200 mm thick reinforced concrete diaphragm walls.

  It should be noted that the risk assessment has conservatively assumed basement walls and floor construction to be approximately 150 mm thick.

- The concrete walls are of sufficient strength/density to prevent tar seepage into the concrete.
- A physical barrier will be constructed inside the basement to prevent dermal contact with any groundwater seepage water within the basement in the unlikely event that groundwater seepage occurs.
- A drainage system will be provided that prevents the accumulation of groundwater seepage and vapour from groundwater seepage that may occur through the basement wall by draining water away from the wall and any cavities will be passively ventilated.
- The lowermost basement floor will be in contact with groundwater, but the basement will have water collection devices and engineering controls, such as damp proof barriers to minimise the potential of groundwater wetting the lower basement floor or walls.
- The smallest occupiable basement dimension that will be independently ventilated and accessible to general building users is an area of 2,500 m^2 based on a dimension of (50 m x 50 m).
- Where basement walls are exposed to groundwater, it is assumed that groundwater will seep through an area equivalent to half of 2 (out of the total 4) basement walls. In the lower basement, it is assumed that in addition to the walls, groundwater will also through half of the basement floor footprint.
- The basement will be mechanically vented in accordance with *Australian Standard AS 1668.2* (Standards Australia, 2002).
- In accordance with *Australian Standard AS1668.2* (Standards Australia, 2002), the basement levels will be maintained at a lower pressure than the overlying occupied areas.
- The air exchange rate within the basement car park has been assumed to be an average of 3.5 air exchanges per hour. This air exchange rate is based on the proposed approach to the basement car park ventilation for the Crown basement (AECOM, 2014) (refer to **Appendix JJ**). It is understood that it is consistent with the Australian Standard AS 1668.2 and accounts for periods of decreased ventilation when vehicle movement in the basement is minimal (AECOM, 2012h).
- The hydraulic conductivity of the basement walls has been calculated based on the Crown performance specification for the Crown Basement which requires that groundwater ingress not exceed 0.75 L/min across the entire basement wall area. The hydraulic conductivity of the concrete is required to determine the potential volume of water which can physically move through the basement walls into the basement for use in the USEPA Water Model (refer to **Section 5.3.5**). The hydraulic conductivity was calculated, based on Darcy's Law which considers flow through porous media, to be 2.04 x 10^{-5} m/day.

5.3.5 Vapour Transport Modelling

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

USEPA Water Model Approach

For exposure scenarios where water seepage is present on walls (relevant for lower and upper basements only in scenario's 1, 2, 7, 9 and 13 – refer to **Section 5.3.6**, 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. 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.
- For Scenario 1, 2 and 7: The model 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:
  - For Scenario 1, 2 and 7: dividing the product of the air exchanges per day (84) and the volume of the smallest occupiable basement space that will be independently ventilated and accessible to general building users (50 m x 50 m x 4.5 m) by the cross sectional dimension of the basement (50 m x 4.5 m) and converting the units from m/day to m/second; and
  - For Scenario 9 and 13: dividing the product of the air exchanges per day (84) and the volume of the smallest occupiable basement space that will be independently ventilated and accessible to general building users (50 m x 50 m x 5 m) by the cross sectional dimension of the basement (50 m x 5 m) and converting the units from m/day to m/second.

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

Johnson and Ettinger approach

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, 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 C** and the vapour modelling calculations for relevant land use scenarios are included in **Appendix D** to **Appendix K** and **Appendix X** to **Appendix CC**.

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 (however biodegradation has been included in the vapour model);
- 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 *ASC NEPM* (2013) Schedule B2, only chemicals with a Henry's Law constant of 1 x 10^{-5} atm-m^3/mol and a vapour pressure of greater than 1 mm Hg at room temperature are considered sufficiently volatile to warrant consideration with respect to vapour intrusion (refer also to **Section 5.1.5**). The only exception to this is naphthalene, which is considered sufficiently volatile.

5.3.6 Soil Vapour Partitioning

Soil vapour partition modelling is known to be overly conservative and theoretical concentrations can be between 10 and 1000 times actual measured values (CCME, 2008; Friebel et al., 2011; 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 field measured results such as contaminant soil adsorption, organic carbon, adsorption at the air/ water interface, soil heterogeneity and biodegradation processes.

The UK Environment Agency (UK EA) (2009) has an adopted value of 10 for volatile soil investigation levels to account for this potential discrepancy. The CCME (2008) has also adopted a value of 10 in the calculation of soil investigation levels in petroleum hydrocarbons to account for overestimation in the soil partitioning modelling. The CRC CARE health screening levels for petroleum hydrocarbons (Friebel and Nadebaum, 2011) has 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_{10} and >C_{10}-C_{16}) and BTEX.

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

Based on the LL and Crown development plans and associated assumptions described in **Section 5.3.1**, land use scenarios for which SSTC have been derived are summarised below in **Table 9** and further described in **Sections 5.3.8** to **Section 5.3.21**.

Table 9 Summary of Land Use Scenarios Considered in the ORWN HHERA

Scenario Number	Name and Description	Most Sensitive Human Receptor	General Assumptions
1	Lower Basement Generic lower-most basement car park level (below water table), with groundwater seepage through walls and floor (i.e. groundwater may be present at inner surface of outer wall and on floor surface).	Adult Worker. Exposed up to 8 hr/day, 240 days/year, for 30 years. Child Resident. Exposure is considered to occur up to 1 hour per day (while en route to and from car), 365 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. Small layer of groundwater is assumed to be permanently present on some sections of the walls and floor. Specifically up to 50% of the total of 2,950m^2 area of two walls and the floor (equalling 1,475m^2) is assumed to be wet and to act as continuous vapour source. This is considered to be a conservative assumption. Advective flow of vapours is assumed to be negligible (airflow through saturated zone cannot occur due to zero air filled porosity). The air exchange rate within the basement car park has been assumed to be an average of 3.5 air exchanges per hour. This air exchange rate is based on the proposed approach to the basement car park ventilation for the Crown basement (AECOM, 2014) (refer to **Appendix JJ**). It is understood that it is consistent with the Australian Standard AS 1668.2 and accounts for periods of decreased ventilation when vehicle movement in the basement is minimal (AECOM, 2012h).
2	Upper Basement Generic 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. 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. Lower 2.5 m of 2 of the 4 walls may have water seepage. It has been conservatively assumed that 125m^2 of the two walls will be covered in water seepage (50% of the total wall area). Advective vapour flow considered possible through unsaturated soils (upper 2 m). The air exchange rate within the basement car park has been assumed to be an average of 3.5 air exchanges per hour. This air exchange rate is based on the proposed approach to the basement car park ventilation for the Crown basement (AECOM, 2014) (refer to **Appendix JJ**). It is understood that it is consistent with the Australian Standard AS 1668.2 and accounts for periods of decreased ventilation when vehicle movement in the basement is minimal (AECOM, 2012h).
3	Unpaved Recreation Generic public domain area with no concrete/hardstand paving, but 50 cm of clean fill at surface.	Adult and Child Recreational Users. Assumed to be exposed 2 hr/day, 365 days/year, for 70 years.	Open Space with no Concrete Surface Covering. Assumed that areas are landscaped with at least 50 cm of Suitable Fill overlying contaminated soil. 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**). Groundwater (GW) depth assumed to be 2 m bgl.
4	Paved Recreation Generic public Domain area with concrete/hardstand paving. It has been assumed that paved recreation areas will also be covered in a 0.5m thick layer of Suitable Fill to accommodate changes in paved and unpaved recreation areas that might occur in the future.	Adult and Child Recreational Users. Assumed to be exposed 2 hr/day, 365 days/year, for 70 years.	Open Space with Concrete surface covering. Assume that there is significant oxygen movement through the top 2 m of the soil based on the oxygen measurements collected during the soil gas sampling (see **Section 2.9**). Concrete assumed to be minimum 15 cm thick and to have a crack fraction of 0.001 (to account for higher cracking possible in surface covering).
5	Commercial Slab on Ground (limited to 2 storeys) Generic typical commercial slab on ground scenario for public domain area where basement car park is not present.	Adult worker. Exposed up to 8 hr/day, 240 days/year, for 30 years. Scenario also protective of child who may visit premises on a less frequent basis.	Assumes typical slab on grade commercial premises at ground level. Assumes a maximum building height of 2 storeys. To account for potential coffee shop, convenience store, restaurant, etc., that could be constructed within the Public Domain.
6	Intrusive Maintenance – potential contact with groundwater Generic short term intrusive maintenance scenario, e.g. for maintenance of utility services.	Adult worker. 8 hrs/day, 15 days/year for 1 year. Direct contact with groundwater contact may occur due to shallow water – no more than 1 hour per day. Vapour may be derived from pooled groundwater or from exposed soils in trench.	Post development, short term maintenance work may be required. Assumed not to exceed 3 working weeks per year by same worker.
7	High Density Residential Generic high density residential overlying a basement carpark. It is possible that the hotel development may include high density residential.	Adult or Child Resident. Assumed to be exposed 24 hrs/day, 365 days/year, for 70 years. Scenario is also considered to be protective of hotel residents and workers in the hotel.	The air exchange rate within the basement car park has been assumed to be an average of 3.5 air exchanges per hour. This air exchange rate is based on the proposed approach to the basement car park ventilation for the Crown basement (AECOM, 2014) (refer to **Appendix JJ**). It is understood that it is consistent with the Australian Standard AS 1668.2 and accounts for periods of decreased ventilation when vehicle movement in the basement is minimal (AECOM, 2012h). 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 5.3.14**). The assumptions adopted for Scenario 2 are applicable for this scenario. 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.
8	Multistorey Commercial Slab on Ground (with Advection) Generic multi-storey commercial / hotel development with slab on grade construction.	Adult commercial worker. Exposed up to 8 hr/day, 240 days/year, for 30 years. Scenario also protective of child who may visit premises on a less frequent basis.	Assumes typical multi-storey commercial premises with slab on grade construction. Assumes 2 Air exchanges per hour. This air exchange rate is based on the upper range of the Australian Standard. Advection driven vapour exposure is considered to be the dominant exposure pathway.

Scenario Number	Name and Description	Most Sensitive Human Receptor	General Assumptions
9	Crown specific Upper Basement Upper-most Crown basement car park level, partially above water table. May be used for loading/unloading, or have full time car park attendant present.	Adult Worker. Exposed up to 8 hr/day, 240 days/year, for 30 years.	Upper 3m of walls may have soil directly adjacent to 2 of the 4 walls as a source of vapour. Lower 2 m of 2 of the 4 walls may have water seepage. It has been conservatively assumed that 100m^2 of the two walls will be covered in water seepage (50% of the total wall area). Advective vapour flow considered possible through unsaturated soils (upper 3 m). The air exchange rate within the basement car park has been assumed to be an average of 3.5 air exchanges per hour. This air exchange rate is based on the proposed approach to the basement car park ventilation for the Crown basement (AECOM, 2014) (refer to **Appendix JJ**). It is understood that it is consistent with the Australian Standard AS 1668.2 and accounts for periods of decreased ventilation when vehicle movement in the basement is minimal (AECOM, 2012h).
10	Crown specific Unpaved Recreation Public open area with no concrete/hardstand paving, but 100 cm of clean fill at surface.	Adult and Child Recreational Users. Assumed to be exposed 2 hr/day, 365 days/year, for 70 years.	Open Space with no Concrete Surface Covering. Assume that areas are landscaped with at least 1.0 m of Suitable Fill overlying contaminated soil. Assume that there is significant oxygen movement through the top 1 m of soil based on the oxygen measurements collected during the soil gas sampling (see **Section 2.9**). Groundwater (GW) depth assumed to be 3 m bgl (where the ground level refers to the finished ground level that will be 1m above the existing ground level).
11	Crown specific Paved Recreation Public open area with concrete/hardstand paving. It has been assumed that paved recreation areas will also be covered in a 1.0 m thick layer of clean fill to accommodate changes in paved and unpaved recreation areas that might occur in the future.	Adult and Child Recreational Users. Assumed to be exposed 2 hr/day, 365 days/year, for 70 years.	Open Space with Concrete surface covering. Assume that areas have at least 1.0 m of Suitable Fill immediately below the concrete surface covering and overlying contaminated soil. Assume that there is significant oxygen movement through the top 1 m of the soil based on the oxygen measurements collected during the soil gas sampling (see **Section 2.9**). Concrete assumed to be minimum 10 cm thick and to have a crack fraction of 0.001 (to account for higher cracking possible in surface covering). Groundwater (GW) depth assumed to be 3 m bgl (where the ground level refers to the finished ground level that will be 1m above the existing ground level).
12	Intrusive Maintenance – no potential contact with groundwater Short term intrusive maintenance scenario, e.g. for maintenance of utility services.	Adult worker. 8 hrs/day, 15 days/year for 1 year.	Post development, short term maintenance work may be required. Assumed not to exceed 3 working weeks per year by same worker. Assume that at least 1.0 m of Suitable Fill overlying contaminated soil. Assume the depth of trench is limited to 2m bgl and therefore will not intersect groundwater based on the finished ground level being 1m above the existing ground level.
13	Crown specific High Density Residential High density residential overlying a basement carpark. It is possible that the hotel development may include high density residential.	Adult or Child Resident. Assumed to be exposed 24 hrs/day, 365 days/year, for 70 years. Scenario is also considered to be protective of hotel residents and workers in the hotel.	The air exchange rate within the basement car park has been assumed to be an average of 3.5 air exchanges per hour. This air exchange rate is based on the proposed approach to the basement car park ventilation for the Crown basement (AECOM, 2014) (refer to **Appendix JJ**). It is understood that it is consistent with the Australian Standard AS 1668.2 and accounts for periods of decreased ventilation when vehicle movement in the basement is minimal (AECOM, 2012h). 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 5.3.14**). The assumptions adopted for Scenario 9 are applicable for this scenario. 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.
14	Crown specific Commercial Multistorey Slab on Ground (with Advection) Multi-storey commercial / hotel development with slab on grade construction.	Adult commercial worker. Exposed up to 8 hr/day, 240 days/year, for 30 years. Scenario also protective of child who may visit premises on a less frequent basis.	Assumes typical multi-storey commercial premises with elevated slab on grade construction. Assumes 5 Air exchanges per hour. This air exchange rate is based on the proposed approach to the ventilation for the Crown Hotel Development podium (AECOM, 2014) (refer to **Appendix JJ**) Advection driven vapour exposure is considered to be the dominant exposure pathway. Assume that at least 1.0 m of Suitable Fill overlying contaminated soil.

Direct human contact with surface water within the potential Southern Cove is considered to not present a potential risk to human health as the surface water is considered to be of the same quality as that currently within Darling/ Sydney Harbour. Based on the proposed design, it is unlikely that there will be public access to sediments as the steps will not extend to the base of the proposed Cove. Therefore this potential exposure pathway has not been considered further within the risk assessment.

5.3.8 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 F5**.

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 out of 4 walls and floor to have water seepage present.
- A physical barrier will be provided to prevent dermal contact between receptors and groundwater that may seep through the basement walls and floor.
- Each basement level has been modelled as separately ventilated airspace. This is more conservative than modelling the mixing of vapours through multiple basement levels, especially for lowermost level.
- It has been assumed that the lowermost basement level may be occupied by full-time workers loading/unloading goods. It is also considered possible that full time car parking attendants may be present.

5.3.8.1 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 10 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	AECOM has conservatively modelled the potential impact of wet walls and floor. It is assumed that the groundwater may continuously wet sections of the two walls and floor within the lower basement to a total surface area of 1,475 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 the basement will be below the saturated zone, contaminants dissolved in groundwater will also reflect soil impacts. 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.

5.3.8.2 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.

It has been assumed that the lower level basement car park may be occupied by a commercial worker (over a working lifetime of 30 years) within loading dock areas. The assessment also considered residents (children) occupying the car park area in transit to and from the car park for an hour each day, 365 days per year.

The most sensitive receptors (i.e. with potential for highest level of exposure to contaminants) are considered to be adult commercial workers undertaking daily operational roles within a loading dock area.

5.3.8.3 Exposure Pathways

In order for a human receptor to be exposed to Site derived contamination 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 for Scenario 1 are summarised in **Table 11** below.

Table 11 Exposure Pathway Analysis - Scenario 1 (Lower Basement)

Exposure Pathway	Complete?	Notes
Adult Commercial Worker 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 the 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)	×	Groundwater seepage is considered to be unlikely to accumulate on walls of floor based on the building design. However, to be conservative, sections of basement wall and floor have been considered for water seepage. Wall seeps will be behind a physical barrier (and not accessible to dermal contact) and receptors are assumed not to have significant direct contact with moist floor. Also note that, even though this scenario has assumed that the basement floor may be partially wetted, it is considered likely that sumps would be installed within the basement to prevent accumulation of groundwater on basement floor if necessary and this would preclude significant water contact in the 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.

Notes: ✓ The exposure pathway is considered to be complete and is assessed further in the HHRA.
× The exposure pathway is not considered to be complete and is not assessed further.

5.3.8.4 Exposure Parameters

Human exposure parameters adopted for Scenario 1 are summarised in **Table 12** and were obtained, where available, from recognised Australian and international sources (primarily *ASC NEPM,* 2013; enHealth, 2012; 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 12**.

Table 12 Exposure Parameters - Scenario 1 (Lower Basement)

Parameter (units)	Adopted Value	Source/Reference
Exposure Time Indoors (hours/day)	8 (adult worker) 1 (child resident)	Adult worker – *ASC NEPM* (2013) Schedule B7, Table 5. Child resident – 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)	240 (adult worker) 365 (child resident)	*ASC NEPM* (2013) Schedule B7, Table 5.
Exposure Duration (years)	30 (adult worker) 6 (child resident)	*ASC NEPM* (2013) Schedule B7, Table 5.

The estimation of volatile CoPC concentrations within the lower basement has been undertaken using USEPA (1994) Water 9 equations as outlined in **Section 5.3.5** above. Further details of the vapour transport modelling are also provided in **Appendix D**.

The geological, hydrogeological and building parameters adopted for the volatilisation seepage model for Scenario 1 are summarised in **Table 13** below. Chemical-specific properties used in the calculations are included in **Appendix D**.

Table 13 Water with Flow Modelling Assumptions - Scenario 1 (Lower Basement)

Parameter (units)	Adopted Value	Source/Justification
Volume of Basement (m^3)	11,250	Assumes basement area of 50 m by 50 m and internal height of 4.5 m.
Volume of Wet Basement (m^3)	14.8	Assumes the wet basement area comprises 50% of two walls with dimensions of 50 m x 4.5 m, plus the area of the floor (50 m x 50 m). The depth of water is expected to be and 0.01m.
Length of the Wet Section of Basement (m)	50	Assumed maximum length of wet area (equivalent to 50% of the floor length).
Width of Wet Section of Basement (m)	29.5	Assumed maximum width of wet area.
Enclosed space air exchange rate per day within basement	84	The air exchange rate within the basement car park has been assumed to be an average of 3.5 air exchanges per hour. This air exchange rate is based on the proposed approach to the basement car park ventilation for the Crown basement (AECOM, 2014) (refer to **Appendix JJ**). It is understood that it is consistent with the Australian Standard AS 1668.2 and accounts for periods of decreased ventilation when vehicle movement in the basement is minimal (AECOM, 2012h).
Fetch to Depth Ratio (wet section)	2,950	Fetch to Depth Ratio is assumed to be 59m (width of wet area) divided by 0.01m (depth of water).

Parameter (units)	Adopted Value	Source/Justification
Volume of water entering the basement (m^3/sec)	3.83 x 10^{-6}	Based on the Crown performance specification for the ORWS Basement which requires that groundwater ingress not exceed 0.75 L/min across the entire basement wall area. This maximum ingress rate has been converted to m^3/sec.
Windspeed within Basement (m/sec)	0.03	Conservative assumption based on the dimensions of the basement and the assumed air exchange rate (see **Section 5.3.5**).

5.3.9 Scenario 2: Upper Basement

The CSM for an Upper Basement Level is depicted in **Figure F5**.

The following points are relevant to this scenario:

- The upper most basement level is assumed to extend from the surface to 4.5 m bgl, such that (assuming an average depth to groundwater of 2 m bgl):
  - ground water seepage is assumed to occur through the lower 2.5 m of the wall;
  - a physical barrier will be provided to prevent dermal contact between receptors and groundwater that may seep through the basement walls; 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.
- Each basement level is modelled as separately ventilated airspace. This is more conservative than modelling the mixing of vapours through multiple basement levels, especially for the lowermost level.
- It has been assumed that the uppermost basement level may be occupied by full-time workers loading/unloading 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 2 m) for soils present in the unsaturated zone.

5.3.9.1 Contaminant Migration Pathways

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

Table 14 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	AECOM has conservatively modelled the potential impact of wet walls below the water table. It is assumed that groundwater may seep through the lower 2.5 m of the basement of two walls, behind a physical barrier preventing dermal contact. The basement dimensions for the upper basement are 50 m x 50 m x 4.5 m. It is assumed that half of the area where water can seep (i.e. 50% of the lower 2.5 m of two walls) will be covered in water i.e. 125 m^2.

Contaminant Migration Pathways	Relevant to Scenario?	Comments
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 m bgl (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.

5.3.9.2 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.

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.

5.3.9.3 Exposure Pathways

Potential pathways via which the above receptors may be exposed to Site-derived contamination for Scenario 2 are summarised in **Table 15** below.

Table 15 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. Wall seeps will be behind a physical barrier which will restrict 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.

Notes: ✓ The exposure pathway is considered to be complete and is assessed further in the HHRA.
× The exposure pathway is not considered to be complete and is not assessed further.

5.3.9.4 Exposure Parameters

Human exposure parameters adopted for Scenario 2 are summarised in **Table 16** below.

Table 16 Exposure Parameters - Scenario 2 (Upper Basement)

Parameter (units)	Adopted Value	Source/Reference
Exposure Time Indoors (hours/day)	8	*ASC NEPM* (2013) Schedule B7, Table 5
Exposure Frequency (days/year)	240	*ASC NEPM* (2013) Schedule B7, Table 5
Exposure Duration (years)	30	*ASC NEPM* (2013) Schedule B7, Table 5.

5.3.9.5 Vapour Transport Modelling

Johnson and Ettinger Approach

Vapour modelling associated with soil was undertaken using the Johnson and Ettinger (1991) vapour transport model (refer to **Section 5.3.5**). It is noted that both diffusive and advective transport processes were considered in the unsaturated zone adjacent to basement wall.

Further detail on the vapour transport modelling and calculations are provided in **Appendix E**.

The geological, hydrogeological and building parameters adopted for vapour intrusion modelling based on the Johnson and Ettinger Approach for Scenario 2 are summarised in **Table 17** below.

Table 17 Vapour Modelling Assumptions - Scenario 2 (Upper Basement)

Parameter (units)	Adopted Value	Source/Justification
Vadose Zone and Hydrogeological 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	USEPA (2004a) defaults for coarse sand/gravel
Air filled porosity in soil source zone (unitless)	0.321	USEPA (2004a) defaults for coarse sand/gravel
Water filled porosity in soil source zone (unitless)	0.054	USEPA (2004a) defaults for coarse sand/gravel
Total porosity in soil source zone (for soil model) (unitless)	0.375	USEPA (2004a) defaults for coarse sand/gravel
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_{10}, >C_{10}-C_{16}, to reflect the differences observed between theoretical estimates of partitioning and field measurements (see CCME, 2010 and Friebel and Nadebaum, 2011).
Building Parameters ⁺ Soil to Indoor Air		
Ratio of enclosed space volume to infiltration area (cm)	5,625	Assumes basement volume of 11,250 m^3 (50 m x 50 m x 4.5 m). The infiltration area for soil was assumed to comprise the upper 2 m of two of the four walls (200 m^2). Enclosed volume to infiltration ratio is calculated as 11,250 m^3 / 200 m^2. It has been assumed that no independently ventilated publically accessible 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 the basement walls are likely to be in the order of 600 mm to 1,000 mm in thickness, but a lesser thickness has been conservatively assumed.
Enclosed space air exchange rate per second	9.72x 10^{-4}	The air exchange rate within the basement car park has been assumed to be an average of 3.5 air exchanges per hour. This air exchange rate is based on the proposed approach to the basement car park ventilation for the Crown basement (AECOM, 2014) (refer to **Appendix JJ**). It is understood that it is consistent with the Australian Standard AS 1668.2 and accounts for periods of decreased ventilation when vehicle movement in the basement is minimal (AECOM, 2012h).
Areal fraction of cracks in foundations/walls	0.0002	USEPA (2004a) default value for basements.

Parameter (units)	Adopted Value	Source/Justification
Air filled porosity in foundation/wall cracks	0.321	Assumes foundation/wall cracks filled with sand (values are USEPA, 2004a defaults for coarse sand).
Water filled porosity in foundation/wall cracks	0.054	
Advective vapour flow rate	Calculated	Calculated based on foundation dimensions, pressure differential and vapour permeability.
Soil vapour permeability (cm^2)	1×10^{-7}	USEPA, 2004a default for sand/gravel.
Indoor-outdoor pressure differential ($g/cm\text{-}s^2$)	40	USEPA, 2004a conservative default.

USEPA Water Model Approach

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 Model Approach (as described in **Section 5.3.5**).

The geological, hydrogeological and building parameters adopted for vapour intrusion modelling based on the USEPA Water Model Approach for Scenario 2 are summarised in **Table 18** below.

Chemical-specific properties used in the calculations are included in **Appendix E**.

Table 18 Water with Flow Modelling Assumptions - Scenario 2 (Upper Basement)

Parameter (units)	Adopted Value	Source/Justification
Volume of Basement (m^3)	11,250	Assumes basement area of 50 m by 50 m and internal height of 4.5 m.
Volume of Wet Basement (m^3)	1.25	Assumes the wet basement area comprises two walls with dimensions of 50 m x 2.5 m. The depth of water is expected to be and 0.01m.
Enclosed space air exchange rate per day within basement	84	The air exchange rate within the basement car park has been assumed to be an average of 3.5 air exchanges per hour. This air exchange rate is based on the proposed approach to the basement car park ventilation for the Crown basement (AECOM, 2014) (refer to **Appendix JJ**). It is understood that it is consistent with the Australian Standard AS 1668.2 and accounts for periods of decreased ventilation when vehicle movement in the basement is minimal (AECOM, 2012h).
Length of the Wet Section of Basement m)	25	Assumed maximum length of wet area (equivalent to half of the wall).
Width of Wet Section of Basement (m)	5	Assumed maximum width of wet area.
Fetch to Depth Ratio (wet section) (m)	500	Fetch to Depth Ratio is assumed to be 5 m (width of wet area) divided by 0.01m (depth of water).
Volume of water entering the basement (m^3/sec)	3.25×10^{-7}	Based on the Crown performance specification for the Proposed Hotel Development Basement which requires that groundwater ingress not exceed 0.75 L/min across the entire basement wall area. This maximum ingress rate has been converted to m^3/sec.
Windspeed within Basement	0.03 m/sec	Conservative assumption based on dimensions of the basement and the assumed air exchange rate (see **Section 5.3.5**).

5.3.10 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:

- VENM;
- Soil which contains contaminant concentrations below the Terrestrial Soil Criteria (TSC) (refer to **Section 8.0**); and
- Soil which contains contaminant concentrations below the relevant SSTC (as described by this HHERA).

5.3.10.1 Contaminant Migration Pathways

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

Table 19 Contaminant Migration Pathways - Scenario 3 (Unpaved Recreation)

<table>
<tr><th>Contaminant Migration Pathways</th><th>Relevant to Scenario?</th><th>Comments</th></tr>
<tr><td>Volatilisation from soil and vapour migration to outdoor air</td><td>Yes</td><td rowspan="2">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).</td></tr>
<tr><td>Volatilisation from groundwater and vapour migration to outdoor air</td><td>Yes</td></tr>
<tr><td>Migration of outdoor air/vapours to indoor airspaces</td><td>Potentially</td><td>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.</td></tr>
</table>

5.3.10.2 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.

5.3.10.3 Exposure Pathways

Potential pathways via which the above receptors may be exposed to Site-derived contamination for Scenario 3 are summarised in **Table 20** below.

Table 20 Exposure Pathway Analysis - Scenario 3 (Unpaved Recreation)

Exposure Pathway	Complete?	Notes
Adult and Child Recreational Users		
Incidental ingestion of chemicals in soil	×	Unpaved recreation areas assumed to be covered/landscaped with minimum 50 cm Suitable Fill as defined in **Section 5.3.10** 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 not less than 2 m bgl 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.

Notes: ✓ The exposure pathway is considered to be complete and is assessed further in the HHRA.
× The exposure pathway is not considered to be complete and is not assessed further.

5.3.10.4 Exposure Parameters

Human exposure parameters adopted for Scenario 3 are summarised in **Table 21** below.

Table 21 Exposure Parameters - Scenario 3 (Unpaved Recreation)

Parameter (units)	Adopted Value	Source/Reference
Exposure Time (hours/day)	2	*ASC NEPM* (2013) Schedule B7, Table 5.
Exposure Frequency (days/year)	365	*ASC NEPM* (2013) Schedule B7, Table 5.
Exposure Duration (years)	6 (child visitor) 29 (adult visitor)	*ASC NEPM* (2013) Schedule B7, Table 5.

5.3.10.5 Vapour Transport Modelling

Soil and groundwater vapour modelling was undertaken using the Johnson and Ettinger (1991) vapour transport model as summarised in **Section 5.3.5** and described in more detail in *Appendix A* of the *Declaration Site HHERA* (AECOM, 2011a). The vapour modelling calculations for Scenario 3 are included in **Appendix F**.

The CRC CARE health screening levels for petroleum hydrocarbons (Friebel and Nadebaum, 2011) 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 (2010) has also reported that not accounting for biodegradation could result in the risks being overestimated 10 to 1000 times.

PAHs 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) 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 m bgl) 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 geological, hydrogeological and construction parameters adopted for vapour intrusion modelling for Scenario 3 are summarised in **Table 22** below.

Table 22 Vapour Modelling Assumptions - Scenario 3 (Unpaved Recreation)

Parameter (units)	Adopted Value	Source/Justification
Vadose Zone and Hydrogeological 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 5.3.10** 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	
Air filled porosity in soil source zone (unitless)	0.321	
Water filled porosity in soil source zone (unitless)	0.054	
Total porosity in soil source zone (for soil model) (unitless)	0.375	
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_{10}, >C_{10}-C_{16}, to reflect the differences observed between theoretical estimates of partitioning and field measurements (see CCME, 2010 and Friebel and Nadebaum, 2011).
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 (2010).
Vadose Zone and Hydrogeological Parameters + Groundwater to Outdoor Air		
Depth to groundwater contamination (cm)	200	Based on reported average depth to groundwater of 2 m. Capillary zone thickness is USEPA (2004a) default value for sand aquifer. 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	

Parameter (units)	Adopted Value	Source/Justification
Air filled porosity in vadose zone (unitless)	0.321	USEPA (2004a) defaults for sand (residual impacted soil and imported fill conservatively assumed to be sandy).
Water filled porosity in vadose zone (unitless)	0.054	
Total porosity in vadose zone (unitless)	0.375	
Air filled porosity in capillary zone (unitless)	0.122	USEPA (2004a) default for sand (considered conservative for mixed soil/fill types reported at site).
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)	4,500	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.

5.3.11 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 10 cm. The SSTCs for soil have been developed based on the assumption that the soil will be present directly below this cover.

It is however noted that, future areas where paving is present may subsequently become unpaved, so it is recommended that at least 0.5 m of Suitable Fill be placed below areas of the Site that will be paved. Suitable Fill is defined in **Section 5.3.10**.

It is noted that there is little change in the developed SSTCs for paved recreation whether the material is placed immediately beneath paving (i.e. at 10 cm depth) or the material is placed below an additional 50 cm buffer of Suitable Fill. 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.

5.3.11.1 Contaminant Migration Pathways

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

Table 23 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.

5.3.11.2 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.

5.3.11.3 Exposure Pathways

Potential pathways via which the above receptors may be exposed to Site-derived contamination in Scenario 4 are summarised in **Table 24** below.

Table 24 Exposure Pathway Analysis - Scenario 4 (Paved Recreation)

Exposure Pathway	Complete?	Notes
Adult and Child Recreational Users		
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 not less than 2 m bgl 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.

Notes: ✓ The exposure pathway is considered to be complete and is assessed further in the HHRA.
× The exposure pathway is not considered to be complete and is not assessed further.

5.3.11.4 Exposure Parameters

Human exposure parameters adopted for Scenario 4 are summarised in **Table 25** below.

Table 25 Exposure Parameters - Scenario 4 (Paved Recreation)

Parameter (units)	Adopted Value	Source/Reference
Exposure Time (hours/day)	2	*ASC NEPM* (2013) Schedule B7, Table 5.
Exposure Frequency (days/year)	365	*ASC NEPM* (2013) Schedule B7, Table 5.
Exposure Duration (years)	6 (child) 29 (adult)	*ASC NEPM* (2013) Schedule B7, Table 5.

5.3.11.5 Vapour Transport Modelling

Soil and groundwater vapour transport modelling was undertaken using the Johnson and Ettinger (1991) vapour transport models summarised in **Section 5.3.5** and described in more detail in *Appendix A* of the *Declaration Site HHERA* (AECOM, 2011a). The vapour modelling calculations for Scenario 4 are included in **Appendix G**.

The geological, hydrogeological and construction parameters adopted for vapour intrusion modelling for Scenario 4 are summarised in **Table 26** below. The vapour transport modelling for paved recreation has also considered the potential for biodegradation as discussed in **Section 5.3.10.5** above.

Table 26 Vapour Modelling Assumptions - Scenario 4 (Paved Recreation)

Parameter (units)	Adopted Value	Source/Justification
Vadose Zone and Hydrogeological 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 0.5 m of suitable material (**Section 5.3.11**) be placed above the remediated / validated soils beneath the proposed paved areas of the Site to account for changes to open space 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 50 cm 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	
Air filled porosity in soil source zone (unitless)	0.321	
Water filled porosity in soil source zone (unitless)	0.054	
Total porosity in soil source zone (for soil model) (unitless)	0.375	
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_{10}, TPH >C_{10}-C_{16}, to reflect the differences observed between theoretical estimates of partitioning and field measurements (see CCME, 2010 and Friebel and Nadebaum, 2011).
Biodegradation adjustment factor (unitless)	10	Adjustment for assumed presence of oxygen (and associated biodegradation of vapours) in unpaved areas. A factor of 10 is considered conservative as it is at lower end of ranges suggested by Davis et al. (2009) and CCME (2010).
Vadose Zone and Hydrogeological 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.
Vadose zone thickness (cm)	173	
Thickness of capillary zone (cm)	17	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.

Parameter (units)	Adopted Value	Source/Justification
Air filled porosity in vadose zone (unitless)	0.321	USEPA (2004a) defaults for sand (residual impacted soil and imported fill conservatively assumed to be sandy)
Water filled porosity in vadose zone (unitless)	0.054	
Total porosity in vadose zone (unitless)	0.375	
Air filled porosity in capillary zone (unitless)	0.122	USEPA (2004a) default for sand (considered conservative for mixed soil/fill types reported at site).
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.
Air filled porosity in concrete cracks	0.00321	Assumes cracks in concrete surface cover are filled with sand (values are USEPA, 2004a defaults for coarse sand).
Water filled porosity in concrete cracks	0.00054	
Total porosity in concrete cracks	0.00375	
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)	4,500	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.

5.3.12 Scenario 5: Commercial Slab on Ground (maximum 2 storeys)

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 storeys (only) in the Public Domain of the final development. It is assumed that these buildings will be 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.

5.3.12.1 Contaminant Migration Pathways

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

Table 27 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	

5.3.12.2 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.

5.3.12.3 Exposure Pathways

Potential pathways via which the above receptors may be exposed to Site-derived contamination in Scenario 5 are summarised in **Table 28** below.

Table 28 Exposure Pathway Analysis - Scenario 5 (Commercial Slab on Ground)

Exposure Pathway	Complete?	Notes
Adult Commercial Worker		
Incidental ingestion of chemicals in soil	×	Recreation areas around retail premises assumed to be covered with concrete hardstand or a 0.5 m thickness of Suitable Fill (refer to **Section 5.3.10**), 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 not less than 2 m bgl 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.

Notes: ✓ The exposure pathway is considered to be complete and is assessed further in the HHRA.
× The exposure pathway is not considered to be complete and is not assessed further.

5.3.12.4 Exposure Parameters

Human exposure parameters adopted for Scenario 5 are summarised in **Table 29** below.

Table 29 Exposure Parameters - Scenario 5 (Commercial Slab on Ground)

Parameter (units)	Adopted Value	Source/Reference
Exposure Time Indoors (hours/day)	8	*ASC NEPM* (2013) Schedule B7, Table 5.
Exposure Frequency (days/year)	240	*ASC NEPM* (2013) Schedule B7, Table 5.
Exposure Duration (years)	30	*ASC NEPM* (2013) Schedule B7, Table 5.

5.3.12.5 Vapour Transport Modelling

Soil and groundwater vapour transport modelling was undertaken using the Johnson and Ettinger vapour transport models summarised in **Section 5.3.5** and described in more detail in *Appendix A* of the *Declaration Site HHERA* (AECOM, 2011a). The vapour modelling calculations for Scenario 5 are included in **Appendix H**.

The geological, hydrogeological and building parameters adopted for vapour intrusion modelling for Scenario 5 are summarised in **Table 30** below.

Table 30 Vapour Modelling Assumptions - Scenario 5 (Commercial Slab on Ground)

Parameter (units)	Adopted Value	Source/Justification
Vadose Zone and Hydrogeological 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	
Air filled porosity in soil source zone (unitless)	0.321	
Water filled porosity in soil source zone (unitless)	0.054	
Total porosity in soil source zone (for soil model) (unitless)	0.375	
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_{10}, >C_{10}-C_{16} to reflect the differences observed between theoretical estimates of partitioning and field measurements (see CCME, 2010 and Friebel and Nadebaum, 2011).
Vadose Zone and Hydrogeological Parameters + Groundwater to Indoor Air		
Depth to groundwater contamination (cm)	200	Based on reported average depth to groundwater of 2 m. Capillary zone thickness is USEPA (2004a) default value for sand aquifer. 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 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	
Air filled porosity in vadose zone (unitless)	0.321	USEPA (2004a) defaults for sand (residual impacted soil and imported fill conservatively assumed to be sandy)
Water filled porosity in vadose zone (unitless)	0.054	
Total porosity in vadose zone (unitless)	0.375	
Air filled porosity in capillary zone (unitless)	0.122	USEPA (2004a) default for sand (considered conservative for mixed soil/fill types reported at site).
Water filled porosity in capillary zone (unitless)	0.253	

Parameter (units)	Adopted Value	Source/Justification
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.
Air filled porosity in foundation/wall cracks	0.321	Assumes foundation/wall cracks filled with sand (values are USEPA, 2004a defaults for coarse sand).
Water filled porosity in foundation/wall cracks	0.054	
Convective vapour flow rate	0.001	Assumes vapour advection from sub-slab 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 car parks) and have a maximum of two storeys above ground level.
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)	4,500	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.

5.3.13 Scenario 6: Intrusive Maintenance – Potential Contact with Groundwater

The intrusive maintenance scenario has been considered to account for potential future intrusive maintenance activities which may be undertaken following redevelopment of the Site where the depth of groundwater below the finished site level will be such that it is possible intrusive maintenance work will result in contact of receptors with groundwater.

It should be noted that modelling of exposure and potential 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 (for example, 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 will be managed in accordance with a site specific occupational health and safety plan to be developed.

5.3.13.1 Contaminant Migration Pathways

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

Table 31 Contaminant Migration Pathways – Scenario 6 (Intrusive Maintenance) – Potential Contact with Groundwater

Contaminant Migration Pathways	Relevant to Scenario?	Comments
Volatilisation from soil and vapour migration to within trenches/excavations	Yes	It is possible that soil derived vapours may accumulate within trench airspaces overlying contaminated soil.
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 m bgl), the more conservative scenario where groundwater is assumed to enter the trench has been modelled for this scenario.

5.3.13.2 Human Receptors

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

5.3.13.3 Exposure Pathways

Potential pathways via which the above receptors may be exposed to Site-derived contamination in Scenario 6 are summarised in **Table 32** below.

Table 32 Exposure Pathway Analysis - Scenario 6 (Intrusive Maintenance) – Potential Contact with Groundwater

Exposure Pathway	Complete?	Notes
Adult Intrusive Maintenance 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.

Notes: ✓ The exposure pathway is considered to be complete and is assessed further in the HHRA.
× The exposure pathway is not considered to be complete and is not assessed further.

5.3.13.4 Exposure Parameters

Human exposure parameters adopted for Scenario 6 are summarised in **Table 33** below.

Table 33 Exposure Parameters - Scenario 6 (Intrusive Maintenance) – Potential Contact with Groundwater

Parameter (units)	Adopted Value	Source/Reference
Body weight (kg)	70	*ASC NEPM* (2013) Schedule B7, Table 5 (Commercial Worker).
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	Friebel, E. and Nadebaum, P. (2011), Part 1, Table 6
Exposed Skin Surface Area for Soil Contact (cm^2/day)	6,800	Friebel, E. and Nadebaum, P. (2011), Part 1, Table 6
Soil to Skin Adherence Factor (mg/cm^2)	0.9	Friebel, E. and Nadebaum, P. (2011), Part 1, Table 6
Exposed Skin Surface Area for Groundwater Contact	6,800	Friebel, E. and Nadebaum, P. (2011), Part 1, Table 6
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.

5.3.13.5 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 *ASC NEPM* (2013), Friebel, E. and Nadebaum, P. (2011) and RAIS (University of Tennessee, 2010). Where DAFs were not published within these sources, 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 T3**.

5.3.13.6 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 I**.

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)

δ_{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 34** below.

Table 34 Vapour Modelling Assumptions - Scenario 6 (Intrusive Maintenance) – Potential Contact with Groundwater

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	
Air filled porosity in soil source zone (unitless)	0.321	
Water filled porosity in soil source zone (unitless)	0.054	
Total porosity in soil source zone (for soil model) (unitless)	0.375	
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_{10}, >C_{10}-C_{16} to reflect the differences observed between theoretical estimates of partitioning and field measurements (see CCME, 2010 and Friebel and Nadebaum, 2011).
Groundwater Parameters + Groundwater to Trench Air		
Groundwater seepage velocity into trench (cm/sec)	1.5 x 10^{-2}	Conservative estimate of maximum expected velocity for a sandy or gravelly aquifer (13 m/day) (AECOM, 2010d).
Depth of groundwater in trench (cm)	50	For surface excavation, assumes trench may extend to 2 m bgl and that average groundwater level over the excavation period is 1.5 m bgl. This is considered conservative given that average depth to groundwater over tidal cycle is reported be approximately 2 m bgl.
Dimension of trench perpendicular to groundwater flow (cm)	200	The width of the source parallel to the wind is the dimension of the length of the source in the direction of wind flow. 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 cm x 300 cm). This is defined separately from the dimension of the trench perpendicular to groundwater flow which has been set at 200 cm.
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 200 cm long and up to 200 cm deep.
Ambient air mixing zone height	200	Conservative default – assumes all emitted vapours are mixed within 2 m deep trench.

5.3.13.7 Particulate Emission Factors

The respirable dust (PM_{10}) concentrations in trench air were estimated assuming a particulate emission factor (PEF) of 3.6 x 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.

5.3.14 Scenario 7: High Density Residential

The CSM for the High Density Residential Scenario (which also includes the potential residential dwellings within a multistorey building constructed above a basement) is similar to that for Scenario 2 (Upper Basement Level depicted in **Figure F5**), 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 4.5 m bgl, such that (assuming an average depth to groundwater of 2 m bgl) groundwater seepage will occur in the lower 2.5 m of the wall over 50% of two 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 F5**.
- 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 one tenth 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 by 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 one with exhaust fans.
    - The study without an exhaust fan and 0 m/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 12th 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 al (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 has 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 and as discussed above, stack effects are not expected to be significant in this instance).

5.3.14.1 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 35 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. Therefore to be conservative water has been modelled which seeps through the lower 2.5 m of the basement of two walls behind a physical barrier. The basement dimensions for the upper basement are 50 m x 4.5 m x50 m. It is considered that half of the area in which groundwater can filtrate (lower 2.5m of wall) will be covered in water i.e. 125m^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 m bgl (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.

5.3.14.2 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.

5.3.14.3 Exposure Pathways

Potential pathways via which the above receptors may be exposed to Site-derived contamination are summarised in **Table 36** below.

Table 36 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	×	

Exposure Pathway	Complete?	Notes
Adult and Child Residents		
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 on the residential floors. Exposure to groundwater ingress into the basement area is considered in Scenario 1 (Lower Basement) and Scenario 2 (Upper Basement).
Dermal absorption of chemicals in groundwater (incidental contact)	×	
Inhalation of groundwater derived vapours	✓	Potentially complete and significant pathway.

Notes: ✓ The exposure pathway is considered to be complete and is assessed further in the HHRA.
× The exposure pathway is not considered to be complete and is not assessed further.

5.3.14.4 Exposure Parameters

Human exposure parameters adopted for Scenario 7 are summarised in **Table 37** below.

Table 37 Exposure Parameters - Scenario 7 (High Density Residential)

Parameter (units)	Adopted Value	Source/Reference
Exposure Time (hours/day)	24	Conservative estimation.
Exposure Frequency (days/year)	365	*ASC NEPM* (2013) Schedule B7, Table 5.
Exposure Duration (years)	6 (child) 29 (adult)	*ASC NEPM* (2013) Schedule B7, Table 5.

5.3.14.5 Vapour Transport Modelling

Johnson and Ettinger Approach

Vapour modelling associated with soil was undertaken using the Johnson and Ettinger (1991) vapour transport model (refer to **Section 5.3.5**). It is noted that both diffusive and advective transport processes were considered in the unsaturated zone adjacent to basement wall.

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

The geological, hydrogeological and building parameters adopted for vapour intrusion modelling based on the Johnson and Ettinger Approach for Scenario 7 are summarised in **Table 38** below.

Table 38 Vapour Modelling Assumptions - Scenario 7 (High Density Residential)

Parameter (units)	Adopted Value	Source/Justification
Vadose Zone and Hydrogeological 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	
Air filled porosity in soil source zone (unitless)	0.321	
Water filled porosity in soil source zone (unitless)	0.054	

Parameter (units)	Adopted Value	Source/Justification
Vadose Zone and Hydrogeological Parameters – Soil to Indoor Air		
Total porosity in soil source zone (for soil model) (unitless)	0.375	
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_{10}, >C_{10}-C_{16} to reflect the differences observed between theoretical estimates of partitioning and field measurements (see CCME, 2010 and Friebel and Nadebaum, 2011).
Building Parameters		
Ratio of enclosed space volume to infiltration area (cm)	5,625	Assumes basement volume of 11,250 m^3 (50 m x 50 m x 4.5 m). The infiltration area for soil was assumed to comprise the upper 2 m of two of the four walls (200 m^2). Enclosed volume to infiltration ratio is calculated as 11,250 m^3 / 200 m^2. It has been assumed that no independently ventilated publically accessible 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 the basement walls are likely to be in the order of 600 mm to 1,000 mm in thickness, but a lesser thickness has been conservatively assumed.
Enclosed space air exchange rate per second	9.72×10^{-4}	The air exchange rate within the basement car park has been assumed to be an average of 3.5 air exchanges per hour. This air exchange rate is based on the proposed approach to the basement car park ventilation for the Crown basement (AECOM, 2014) (refer to **Appendix JJ**). It is understood that it is consistent with the Australian Standard AS 1668.2 and accounts for periods of decreased ventilation when vehicle movement in the basement is minimal (AECOM, 2012h).
Areal fraction of cracks in foundations/walls	0.0002	USEPA (2004a) default value for basements.
Air filled porosity in foundation/wall cracks	0.321	Assumes foundation/wall cracks filled with sand (values are USEPA, 2004a defaults for coarse sand).
Water filled porosity in foundation/wall cracks	0.054	
Indoor Attenuation Factor (Unitless)	0.1	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 5.3.14** above.
Advective vapour flow rate	Calculated	Calculated based on foundation dimensions, pressure differential and vapour permeability.
Soil vapour permeability (cm^2)	1×10^{-7}	USEPA, 2004a default for sand/gravel.
Indoor-outdoor pressure differential ($g/cm\text{-}s^2$)	40	USEPA, 2004a conservative default.

USEPA Water Model Approach

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 Model Approach (as described in **Section 5.3.5**).

The geological, hydrogeological and building parameters adopted for the USEPA Water Model Approach for Scenario 7 are summarised in **Table 39** below.

Chemical-specific properties used in the calculations are included in **Appendix J**.

Table 39 Seepage Modelling Assumptions - Scenario 7 (High Density Residential)

Parameter (units)	Adopted Value	Source/Justification
Volume of Basement (m^3)	11,250	Assumes basement area of 50 m by 50 m and internal height of 4.5 m.
Volume of Wet Basement (m^3)	1.25	Assumes the wet basement area comprises two walls with dimensions of 50 m x 2.5 m. The depth of water is expected to be and 0.01m.
Enclosed space air exchange rate per day within basement	84	The air exchange rate within the basement car park has been assumed to be an average of 3.5 air exchanges per hour. This air exchange rate is based on the proposed approach to the basement car park ventilation for the Crown basement (AECOM, 2014) (refer to **Appendix JJ**). It is understood that it is consistent with the Australian Standard AS 1668.2 and accounts for periods of decreased ventilation when vehicle movement in the basement is minimal (AECOM, 2012h).
Length of Wet Section of Basement (m)	25	Assumed maximum length of wet area (equivalent to half of the wall).
Width of Wet Section of Basement (m)	5	Assumed maximum width of wet area.
Fetch to Depth Ratio (wet section) (m)	500	Fetch to depth ratio is assumed to be 5m (width of water) divided by 0.01m (depth of water).
Volume of water entering the basement (m/day)	3.25×10^{-7}	Based on the Crown performance specification for the Proposed Hotel Development Basement which requires that groundwater ingress not exceed 0.75 L/min across the entire basement wall area. This maximum ingress rate has been converted to m^3/sec.
Windspeed within Basement (m/sec)	0.03	Conservative assumption based on dimensions of the basement and the air exchange rate (see **Section 5.3.5**).

5.3.15 Scenario 8: Multistorey Commercial Slab on Ground (with advection)

This scenario assumes a multi-story commercial slab on ground construction where vapour intrusion via advective flows may be a consideration when accounting for exposures to commercial workers.

It is assumed that the development is multiple stories (significantly more than two) high with an internal elevator system installed. It has been assumed that advection may be the dominant pathway for vapour intrusion for soil and groundwater.

5.3.15.1 Contaminant Migration Pathways

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

Table 40 Contaminant Migration Pathways - Scenario 8 (Multistorey Commercial Slab on Ground, with advection)

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. It is noted that the consideration of advection has been undertaken for soils within the unsaturated zone. AECOM has also considered the potential for advection from groundwater impacts.
Volatilisation from groundwater and vapour migration to indoor air	Yes	

5.3.15.2 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 commercial premises but for shorter periods of time.

5.3.15.3 Exposure Pathways

Potential pathways via which the above receptors may be exposed to Site-derived contamination are summarised in **Table 41** below.

Table 41 Exposure Pathway Analysis – Scenario 8 (Multistorey Commercial Slab on Ground, with advection)

Exposure Pathway	Complete?	Notes
Adult Commercial Worker		
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 not less than 2 m bgl 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.

Notes: ✓ The exposure pathway is considered to be complete and is assessed further in the HHRA.
× The exposure pathway is not considered to be complete and is not assessed further.

5.3.15.4 Exposure Parameters

Human exposure parameters adopted for Scenario 8 are summarised in **Table 42** below.

Table 42 Exposure Parameters - Scenario 8 (Multistorey Commercial Slab on Ground, with advection)

Parameter (units)	Adopted Value	Source/Reference
Exposure Time Indoors (hours/day)	8	*ASC NEPM* (2013) Schedule B7, Table 5.
Exposure Frequency (days/year)	240	*ASC NEPM* (2013) Schedule B7, Table 5.
Exposure Duration (years)	30	*ASC NEPM* (2013) Schedule B7, Table 5.

5.3.15.5 Vapour Transport Modelling

Soil and groundwater vapour transport modelling was undertaken using the Johnson and Ettinger vapour transport models (summarised in **Section 5.3.5**) and further details of the equations and assumptions are presented in **Appendix C**. The vapour modelling calculations for Scenario 8 are included in **Appendix K**.

The geological, hydrogeological and building parameters adopted for vapour intrusion modelling for Scenario 8 are summarised in **Table 43** below.

Table 43 Vapour Modelling Assumptions - Scenario 8 (Multistorey Commercial Slab on Ground, with advection)

Parameter (units)	Adopted Value	Source/Justification
Vadose Zone and Hydrogeological Parameters – Soil to Indoor/Outdoor 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	
Air filled porosity in soil source zone (unitless)	0.321	
Water filled porosity in soil source zone (unitless)	0.054	
Total porosity in soil source zone (for soil model) (unitless)	0.375	
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_{10}, >C_{10}-C_{16} to reflect the differences observed between theoretical estimates of partitioning and field measurements (see CCME, 2010 and Friebel and Nadebaum, 2011).
Vadose Zone and Hydrogeological Parameters – Groundwater to Indoor/Outdoor Air		
Depth to groundwater contamination (cm)	200	Based on reported average depth to groundwater of 2 m. Capillary zone thickness is USEPA (2004a) default value for sand aquifer. 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 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	
Air filled porosity in vadose zone (unitless)	0.321	USEPA (2004a) defaults for sand (residual impacted soil and imported fill conservatively assumed to be sandy)
Water filled porosity in vadose zone (unitless)	0.054	
Total porosity in vadose zone (unitless)	0.375	
Air filled porosity in capillary zone (unitless)	0.122	USEPA (2004a) default for sand (considered conservative for mixed soil/fill types reported at site).
Water filled porosity in capillary zone (unitless)	0.253	

Parameter (units)	Adopted Value	Source/Justification
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 per second	$5.6x10^{-4}$	2 exchanges per hour (on average) have been assumed for commercial buildings.
Areal fraction of cracks in foundations/walls	0.00038	USEPA (2004a) default value for slab on ground.
Air filled porosity in foundation/wall cracks	0.321	Assumes foundation/wall cracks filled with sand (values are USEPA, 2004a defaults for coarse sand).
Water filled porosity in foundation/wall cracks	0.054	
Convective vapour flow rate (cm^3/sec)	83	The default advection rate for residential slab on ground properties above coarse grain soil (USEPA, 2004). This is considered to be a conservative assumption as it is likely that advective flow rates will be considerably lower in a newly built commercial building. This is due to heating and cooling requirements, thus it is likely that internal conditions will be under positive pressures.
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)	4,500	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.

5.3.16 Scenario 9: Crown Specific Upper Basement

The CSM for an Upper Basement Level is depicted in **Figure F15**.

The following points are relevant to this scenario:

- The upper most basement level is assumed to extend from the future finished surface (that will be at least 1.0m above the existing surface level) to 5 m bgl (where ground level is the future finished surface), such that (assuming an average depth to groundwater of 3 m bgl):
  - groundwater seepage is assumed to occur through the lower 2 m of the wall;
  - a physical barrier will be provide to prevent dermal contact between receptors and groundwater that may seep through the basement walls; and
  - vapours intruding through the upper 3 m of the wall may be derived from impacted soil, which is assumed to be present directly adjacent the outside of the wall. It is noted that this is a conservative assumption because the top 1m of the unsaturated soil will actually be Suitable Fill (as defined in **Section 5.3.10**).
- Each basement level is modelled as separately ventilated airspace. This is more conservative than modelling the mixing of vapours through multiple basement levels, especially for the lowermost level.
- It has been assumed that the uppermost basement level may be occupied by full-time workers loading/unloading 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 3 m) for soils present in the unsaturated zone.

5.3.16.1 Contaminant Migration Pathways

Contaminant migration pathways relevant to potential human exposure to contaminants within an upper level basement are summarised in **Table 44** below.

Table 44 Contaminant Migration Pathways - Scenario 9 (Crown Specific 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	AECOM has conservatively modelled the potential impact of wet walls below the water table. It is assumed that groundwater may seep through the lower 2.0 m of the basement of two walls, where a physical barrier will stop direct contact with seeped groundwater. The basement dimensions for the upper basement are 50 m x 50 m x 5 m. It is assumed that half of the area where water can seep (i.e. 50% of the lower 2 m of two walls) will be covered in water i.e. 100 m^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 0-3 m bgl (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.

5.3.16.2 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.

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.

5.3.16.3 Exposure Pathways

Potential pathways via which the above receptors may be exposed to Site-derived contamination for Scenario 9 are summarised in **Table 45** below.

Table 45 Exposure Pathway Analysis - Scenario 9 (Crown Specific 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. Wall seeps will be behind a physical barrier which will restrict 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.

Notes: ✓ The exposure pathway is considered to be complete and is assessed further in the HHRA.
× The exposure pathway is not considered to be complete and is not assessed further.

5.3.16.4 Exposure Parameters

Human exposure parameters adopted for Scenario 9 are summarised in **Table 46** below.

Table 46 Exposure Parameters - Scenario 9 (Crown Specific Upper Basement)

Parameter (units)	Adopted Value	Source/Reference
Exposure Time Indoors (hours/day)	8	*ASC NEPM* (2013) Schedule B7, Table 5
Exposure Frequency (days/year)	240	*ASC NEPM* (2013) Schedule B7, Table 5
Exposure Duration (years)	30	*ASC NEPM* (2013) Schedule B7, Table 5.

5.3.16.5 Vapour Transport Modelling

Johnson and Ettinger Approach

Vapour modelling associated with soil was undertaken using the Johnson and Ettinger (1991) vapour transport model (refer to **Section 5.3.5**). It is noted that both diffusive and advective transport processes were considered in the unsaturated zone adjacent to basement wall.

Further detail on the vapour transport modelling and calculations are provided in **Appendix X**.

The geological, hydrogeological and building parameters adopted for vapour intrusion modelling based on the Johnson and Ettinger Approach for Scenario 9 are summarised in **Table 47** below.

Table 47 Vapour Modelling Assumptions - Scenario 9 (Crown Specific Upper Basement)

Parameter (units)	Adopted Value	Source/Justification
Vadose Zone and Hydrogeological 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	
Air filled porosity in soil source zone (unitless)	0.321	
Water filled porosity in soil source zone (unitless)	0.054	
Total porosity in soil source zone (for soil model) (unitless)	0.375	
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_{10}, >C_{10}-C_{16}, to reflect the differences observed between theoretical estimates of partitioning and field measurements (see CCME, 2010 and Friebel and Nadebaum, 2011).
Building Parameters – Soil to Indoor Air		
Ratio of enclosed space volume to infiltration area (cm)	4,167	Assumes basement volume of 12,500 m^3 (50 m x 50 m x 5 m). The infiltration area for soil was assumed to comprise the upper 3 m of two of the four walls (300 m^2). Enclosed volume to infiltration ratio is calculated as 12,500 m^3 / 300 m^2. It has been assumed that no independently ventilated publically accessible 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 the basement walls are likely to be in the order of 800 mm to 1,200 mm in thickness, but a lesser thickness has been conservatively assumed.
Enclosed space air exchange rate per second	9.72x 10^{-4}	The air exchange rate within the basement car park has been assumed to be an average of 3.5 air exchanges per hour. This air exchange rate is based on the proposed approach to the basement car park ventilation for the Crown basement (AECOM, 2014) (refer to **Appendix JJ**). It is understood that it is consistent with the Australian Standard AS 1668.2 and accounts for periods of decreased ventilation when vehicle movement in the basement is minimal (AECOM, 2012h).
Areal fraction of cracks in foundations/walls	0.0002	USEPA (2004a) default value for basements.
Air filled porosity in foundation/wall cracks	0.321	Assumes foundation/wall cracks filled with sand (values are USEPA, 2004a defaults for coarse sand).

Parameter (units)	Adopted Value	Source/Justification
Water filled porosity in foundation/wall cracks	0.054	
Advective vapour flow rate	Calculated	Calculated based on foundation dimensions, pressure differential and vapour permeability.
Soil vapour permeability (cm^2)	1×10^{-7}	USEPA, 2004a default for sand/gravel.
Indoor-outdoor pressure differential ($g/cm\text{-}s^2$)	40	USEPA, 2004a conservative default.

USEPA Water Model Approach

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 Model Approach (as described in **Section 5.3.5**).

The geological, hydrogeological and building parameters adopted for vapour intrusion modelling based on the USEPA Water Model Approach for Scenario 9 are summarised in **Table 48** below.

Chemical-specific properties used in the calculations are included in **Appendix X**.

Table 48 Water with Flow Modelling Assumptions - Scenario 9 (Crown Specific Upper Basement)

Parameter (units)	Adopted Value	Source/Justification
Volume of Basement (m^3)	12,500	Assumes basement area of 50 m by 50 m and internal height of 5 m.
Volume of Wet Basement (m^3)	1	Assumes the wet basement area comprises two walls with dimensions of 50 m x 2 m. The depth of water is expected to be and 0.01m.
Enclosed space air exchange rate per day within basement	84	The air exchange rate within the basement car park has been assumed to be an average of 3.5 air exchanges per hour. This air exchange rate is based on the proposed approach to the basement car park ventilation for the Crown basement (AECOM, 2014) (refer to **Appendix JJ**). It is understood that it is consistent with the Australian Standard AS 1668.2 and accounts for periods of decreased ventilation when vehicle movement in the basement is minimal (AECOM, 2012h).
Length of the Wet Section of Basement m)	25	Assumed maximum length of wet area (equivalent to half of the wall).
Width of Wet Section of Basement (m)	4	Assumed maximum width of wet area.
Fetch to Depth Ratio (wet section) (m)	400	Fetch to Depth Ratio is assumed to be 4 m (width of wet area) divided by 0.01 m (depth of water).
Volume of water entering the basement (m^3/sec)	2.60×10^{-7}	Based on the Crown performance specification for the Proposed Hotel Basement which requires that groundwater ingress not exceed 0.75 L/min across the entire basement wall area. This maximum ingress rate has been converted to m^3/sec.
Windspeed within Basement	0.03 m/sec	Conservative assumption based on dimensions of the basement and the assumed air exchange rate (see **Section 5.3.5**).

5.3.17 Scenario 10: Crown Specific 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 10) areas of the Site will be covered in a minimum of 1.0 m of Suitable Fill as defined in **Section 5.3.10**.

5.3.17.1 Contaminant Migration Pathways

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

Table 49 Contaminant Migration Pathways - Scenario 10 (Crown 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.

5.3.17.2 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.

5.3.17.3 Exposure Pathways

Potential pathways via which the above receptors may be exposed to Site-derived contamination for Scenario 10 are summarised in **Table 50** below.

Table 50 Exposure Pathway Analysis - Scenario 10 (Crown Unpaved Recreation)

Exposure Pathway	Complete?	Notes
Adult and Child Recreational Users		
Incidental ingestion of chemicals in soil	×	Unpaved recreation areas assumed to be covered/landscaped with minimum 100 cm Suitable Fill as defined in **Section 5.3.10** 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 not less than 3 m bgl (where ground level refers to the Site finished surface level) 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.

Notes: ✓ The exposure pathway is considered to be complete and is assessed further in the HHRA.
× The exposure pathway is not considered to be complete and is not assessed further.

5.3.17.4 Exposure Parameters

Human exposure parameters adopted for Scenario 10 are summarised in **Table 51** below.

Table 51 Exposure Parameters - Scenario 10 (Unpaved Recreation)

Parameter (units)	Adopted Value	Source/Reference
Exposure Time (hours/day)	2	*ASC NEPM* (2013) Schedule B7, Table 5.
Exposure Frequency (days/year)	365	*ASC NEPM* (2013) Schedule B7, Table 5.
Exposure Duration (years)	6 (child visitor) 29 (adult visitor)	*ASC NEPM* (2013) Schedule B7, Table 5.

5.3.17.5 Vapour Transport Modelling

Soil and groundwater vapour modelling was undertaken using the Johnson and Ettinger (1991) vapour transport model as summarised in **Section 5.3.5** and described in more detail in *Appendix A* of the *Declaration Site HHERA* (AECOM, 2011a). The vapour modelling calculations for Scenario 10 are included in **Appendix Y**.

Refer to **Section 5.3.10.5** for further information on attenuation factors applied to this scenario.

The geological, hydrogeological and construction parameters adopted for vapour intrusion modelling for Scenario 10 are summarised in **Table 52** below.

Table 52 Vapour Modelling Assumptions - Scenario 10 (Crown Specific Unpaved Recreation)

Parameter (units)	Adopted Value	Source/Justification
Vadose Zone and Hydrogeological Parameters + Soil to Outdoor Air		
Depth to soil contamination (cm)	100	Unpaved recreation areas assumed to be covered/landscaped with minimum 100 cm Suitable Fill as defined in **Section 5.3.10** 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	
Air filled porosity in soil source zone (unitless)	0.321	
Water filled porosity in soil source zone (unitless)	0.054	
Total porosity in soil source zone (for soil model) (unitless)	0.375	
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_{10}, >C_{10}-C_{16}, to reflect the differences observed between theoretical estimates of partitioning and field measurements (see CCME, 2010 and Friebel and Nadebaum, 2011).
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 (2010).

Parameter (units)	Adopted Value	Source/Justification
Vadose Zone and Hydrogeological Parameters + Groundwater to Outdoor Air		
Depth to groundwater contamination (cm)	300	Based on reported average depth to groundwater of 3 m. Capillary zone thickness is USEPA (2004a) default value for sand aquifer. 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)	283	
Thickness of capillary zone (cm)	17	
Air filled porosity in vadose zone (unitless)	0.321	USEPA (2004a) defaults for sand (residual impacted soil and imported fill conservatively assumed to be sandy).
Water filled porosity in vadose zone (unitless)	0.054	
Total porosity in vadose zone (unitless)	0.375	
Air filled porosity in capillary zone (unitless)	0.122	USEPA (2004a) default for sand (considered conservative for mixed soil/fill types reported at site).
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)	4,500	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.

5.3.18 Scenario 11: Crown Specific 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 10 cm; and
- and at least 1.0 m of Suitable Fill (as defined in **Section 5.3.10**) (including concrete/hardstand) placed immediately below the surface concrete/hardstand.

5.3.18.1 Contaminant Migration Pathways

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

Table 53 Contaminant Migration Pathways - Scenario 11 (Crown Specific 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.

5.3.18.2 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.

5.3.18.3 Exposure Pathways

Potential pathways via which the above receptors may be exposed to Site-derived contamination in Scenario 11 are summarised in **Table 54** below.

Table 54 Exposure Pathway Analysis - Scenario 11 (Crown Specific Paved Recreation)

Exposure Pathway	Complete?	Notes
Adult and Child Recreational Users		
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 not less than 3 m bgl 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.

Notes: ✓ The exposure pathway is considered to be complete and is assessed further in the HHRA.
× The exposure pathway is not considered to be complete and is not assessed further.

5.3.18.4 Exposure Parameters

Human exposure parameters adopted for Scenario 11 are summarised in **Table 55** below.

Table 55 Exposure Parameters - Scenario 11 (Crown Specific Paved Recreation)

Parameter (units)	Adopted Value	Source/Reference
Exposure Time (hours/day)	2	*ASC NEPM* (2013) Schedule B7, Table 5.
Exposure Frequency (days/year)	365	*ASC NEPM* (2013) Schedule B7, Table 5.
Exposure Duration (years)	6 (child) 29 (adult)	*ASC NEPM* (2013) Schedule B7, Table 5.

5.3.18.5 Vapour Transport Modelling

Soil and groundwater vapour transport modelling was undertaken using the Johnson and Ettinger (1991) vapour transport models summarised in **Section 5.3.5** and described in more detail in *Appendix A* of the *Declaration Site HHERA* (AECOM, 2011a). The vapour modelling calculations for Scenario 11 are included in **Appendix Z**.

The geological, hydrogeological and construction parameters adopted for vapour intrusion modelling for Scenario 11 are summarised in **Table 56** below. The vapour transport modelling for paved recreation has also considered the potential for biodegradation as discussed in **Section 5.3.10.5** above.

Table 56 Vapour Modelling Assumptions - Scenario 11 (Crown Specific Paved Recreation)

Parameter (units)	Adopted Value	Source/Justification
Vadose Zone and Hydrogeological Parameters + Soil to Outdoor Air		
Depth to soil contamination (cm)	100	Assumes soil contamination may be present beneath at least 1.0 m of Suitable Fill (**Section 5.3.10**) including paving.
Fraction of organic carbon in soil source (unitless)	0.002	
Soil bulk density (g/cm^3)	1.66	
Air filled porosity in soil source zone (unitless)	0.321	
Water filled porosity in soil source zone (unitless)	0.054	USEPA (2004a) defaults for coarse sand/gravel
Total porosity in soil source zone (for soil model) (unitless)	0.375	
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_{10}, TPH >C_{10}-C_{16}, to reflect the differences observed between theoretical estimates of partitioning and field measurements (see CCME, 2010 and Friebel and Nadebaum, 2011).
Biodegradation adjustment factor (unitless)	10	Adjustment for assumed presence of oxygen (and associated biodegradation of vapours) in unpaved areas. A factor of 10 is considered conservative as it is at lower end of ranges suggested by Davis et al. (2009) and CCME (2010).
Vadose Zone and Hydrogeological Parameters + Groundwater to Outdoor Air		
Depth to groundwater contamination (cm)	300	Based on reported average depth to groundwater of 3 m, allowing for USEPA (2004a) default capillary zone thickness for sand aquifer and for concrete surface covering.
Vadose zone thickness (cm)	273	Vadose zone thickness calculated as depth to water less capillary zone thickness less concrete thickness.
Thickness of capillary zone (cm)	17	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.

Parameter (units)	Adopted Value	Source/Justification
Air filled porosity in vadose zone (unitless)	0.321	USEPA (2004a) defaults for sand (residual impacted soil and imported fill conservatively assumed to be sandy)
Water filled porosity in vadose zone (unitless)	0.054	
Total porosity in vadose zone (unitless)	0.375	
Air filled porosity in capillary zone (unitless)	0.122	USEPA (2004a) default for sand (considered conservative for mixed soil/fill types reported at site).
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.
Air filled porosity in concrete cracks	0.00321	Assumes cracks in concrete surface cover are filled with sand (values are USEPA, 2004a defaults for coarse sand).
Water filled porosity in concrete cracks	0.00054	
Total porosity in concrete cracks	0.00375	
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)	4,500	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.

5.3.19 Scenario 12: Intrusive Maintenance – No Potential Contact with Groundwater

The intrusive maintenance scenario has been considered to account for potential future intrusive maintenance activities which may be undertaken following redevelopment of the Site where the depth to groundwater below the finished site level will be such that it is considered unlikely that intrusive maintenance work will result in contact of receptors with groundwater.

Further information on the modelling of exposure and potential risks to intrusive receptors is presented in **Section 5.3.13**.

5.3.19.1 Contaminant Migration Pathways

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

Table 57 Contaminant Migration Pathways – Scenario 12 (Intrusive Maintenance – No Potential Contact with Groundwater)

Contaminant Migration Pathways	Relevant to Scenario?	Comments
Volatilisation from soil and vapour migration to within trenches/excavations	Yes	It is possible that soil and groundwater derived vapours may accumulate within trench airspaces overlying contaminated soil and groundwater.
Volatilisation from groundwater and vapour migration within trenches/excavations	Yes	
Seepage of groundwater to within trenches or excavations	No	The depth to groundwater below the finished site level will be not less than 3m due to the placement of a minimum of 1.0 m of Suitable Fill across the Crown Site, outside the basement. Therefore, it is assumed that groundwater will not to be contacted by intrusive maintenance workers in this scenario.

5.3.19.2 Human Receptors

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

5.3.19.3 Exposure Pathways

Potential pathways via which the above receptors may be exposed to Site-derived contamination in Scenario 12 are summarised in **Table 58** below.

Table 58 Exposure Pathway Analysis - Scenario 12 (Intrusive Maintenance – No Potential Contact with Groundwater)

Exposure Pathway	Complete?	Notes
Adult Intrusive Maintenance 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)	×	Due to groundwater being present 3.0 m bgl, workers are assumed not to come into contact with groundwater while working in a trench to a maximum depth of 2.0 m bgl.
Dermal absorption of chemicals in groundwater (incidental contact)	×	
Inhalation of groundwater derived vapours	✓	Groundwater derived vapours are assumed to volatilise from groundwater beneath the trench.

Notes: ✓ The exposure pathway is considered to be complete and is assessed further in the HHRA.
× The exposure pathway is not considered to be complete and is not assessed further.

5.3.19.4 Exposure Parameters

Human exposure parameters adopted for Scenario 12 are summarised in **Table 59** below.

Table 59 Exposure Parameters - Scenario 12 (Intrusive Maintenance – No Potential Contact with Groundwater)

Parameter (units)	Adopted Value	Source/Reference
Body weight (kg)	70	*ASC NEPM* (2013) Schedule B7, Table 5 (Commercial Worker).
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	Friebel, E. and Nadebaum, P. (2011), Part 1, Table 6
Exposed Skin Surface Area for Soil Contact (cm^2/day)	6,800	Friebel, E. and Nadebaum, P. (2011), Part 1, Table 6
Soil to Skin Adherence Factor (mg/cm^2)	0.9	Friebel, E. and Nadebaum, P. (2011), Part 1, Table 6

5.3.19.5 Chemical-Specific Factors for Dermal Exposure Assessment

The approach for chemical-specific factors for dermal exposure assessment is consistent with that presented in **Section 5.3.13.5**. The DAF and K_p values adopted for this assessment are included in **Table T3**.

5.3.19.6 Vapour Transport Modelling

Soil and groundwater vapour transport modelling was undertaken using the Johnson and Ettinger (1991) vapour transport models summarised in **Section 5.3.5** and described in more detail in *Appendix A* of the *Declaration Site HHERA* (AECOM, 2011a). The vapour modelling calculations for Scenario 12 are included in **Appendix AA**.

The parameters required for the intrusive maintenance scenario vapour modelling for Scenario 12 are summarised in **Table 60** below.

Table 60 Vapour Modelling Assumptions - Scenario 12 (Intrusive Maintenance – No Potential Contact with Groundwater)

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	
Air filled porosity in soil source zone (unitless)	0.321	
Water filled porosity in soil source zone (unitless)	0.054	
Total porosity in soil source zone (for soil model) (unitless)	0.375	

Parameter (units)	Adopted Value	Source/Justification
Vadose Zone/Soil Parameters + Soil to Trench Air		
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_{10}, >C_{10}-C_{16} to reflect the differences observed between theoretical estimates of partitioning and field measurements (see CCME, 2010 and Friebel and Nadebaum, 2011).
Groundwater Parameters + Groundwater to Trench Air		
Depth to groundwater contamination (cm)	100	Based on reported average depth to groundwater of 3 m bgl (1 m below the base of the trench), allowing for USEPA (2004a) default capillary zone thickness for sand aquifer.
Vadose zone thickness (cm)	83	Vadose zone thickness calculated as depth to water less capillary zone thickness less concrete thickness.
Thickness of capillary zone (cm)	17	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.
Air filled porosity in vadose zone (unitless)	0.321	USEPA (2004a) defaults for sand (residual impacted soil and imported fill conservatively assumed to be sandy)
Water filled porosity in vadose zone (unitless)	0.054	
Total porosity in vadose zone (unitless)	0.375	
Air filled porosity in capillary zone (unitless)	0.122	USEPA (2004a) default for sand (considered conservative for mixed soil/fill types reported at site).
Water filled porosity in capillary zone (unitless)	0.253	
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 200 cm long and up to 200 cm deep.
Ambient air mixing zone height	200	Conservative default – assumes all emitted vapours are mixed within 2 m deep trench.

5.3.19.7 Particulate Emission Factors

The respirable dust (PM_{10}) concentrations in trench air were estimated assuming a particulate emission factor (PEF) of 3.6 x 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.

5.3.20 Scenario 13: Crown Specific High Density Residential

The CSM for the High Density Residential Scenario (which also includes the potential residential dwellings within the tower area of the proposed Crown Hotel Development that will be constructed over the proposed Crown basement) is similar to that for Scenario 9 (Crown Specific Upper Basement Level) depicted in **Figure F15**), 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 5.0 m bgl, such that (assuming an average depth to groundwater of 3 m bgl) groundwater seepage behind a physical barrier stoping potential direct contact with groundwater will occur in the lower 2.0 m of the wall over 50% of two walls. Vapours intruding through the upper 3.0 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 F15**.
- All other points listed in **Section 5.3.14** are also relevant to this scenario.

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 has 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 and as discussed above, stack effects are not expected to be significant in this instance).

5.3.20.1 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 61 Contaminant Migration Pathways - Scenario 13 (Crown Specific 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. Therefore to be conservative water has been modelled which seeps through half of the lower 2.0 m of the basement of two walls behind a physical barrier separating receptors from the groundwater. The basement dimensions for the upper basement are 50 m x 50 m x 5m. It is considered that half of the area in which groundwater can filtrate (lower 2.0m of wall) will be covered in water i.e. 100m^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 0-3 m bgl (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.

5.3.20.2 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.

5.3.20.3 Exposure Pathways

Potential pathways via which the above receptors may be exposed to Site-derived contamination are summarised in **Table 62** below.

Table 62 Exposure Pathway Analysis - Scenario 13 (Crown Specific 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 on the residential floors. Exposure to groundwater ingress into the basement area is considered in Scenario 1 (Lower Basement), Scenario 2 (Upper Basement) and Scenario 9 (Crown Upper Basement).
Dermal absorption of chemicals in groundwater (incidental contact)	×	
Inhalation of groundwater derived vapours	✓	Potentially complete and significant pathway.

Notes: ✓ The exposure pathway is considered to be complete and is assessed further in the HHRA.
× The exposure pathway is not considered to be complete and is not assessed further.

5.3.20.4 Exposure Parameters

Human exposure parameters adopted for Scenario 13 are summarised in **Table 63** below.

Table 63 Exposure Parameters - Scenario 13 (Crown Specific High Density Residential)

Parameter (units)	Adopted Value	Source/Reference
Exposure Time (hours/day)	24	Conservative estimation.
Exposure Frequency (days/year)	365	*ASC NEPM* (2013) Schedule B7, Table 5.
Exposure Duration (years)	6 (child) 29 (adult)	*ASC NEPM* (2013) Schedule B7, Table 5.

5.3.20.5 Vapour Transport Modelling

Johnson and Ettinger Approach

Vapour modelling associated with soil was undertaken using the Johnson and Ettinger (1991) vapour transport model (refer to **Section 5.3.5**). It is noted that both diffusive and advective transport processes were considered in the unsaturated zone adjacent to basement wall.

Further detail on the vapour transport modelling is provided in **Appendix C** and the calculations are provided in **Appendix BB**.

The geological, hydrogeological and building parameters adopted for vapour intrusion modelling based on the Johnson and Ettinger Approach for Scenario 13 are summarised in **Table 64** below.

Table 64 Vapour Modelling Assumptions - Scenario 13 (Crown Specific High Density Residential)

Parameter (units)	Adopted Value	Source/Justification
Vadose Zone and Hydrogeological 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	
Soil bulk density (g/cm^3)	1.66	
Air filled porosity in soil source zone (unitless)	0.321	USEPA (2004a) defaults for coarse sand/gravel.
Water filled porosity in soil source zone (unitless)	0.054	
Total porosity in soil source zone (for soil model) (unitless)	0.375	
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_{10}, C_{10}-C_{16} to reflect the differences observed between theoretical estimates of partitioning and field measurements (see CCME, 2010 and Friebel and Nadebaum, 2011).
Building Parameters		
Ratio of enclosed space volume to infiltration area (cm)	4,167	Assumes basement volume of 12,500 m^3 (50 m x 50 m x 5 m). The infiltration area for soil was assumed to comprise the upper 2 m of two of the four walls (300 m^2). Enclosed volume to infiltration ratio is calculated as 12,500 m^3 / 300 m^2. It has been assumed that no independently ventilated publically accessible 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 the basement walls are likely to be in the order of 800 mm to 1,200 mm in thickness, but a lesser thickness has been conservatively assumed.
Enclosed space air exchange rate per second	9.72×10^{-4}	The air exchange rate within the basement car park has been assumed to be an average of 3.5 air exchanges per hour. This air exchange rate is based on the proposed approach to the basement car park ventilation for the Crown basement (AECOM, 2014) (refer to **Appendix JJ**). It is understood that it is consistent with the Australian Standard AS 1668.2 and accounts for periods of decreased ventilation when vehicle movement in the basement is minimal (AECOM, 2012h).
Areal fraction of cracks in foundations/walls	0.0002	USEPA (2004a) default value for basements.

Parameter (units)	Adopted Value	Source/Justification
Air filled porosity in foundation/wall cracks	0.321	Assumes foundation/wall cracks filled with sand (values are USEPA, 2004a defaults for coarse sand).
Water filled porosity in foundation/wall cracks	0.054	
Indoor Attenuation Factor (Unitless)	0.1	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 5.3.14** above.
Advective vapour flow rate	Calculated	Calculated based on foundation dimensions, pressure differential and vapour permeability.
Soil vapour permeability (cm^2)	1×10^{-7}	USEPA, 2004a default for sand/gravel.
Indoor-outdoor pressure differential ($g/cm\text{-}s^2$)	40	USEPA, 2004a conservative default.

USEPA Water Model Approach

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 Model Approach (as described in **Section 5.3.5**).

The geological, hydrogeological and building parameters adopted for the USEPA Water Model Approach for Scenario 13 are summarised in **Table 65** below.

Chemical-specific properties used in the calculations are included in **Appendix BB**.

Table 65 Seepage Modelling Assumptions - Scenario 13 (Crown Specific High Density Residential)

Parameter (units)	Adopted Value	Source/Justification
Volume of Basement (m^3)	12,500	Assumes basement area of 50 m by 50 m and internal height of 5 m.
Volume of Wet Basement (m^3)	1	Assumes the wet basement area comprises two walls with dimensions of 50 m x 2 m. The depth of water is expected to be and 0.01m.
Enclosed space air exchange rate per day within basement	84	The air exchange rate within the basement car park has been assumed to be an average of 3.5 air exchanges per hour. This air exchange rate is based on the proposed approach to the basement car park ventilation for the Crown basement (AECOM, 2014) (refer to **Appendix JJ**). It is understood that it is consistent with the Australian Standard AS 1668.2 and accounts for periods of decreased ventilation when vehicle movement in the basement is minimal (AECOM, 2012h).
Length of Wet Section of Basement (m)	25	Assumed maximum length of wet area (equivalent to half of the wall)
Width of Wet Section of Basement (m)	4	Assumed maximum width of wet area.
Fetch to Depth Ratio (wet section) (m)	400	Fetch to depth ratio is assumed to be 4 m (width of water) divided by 0.01m (depth of water).
Volume of water entering the basement (m/day)	2.60×10^{-7}	Based on the Crown performance specification for the Proposed Hotel Development Basement which requires that groundwater ingress not exceed 0.75 L/min across the entire basement wall area. This maximum ingress rate has been converted to m^3/sec.
Windspeed within Basement (m/sec)	0.03	Conservative assumption based on dimensions of the basement and the air exchange rate (see **Section 5.3.5**).

5.3.21 Scenario 14: Crown Specific Multistorey Commercial Elevated Slab on Ground (with advection)

This scenario assumes a multi-story commercial elevated slab on ground construction where vapour intrusion via advective flows may be a consideration when accounting for exposures to commercial workers. This scenario has been conservatively applied to the podium area of the Proposed Crown Hotel Development to account for the portion which may potentially be constructed on grade.

It is assumed that the development is multiple stories (significantly more than two) high with an internal elevator system installed. It has been assumed that advection may be the dominant pathway for vapour intrusion for soil and groundwater.

5.3.21.1 Contaminant Migration Pathways

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

Table 66 Contaminant Migration Pathways - Scenario 14 (Crown Specific Multistorey Commercial Slab on Ground, with advection)

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. It is noted that the consideration of advection has been undertaken for soils within the unsaturated zone. AECOM has also conservatively considered the potential for advection from groundwater impacts.
Volatilisation from groundwater and vapour migration to indoor air	Yes	

5.3.21.2 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 commercial premises but for shorter periods of time.

5.3.21.3 Exposure Pathways

Potential pathways via which the above receptors may be exposed to Site-derived contamination are summarised in **Table 67** below.

Table 67 Exposure Pathway Analysis – Scenario 14 (Crown Specific Multistorey Commercial Slab on Ground, with advection)

Exposure Pathway	Complete?	Notes
Adult Commercial Worker		
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 not less than 3 m bgl 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.

Notes: ✓ The exposure pathway is considered to be complete and is assessed further in the HHRA.
× The exposure pathway is not considered to be complete and is not assessed further.

5.3.21.4 Exposure Parameters

Human exposure parameters adopted for Scenario 14 are summarised in **Table 68** below.

Table 68 Exposure Parameters - Scenario 14 (Crown Specific Multistorey Commercial Slab on Ground, with advection)

Parameter (units)	Adopted Value	Source/Reference
Exposure Time Indoors (hours/day)	8	*ASC NEPM* (2013) Schedule B7, Table 5.
Exposure Frequency (days/year)	240	*ASC NEPM* (2013) Schedule B7, Table 5.
Exposure Duration (years)	30	*ASC NEPM* (2013) Schedule B7, Table 5.

5.3.21.5 Vapour Transport Modelling

Soil and groundwater vapour transport modelling was undertaken using the Johnson and Ettinger vapour transport models (summarised in **Section 5.3.5**) and further details of the equations and assumptions are presented in **Appendix C**. The vapour modelling calculations for Scenario 14 are included in **Appendix CC**.

The geological, hydrogeological and building parameters adopted for vapour intrusion modelling for Scenario 14 are summarised in **Table 69** below.

Table 69 Vapour Modelling Assumptions - Scenario 14 (Crown Specific Multistorey Commercial Slab on Ground, with advection)

Parameter (units)	Adopted Value	Source/Justification
Vadose Zone and Hydrogeological Parameters – Soil to Indoor/Outdoor Air		
Depth to soil contamination (cm)	100	Assumes a minimum of 1.0 m Suitable Fill.
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	
Air filled porosity in soil source zone (unitless)	0.321	
Water filled porosity in soil source zone (unitless)	0.054	
Total porosity in soil source zone (for soil model) (unitless)	0.375	
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_{10}, >C_{10}-C_{16} to reflect the differences observed between theoretical estimates of partitioning and field measurements (see CCME, 2010 and Friebel and Nadebaum, 2011).
Vadose Zone and Hydrogeological Parameters – Groundwater to Indoor/Outdoor Air		
Depth to groundwater contamination (cm)	300	Based on reported average depth to groundwater of 3 m. Capillary zone thickness is USEPA (2004a) default value for sand aquifer. Vadose zone thickness calculated as depth to water less capillary zone thickness.
Vadose zone thickness (cm)	283	
Thickness of capillary zone (cm)	17	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.

Parameter (units)	Adopted Value	Source/Justification
Air filled porosity in vadose zone (unitless)	0.321	USEPA (2004a) defaults for sand (residual impacted soil and imported fill conservatively assumed to be sandy)
Water filled porosity in vadose zone (unitless)	0.054	
Total porosity in vadose zone (unitless)	0.375	
Air filled porosity in capillary zone (unitless)	0.122	USEPA (2004a) default for sand (considered conservative for mixed soil/fill types reported at site).
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 per second	$1.38x10^{-3}$	5 exchanges per hour (on average) have been adopted for the Crown Podium based on the Crown proposed ventilation system design (refer to **Appendix JJ**).
Areal fraction of cracks in foundations/walls	0.00038	USEPA (2004a) default value for slab on ground.
Air filled porosity in foundation/wall cracks	0.321	Assumes foundation/wall cracks filled with sand (values are USEPA, 2004a defaults for coarse sand).
Water filled porosity in foundation/wall cracks	0.054	
Convective vapour flow rate (cm^3/sec)	83	The default advection rate for residential slab on ground properties above coarse grain soil (USEPA, 2004). This is considered to be a conservative assumption as it is likely that advective flow rates will be considerably lower in a newly built commercial building. This is due to heating and cooling requirements, thus it is likely that internal conditions will be under positive pressures. The rate is also considered to be conservative given the increased depth to groundwater across in areas of the Crown Site that will be outside the proposed basement.
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)	4,500	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.

5.3.22 Re-Use of Soil in the ORWN Public Domain

It is understood that material and/or soil from the Site, or elsewhere within Barangaroo South, which meets relevant SSTC may also be re-used to build up the elevation of areas within the Site that are outside the Crown Site. It is understood that Crown does not intend to reuse material from within the Site or elsewhere within Barangaroo South on the Crown Site.

The SSTC derived for Scenarios 3 to 6 and 8 above (Unpaved Recreation, Paved Recreation, Commercial 2 storey Slab on Grade, Intrusive Maintenance and Multi Storey slab on Grade) are considered to be broadly applicable to the re-use of material within the ORWN Public domain. It is noted that any material placed within open space areas outside of the Crown Site within the top 0.5 m must meet the TSC outlined in **Table 85**. In the event that the proposed Southern Cove is created by excavation of existing fill materials, soils within the base of the proposed potential Southern Cove from 0 to 0.5 m bgl will meet the ISQG (High) Criteria (**Table 84**).

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 and 8 SSTC are considered to provide an appropriate 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.

5.3.23 Potential Exposure to Asbestos

The future land use scenarios outlined in **Section 5.3.7** are such that the only receptor that may potentially be exposed to bonded ACM in soils under future conditions at the Site are intrusive maintenance workers. All other receptors are not considered likely to be exposed as a result of the future conditions proposed for the Site (refer to **Section 5.3.7**). Intrusive maintenance workers are considered to be present for eight (8) hours per day, for a maximum of 15 days per year over a one year period. These receptors are not considered likely to be present at the Site for longer periods of time because it is assumed that the same worker would not conduct intrusive works over more than 15 days per year.

The assumed exposure duration for intrusive maintenance workers is considered to be consistent with an acute exposure (in the event that airborne asbestos fibres are generated during works). The available information pertaining to health risks as a result of exposure to asbestos fibres indicates that acute exposures are unlikely to result in health effects. Further detail pertaining to asbestos exposure and potential for health risks to intrusive maintenance workers has been presented in Section 5.3 and Section 5.4 of the *ORWS Addendum Risk Assessment* (AECOM, 2013d) and will not be further discussed herein.

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, 2012) 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 to 14) 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 1×10^{-5} has been adopted as the acceptable cancer risk threshold for each individual chemical, based on *ASC NEPM* (2013) Schedule B4.

As described in **Appendix L** carcinogenic PAHs (CPAH) were assessed as one (based on TEF equivalents), rather than individually. This approach was taken to allow for the co-location of CPAH across the Site.

5.5 Estimation of Site-Specific Target Criteria

SSTC were estimated for specific environmental media (e.g. soil or groundwater) and receptors, with consideration for each pathway and exposure scenario relevant to the receptor and medium. For example, the intrusive maintenance worker (Scenario 6 and Scenario 12) was assumed to be exposed to chemicals in soil via incidental ingestion, dermal absorption, inhalation of particulates and inhalation of 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.

5.5.1 Threshold Chemicals

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 Available 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.

5.5.2 Non-threshold chemicals

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.

5.5.3 SSTC Derivation

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.

5.5.4 Theoretical Saturation and Solubility Limit considerations in SSTC derivation (Vapour)

In the instance where: the derived soil SSTC is greater than the estimated pore vapour concentration based on the theoretical saturation limit for a chemical component (C_{sat}); and, the complete exposure pathway for a receptor is via the vapour inhalation pathway only; the specific target risk level cannot be physically achieved, even where PSH is present (USEPA, 2004a). In these cases, the SSTC is not reported and is denoted as ## (see **Section 5.5.5** for further details). Theoretical C_{sat} values for each CoPC are included in **Appendix D** to **Appendix K**, and **Appendix X** to **Appendix CC**.

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 are not reported and are denoted as "##". Pure component aqueous solubilities for each CoPC are included in **Appendix D** to **Appendix K**, and **Appendix X** to **Appendix CC**.

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 D** to **Appendix K** and **Appendix M** to **Appendix T** for Scenario 1 to Scenario 8, and **Appendix X** to **Appendix CC** and **Appendix DD** to **Appendix II** for Scenario 9 to Scenario 14 respectively.

5.5.5 Saturation and Solubility Considerations in SSTC Derivation

The SSTC 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 exceedances of numerous orders of magnitude above theoretical saturation/ solubility limit (presented **Table 71** and **Table 72**) 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 **Table 71** and **Table 72** 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, which is required by policy of the EPA (NSW DEC 2007), 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:

- Risk and odour SSTCs were derived for soil and groundwater and compared to saturation /solubility limits and maximum concentrations of CoPC across Barangaroo (refer to **Section 6.1**).
- Where derived SSTCs 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.
- Where SSTCs are not saturation or solubility limited (refer to **Section 5.5.4**), or are within 10 times the saturation/ solubility limits the SSTC was adopted.
- In instances where the derived TPH soil and groundwater SSTCs for fractions C_6-C_{10} and >C_{10}-C_{16} are over 10 times the saturation/ solubility limits, the derived SSTC have been adopted (with the exception of soil, where the derived SSTCs were adopted to concentrations equal to the maximum concentrations present at Barangaroo, TPH C_6-C_{10} 7,500 mg/kg, >C_{10}-C_{16} 70,000 mg/kg and C_{16+} 130,000 mg/kg) where a derived SSTC is solubility limited. 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.
- SSTCs for carcinogenic PAHs were determined as a "total cPAH" based on the SSTC derived for benzo(a)pyrene. It is noted that the soil SSTC is strongly influenced 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 71** and **Table 72**.

5.5.6 Asbestos Site-Specific Target Criteria

The asbestos reported to be present in soils within the ORWS Area is predominately bonded ACM and the potential for asbestos fibre (AF) generation has been demonstrated to be minimal. In particular, investigations undertaken within the ORWS Area did not detect asbestos fibres as part of the air quality monitoring program undertaken during the excavation works within the ORWS Area. These excavation works included excavation, stockpiling and mechanical reworking and are considered representative of a worst case scenario for the potential generation of AF from bonded ACM. Therefore, the likelihood of the generation of asbestos fibres to air from the bonded ACM identified at the Site is considered to be low based on conditions within the ORWS Area.

It has been assumed that asbestos which may be present within the ORWN Area is likely to be similar – that is predominantly bonded ACM.

5.5.6.1 Scenario 6 and Scenario 12 - Intrusive Maintenance Worker

Based on the *ASC NEPM* (2013) and to account for the potential that bonded ACM present at the Site may degrade over time and generate asbestos fibres as a result of future physical disturbance by intrusive maintenance works, the asbestos SSTC for the Intrusive Maintenance Exposure Scenario is:

- 0.05 % w/w asbestos in soil – taken from the *ASC NEPM* (2013) guideline for protection of commercial / industrial receptors from bonded ACM in soil.

The *ASC NEPM* (2013) guideline of 0.02% w/w (for recreational users) has not been adopted as recreational receptors are not considered likely to contact soils at the Site under proposed future land use conditions.

5.5.6.2 Suitable Fill

Section 5.3.10 assumes and **Section 5.3.11** recommends that 0.5 m of Suitable Fill be placed within all paved and unpaved recreation land use areas; **Section 5.3.17** and **Section 5.3.18** assume that 1.0 m of Suitable Fill be placed in all paved and unpaved recreation land use areas within the Crown Site. Suitable Fill is defined as:

- VENM; or
- Soil which contains contaminant concentrations below the TSC (refer to **Section 8.0**); and
- Soil which contains contaminant concentrations below the relevant SSTC (as described by this HHERA).

With the exception of the definition of VENM, neither the TSC nor the SSTC (for paved or unpaved recreational land use) include a SSTC for asbestos in soil. Therefore, to ensure that Suitable Fill will prevent the exposure of receptors (other than intrusive maintenance workers) to underlying asbestos contamination an asbestos SSTC will also be adopted for Suitable Fill.

The *ASC NEPM* (2013) states that surface soils must be free of “visible asbestos” under all land use scenarios. Surface soils are interpreted by the *ASC NEPM* (2013) to be the top 0.1 to 0.3 m of soil[1].

Therefore, based on the *ASC NEPM* (2013) the asbestos SSTC for Suitable Fill is:

- No visible asbestos.

As above, the depth of Suitable Fill assumed or required by this HHERA in paved and unpaved recreation land use areas ranges from 0.5m (refer to **Section 5.3.10** and **Section 5.3.11**) to 1.0 m (refer to **Section 5.3.17** and **Section 5.3.18**). While the requirement of the *ASC NEPM* (2013) is that the top 0.3m of soil be visually free from asbestos, it is not considered practicable to have two criteria for Suitable Fill. It is therefore recommended that the same asbestos SSTC should be adopted for all Suitable Fill placed within all paved and unpaved recreation land use areas

5.5.6.3 Summary of Asbestos SSTC

Table 70 summarises asbestos SSTC that are to be adopted for the Site. For clarity, the asbestos SSTC are to be applied in addition to the SSTC (refer to **Section 5.5**) and TSC, in the case of Suitable Fill (refer to **Section 8.0**).

Table 70 Summary of Asbestos SSTC

Exposure Scenario	Asbestos Site Specific Target Criteria
Intrusive Maintenance Worker (Scenario 6 and Scenario 12) [3]	0.05 % w/w [2]
Suitable Fill	No Visible Asbestos [1]

Notes:

1) The methodology to be adopted to demonstrate application of the “No Visible Asbestos” SSTC will be described by the future *ORWN RAP(s)*;
2) To be measured in accordance with the methodology described by Schedule B1 of the *ASC NEPM* (2013)
3) The Intrusive Maintenance Worker exposure scenario (Scenario 6 and Scenario 12) is applicable to soil in areas used for paved and unpaved recreation land use (Scenario 3, 4, 10 and 11) at depths below assumed or recommended Suitable Fill and above the groundwater table.

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[1] The understanding that the surface soils relates to the top 0.3 m of the soil profile is based on the WA DoH (2009) which states (in Section 4.1.4) that where “*asbestos extends below surface soils (> 30 cm) sampling by test pits and trenches are most common and effective*”. WA DoH (2009) also outlines methods for removing visible asbestos in surface soils. The first is hand picking, which is suitable to a depth of 10 cm. The second is tilling, which is relevant for contamination within the top 20 cm of soil. In the absence of specific guidance in the *ASC NEPM* (2013), adopting a depth of 0.3 m was considered appropriate.

5.5.7 Derived SSTCs for Groundwater and Soil

Table 71 Comparison of Derived and Proposed Groundwater SSTC – Scenario 1 to Scenario 8

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		Scenario 8 – Commercial Slab on Ground (Multi-storey Building)	
		Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed
Acenaphthene	3.9	***1,320***	***##***	***15,600***	***##***	***1730000***	***##***	***16,800,000***	***##***	***49,700***	***##***	34.7	35	***35,600***	***##***	***739***	***##***
Acenaphthylene	16	-	-	-	-	-	-	-	-	-	-	32.7	33	-	-	-	-
Ammonia	482,000	919	920	10,800	11,000	2,400,000	2,400,000	28,700,000	##	86,800	87,000	153	150	24,800	25,000	1,580	1,600
Aniline	36,000	***67,300***	***67,000***	***775,000***	***##***	***1,570,000,000***	***##***	***36,200,000***	***##***	***113,000,000***	***##***	676	680	***1,770,000***	***##***	***918,000***	***##***
Anthracene	0.0434	-	-	-	-	-	-	-	-	-	-	105	##	-	-	-	-
Arsenic	-	-	-	-	-	-	-	-	-	-	-	144	140	-	-	-	-
Barium	-	-	-	-	-	-	-	-	-	-	-	834	830	-	-	-	-
Benz(a)anthracene	0.0094	-	-	-	-	-	-	-	-	-	-	(See cPAH)		-	-	-	-
Benzene	1,790	48.8	49	598	600	1,240	1,200	10,600	10,600	36	36	6.8	7	1,170	1,200	0.656	1.0
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	-	-	-	-	-	-	-	-	-	-	5.54	##	-	-	-	-
Cadmium	-	-	-	-	-	-	-	-	-	-	-	109	110	-	-	-	-
Chrysene	0.002	-	-	-	-	-	-	-	-	-	-	(See cPAH)		-	-	-	-
Cobalt	-	-	-	-	-	-	-	-	-	-	-	247	250	-	-	-	-
Cresols (total)	25,900	***22.4***	***22***	***255***	***260***	***741,000***	***##***	***17,800,000***	***##***	***55,800***	***56,000***	***2.7***	***2.7***	***583***	***580***	***441***	***440***
Dibenz(a,h)anthracene	0.00249	-	-	-	-	-	-	-	-	-	-	(See cPAH)		-	-	-	-
Dibenzofuran	3.1	***13,100***	***##***	***154,000***	***##***	***18,400,000***	***##***	***178,000,000***	***##***	***525,000***	***##***	153	##	***353,000***	***##***	***7,690***	***##***
Dimethylphenol, 2,4-	7,870	-	-	-	-	-	-	-	-	-	-	431	430	-	-	-	-
Ethylbenzene	169	4,220	##	49,900	##	111,000	##	947,000	##	2,760	##	104	100	114,000	##	48.4	48
Fluoranthene	0.26	-	-	-	-	-	-	-	-	-	-	6.49	##	-	-	-	-
Fluorene	1.69	-	-	-	-	-	-	-	-	-	-	18.1	##	-	-	-	-
Indeno(1,2,3-cd)pyrene	0.00019	-	-	-	-	-	-	-	-	-	-	(See cPAH)		-	-	-	-
Lead	-	-	-	-	-	-	-	-	-	-	-	630	630	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-	-	-	27,300	27,000	-	-	-	-
Methylnaphthalene, 1-	28	-	-	-	-	-	-	-	-	-	-	4,770	##	-	-	-	-
Methylnaphthalene, 2-	24.6	***152***	***150***	***1,790***	***##***	***75,400***	***##***	***670,000***	***##***	***1,960***	***##***	21.7	22	***4,090***	***##***	***31.9***	***32***
Naphthalene	31	7.83	7.8	92.4	92	3,950	##	35,300	##	103	100	1.25	1.3	211	210	1.7	1.7
Nickel	-	-	-	-	-	-	-	-	-	-	-	1,290	1,300	-	-	-	-
Phenanthrene	1.15	-	-	-	-	-	-	-	-	-	-	20.8	##	-	-	-	-

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		Scenario 8 – Commercial Slab on Ground (Multi-storey Building)	
		Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed
Phenol	82,800	***4,830***	***4,800***	***52,800***	***53,000***	***309,000,000***	***##***	***7,850,000,000***	***##***	***2,470,000***	***##***	***340***	***340***	***121,000***	***120,000***	***189,000***	***190,000***
Pyrene	0.135	-	-	-	-	-	-	-	-	-	-	7.45	##	-	-	-	-
Styrene	310	3,390	##	40,000	##	246,000	##	2,100,000	##	6,140	##	46.7	47	91,400	##	108	110
Toluene	526	16,300	##	192,000	##	449,000	##	3,820,000	##	11,200	##	374	370	44,000	##	199	200
TPH C_6-C_8 aliphatic ($)	5.4	17900	19,000	211,000	225,000	3,870	6,900	32,800	59,000	95.8	170	527	560	483,000	515,000	1.79	3
TPH >C_8-C_{10} aliphatic ($)	0.43	974		11,500		149		1,270		3.7		10.5		26,300		0.0689	
TPH >C_8-C_{10} aromatic ($)	65	195		2,300		2,900		24,700		72.1		18.1		5,250		1.34	
TPH >C_{10}-C_{12} aliphatic ($)	0.034	733	1,800	8,650	21,000	35.6	22,000	302	189,000	0.882	550	1.21	12	19,800	47,500	0.0164	10
TPH >C_{12}-C_{16} aliphatic ($)	0.00076	733		8,650		8.22		69.7		0.204		1.21		19,800		0.00379	
TPH >C_{10}-C_{12} aromatic ($)	0.00063	147		1,730		6,070		51,800		151		4.86		3,960		2.8	
TPH >C_{12}-C_{16} aromatic ($)	0.000048	147		1,730		15,900		137,000		399		4.86		3,960		7.35	
TPH >C_{16}-C_{21} aliphatic ($)	0.0000025	-	-	-	-	-	-	-	-	-	-	61.8	130	-	-	-	-
TPH >C_{21}-C_{34} aliphatic ($)	0.0000025	-	-	-	-	-	-	-	-	-	-	61.8		-	-	-	-
TPH >C_{16}-C_{21} aromatic ($)	0.65	-	-	-	-	-	-	-	-	-	-	1.32		-	-	-	-
TPH >C_{21}-C_{34} aromatic ($)	0.0066	-	-	-	-	-	-	-	-	-	-	1.32		-	-	-	-
TPH >C_{34}-C_{40} aliphatic ($)	-	-	-	-	-	-	-	-	-	-	-	852,000	853,000	-	-	-	-
TPH >C_{34}-C_{40} aromatic ($)	-	-	-	-	-	-	-	-	-	-	-	1,280		-	-	-	-
Trimethylbenzene, 1,2,4-	57	91	91	1,080	##	3,460	##	29,500	##	86	86	15.5	16	2,460	##	1.48	1.5
Trimethylbenzene, 1,3,5-	48.2	456	460	5,390	##	12,300	##	104,000	##	304	300	26.3	26	1,230	##	5.25	5.3
Xylenes (total)	6.7	2,840	##	33,500	##	91,600	##	781,000	##	2,280	##	230	##	76,500	##	41.1	41
CPAH#[1]	-	-	-	-	-	-	-	-	-	-	-	0.491	#	-	-	-	-

Notes:

Shading = SSTC exceeds aqueous solubility limit however the derived SSTC is within 10 times the solubility limit.
= 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 0.491 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)
Italics= odour SSTC (were lower than human health SSTC). Refer to Section 6.1 for odour SSTC calculations.
$ = 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 design concepts and assumptions provided by LL and Crown.
- The development of SSTCs has assumed that tar will not be present in the immediate vicinity of outer basement walls, 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) and vapour pressure greater than 1mmHg at room temperature (*ASC NEPM*, 2013).
- The air exchange rate within the basement car park has been assumed to be an average of 3.5 air exchanges per hour. This air exchange rate is based on the proposed approach to the basement car park ventilation for the Crown basement (AECOM, 2014) (refer to **Appendix JJ**). It is understood that it is consistent with the Australian Standard AS 1668.2 and accounts for periods of decreased ventilation when vehicle movement in the basement is minimal (AECOM, 2012h).
- 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 (Scenario 1 also assumes the floor is in contact with contaminated soil / groundwater). It has also 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, where present, will comprise a reinforced concrete wall (diaphragm wall or equivalent). A physical barrier will be constructed close to the reinforced concrete basement wall to prevent direct contact of basement users with seepage.

Table 72 Comparison of Derived and Proposed Soil SSTC – Scenario 2 to Scenario 8

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		Scenario 8 – Commercial Slab on Ground (Multi-storey Building)	
		Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed
Acenaphthylene	163	-	-	-	-	-	-	-	-	29,300	##	-	-	-	-
Benz(a)anthracene	3.33	-	-	-	-	-	-	-	-	(see CPAH)		-	-	-	-
Benzene	659	126	130	377	380	34,500	##	131	130	1,320	1,320	515	520	0.405	0.4
Benzo(a)pyrene	1.90	-	-	-	-	-	-	-	-	(see CPAH)		-	-	-	-
Benzo(b)fluoranthene	1.80	-	-	-	-	-	-	-	-	(see CPAH)		-	-	-	-
Benzo(g,h,i)perylene	1.01	-	-	-	-	-	-	-	-	(see CPAH)		-	-	-	-
Benzo(k)fluoranthene	0.94	-	-	-	-	-	-	-	-	(see CPAH)		-	-	-	-
Chrysene	0.72	-	-	-	-	-	-	-	-	(see CPAH)		-	-	-	-
Cresols (total)	8,510	***16,500***	***17,000***	***61,300***	***61,000***	***51,610,000***	***##***	***18,200***	***18,000***	***3,080***	***3,100***	***78,800***	***79,000***	***53.1***	***53***
Dibenz(a,h)anthracene	9.51	-	-	-	-	-	-	-	-	(see CPAH)		-	-	-	-
Dibenzofuran	56.9	***4,190,000***	***##***	***32,000,00***	***##***	***2,930,000,000***	***##***	***9,500,00***	***##***	***300,000***	***##***	***20,000,000***	***##***	***##***	***##***
Dimethylphenol-2,4	8,000	-	-	-	-	-	-	-	-	36,200	36,000	-	-	-	-
Ethylbenzene	167	***3,050***	***##***	***13,900***	***##***	***1,280,000***	***##***	***4,140***	***##***	26,600	##	***14,600***	***##***	***9.83***	***10***
Fluoranthene	28.9	-	-	-	-	-	-	-	-	19,500	##	-	-	-	-
Indeno(1,2,3-cd)pyrene	0.74	-	-	-	-	-	-	-	-	(see CPAH)		-	-	-	-
Lead	-	-	-	-	-	-	-	-	-	10,800	11,000	-	-	-	-
Methylnaphthalene, 1	129	-	-	-	-	-	-	-	-	72,200	##	-	-	-	-
Methylnaphthalene, 2-	123	***5,450***	***##***	***32,600***	***##***	***2,980,000***	***##***	***9,670***	***##***	41,300	##	***26,100***	***##***	***17.6***	***18***
Naphthalene	96.6	207	210	1,070	##	979,000	##	318	320	4,750	##	988	##	0.666	0.7
Pyrene	14.7	-	-	-	-	-	-	-	-	14,700	##	-	-	-	-
Toluene	291	***30,600***	***##***	***123,000***	***##***	***11,300,000***	***##***	***36,600***	***##***	88,000	##	146,000	##	***98.6***	***99***
TPH C_6-C_8 aliphatic ($)	71.4	13,400	##	41,900	##	3,840,000	##	12,500	##	455,000	##	64,000	##	43.1	60
TPH >C_8-C_{10} aliphatic ($)	30.4	2,760	##	8,660	##	792,000	##	2,570	##	9,090	##	13,200	##	8.9	
TPH >C_8-C_{10} aromatic ($)	213	2,500	##	7,830	##	716,000	##	2,330	##	3,570	##	11,900	##	8.05	
TPH >C_{10}-C_{12} aliphatic ($)	17.9	4,900	##	15,400	##	1,410,000	##	4,570	##	6,850	19,000	23,400	##	15.8	250
TPH >C_{12}-C_{16} aliphatic ($)	7.69	21,800	##	68,300	##	6,250,000	##	20,300	##	6,850		104,000	##	70.2	
TPH >C_{10}-C_{12} aromatic ($)	0.003	8,130	##	25,500	##	2,330,000	##	7,570	##	2,740		38,900	##	26.2	
TPH >C_{12}-C_{16} aromatic ($)	0.0005	42,500	##	133,000	##	12,200,000	##	39,600	##	2,740		203,000	##	137	
TPH >C_{16}-C_{21} aliphatic ($)	3.16	-	-	-	-	-	-	-	-	137,000	##	-	-	-	-
TPH >C_{21}-C_{34} aliphatic ($)	3.16	-	-	-	-	-	-	-	-	137,000	##	-	-	-	-
TPH >C_{16}-C_{21} aromatic ($)	20.6	-	-	-	-	-	-	-	-	2,060	##	-	-	-	-
TPH >C_{21}-C_{34} aromatic ($)	1.66	-	-	-	-	-	-	-	-	2,060	##	-	-	-	-
TPH >C_{34}-C_{40} aliphatic ($)	-	-	-	-	-	-	-	-	-	2,720,000	##	-	-	-	-

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		Scenario 8 – Commercial Slab on Ground (Multi-storey Building)	
		Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed
TPH >C_{34}-C_{40} aromatic ($)	-	-	-	-	-	-	-	-	-	4,110	##	-	-	-	-
Trimethylbenzene, 1,2,4-	74.6	72.3	70	374	370	34,200	##	111	110	16,000,000	##	346	350	0.233	0.2
Xylenes (total)	8.90	***8,540***	***##***	***31,600***	***##***	***2,890,000***	***##***	***9,390***	***##***	72,000	##	***40,800***	##	***27.5***	***28***
CPAH	-	-	-	-	-	-	-	-	-	128	130	-	-	-	-

Notes:
Shading = SSTC exceeds saturation limit however the derived SSTC is within 10 times the saturation limit.
= an SSTC has not been determined for remediation purposes as the derived level is at least 10 times greater than saturation 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)
Italics= odour SSTC (where lower than human health SSTC). Refer to Section 6.1 for odour SSTC calculations.

$ = SSTC is greater than 10 times the saturation/ solubility limit: **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_{10} 7,500 mg/kg, >C_{10}-C_{16} 70,000 mg/kg and C_{16+} 130,000 mg/kg.

Key Assumptions:

- The derivation of SSTCs has been based on design concepts and assumptions provided by LL and Crown.
- The development of SSTCs has assumed that tar will not be present in the immediate vicinity of outer basement walls, 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_{10} and >C_{10}-C_{16} to account for the overconservative nature of vapour modelling associated with these chemicals (CCME, 2010 and Friebel and Nadebaum, 2011)
- 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) and vapour pressure is greater than 1mmHg at room temperature (*ASC NEPM*, 2013)
- The air exchange rate within the basement car park has been assumed to be an average of 3.5 air exchanges per hour (AECOM, 2012f). This air exchange rate is based on the proposed approach to the basement car park ventilation for the Crown basement (AECOM, 2014) (refer to **Appendix JJ**). It is understood that it is consistent with the Australian Standard AS 1668.2 and accounts for periods of decreased ventilation when vehicle movement in the basement is minimal. .
- 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 in **Section 5.3.10.**

Table 73 Comparison of Derived and Proposed Groundwater SSTC – Scenario 9 to Scenario 14

Chemical	Solubility Limits (mg/L)	Groundwater Health and /or Odour Target Criteria (SSTC) (lowest of health and odour based) (mg/L)											
		Scenario 9 – Crown Upper Basement		Scenario 10 – Crown Unpaved Recreation		Scenario 11 – Crown Paved Recreation		Scenario 12 – Crown Intrusive Maintenance		Scenario 13 – Crown High Density Residential		Scenario 14 – Crown Commercial Slab on Ground (Multi-storey Building)	
		Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed
Acenaphthene	3.9	***21,600***	##	***2,060,000***	##	***17,100,000***	##	***222***	##	***49,400***	##	***2,150***	##
Acenaphthylene	16	-	-	-	-	-	-	-	-	-	-	-	-
Ammonia	482,000	15,000	15,000	2,980,000	2,980,000	29,300,000	##	***39,700***	***40,000***	34,400	34,000	4,500	4,500
Aniline	36,000	***1,070,000***	##	***2,330,000,000***	##	***37,000,000,000***	##	***9,250***	***9,300***	***2,460,000***	##	***2,990,000***	##
Anthracene	0.0434	-	-	-	-	-	-	-	-	-	-	-	-
Arsenic	-	-	-	-	-	-	-	-	-	-	-	-	-
Barium	-	-	-	-	-	-	-	-	-	-	-	-	-
Benz(a)anthracene	0.0094	-	-	-	-	-	-	-	-	-	-	-	-
Benzene	1,790	831	800	1,450	1,500	10,800	11,000	1,060	1,000	1,630	1,600	1.87	2
Benzo(a)pyrene	0.00162	-	-	-	-	-	-	-	-	-	-	-	-
Benzo(b)fluoranthene	0.0015	-	-	-	-	-	-	-	-	-	-	-	-
Benzo(g,h,i)perylene	0.00026	-	-	-	-	-	-	-	-	-	-	-	-
Benzo(k)fluoranthene	0.0008	-	-	-	-	-	-	-	-	-	-	-	-
Bis(2-ethylhexyl)phalate	0.27	-	-	-	-	-	-	-	-	-	-	-	-
Cadmium	-	-	-	-	-	-	-	-	-	-	-	-	-
Chrysene	0.002	-	-	-	-	-	-	-	-	-	-	-	-
Cobalt	-	-	-	-	-	-	-	-	-	-	-	-	-
Cresols (total)	25,900	***353***	***350***	***1,110,000***	##	***18,100,000***	##	***2.73***	***3***	***808***	***800***	***1,450***	***1,500***
Dibenz(a,h)anthracene	0.00249	-	-	-	-		-	-	-	-	-	-	-
Dibenzofuran	3.1	***214,000***	##	***21,900,000***	##	***181,000,000***	##	***2,210***	##	***490,000***	##	***7,690***	##
Dimethylphenol, 2,4-	7,870	-	-	-	-	-	-	-	-	-	-	-	-
Ethylbenzene	169	69,200	##	130,000	##	965,000	##	***1,100***	***1,000***	158,000	##	138	140
Fluoranthene	0.26	-	-	-	-	-	-	-	-	-	-	-	-
Fluorene	1.69	-	-	-	-	-	-	-	-	-	-	-	-
Indeno(1,2,3-cd)pyrene	0.00019	-	-	-	-	-	-	-	-	-	-	-	-
Lead	-	-	-	-	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-	-	-	-	-
Methylnaphthalene, 1-	28	-	-	-	-	-	-	-	-	-	-	-	-
Methylnaphthalene, 2-	24.6	***2,490***	##	***88,400***	##	***683,000***	##	***25.7***	***26***	***5,680***	##	***91.6***	***90***
Naphthalene	31	128	130	4,640	##	36,000	##	***194***	***195***	293	290	4.91	5
Nickel	-	-	-	-	-	-	-	-	-	-	-	-	-
Phenanthrene	1.15	-	-	-	-	-	-	-	-	-	-	-	-
Phenol	82,800	***72,800***	***73,000***	***475,000,000***	##	***8,010,000,000***	##	***340***	***340***	***166,000***	***170,000***	***625,000***	***625,000***

Chemical	Solubility Limits (mg/L)	Groundwater Health and /or Odour Target Criteria (SSTC) (lowest of health and odour based) (mg/L)											
		Scenario 9 – Crown Upper Basement		Scenario 10 – Crown Unpaved Recreation		Scenario 11 – Crown Paved Recreation		Scenario 12 – Crown Intrusive Maintenance		Scenario 13 – Crown High Density Residential		Scenario 14 – Crown Commercial Slab on Ground (Multi-storey Building)	
		Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed
Pyrene	0.135	-	-	-	-	-	-	-	-	-	-	-	-
Styrene	310	55,600	##	287,000	##	2,140,000	##	***3,000***	***3,000***	127,000	##	307	310
Toluene	526	267,000	##	523,000	##	3,890,000	##	***16,600***	##	611,000	##	567	570
TPH C_6-C_8 aliphatic ($)	5.4	294,000	310,000	4,500	8,000	33,500	60,000	31.2	6,500	671,000	715,000	5.06	9
TPH >C_8-C_{10} aliphatic ($)	0.43	16,000		174		1,290		22.1		36,500		0.195	
TPH >C_8-C_{10} aromatic ($)	65	3,190		3,380		25,200		6,460		7,300		3.8	
TPH >C_{10}-C_{12} aliphatic ($)	0.034	12,000	29,000	41.5	26,000	308	190,000	5.28	49,000	27,500	66,000	0.0466	30
TPH >C_{12}-C_{16} aliphatic ($)	0.00076	12,000		9.57		71.1		1.22		27,500		0.0108	
TPH >C_{10}-C_{12} aromatic ($)	0.00063	2,400		7,070		52,800		13,500		5,490		7.96	
TPH >C_{12}-C_{16} aromatic ($)	0.000048	2,400		18,500		139,000		35,200		5,500		20.9	
TPH >C_{16}-C_{21} aliphatic ($)	0.0000025	-	-	-	-	-	-	-	-	-	-	-	-
TPH >C_{21}-C_{34} aliphatic ($)	0.0000025	-	-	-	-	-	-	-	-	-	-	-	-
TPH >C_{16}-C_{21} aromatic ($)	0.65	-	-	-	-	-	-	-	-	-	-	-	-
TPH >C_{21}-C_{34} aromatic ($)	0.0066	-	-	-	-	-	-	-	-	-	-	-	-
TPH >C_{34}-C_{40} aliphatic ($)	-	-	-	-	-	-	-	-	-	-	-	-	-
TPH >C_{34}-C_{40} aromatic ($)	-	-	-	-	-	-	-	-	-	-	-	-	-
Trimethylbenzene, 1,2,4-	57	1,500	##	4,030	##	30,100	##	1,320	##	3,420	##	4.25	4
Trimethylbenzene, 1,3,5-	48.2	7,480	##	1,4300	##	106,000	##	4,680	##	17,100	##	15	15
Xylenes (total)	6.7	46,500	##	107,000	##	796,000	##	***2,390***	##	106,000	##	117	##
CPAH # [1]	-	-	-	-	-	-	-		-	-	-	-	-

Notes:
Shading = SSTC exceeds aqueous solubility limit however the derived SSTC is within 10 times the solubility limit.
= an SSTC has not been determined for remediation purposes as the derived level is at least 10 times greater than 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)
Italics= odour SSTC (were lower than human health SSTC). Refer to Section 6.1 for odour SSTC calculations.
$ = 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 characteristics of an analytical surrogate.

Key Assumptions:

- The derivation of SSTCs has been based on design concepts and assumptions provided by Crown.
- The development of SSTCs has assumed that tar will not be present in the immediate vicinity of outer basement walls, 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 upper basements a windspeed of 0.03 m/sec within the basements (Scenario 9 and 13) has been modelled
- Chemicals are assumed to be volatile if Henry's Law constant is greater than 1×10^{-5} atm-m^3/mole (USEPA,2004) and vapour pressure greater than 1mmHg at room temperature (*ASC NEPM*, 2013).
- The air exchange rate within the basement car park has been assumed to be an average of 3.5 air exchanges per hour. This air exchange rate is based on the proposed approach to the basement car park ventilation for the Crown basement (AECOM, 2014) (refer to **Appendix JJ**). It is understood that it is consistent with the Australian Standard AS 1668.2 and accounts for periods of decreased ventilation when vehicle movement in the basement is minimal (AECOM, 2012h).
- In basement scenarios (9 and 13) it has been assumed that no more than two walls will be in contact with contaminated soil / groundwater. It has also 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, where present, will comprise a reinforced concrete wall (diaphragm wall or equivalent). A physical barrier will be constructed close to the reinforced concrete basement wall to prevent direct contact of basement users with seepage.

Table 74 Comparison of Derived and Proposed Soil SSTC – Scenario 9 to Scenario 14

Chemical	Saturation Limits (mg/kg)	Soil Health and /or Odour Target Criteria (SSTC) (lowest of health and odour based) (mg/kg)											
		Scenario 9 – Crown Upper Basement		Scenario 10 – Crown Unpaved Recreation		Scenario 11 – Crown Paved Recreation		Scenario 12 – Crown Intrusive Maintenance Worker		Scenario 13 – Crown High Density Residential		Scenario 14 – Crown Commercial Slab on Ground (Multi-storey Building)	
		Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed
Acenaphthylene	163	-	-	-	-	-	-	29,300	##	-	-	-	-
Benz(a)anthracene	3.33	-	-	-	-	-	-	See CPAH		-	-	-	-
Benzene	659	93	90	754	750	35,200	##	1,320	1,320	381	380	1.83	2
Benzo(a)pyrene	1.90	-	-	-	-	-	-	See CPAH		-	-	-	-
Benzo(b)fluoranthene	1.80	-	-	-	-	-	-	See CPAH		-	-	-	-
Benzo(g,h,i)perylene	1.01	-	-	-	-	-	-	See CPAH		-	-	-	-
Benzo(k)fluoranthene	0.94	-	-	-	-	-	-	See CPAH		-	-	-	-
Chrysene	0.72	-	-	-	-	-	-	See CPAH		-	-	-	-
Cresols (total)	8,510	***12,200***	***12,000***	***123,000***	##	***5,720,000***	##	***3,080***	***3,100***	***584,000***	##	***247***	***250***
Dibenz(a,h)anthracene	9.51	-	-	-	-	-	-	See CPAH		-	-	-	-
Dibenzofuran	56.9	***3,110,000***	##	***64,100,000***	##	***2,990,000,000***	##	300,000	##	***14,800,000***	##	***13,500***	##
Dimethylphenol-2,4	8,000	-	-	-	-	-	-	36,200	36,000	-	-	-	-
Ethylbenzene	167	***2,260***	##	***27,900***	##	***1,300,000***	##	26,600	##	***43,200***	##	***50.5***	***50***
Fluoranthene	28.9	-	-	-	-	-	-	19,500	##	-	-	-	-
Indeno(1,2,3-cd)pyrene	0.74	-	-	-	-	-	-	See CPAH		-	-	-	-
Lead	-	-	-	-	-	-	-	10,800	11,000	-	-	-	-
Methylnaphthalene, 1	129	-	-	-	-	-	-	72,200	##	-	-	-	-
Methylnaphthalene, 2-	123	***4,040***	##	***65,200***	##	***3,040,000***	##	41,300	##	***19,300***	##	***105***	***100***
Naphthalene	96.6	153	150	2,140	##	99,900	##	4,750	##	732	730	3.66	4
Pyrene	14.7	-	-	-	-	-	-	14,700	##	-	-	-	-
Toluene	291	***22,700***	##	***246,000***	##	***11,500,000***	##	88,000	##	***108,000***	##	***476***	***480***
TPH C_6-C_8 aliphatic ($)	71.4	9,910		83,900		3,910,000		455,000		47,400		186	
TPH >C_8-C_{10} aliphatic ($)	30.4	2,050	##	17,300	##	808,000	##	9,090	##	9,780	##	38.3	260
TPH >C_8-C_{10} aromatic ($)	213	1,850		15,700		730,000		3,570		8,850		34.7	
TPH >C_{10}-C_{12} aliphatic ($)	17.9	3,630		30,700		1,430,000		6,850		17,400		68	
TPH >C_{12}-C_{16} aliphatic ($)	7.69	16,100	##	137,000	##	6,370,000	##	6,850	19,000	77,200	##	302	1,100
TPH >C_{10}-C_{12} aromatic ($)	0.003	6,020		50,900		2,380,000		2,740		28,800		113	
TPH >C_{12}-C_{16} aromatic ($)	0.0005	31,500		266,000		12,400,000		2,740		151,000		590	
TPH >C_{16}-C_{21} aliphatic ($)	3.16	-	-	-	-	-	-	13,700	##	-	-	-	-
TPH >C_{21}-C_{34} aliphatic ($)	3.16	-	-	-	-	-	-	13,700	##	-	-	-	-
TPH >C_{16}-C_{21} aromatic ($)	20.6	-	-	-	-	-	-	2,060	##	-	-	-	-
TPH >C_{21}-C_{34} aromatic ($)	1.66	-	-	-	-	-	-	2,060	##	-	-	-	-
TPH >C_{34}-C_{40} aliphatic ($)	-	-	-	-	-	-	-	2,720,000	##	-	-	-	-

Chemical	Saturation Limits (mg/kg)	Soil Health and /or Odour Target Criteria (SSTC) (lowest of health and odour based) (mg/kg)											
		Scenario 9 – Crown Upper Basement		Scenario 10 – Crown Unpaved Recreation		Scenario 11 – Crown Paved Recreation		Scenario 12 – Crown Intrusive Maintenance Worker		Scenario 13 – Crown High Density Residential		Scenario 14 – Crown Commercial Slab on Ground (Multi-storey Building)	
		Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed	Derived	Proposed
TPH >C_{34}-C_{40} aromatic ($)	-	-	-	-	-	-	-	4,110	##	-	-	-	-
Trimethylbenzene, 1,2,4-	74.6	53.6	50	747	##	34,900	##	16,000,000	##	256	250	1.28	1
Xylenes (total)	8.90	***6,330***	##	***63,200***	##	***2,950,000***	##	72,000	##	***30,200***	##	***128***	***##***
CPAH	-	-	-	-	-	-	-	128	130	-	-	-	-

Notes:
Shading = SSTC exceeds saturation limit however the derived SSTC is within 10 times the saturation limit.
= an SSTC has not been determined for remediation purposes as the derived level is at least 10 times greater than saturation 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)
Italics= odour SSTC (where lower than human health SSTC). Refer to Section 6.1 for odour SSTC calculations.

$ = SSTC is greater than 10 times the saturation/ solubility limit: **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_{10} 7,500 mg/kg, >C_{10}-C_{16} 70,000 mg/kg and C_{16+} 130,000 mg/kg.

Key Assumptions:
- The derivation of SSTCs has been based on design concepts and assumptions provided by Crown.
- The development of SSTCs has assumed that tar will not be present in the immediate vicinity of outer basement walls, 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_{10} and >C_{10}-C_{16} to account for the overconservative nature of vapour modelling associated with these chemicals (CCME, 2010 and Friebel and Nadebaum, 2011)
- 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) and vapour pressure is greater than 1mmHg at room temperature (*ASC NEPM*, 2013)
- The air exchange rate within the basement car park has been assumed to be an average of 3.5 air exchanges per hour (AECOM, 2012f). This air exchange rate is based on the proposed approach to the basement car park ventilation for the Crown basement (AECOM, 2014) (refer to **Appendix JJ**). It is understood that it is consistent with the Australian Standard AS 1668.2 and accounts for periods of decreased ventilation when vehicle movement in the basement is minimal. .
- It has been assumed that 1.0 m of Suitable Fill, as defined by **Section 5.3.10**, will be used to raise the ground level within the Crown Site.

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 T4** to **Table T9** and **Table T25** to **Table T29**, for Scenarios 2 to 14, respectively (note that soil SSTC were not derived for Scenario 1 as this scenario relates to exposure to groundwater derived contaminants only).

The tables presented in **Section 5.5.7** provide a summary of the proposed SSTC for TPH in soil and groundwater. It is noted that proposed SSTC for the TPH C_6-C_{10} fraction are the sum of SSTC derived for the following fractions: TPH C_6-C_8 aliphatic, TPH C_8-C_{10} aliphatic and aromatic. Therefore the proposed TPH C_6-C_{10} SSTC does not include consideration of TPH C_6-C_8 aromatic (which consists mostly of the BTEX compounds), i.e. it applies to TPH C_6-C_{10} minus BTEX. It was not considered necessary to include TPH C_6-C_8 aromatic when deriving the criteria for TPH C_6-C_{10} because the primary constituents in the TPH C_6-C_8 aromatic range are BTEX compounds for which individual SSTC have been separately derived, therefore including TPH C_6-C_8 aromatic when deriving the criteria for TPH C_6-C_{10} would result in the BTEX compounds effectively being assessed twice.

As the soil data available for the Site were collected prior to release of the amended ASC NEPM (NEPC, 2013) the results are reported as TPH C6-C9. Therefore as a conservative approach the TPH C_6-C_{10} (minus BTEX) SSTC have been used to screen the TPH C_6-C_9 data, with BTEX concentrations also being screened separately. No exceedences of TPH C_6-C_{10} SSTC were reported in soil within the ORWN Area therefore it was not considered necessary to refine the screening approach any further.

The nature and extent of soil SSTC exceedances are summarised in **Table 75** below. Relevant exceedances of soil SSTC for Scenario 8 are illustrated in **Figure F9**. Note that only scenarios with relevant exceedances (i.e. Scenario 8) are illustrated on the figures in **Appendix A**.

The exceedances shown in **Table 75** below are representative of soil concentrations within the unsaturated zone (i.e. collected from depths ranging from 0 m bgl to 2 m bgl based on existing surface levels) of the Site.

Table 75 Summary of Soil SSTC Exceedances with the ORWN Area

Scenario	Chemicals Exceeding SSTC	Locations/ Depths of Key Concern	Notes
1 – Lower Basement	Not applicable; soil exposure pathways not complete for this scenario, therefore no soil SSTC have been derived / proposed.		
2 – Upper Basement	None	NA	Note that naphthalene concentrations exceeded the soil SSTC within five samples locations (BH40 at 16.5-16.7, BH46 at 14.5-14.7, BH60 at 16-16.4 and 17.5-17.7 and BH191 at 16.5) considered to be within the saturated zone (i.e. >2m below the current ground level). These impacts are not considered to contribute to vapour risks from soil at the Site.
3 – Unpaved Recreation	None	NA	NA
4 – Paved Recreation	All derived soil SSTC are greater than 10 times theoretical saturation limits therefore no soil SSTC are proposed for this exposure scenario (see **Table 72**).		
5 – Commercial Slab on Ground (2 storey)	None	NA	NA
6 – Intrusive Maintenance – contact with groundwater	None	NA	NA
7 – High Density Residential	None	NA	NA

Scenario	Chemicals Exceeding SSTC	Locations/ Depths of Key Concern	Notes
8 – Multistorey Commercial Slab on Ground (with advection)	Naphthalene	BH063 (1.5-1.65 m) (See **Figure F9**)	Potential risks (associated with on-Site concentrations of naphthalene) have been identified based on modelling assumptions used in this scenario. Benzene, xylene, 2,-methylnaphthalene, naphthalene, TPH C_6 – C_{10} and TPH >C_{10}-$C_{16,}$ exceeded the soil SSTC at a number of locations considered to be within the saturated zone (>2m bgl). These impacts are not considered to contribute to vapour risks from soil at the Site.
9 – Crown Specific Upper Basement	None	NA	Note that naphthalene concentrations exceeded the soil SSTC within two samples (BH60_16-16.4 and BH60_ 17.5-17.7) considered to be within the saturated zone (i.e. >2m below the current ground level). These impacts are not considered to contribute to vapour risks from soil at the Site.
10 – Crown Specific Unpaved Recreation	None	NA	NA
11 – Paved Recreation	All derived soil SSTC are greater than 10 times theoretical saturation limits therefore no soil SSTC are proposed for this exposure scenario (see **Table 74**).		
12 – Intrusive Maintenance – no potential contact with groundwater	None	NA	NA
13 – Crown Specific High Density Residential	None	NA	NA
14 – Crown Specific Multistorey Commercial Slab on Ground (with advection)	None	NA	Benzene, 1,2,4-trimethylbenzene and naphthalene concentrations exceeded the soil SSTC at a number of locations considered to be within the saturated zone (i.e. >2m below the current ground level) (BH40 at 16.5-16.7, 17.8-18, 19-19.4, BH46 at 14.5-14.7, BH56 at 7-7.2, BH60 at 16-16.4 and 17.5-17.7, BH72 at 13-13.5 and 16-16.2, BH021 at 16-16.5 and BH191 at 3.7 and 16.5). These impacts are not considered to contribute to vapour risks from soil at the Site.

5.6.1.2 Groundwater

SSTC for groundwater are compared to reported CoPC concentrations in groundwater samples from the Site in **Table T10** to **Table T17** and **Table T30** to **Table T35** for Scenario 1 to Scenario 14, respectively.

As noted in **Section 5.6.1.1**, the tables presented in **Section 5.5.7** provide a summary of the proposed SSTC for TPH in soil and groundwater. It is noted that proposed SSTC for the TPH C_6-C_{10} fraction are the sum of SSTC derived for the following fractions: TPH C_6-C_8 aliphatic, TPH C_8-C_{10} aliphatic and aromatic. Therefore the proposed TPH C_6-C_{10} SSTC does not include consideration of TPH C_6-C_8 aromatic (which consists mostly of the BTEX compounds), i.e. it applies to TPH C_6-C_{10} minus BTEX. It was not considered necessary to include TPH C_6-C_8 aromatic when deriving the criteria for TPH C_6-C_{10}, because the primary constituents in the TPH C_6-C_8

aromatic range are BTEX compounds, for which individual SSTC have been separately derived. Including TPH C_6-C_8 aromatic when deriving the criteria for TPH C_6-C_{10} would result in the BTEX compounds effectively being assessed twice.

As the groundwater data available for the Site were collected prior to release of the amended ASC NEPM (NEPC, 2013) the results are reported as TPH C_6-C_9. Therefore as a conservative approach the TPH C_6-C_{10} (minus BTEX) SSTC have been used to screen the TPH C_6-C_9 data, with BTEX concentrations also being screened separately.

The nature and extent of groundwater SSTC exceedances detailed in **Table T10** to **Table T17** and **Table T30** to **Table T35** are summarised in **Table 76** below. Exceedances of SSTC for Scenarios 6 and 8 are shown in **Figure F10** and **Figure F11**.

Note that only scenarios with relevant exceedances (i.e. Scenarios 6 and 8) are illustrated on the figures in **Appendix A**.

Table 76 Summary of Groundwater SSTC Exceedances

Scenario	Chemicals Exceeding SSTC	Locations/ Depths of Key Concern	Notes
1 – Lower Basement	None	NA	NA
2 – Upper Basement	None	NA	NA
3 – Unpaved Recreation	None	NA	NA
4 – Paved Recreation	None	NA	NA
5 – Commercial Slab on Ground (2 storey)	None	NA	NA
6 – Intrusive Maintenance – contact with groundwater	Naphthalene TPH >C_{10}-C_{16}	BH60/MW60 (See **Figure F10**)	MW60 is screened across the fill/natural interface therefore contamination is likely to be present within the marine sediments. SSTC are driven primarily by dermal water contact pathway.
7 – High Density Residential	None	NA	NA
8 – Multistorey Commercial Slab on Ground (with advection)	Benzene TPH C_6 – C_{10} TPH >C_{10} – C_{16}	BH60/MW60 (See **Figure F11**)	MW60 is screened across the fill/natural interface therefore contamination is likely to be present within the marine sediments. SSTC are driven primarily by the inhalation pathway only.
9 – Crown Specific Upper Basement	None	NA	NA
10 – Crown Specific Unpaved Recreation	None	NA	NA
11 – Crown Specific Paved Recreation	None	NA	NA
12 – Intrusive Maintenance – no potential contact with groundwater	None	NA	NA
13 – Crown Specific High Density Residential	None	NA	NA
14 – Crown Specific Multistorey Commercial Slab on Ground (with advection)	None	NA	NA

5.6.2 Asbestos

As described by **Section 4.2.1**, only a limited number of samples from the Site have been analysed for asbestos. In particular:

- No visual evidence of asbestos was recorded in any of the investigations;
- A total of 44 soil samples (5 collected by AECOM (2010c) and 39 collected by ERM (2008a)) were analysed for the presence of asbestos using standard Polarised Light Microscopy techniques including dispersion staining. Chrysotile asbestos was detected in a single sample (BH203_1.5) which was not located within the Site.
- No samples were analysed for the asbestos concentration in soil in accordance with the gravimetric approach recommended by Schedule B1 of the NEPM (*ASC NEPM*, 2013).

As such, none of the data is suitable for direct comparison against the asbestos SSTC for intrusive maintenance workers.

However, data collected and observations made, during excavation of the Stage 1A basement (within the ORWS Area) indicates that there is potential for asbestos to be present at the Site.

5.7 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, unacceptable human health risks are generally not expected at the Site following redevelopment, with the exception of the following.

- **Scenario 6 (Intrusive Maintenance) – potential contact with groundwater**: The highest reported concentrations of naphthalene and TPH C_{10}-C_{14} fraction in groundwater within the ORWN Area have the potential to result in unacceptable health risks to intrusive maintenance workers. The predominant risk driving pathway was identified as dermal contact of intrusive maintenance workers with groundwater. Locations where reported concentrations may result in a potential risk are near the northern edge of the Site, and based on the proposed Crown Hotel Development, the location of these exceedances would be within the proposed Crown Basement. It is considered unlikely that services installed in this area would be constructed at a depth where groundwater contact was probable (that is, the depth to groundwater is approximately 2.5 m (outside of the Crown Hotel Development) and the groundwater is saline which would be corrosive to below ground services). In addition, it is likely that the reported elevated groundwater concentrations are representative of groundwater quality within marine sediments which are present at depths significantly greater than 2.5 m and from which contaminant flux has been shown to be minimal. Consequently, under the assumed exposure scenarios presented in the HHERA it is considered unlikely that the reported groundwater concentrations in the ORWN would result in an unacceptable health risk for the intrusive maintenance worker. It is also considered that all intrusive maintenance works will be undertaken in accordance with state occupational health and safety requirements and personal protective equipment will be worn.
- **Scenario 8 (Multistorey Commercial Slab on Ground, with Advection)**: The highest reported concentrations of naphthalene in soil and benzene, TPH C_6-C_{10} and TPH >C_{10}-C_{16} in groundwater within the ORWN Area have the potential to result in unacceptable health risks to commercial employees working in a building where advection vapour intrusion processes occur. Locations where reported concentrations may result in a potential risk are near the eastern and northern edges of the Site, and the potential health risk assumes that the future multi-storey commercial slab-on-ground building is on top of these impacted areas. Based on the proposed Crown Hotel Development, the location of these exceedances would be within the proposed Crown Basement and therefore this exposure scenario would not be relevant.

Based on proposed future land use at the Site, there is also potential for intrusive maintenance workers (only) to encounter asbestos in soils during intrusive works. There is currently insufficient data to determine the potential for risks associated with asbestos in soil within the ORWN Area. However, available data collected during excavation of the ORWS Area indicates that there is a significant potential for asbestos containing material to be present. In order to address the potential for future exposures to asbestos at the Site, the current HHERA presents risk based SSTC for asbestos in soils. The future ORWN RAP will be required to consider these SSTCs to minimise the potential for unacceptable risks to intrusive maintenance workers.

Human health risks are not expected to be associated with Scenarios other than 6 and 8. This is because SSTC for these scenarios were not exceeded by reported Site contaminant concentrations, or reported exceedances are not considered to pose a health risk based on consideration of their location, nature and/or extent.

Furthermore is considered that remediation works undertaken in the NSW EPA Declaration Area (including the Block 4 Development Works Area) will result in an overall reduction in groundwater contaminant concentrations within the ORWN Area.

A separate assessment of potential risks to human health from exposure to sediments and surface water within the potential Southern Cove has not been undertaken. This is because, in the event that construction of the potential Southern Cove requires excavation of existing fill, the material at the new surface of the potential Southern Cove will be required to meet the ANZECC (2000) ISQG, which are considered to be suitably protective of incidental recreational exposures for humans and the surface water will be of the same composition and makeup of Darling Harbour. It is also considered that any future design within Southern Cove will prevent direct contact with sediments under normal exposures.

With respect to potential human health risks associated with material which may be reused within the Site, it is expected that material which meets criteria for Scenarios 3 through 6 and 8 would be suitable for reuse from a human health perspective in areas/locations where respective land use and human exposure assumptions are met. It is understood that the proposed Crown Hotel Development specifically excludes the reuse material.

Criteria for the suitability of materials for placement in:

- Other areas of Barangaroo South have been developed by the *ORWS HHERA Addendum* (AECOM, 2011b) and *Declaration Area (Development Works) HHERA* (AECOM, 2011b); and
- Barangaroo Central and Headland Park have been developed by the Authority (JBS, 2011).

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, given the proximity of the Site to a former gasworks and the presence of gasworks related contamination within the Site, it is expected that odours are likely to be emitted during remediation of the Site. It is for this reason that this HHERA provides an indication of the chemicals likely to be present at the Site at concentrations that have the potential to be odorous. In order to aid the remediation process, odour-based SSTC ($SSTC_{odour}$) have been derived, which will 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 14 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 T18** of **Appendix B**. These odour thresholds have been considered to be most relevant to this HHERA as they have been reviewed by ATSDR and IRIS and found to be acceptable. This approach is consistent with recommended sources published by *ASC NEPM* (2013) and enHealth (2012).

  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 this 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 on the threshold at which some members of the population may be able to detect the odour under certain conditions. In reality the threshold at which the general population is able to detect odours are highly dependent on weather conditions such as wind speed and temperature and the 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 $SSTC_{odour}$.

- 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 has conservatively removed the 10 fold soil partitioning factor applied in the derivation of risk based SSTCs (see **Section 5.3.6**).

- 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.

- To date there is limited information available with regards to the effects of chemical mixtures on odour levels and 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 estimated $SSTC_{odour}$ are detailed in **Appendix M** to **Appendix T** and **Appendix DD** to **Appendix II** and compared to reported soil and groundwater concentrations at the Site in **Table T4** to **Table T9** and **Table T25** to **Table T29** (for soil) and **Table T10** to **Table T17** and **Table T30** to **Table T35** (for groundwater).

One exceedance of the $SSTC_{odour}$ by reported soil concentrations at the Site was noted for 2-methylnapthalene for Scenario 8, in BH40 at 16.5 m to 16.7 m. Due to the depth of this exceedance it is considered unlikely that this material will be exposed.

AECOM notes that while comparison of Site data to derived $SSTC_{odour}$ indicates only one exceedance within the Site, observations during intrusive Site investigations have indicated that relatively small scale excavations or intrusive works have potential to result in localised odour issues.

Locations where odour issues may occur are likely to be a result of 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 to mitigate risks to human health and excavation of the proposed basement will remove contamination with the potential to generate odour and therefore result in a reduction in the potential for odour generation. It should also be noted that areas of the Site that will not be the subject of remediation or basement excavation and in which potentially odorous material may remain *in situ* will be covered by clean fill (referred to as 'Suitable Fill') and/or concrete paving / hardstand which will further reduce the potential for odour generation (**Figure F14** of **Appendix A**).

6.2 Visual Amenity

6.2.1 Fill Material

It is noted that observations made during previous intrusive works have indicated the presence of highly variable fill material at the Site, including gravel, sand, bricks, timber, slag and steel. 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 Asbestos

As required by the *ASC NEPM* (2013), all surface soils, which based on considerations of practicality has for the purpose of the HHERA been taken to include Suitable Fill (refer to **Section 5.5.6**), must contain 'no visible asbestos'.

6.2.3 Tar Seepage into Basements

As noted in **Section 3.4**, the vertical extent of SPGWT within fractured bedrock underlying the Site is not known with certainty. Given the depth to bedrock within the Site, it is considered unlikely that any future excavation works will extend to bedrock. Visual amenity issues due to tar seeps within basements are therefore not expected.

However, in the event that excavation to bedrock is required, SPGWT may cause visual amenity impacts within basements excavated into bedrock if:

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

As noted above in **Section 5.5.5**, for the purposes of SSTC derivation it has been assumed that SPGWT will not be present in soil within the immediate vicinity of the basement retention walls; this is in accordance with the NSW EPA Guidelines (NSW DEC, 2007).

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.

If necessary based on the final basement design, the RAP will provide contingency measures to mitigate the risk of SPGWT seepage into basements in the unlikely event that SPGWT is present in exposed sandstone walls within basements.

6.2.4 Potential Sheen Impacts to Surface Water Bodies

Sheen has not been reported in groundwater monitoring wells at the Site. These observations suggest that under the current hydrogeological regime, although SPGWT is present within the former gasworks footprint (located hydraulically up-gradient) and has been identified at one on-Site location, impacts (including sheen) in groundwater are not laterally extensive and groundwater with CoPC concentrations high enough to cause sheen is unlikely to be present within the Site.

SPGWT was observed at BH60/MW60 within the marine sediments as shown in **Figure F12**. Also shown on **Figure F12** are locations where SPGWT has been observed within Barangaroo South.

Based on the above, limited visual impacts as a result of sheen or tar are considered to be possible within the Site and particularly within the potential Southern Cove. Therefore, the remediation work described by the future ORWN RAP will need to consider the potential negative impacts from tar or sheen on visual amenity.

7.0 Ecological Risk Assessment

7.1 Introduction

The assessment of potential risks to ecological receptors within the Site and at the down hydraulic gradient boundary of the Site was undertaken using a qualitative, lines of evidence approach.

The ERA comprised of the following scope of works:

- Identification of appropriate ecological receptors, including both terrestrial and aquatic ecosystems (including groundwater dependant ecosystems) based on the proposed future use of the Site.
- Identification of relevant MWQC from a nationally adopted hierarchy of acceptable guidance documents plus consideration of additional international sources based on the protection of the identified nearest surface water receptor, Darling Harbour and the proposed Southern Cove.
- Identification of non-gasworks CoPC noting that the *VMP Remediation Extent* report (AECOM, 2013b) considered that if the *VMP / Block 4 RAP* (AECOM, 2013c) is implemented, residual gasworks related contamination remaining *in situ* down hydraulic gradient of the Declaration Area will not represent an unacceptable risk to the environment.
- Identification of potential risks associated with the non-gasworks related CoPC based on the comparison of concentrations of CoPC (reported both within the Site and at the down hydraulic gradient Site boundary) with the adopted MWQC.
- Assessment of whether (or not) the concentrations of non-gasworks related CoPC within the Site and at the down hydraulic gradient Site boundary represent a risk to Darling Harbour.

This assessment is based on the assumption that the remediation works described by the *VMP / Block 4 RAP* (AECOM, 2103c) have been undertaken.

It is noted that the proposed development may also include a new potential Southern Cove, which would be located in the southern portion of the Site. It is understood that the proposed Southern Cove and Darling Harbour will be connected and are therefore interchangeable as terms throughout this report as they are considered to be the same entity.

The assessment includes consideration of groundwater concentrations both within the Site and at the down hydraulic gradient boundary of the Site in consideration of uncertainties regarding whether existing groundwater monitoring results are representative of groundwater leaving the Site boundary (refer to **Section 3.4**).

7.2 Approach to Ecological Risk Assessment

The ERA was undertaken with consideration of the following Australian guidance documents:

- *National Environmental Protection (Assessment of Site Contamination) Measure 1999*, Schedule B5a, Guideline on Ecological Risk Assessment. (*ASC NEPM*, 2013); and
- *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. ANZECC and Agriculture and Resource Management Council of Australia and New Zealand (ANZECC, 2000).

As required by the NSW EPA, the point of compliance for the purpose of assessing ecological risk is the down hydraulic gradient boundary of the Site, Darling Harbour. This approach is consistent with the policies of the NSW EPA, in particular:

- The *CLM Act* (1997).
- The NSW DEC (now the NSW EPA) *Guidelines for the Assessment and Management of Groundwater Contamination*, March 2007 which reemphasises the requirements of the *CLM Act* (1997) requiring protection of groundwater ecosystems according to the precautionary principle.
- The ANZECC (2000) *Water Quality Guidelines*, which requires that the protection of underground aquatic ecosystems and their novel fauna require the highest level of protection.
- The *ASC NEPM Schedule B6* (2013) which states that the relevant jurisdictional policy should be consulted when modifying the groundwater investigation levels at the point of use. *ASC NEPM* (2013) also states that determining criteria for groundwater should be undertaken on a site-specific basis as some jurisdictions allow for a mixing zone or water treatment, whereas other jurisdictions apply the groundwater investigation levels at the point of discharge in order to be protective of benthic organisms.

7.3 Ecological Setting

7.3.1 Terrestrial Habitat

The Site currently comprises 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). The terrestrial habitat at the Site is considered to have a low level of environmental sensitivity.

It is considered that an assessment of the potential for Site related contamination to impact the current limited terrestrial environment is not warranted. Therefore no further assessment of the terrestrial habitat has been undertaken.

7.3.2 Aquatic Habitat

The closest aquatic ecological receptor/receiving environment is Darling Harbour located immediately west of the Site. 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. Until recently, the area of Darling Harbour adjacent to the Site has served as a passenger terminal for cruise vessels.

Surface Water

Analytical results for a sample of surface water collected from a stilling well adjacent to the Site as part of the *GDS* (AECOM, 2010d) did not indicate the presence of metals above the adopted assessment criteria. 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 (AECOM 2010c).

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 at 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 is practical and that remediation is an important component of ecological improvement over time.

7.3.3 Management Objectives for Darling Harbour

Guidance from the NSW EPA (then NSW DECCW, 2010) indicates that although Darling Harbour is classified as a waterway affected by urban development, the applicable aquatic ecosystem management 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 NSW EPA 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 EPA has therefore requested that in order to meet the objective outlined above the following protection objectives should apply to the down hydraulic gradient Site boundary with Darling Harbour:

- to reduce impacts to Darling Harbour 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 described in **Section 7.6** which provide a similar level of ecological protection to the ANZECC (2000) trigger values.

7.4 Conceptual Site Model

The Site layout is presented in **Figure F2** in **Appendix A**. The Site is currently vacant, however is being used as a staging area for the Barangaroo South development. The Site shares its down hydraulic gradient boundary with the closest identified ecological receptor, Darling Harbour.

The proposed development may include a potential Southern Cove, located in the southern portion of the Site. For the purposes of the assessment of ecological risks, it has been assumed that Darling Harbour and the proposed Southern Cove are interchangeable – that is they have the same receptors and require the same level of protection and are therefore considered to be the same entity.

Groundwater is present at the Site at a depth of approximately 2 m bgl (relative to the existing ground surface). As there are no sensitive terrestrial receptors identified on the Site (see **Section 7.3.1** above), the focus of the ERA will be on the identified receptor, namely Darling Harbour (including the proposed Southern Cove). The CSM for the Site is discussed in more detail in **Section 4.0** and an overall visual representation is presented as **Figure F8**.

The Site is influenced by the changes in tide within Darling Harbour, especially within the unconfined fill aquifer. This is described further below and within the *GDS*, (AECOM 2010d).

As no terrestrial ecological receptors were identified at the Site (refer **Section 7.3**) AECOM has only considered groundwater in relation to ecological protection. Soil contamination has not been assessed further for ecological risk.

7.4.1 Tidal Exchange Prism

The *GDS* (AECOM 2010d) was undertaken in order to understand site configuration influences on groundwater, tidal and dilution attenuation relevant to the Barangaroo South area.

In summary, the *GDS* (AECOM 2010d) concluded:

- A very efficient hydraulic connection exists between the harbour and the fill aquifer immediately adjacent (the tidal exchange prism), with head in this portion of the aquifer responding rapidly to changes in the tide; the caisson structure in this area is therefore considered 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;
- 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 as a result of the low hydraulic conductivity and gradient. Groundwater discharge occurring via the basal Hawkesbury Sandstone was not considered significant in the context of site-derived contaminant flux to Darling Harbour; and
- The proportion of groundwater to seawater discharging during the low tide cycle to Darling Harbour was derived from a connate water displacement model. The estimated proportion of groundwater (which in this instance is connate water) suggests 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.
- The entire Barangaroo site is tidally influenced to some extent; that is where water levels change due to the tide either by physical inundation or the transmission of head (pressure) through the aquifer.

The *GDS* (AECOM, 2010d) conservatively estimated that the tidal prism extends approximately 10 metres from the landward side of the caisson wall.

Not withstanding the conclusions of the *GDS* (AECOM, 2010d), no dilution or mixing effects have been applied to the assessment of groundwater quality beneath the ORWN by comparison to the MWQC.

7.4.2 Proposed Declaration Site and Block 4 Remediation Works

As described by **Section 7.1**, a key assumption of this ERA is that the remediation works prescribed by the *VMP / Block 4 RAP* (AECOM, 2013c) will be implemented. As a consequence of the remediation works described by the *VMP / Block 4 RAP* (AECOM, 2013c), a large portion of the original source area of gasworks contamination will be removed or remediated. Further, if the Block 4 Development works are undertaken as proposed, the majority of Block 4, extending beyond the prescribed VMP remediation extent, will be excavated for the construction of basement car park including construction of a basement groundwater retention wall system which will effectively isolate both the basement car park and any material remaining *in situ* under the basement from the surrounding ground conditions including the Site and Darling Harbour.

7.5 Redevelopment Considerations within the Ecological Risk Assessment

7.5.1 Proposed VMP and Block 4 Remediation Works

The *VMP / Block 4 RAP* (AECOM, 2013c) describes the remedial works required to:

- enable the NSW EPA Declaration to be revoked (VMP Remediation Works); and
- ensure that Block 4 is remediated to a standard that is suitable for the proposed development in Block 4 (Block 4 Development Remediation Works).

As described above, for the purpose of this *ORWN HHERA*, it is assumed that the remedial works described by the *VMP / Block 4 RAP* (AECOM, 2013c) are completed.

The *VMP / Block 4 RAP* (AECOM, 2013c) was prepared as an outcome of:

- the *VMP HHERA* (AECOM, 2012b); and
- the *Declaration Site (Development Works) HHERA* (AECOM, 2011a).

The *VMP HHERA* (AECOM, 2012b) concluded that soil and groundwater concentrations within the NSW EPA Declaration Area represented an unacceptable risk to human health and ecological receptors in the context of the current landuse. In particular, the *VMP HHERA* (AECOM, 2012b) reported that there were widespread exceedances of the MWQC within groundwater in the Declaration Area and that impacted groundwater was migrating to the ORWN Area (which is located down hydraulic gradient of the Declaration Area). The *VMP HHERA* (AECOM, 2012b) concluded that that remediation to the extent practicable (here-in referred to as the VMP Remediation Works) is required to address both human and ecological protection with respect to the Remediation Site Declaration 21122.

The *Declaration Site (Development Works) HHERA* (AECOM, 2011a) concluded that soil and groundwater concentrations within the Declaration Area also represented an unacceptable risk to human health in the context of the proposed future land use. The HHERA assumed that the proposed future land use would incorporate construction of a basement groundwater retention wall system that would extent and be keyed into bedrock and effectively isolate materials remaining *in situ* beneath the basement from surrounding areas. Therefore, consideration of ecological risk was not required as part of the assessment. The *Declaration Site (Development Works) HHERA* (AECOM, 2011a) concluded that remediation to the extent practicable was required within those parts of Hickson Road, Block 5 and Block 4 (here-in referred to as the Block 4 Development Works) which are within the Declaration Area.

VMP Remediation Works

The extent of remediation required for the VMP Remediation Works is described by the *VMP Remediation Extent* report (AECOM, 2103b). In developing the recommended extent of remediation, the *VMP Remediation Extent* report (AECOM, 2013b) considered gasworks related contamination within:

- the NSW EPA Declaration Area;
- those parts of Block 4 down hydraulic gradient of the NSW EPA Declaration Area;
- those parts of Block 5 down hydraulic gradient of the NSE EPA Declaration Area; and
- the ORWN Area / the Site.

Gasworks related contamination was considered to be those chemicals specified within the NSW EPA Declaration, specifically: PAHs; BTEX; TPH; Ammonia; Phenol; and Cyanide.

The remediation goals for the protection of the environment presented in the *VMP Remediation Extent* Report (AECOM, 2013b) are:

- As a preliminary goal, removal / remediation of SPGWT to the extent practicable; and
- As a secondary goal – remediation of the soil within the unsaturated and saturated zones, to the extent practicable, such that groundwater within fill material leaving the Declaration Area measured at the down hydraulic gradient site boundary (the eastern boundary of the ORWN) approaches the MWQC.

The *VMP Remediation Extent* report (AECOM, 2013b) developed the proposed extent of remediation to the extent practicable based on consideration of the key requirements of the NSW DEC (2007). In particular:

- Source Control and remediation of NAPL to the extent practicable – the proposed extent of remediation includes 100% of all primary contaminant sources (i.e. historical gasworks structures) and 97% of all secondary contaminant sources in fill (i.e. areas where SPGWT has been observed); and
- Clean Up to the Extent Practicable – based on consideration of:
  - *Technical capability to achieve the clean-up* – the technical capability of the most likely remediation technologies applied to the proposed remediation extent will result in a reduction in gasworks related contaminant mass of between 88-92% within fill materials.
  - *Threats the contamination poses to human or ecological health* – following the proposed remedial works, it is expected that there will not be an unacceptable ongoing risk to human health (under current land use as opposed to the proposed future land use) or the environment (including Darling Harbour). Protection of the environment has been demonstrated by contaminant mass flux modelling which has shown:
    - significant improvement to the groundwater quality in fill at the down hydraulic gradient boundary of the Declaration Area / Block 4; and,
    - groundwater quality discharging to Darling Harbour from residual contamination will not represent a risk to the environment.
  - *The value of the groundwater resource* - multiple lines of evidence demonstrated that residual contamination that will remain *in situ* following completion of the proposed remediation will not represent a threat to ecological health and will be protective of the identified groundwater value.
  - *Clean-up costs* – Any proposal to achieve a higher level of protection for the environment than proposed would be inconsistent with the principles of ESD (as required by the *CLM Act* [1997]), the *Waste Avoidance and Resource Recovery Act* (2001) and *Section 4.4* of *NSW DEC* (2007) which requires that the benefits from undertaking groundwater clean-up (for example the reduction in contaminant mass) must outweigh any incidental negative impacts to human health or the environment that could arise from the clean-up (for example the volume of remediation required to accomplish the requisite contaminant mass reduction).

Based on the outcomes of the *VMP Remediation Extent* report (AECOM, 2013b), the lateral and vertical extent of remediation described by the document:

- is considered to be protective of the environment such that gasworks related contamination remaining within the areas down hydraulic gradient of the Declaration Area (including the ORWN Area / the Site) will not represent an unacceptable risk to ecological receptors;
- is expected to result in a significant improvement to the quality of groundwater crossing the down-hydraulic gradient of the Declaration Area, such that over time, the concentration of gasworks related contaminants entering the ORWN Area / the Site will approach the MWQC.

Block 4 Development Remediation Works

The extent of remediation required for the Block 4 Development Remediation Works is described in the *VMP / Block 4 RAP* (AECOM, 2013c).

The proposed Block 4 Development Works are likely to include construction of a basement across the entire footprint of Block 4 (i.e. including both the eastern portion of Block 4 within the Declaration Area and the western portion of Block 4 located outside the Declaration Area as shown in **Figure F3** in **Appendix A**).

As a result of the basement groundwater retention wall system that will be constructed around Block 4, there will be negligible groundwater movement from materials retained *in situ* beneath the Block 4 basement, through the retention wall system, to down hydraulic gradient areas such as the ORWN.

7.5.2 Redevelopment Considerations

Key elements of the future Site development relevant to the ERA for the Site include:

- Potential excavation of the southern portion of the Site for development as a waterway (potential Southern Cove) that is open to Darling Harbour.
- The existing caisson walls associated with the historic wharf structures will be retained along the western (Darling Harbour) side of the Site and within the Site – potentially along the northern boundary of the potential Southern Cove.
- The basement groundwater retention wall system will be keyed into the underlying bedrock. It is expected that the basement groundwater retention wall system will effectively isolate both the basement car park and any material remaining *in situ* adjacent or under it from the surrounding ground conditions and Darling Harbour.
- Areas outside the proposed basement groundwater retention wall system will continue to have hydraulic connection with Darling Harbour (**Figure F13**).
- Excavated material from within the Site and/or other parts of Barangaroo South may be reused to raise the elevation in the ORWN Public Domain area subject to meeting appropriate SSTC and TSC and the removal of any SPGWT (**Figure F14**) (note that material will not be reused as part of the Proposed Crown Hotel Development).
- The ERA is only relevant to areas within the Site that are outside any future basement groundwater retention wall system.

7.6 Marine Water Quality Protection

Tier 1 screening criteria relevant to protection of aquatic ecological receptors within Darling Harbour are those published by ANZECC (2000) for assessment of surface water and sediment, specifically:

- surface water: ANZECC (2000) trigger values for marine water (95% protection level). Low reliability trigger values have been adopted where no other value is available; and
- surface water: ANZECC (2000) trigger values for marine water (99% protection level) for chemicals with the potential to have bioaccumulative impacts.

In addition, where ANZECC (2000) guidelines did not include appropriate criteria, the following secondary sources were adopted:

- CCME (1999) Canadian environmental quality guidelines. Canadian Council of Ministers of the Environment, Winnipeg, and
- Oakridge (Suter and Tsao, 1996) Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota, 1996 Revision. Risk Assessment Program Health Sciences Research Division. US Department of Energy Office of Environmental Management. Tier II Secondary Chronic Values. June.

The selected MWQC are summarised in **Table 77.** The MWQC were used in selection of CoPCs (refer to **Section 7.7**).

Table 77 Marine Water Quality Criteria

Analyte	Criteria (µg/L)	Source
Metals and Inorganics		
Arsenic	2.3	ANZECC (2000) 95% Marine Water Environmental Concern Level
Cadmium	0.7	ANZECC (2000) 99% Marine Water Trigger Value
Chromium (hexavalent)	4.4	ANZECC (2000) 95% Marine Water Trigger Value
Chromium III	27.4	ANZECC (2000) 95% Marine Water Trigger Value
Cobalt	1	ANZECC (2000) 95% Marine Water Trigger Value
Copper	1.3	ANZECC (2000) 95% Marine Water Trigger Value
Lead	4.4	ANZECC (2000) 95% Marine Water Trigger Value
Mercury	0.1	ANZECC (2000) 99% Marine Water Trigger Value
Nickel	70	ANZECC (2000) 95% Marine Water Trigger Value
Vanadium	100	ANZECC (2000) 95% Marine Water Trigger Value
Zinc	15	ANZECC (2000) 95% Marine Water Trigger Value
Ammonia	910	ANZECC (2000) 95% Marine Water Trigger Value
Cyanide	4	ANZECC (2000) 95% Marine Water Trigger Value
Low MW PAHs		
Acenaphthene	5.8	CCME (1999) Freshwater Guideline
Acenaphthylene	5.8	Adopted criteria for Acenaphthene as surrogate
Anthracene	0.01 [a]	ANZECC (2000) 99% Marine Water Trigger Value
Fluorene	3	CCME (1999) Freshwater Guideline
Naphthalene	70	ANZECC (2000) 95% Marine Water Trigger Value, moderate reliability
Phenanthrene	0.6 [a]	ANZECC (2000) 99% Marine Water Trigger Value
2-methylnaphthalene	2.1	Oakridge Secondary Chronic Value (1996) for 1-methylnaphthalene
High MW PAHs		
Benz(a)anthracene Benzo(a)pyrene Benzo(b)fluoranthene Benzo(g,h,i)perylene Benzo(k)fluoranthene Chrysene Dibenz(a,h)anthracene Indeno(1,2,3-c,d)pyrene	0.1 [a,b]	Value for high molecular weight PAHs is based off the ANZECC (2000) 99% Marine Water Trigger Values for benzo(a)pyrene. A TEF approach is presented below in accordance with *ASC NEPM* (2013), CCME (2010) and the *Declaration Site HHERA* (AECOM, 2011a) *Appendix K*, toxicity profile for PAHs: - Benzo(a)anthracene (0.1) - Benzo(a)pyrene (1) - Benzo(b)fluoranthene (0.1) - Benzo(g,h,i)perylene (0.01) - Benzo(k)fluoranthene (0.1) - Chrysene (0.01) - Dibenzo (a,h) anthracene (1) - Indeno (1,2,3-cd)pyrene (0.1)
Fluoranthene	1	ANZECC (2000) 99% Marine Water Trigger Value
Pyrene	0.025 [a]	CCME (1999) Freshwater Guideline
Other Organics		
2,4-dimethylphenol	2	ANZECC (2000) 95% Marine Water Trigger Value, low reliability
2-methylphenol	13	Oakridge Secondary Chronic Value (1996)
3-&4-methylphenol	13	Adopted value for 2-methylphenol as surrogate
Dibenzofuran	3.7	Oakridge Secondary Chronic Value (1996)
Pentachlorophenol	22	ANZECC (2000) 95% Marine Water Trigger Value

Analyte	Criteria (µg/L)	Source
Phenol	400	ANZECC (2000) 95% Marine Water Trigger Value
2,4 dinitrophenol	45	ANZECC (2000) 95% Fresh Water Trigger Value
Styrene	72	CCME (1999) Freshwater Guideline
Petroleum Hydrocarbons		
Benzene	700	ANZECC (2000) 95% Marine Water Trigger Value, moderate reliability
Ethylbenzene	80	ANZECC (2000) 95% Fresh Water Trigger Value
Toluene	180	ANZECC (2000) 95% Marine Water Trigger Value, low reliability
Xylene (m & p)	75	ANZECC (2000) 95% Marine Water Trigger Value, low reliability for m-xylene.
Xylene (o)	350	ANZECC (2000) 95% Marine Water Trigger Value, low reliability for o-xylene.
TPH C_6 - C_{10}	110	CCME (2008 Canada-Wide Standard for Petroleum Hydrocarbons (PHC) in Soil – Table B-9 values for TPH C_6 to C_8 and >C_8 to C_{10}. Criteria calculated from a weighted average assuming a Coal Tar composition of 25% aliphatic and 75% aromatic components
TPH >C_{10} - C_{16}	40	CCME (2008) Canada-Wide Standard for Petroleum Hydrocarbons (PHC) in Soil – Table B-9 values for TPH >C_{10} to C_{12} and >C_{12} to C_{16}. Criteria calculated from a weighted average assuming a Coal Tar composition of 25% aliphatic and 75% aromatic components
TPH >C_{16} - C_{34}	-	No guidelines values available
TPH >C_{34} - C_{40}	-	No guidelines values available

Notes: (a) It is noted that these MWQC are less than the laboratory standard LOR. The laboratory standard LOR will be adopted in place of the MWQC where: (i) analysis of these chemicals is required; or, (ii) where the MWQC are considered in derivation of risk based criteria. This approach is consistent with Section 3.4.3.2 and Section 8.3.5.4 of ANZECC (2000) and has been agreed with the Auditor and the NSW EPA. It is noted that it is not practical to use the laboratory ultra-trace LOR because: (i) the high salinity present in the water (particularly in areas close to the harbour) will cause interferences in the reporting of some analytes and therefore an increased LOR; (ii) the presence of other contaminants (matrix interference) will raise the LOR; and (iii) groundwater turbidity can lead to raised LOR.

(b) In the case of high molecular weight PAHs the standard limit of reporting is greater than the adopted MWQC presented in **Table 77** above which is based on B(a)P (99% Marine Water Guideline). Therefore it is considered appropriate to adopt the standard laboratory limit of reporting for these compounds in applying the TEF approach outlined in CCME, 2010 (*Appendix I PAH Toxicity Profile*).

It is noted that there were no identified ecological screening guidelines for TPH C_{15}-C_{28} and TPH C_{29}- C_{36}. The assessment of TPH is discussed further in **Section 7.7.4** below.

7.7 Identification of Chemicals of Potential Concern

The staged approach adopted by AECOM for the identification of CoPC for the ERA is summarised below.

1) Do the chemical concentrations reported in groundwater exceed the MWQC, as presented in **Table 77**?

2) Do the chemical concentrations reported in filtered groundwater exceed the MWQC, as presented in **Table 77**?

3) Do the chemical concentrations exceed the MWQC within the fill or natural materials, as presented in **Table 77**?

4) Do the chemical concentrations reported in neutral leachate samples (where available) (by ASLP) in representative soil samples exceed the MWQC, as presented in **Table 77**?

5) Are the locations of the neutral leachate concentrations and or groundwater concentrations reported above the MWQC widespread (or restricted to a discrete location[s])? The definition of “widespread” is described in **Section 7.7.5** below.

6) Will the contaminants be remediated as part of the up-gradient VMP Remedial Works and therefore reduce contaminant concentrations down gradient (i.e. within the Site) such that the contaminants do not need to be considered further? In applying this approach (refer to **Section 7.7.6**), the following points were considered:

- sorption to organic matter is a significant factor in a retardation of the fate and transport of PAHs and phenols in both the saturated and unsaturated zone;
- the potential for PAHs to be present as suspended solids in the dissolved phase mobilised during the sampling process is significant;
- consideration of the Laboratory Limit of Reporting (LOR) relative to the MWQC. There is inherent difficulty in analysing PAHs and phenols, for example, in highly saline groundwater samples; and
- if the CoPC concentrations reported in filtered groundwater and leachate are both less than the MWQC, there is no mechanism for the CoPC to impact on the environment, as impacts are expected to be associated with suspended sediment in groundwater or soil impacts for which there is no completed migration pathway to Darling Harbour.

Where available, data from the following areas were considered for the identification of CoPCs:

- for material potentially remaining *in situ* within the ORWN Area (refer to **Figure F13**) data from the Site have been considered; and
- for material that may potentially be reused above the existing ground level in the ORWN (refer to **Figure F14**) data from the NSW EPA Declaration Area have been considered.

The selection process for determining CoPC for materials to be beneficially reused has been undertaken separately and is presented in **Appendix W**. It should be noted that:

- Material from within the Site may also be reused within the Site. Use of data from the NSW EPA Declaration Area for identification of CoPCs for reuse within the Site is considered conservative.
- The potential reuse of material from the Declaration Area within the Site must exclude the material removed from within the proposed VMP Remediation Extent. This is because the proposed VMP Remediation Extent is based, in part, on removal or remediation (to the extent practicable) of the majority of the gasworks related contamination from within the remediation extent (calculated by the *VMP Remediation Extent* report (AECOM, 2013b) to be between 88% and 92% of contamination from within fill materials).

7.7.1 Identification of CoPCs based on Groundwater Analysis Data

The comparison of groundwater concentrations present at the Site to the adopted MWQC specified in **Section 7.6** above is presented in **Table T21**.

The data presented in **Table T21** is considered representative of the groundwater quality that might be expected based on the material remaining *in situ* in hydraulic connection with Darling Harbour within the ORWN public domain (refer to **Figure F13** of **Appendix A**).

The data presented in **Appendix W** presents groundwater quality for the NSW EPA Declaration Area, and has been screened against the adopted MWQC. This screen has been undertaken to identify CoPC which may be leaching from soil within the NSW EPA Declaration Area that might be beneficially reused within the ORWN (refer to **Figure F14** of **Appendix A**).

For the ORWN Area (material to remain *in situ*) and NSW EPA Declaration Area (material to be potentially reused) **Table 78** presents:

- CoPCs reported in groundwater at concentrations exceeding the MWQC; or
- CoPCs where the LOR in groundwater was greater than the MWQC and therefore it is not possible to discount the presence of the CoPC.

Table 78 presents the potential CoPC within groundwater based on comparison of contaminants to the MWQC as described above.

Table 78 CoPCs selected based on Groundwater Analytical Data Initial Screen

CoPC which require further assessment (material to remain *in situ*)
Metals – arsenic, cadmium, chromium, cobalt, copper, mercury, nickel and zinc
Other inorganics – ammonia, cyanide
Low MW PAHs – 2-methylnaphthalene, acenaphthene, acenaphthylene. anthracene, fluorene, naphthalene and phenanthrene
High MW PAHs – benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, fluoranthene, Indeno(1,2,3-c,d)pyrene, pyrene and dibenzofuran[1]
Phenols – 2,4-dimethlyphenol, 2-methylphenol and 3&4-methylphenol
TPH – C_6-C_9 and C_{10}-C_{14}
BTEX – benzene, toluene and xylenes
SVOCs / VOCs – styrene
CoPC which require further assessment (material to be potentially reused)
Metals – arsenic, cadmium, chromium, cobalt, copper, mercury, nickel and zinc
Other inorganics – ammonia, cyanide
Low MW PAHs – 2-methylnaphthalene, acenaphthene, acenaphthylene. anthracene, fluorene, naphthalene and phenanthrene
High MW PAHs – benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, fluoranthene, Indeno(1,2,3-c,d)pyrene, pyrene and dibenzofuran[1]
Phenols – 2,4-dimethlyphenol, 2-methylphenol, 3&4-methylphenol and phenol
TPH – C_6-C_9 and C_{10}-C_{14}
BTEX – benzene, toluene, ethylbenzene and xylenes
SVOCs / VOCs – styrene

[1.] It is noted that dibenzofuran is not a PAH, however it has been included with this group as it is considered that it has similar chemical properties.

It should be noted that total cyanide was reported in groundwater samples at concentrations in exceedance of the MWQC. It is commonly understood that cyanide present in the environment as a result of gasworks activities has been found in the form of complexed cyanides which are tightly bound to metals within the environment. Therefore it is expected that the cyanide reported in groundwater is in non-toxic forms and is bound within solid particles within the groundwater (see **Section 7.7.5**).

It is noted that the list of CoPC which require further assessment for *"Soils to remain in situ"* and *"Soils to be reused"* are identical with the exception of ethylbenzene and phenol.

7.7.2 Identification of CoPCs present in the Groundwater Soluble Phase

Additional analyses was undertaken by AECOM as part of the *Supplementary VMP DGI* (AECOM, 2012a) to confirm whether potential CoPC identified in groundwater were present in the soluble phase of groundwater and therefore to better understand the potential mobility and bioavailability of the potential CoPCs. These analyses used groundwater samples derived from locations across the Barangaroo South (including locations outside of the Site considered to represent a worst-case scenario for groundwater impacts. The analyses 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 MWQC;
- 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 from 14 groundwater monitoring wells selected to include more significant contamination identified by the previous investigations at the Site. The locations of the additional groundwater monitoring wells are presented in **Figure F3** in **Appendix A**. Results of the analysis are presented in **Table T22** in **Appendix B**. Review of the results indicates that:

- PAHs and phenols were detected in all but two unfiltered groundwater samples analysed;
- 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 phenol reported within the filtered samples were marginally lower than those in the unfiltered samples. The exceptions to this were exceedances of the MWQC in the filtrate samples for some low molecular weight PAHs (such as 2-methylnaphthalene, acenaphthene, acenaphthylene, anthracene and naphthalene) and phenol.
- It is considered that whilst dibenzofuran was not selected for filtrate testing, it would also behave similarly to the higher molecular weight PAH compounds outlined above. It is therefore considered that dibenzofuran would not be present within the dissolved phase- rather will be present in the solid phase due to the chemical structure and its co-location with PAHs. Therefore potential consideration as a CoPC is not warranted. This is further explained below:
  - dibenzofuran comprises of two benzene rings and a furan ring, with a similar molecular weight to pyrene (dibenzofuran is 168 and pyrene is 202);
  - it is considered to behave similarly to PAHs with respect to toxic action; and
  - it co-occurs where the highest reported concentrations of PAHs, and hence targeted remediation of PAHs will decrease dibenzofuran concentrations.

The differences in concentrations with filtration are summarised in **Table 79** below. The table presents the range in ratios of the unfiltered sample concentrations to the filtered sample concentrations for the range of individual PAHs and phenols. For example, in Sample IT3S, the concentration of PAHs in the unfiltered samples was between 14 and 76 times greater than the concentration reported in the filtered sample.

Because many of the high molecular weight PAHs and phenol (as discussed above) were not reported to be present above the laboratory LOR in the dissolved phase, they are not present at soluble concentrations above the adopted MWQC and do not present a risk to aquatic ecosystems. Therefore, they have not been identified as CoPC for the purpose of the ERA. This approach of comparison of filtered groundwater results is in accordance with the application of the ANZECC (2000) guidelines where refinement of the approach of direct comparison of unfiltered data to the ANZECC (2000) guidelines (which over-estimates potential risk and is too conservative) is adopted.

Table 79 Reduction in Concentration of PAHs and Phenols in Unfiltered versus Filtered Samples

Sample	Detected PAHs *	Detected Phenol *
IT3S	14 to 76	<LOR
IT3M	10	<LOR
IT3D	4.7 to 418	<LOR
MW198	3.5	<LOR
MW200	1.6 to 2.7	1.8
MW204S	7.8 to 546	<LOR
MW209	5.4 to 62	<LOR
MW210	10.3 to 42	<LOR
MW401	4.1 to 94	2.3
MW62	All < LOR	<LOR

* Values presented are the ratios of the unfiltered sample concentrations to the filtered sample concentrations, and therefore indicate the reduction in concentration due to filtering.

It is also noted that:

- The results of the analysis of the Suspended Material (i.e. filter cake) demonstrate that the difference between the unfiltered and filtered groundwater concentrations can be explained by the contaminant concentrations reported in the suspended material (i.e. mass balance was achieved between the mass of chemical present in the unfiltered sample and that present in the filtrate and filter cake);
- High molecular weight 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 all but one of the Filtered samples (IT07M). One sample (MW200) exhibited matrix effects with elevated LOR marginally above the MWQC;
- These findings are consistent with the published chemical properties of benzo(a)pyrene (and the other high molecular weight 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);
- Phenol was detected above the MWQC in one Filtered sample only (MW200). These findings are consistent with the published chemical properties of this chemical. It is also noted that MW200 is located in the centre of the Site and groundwater between this location and the Site boundary was not observed to contain phenol concentrations exceeding the adopted screening value for phenol;
- High molecular weight PAHs and phenol which are bound in the solid phase are less bioavailable to potential marine ecosystems than those in the dissolved phase because they are likely to be tightly bound in the solid matrix; and
- Because the high molecular weight PAHs and phenol are not present in the dissolved phase they are not considered to be bioavailable to marine ecological receptors within Darling Harbour and are not assessed further as CoPC.
- Recent filtrate samples collected from IT04 and IT05 were analysed for metals. Filtered samples from IT04 reported exceedances of MWQC for cobalt, copper and zinc (at one or more depths within IT04). Filtered samples from IT05 reported exceedances of MWQC for arsenic, cadmium, cobalt, copper, lead, nickel and zinc. This was consistent with exceedances reported in unfiltered samples, however the concentration was not seen to reduce significantly between unfiltered and filtered samples, thus indicating that metals in groundwater are present in the soluble phase in these locations.

Based on the review described above, **Table 80** presents those chemicals which are present within groundwater (filtered) at concentrations above the adopted MWQC and are therefore assessed further as potential CoPC.

Table 80 CoPCs Selected Based on Filtrate Results

CoPC which require further assessment (material to remain *in situ*)
Metals – arsenic, cadmium, chromium, cobalt, copper, mercury, nickel and zinc
Other inorganics – ammonia, cyanide
Low MW PAHs – 2-methylnaphthalene, acenaphthene, acenaphthylene. anthracene, fluorene, naphthalene and phenanthrene
Phenols – 2,4-dimethlyphenol, 2-methylphenol and 3&4-methylphenol
TPH – C_6-C_9 and C_{10}-C_{14}
BTEX – benzene, toluene and xylenes
SVOCs / VOCs – styrene
CoPC which require further assessment (material to be potentially reused)
Metals – arsenic, cadmium, chromium, cobalt, copper, mercury, nickel and zinc
Other inorganics – ammonia, cyanide
Low MW PAHs – 2-methylnaphthalene, acenaphthene, acenaphthylene. anthracene, fluorene, naphthalene and phenanthrene
Phenols – 2,4-dimethlyphenol, 2-methylphenol and 3&4-methylphenol
TPH – C_6-C_9 and C_{10}-C_{14}
BTEX – benzene, toluene, ethylbenzene and xylenes
SVOCs / VOCs – styrene

7.7.3 Consideration of TPH as a CoPC

TPH as reported by analytical laboratories is complex mixture of potentially hundreds of compounds which are solvent extractable and are responsive to the detector employed. The concentrations of TPH reported within the Site are likely to be a combination of multiple chemicals - mostly associated with coal tar based on the historical use of the adjacent site as a gas works.

Further consideration has been given to the question of TPH presence at gasworks sites. According to ATSDR (2002):

> *Coal tars are complex combinations of polycyclic aromatic hydrocarbons (PAHs), phenols, heterocyclic oxygen, sulfur, and nitrogen compounds. PAH composition of coal tars is variable. Analyses of PAHs in four coal tar samples revealed 2- to 20-fold differences in concentration of selected PAHs among the samples. For example, benzo[a]pyrene ranged from non-detectable levels to 1.7, 3.9, and 6.4 g/kg of coal tar. By comparison, coal tar creosotes have an oily liquid consistency and range in color from yellowish-dark green to brown. The coal tar creosotes consist of PAHs and PAH derivatives. At least 75% of the coal tar creosote mixture is PAHs. Coal tar pitch is a shiny, dark brown-to-black residue that contains PAHs and their methyl and polymethyl derivatives, as well as heteronuclear compounds.*
>
> *Coal tar creosotes, coal tar, coal tar pitch, and coal tar pitch volatiles are composed of many individual compounds of varying physical and chemical characteristics. In addition, the composition of each, although referred to by specific name (e.g., coal tar creosote) is not consistent. For instance, the components and properties of the mixture depend on the temperature of the destructive distillation (carbonization) and on the nature of the carbon-containing material used as a feedstock for combustion.*

In consideration of these definitions, the following observations can be made:

- there is a general expectation that PAHs have a much higher molar toxicity than the other substances that will be routinely quantified in a TPH analysis. Therefore, a focus on PAHs is likely to address both the class of compounds that is among the most abundant in coal tar and among the most toxic; and
- since the TPH concentrations measured at a gasworks typically reflect an underlying composition that is substantially different than that of various new or used petroleum products (on which TPH guidelines are typically based), it is difficult to place the numbers in a meaningful context: the values cannot be compared to toxicological thresholds based on experimental or field exposures to petroleum whole products or constituents.

Review of TPH chromatograms for representative soil and groundwater samples from Barangaroo South by the analytical laboratory (**Appendix U**) suggests that:

- the observed profiles are representative of those typically associated with coal tar;
- the general character of the samples is more aromatic than a typical fresh petroleum hydrocarbon product as the aliphatic component appears negligible;
- the profiles variously include BTEX, various alkylated benzenes, phenol, alkylated phenols, PAHs, and alkylated PAHs; and
- more than 50% of the sample is typically comprised of compounds not targeted by standard PAH, BTEX or phenols analysis.

In consideration of these observations, AECOM considers the elevated concentrations and widespread distribution of TPH requires further ecological risk characterisation to ensure compounds not targeted by the standard PAH, BTEX and phenols analysis are appropriately identified and assessed.

7.7.4 Identification of CoPCs based on Frequency and Distribution

The following CoPC from **Table 80** were not assessed further as they were only present at concentrations above the MWQC within the natural marine sediments. Monitoring wells that were screened across the fill/natural boundary were considered to be representative of marine sediments (See **Table 5** for well screening information). As described by **Section 4.2.5**, it has been demonstrated that there is no significant flux of contamination from the marine sediments either to the overlying fill material or to Darling Harbour.

- Naphthalene;
- 2-methylphenol;
- 3&4-methylphenol;
- TPH C_6-C_{10};
- BTEX;

- Chromium (VI); and
- Styrene.

The following CoPC were not considered further due to the frequency of exceedances in the fill material as detailed below.

- 2,4-dimethylphenol was reported at concentrations (2 µg/L and 10 µg/L) at or above the MWQC (2 µg/L) in one location (IT2S and IT2M). The down-gradient well, MW14, IT1 and IT05 reported concentrations of 2,4-dimethylphenol below the LOR and/or MWQC, indicating concentrations entering Darling Harbour are below the MWQC.
- Arsenic was reported at a concentration (2.7 µg/L) marginally above the MWQC (2.3 µg/L) in one location (IT1M and its duplicate (2.5 µg/L)). The down-gradient wells, MW14, IT1 and IT05 reported concentrations of arsenic below the LOR and/or MWQC, indicating concentrations entering Darling Harbour are below the MWQC.
- Chromium (total) was reported at a concentration (102 µg/L) above the MWQC (4.4 µg/L) in one location (IT1M). This concentration was reported in a primary sample, its duplicate and triplicate samples both reported concentrations below the LOR and MWQC (<0.5 µg/L and <5 µg/L). Furthermore, the down-gradient well, IT05 reported concentrations of chromium (total) below the MWQC, indicating concentrations entering Darling Harbour are below the MWQC.
- Mercury was reported at a concentration (0.7 µg/L) above the MWQC (0.1 µg/L) in one location (MW14) and at the MWQC in IT2S. The concentration in MW14 was reported in a sample collected in 2008. A sample collected from the same location in 2010 was below the laboratory LOR. Furthermore, the down-gradient well, IT05 reported concentrations of mercury below the laboratory LOR and MWQC, indicating concentrations entering Darling Harbour are below the MWQC.
- Nickel was reported at a concentration of (78.8 µg/L) above the MWQC (70 µg/L) in one location (MW14). This concentration was reported in a sample collected in 2008. A samples collected from the same location in 2010 was below the MWQC at a concentration of 1.1 µg/L. Furthermore, the down-gradient well, IT05 reported concentrations of nickel below the MWQC, indicating concentrations entering Darling Harbour are below the MWQC.

CoPC which are still considered to require further assessment are detailed in **Table 81**.

Table 81 CoPCs Selected Based on Frequency and Distribution

CoPC which require further assessment (material to remain *in situ*)
Metals – cadmium, cobalt, copper and zinc
Other inorganics – ammonia, cyanide
Low MW PAHs – 2-methylnaphthalene, acenaphthene, acenaphthylene. anthracene, fluorene and phenanthrene
TPH –C_{10}-C_{14}
CoPC which require further assessment (material to be potentially reused)
Metals – cadmium, cobalt, copper and zinc
Other inorganics – ammonia, cyanide
Low MW PAHs – 2-methylnaphthalene, acenaphthene, acenaphthylene. anthracene, fluorene and phenanthrene
TPH – C_{10}-C_{14}

At this stage the CoPC requiring further assessment are identical for "Soils to remain *in situ"* and "Soils to potentially be reused", therefore further separation is not necessary.

7.7.5 Identification of CoPCs based on Leachate Analysis Data

There have been a number of assessments of the potential for Site related contamination present within soils to leach. The results of these leach tests are presented in **Table T23**.

Initial leach (ASLP) testing was performed at the standard laboratory LOR, and therefore for some analytes (particularly PAHs) the MWQC were below the laboratory LOR.

Further analyses undertaken by AECOM as part of the Supplementary *VMP DGI* (AECOM, 2012a) provided additional 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. The additional analysis included ultra-trace (low level) neutral leachate testing of PAH, phenols, BTEX, inorganics and metals. The laboratory limits of reporting (LOR) for all ultra-trace analysis were less than the adopted MWQC. The additional ultra trace leachate analyses were undertaken on soil samples from across the Barangaroo South (including locations outside of the Site which exhibited evidence of gasworks contamination.

These results, shown in **Table T23** indicate that:

- Cyanide was not detected at concentrations above the laboratory LOR in leachate samples (refer to **Table T23**). While it is noted that the laboratory LOR was equal to the MWQC, it is not considered to be a COPC because numerous studies have demonstrated that the most dominant species of cyanide present in soil and groundwater at former gasworks sites are the relatively nontoxic strong metal-cyanide complexes (primarily the iron-complexed species). These studies have demonstrated that free cyanide is generally not detectable in soils or groundwater collected from former gasworks sites; this is also the case at the current Site. The presence of significant concentrations of iron in soil and groundwater at the Site indicates that it is highly likely that the majority of the cyanide present at the Site would be bonded to iron forming comparatively, non-toxic complexes;
- High molecular weight PAHs exhibited very limited if any leachability behaviour refer to **Table T23**, it is however noted that higher molecular weight CoPCs are not present in groundwater filtrate and therefore they are not considered further as a potential CoPC;
- In four 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;
- Of the metals listed above arsenic, cadmium, cobalt, copper and zinc exhibited leaching behaviour; and
- Of the organics listed above 2-methylnaphthalene, acenaphthene, acenaphthylene, anthracene, naphthalene, fluorene and phenanthrene exhibited leaching behaviour (**Table T23**).

CoPC from **Table 81** which are still considered to require further assessment are detailed in **Table 82**.

Table 82 CoPCs Selected Based on Leachate Analysis Data

CoPC which require further assessment
Metals – cadmium, cobalt, copper and zinc
Other inorganics – ammonia
Low MW PAHs – 2-methylnaphthalene, acenaphthene, acenaphthylene. anthracene, fluorene and phenanthrene
TPH –C_{10}-C_{14}

7.7.6 Exclusion of CoPC to be Remediated in VMP Area

As discussed in **Section 7.1**, for the purpose of this assessment it has been assumed that remedial works will be undertaken within the Declaration Area, up hydraulic gradient of the ORWN area, in accordance with the *VMP / Block 4 RAP* (AECOM, 2013c) and *VMP Remediation Extent* document (AECOM, 2013b).

The *VMP Remediation Extent report* (AECOM, 2013b) concluded, among other things, that if the remediation works described by the *VMP / Block 4 RAP* (AECOM, 2013c) are completed, residual gasworks related contamination that remaining *in situ* within the ORWN Area will not represent an unacceptable risk to the environment.

Therefore, based on the outcomes of the *VMP Remediation Extent* document (AECOM, 2013b), further consideration of the risk to the environment represented by gasworks related contaminants is not considered warranted and gasworks related contaminant have therefore been excluded as CoPC from this assessment.

Gasworks related contaminants are considered to be those chemicals specified by the NSW EPA Declaration, specifically:

- Benzene;
- Ethylbenzene;
- Toluene;
- Xylenes;
- PAHs;

- Phenol;
- TPH (C_6-C_9, C_{10}-C_{14}, C_{15}-C_{28}, C_{29}-C_{36});
- Ammonia; and
- Cyanide.

CoPC which are still considered to require further assessment are detailed in **Table 83**.

Table 83 CoPCs Selected Based on CoPC to be Remediated in VMP Area

CoPC which require further assessment
Metals – cadmium, cobalt, copper and zinc

7.8 Re-Use of Soil within the ORWN

It is understood that material and/or soil from the Site, or elsewhere within Barangaroo South, which meets relevant human health SSTC may also be re-used to build up the elevation of Public Domain areas within the Site. In addition to meeting the human health SSTC, any material placed within open space areas within the top 0.5 m must meet the TSC outlined in **Table 63**. One possible exception to this is the proposed Southern Cove. If the proposed Southern Cove is created by excavation of existing fill materials, the soils remaining at the surface of the potential Southern Cove must meet the ANZECC (2000) ISQG values.

The application of the TSC criteria for Suitable Fill within the top 0.5 m (or 1.0m within the Crown Site) is considered to be suitably protective of closest down gradient ecological receptor, Darling Harbour, based on the potential for soil leachate to discharge to groundwater.

Soil material which may be reused within the unsaturated zone (to a depth of 2m) must also demonstrate neutral leachate concentrations which are below the adopted MWQC as outlined in **Table 77** above. This requirement is in addition to soil concentration relevant human health SSTC. The human health have not been derived to be protective of the closest down gradient ecological receptor, Darling Harbour, based on the potential for soil leachate to discharge to groundwater.

7.9 Ecological Risk Characterisation

The following chemicals have been identified as potential non-gasworks related CoPCs within groundwater based on consideration of the chemical being present within the groundwater beneath the Site.

- Cadmium;
- Cobalt;
- Copper; and
- Zinc.

A qualitative assessment of the risk to the environment represented by these CoPC is provided following based on the CSM for the Site and multiple lines of evidence. Construction details for the groundwater wells, as referenced below, are presented in **Table 5**.

7.9.1 Cadmium

- Cadmium concentrations in five of 39 samples were reported at concentrations above the MWQC (0.7 µg/L).
- Of these exceedances, three were reported at IT05 (0.7 µg/L – 1.1 µg/L), one was reported at MW14 (16 µg/L) and one at IT1S (1.3 µg/L). Of these exceedances, the concentration of 1.1 µg/L was reported within the marine sediments. Based on the negligible contaminant flux between the marine sediment and the overlying fill or Darling Harbour, the reported concentrations of cobalt exceeding the MWQC in marine sediment are not considered to represent an unacceptable risk to ecological receptors in Darling Harbour.
- The concentration of 16 µg/L in MW14 was reported in 2007. Samples taken from the same location in 2008 and 2010 reported concentrations of 0.3 µg/L, below the MWQC.
- IT1 is located up-gradient of IT05 which suggests that there is some reduction in groundwater concentrations between the locations. There is also likely to be some reduction in the groundwater concentration between IT05 and Darling Harbour and therefore concentrations entering Darling Harbour are likely to be below the MWQC.

- As demonstrated by the *GDS* (AECOM, 2010d) (see **Section 2.6.8**), there will be some dilution and attenuation of contamination in groundwater as it approaches the down hydraulic gradient Site boundary (in the order of 5 times). Given that the cadmium concentrations in the most recent samples from within the fill materials are within the same magnitude as the adopted MWQC of 0.7 µg/L, consideration of this dilution and attenuation demonstrates that the reported concentrations do not represent an ongoing unacceptable risk to the ecological receptors in Darling Harbour.

7.9.2 Cobalt

- Cobalt concentrations in 13 of 26 samples were reported at concentrations above the MWQC (1 µg/L).
- It is noted that the highest concentrations of cobalt within the dissolved phase were reported within groundwater well locations which are screened within the marine sediments (nine samples). In particular, the maximum concentration reported in the marine sediment (146 µg/L) was significantly higher than the maximum concentration reported in fill material (3.7 µg/L). Based on the negligible contaminant flux between the marine sediment and the overlying fill or Darling Harbour, the reported concentrations of cobalt exceeding the MWQC in marine sediment are not considered to represent an unacceptable risk to ecological receptors in Darling Harbour.
- Three of the exceedances within the fill materials were reported in IT1 and IT2 (1.6 µg/L to 3.7 µg/L). The remaining exceedances within the fill material was reported in down-gradient well IT04 (1.1 µg/L), marginally above the MWQC, suggesting some reduction in groundwater concentrations between the two locations. There is likely to be some reduction in the groundwater concentration between IT04 and Darling Harbour and therefore concentrations entering Darling Harbour are likely to be below the MWQC.
- As demonstrated by the *GDS* (AECOM, 2010d) (see **Section 2.6.8**), there will be some dilution and attenuation of contamination in groundwater as it approaches the down hydraulic gradient Site boundary (in the order of 5 times). Given that the cobalt concentrations reported are within the same magnitude as the adopted MWQC of 1µg/L, consideration of this dilution and attenuation demonstrates that the reported concentrations do not represent an ongoing unacceptable risk to the ecological receptors in Darling Harbour.

7.9.3 Copper

- Copper concentrations in 16 of 39 samples were reported at concentrations above the MWQC.
- Of these exceedances, five were within the marine sediments. Based on the negligible contaminant flux between the marine sediment and the overlying fill or Darling Harbour, the reported concentrations of cobalt exceeding the MWQC in marine sediment are not considered to represent an unacceptable risk to ecological receptors in Darling Harbour.
- The exceedance reported in MW14 was from 2008, however concentrations in 2010 were reported to be below the LOR. Concentrations of copper in MW24 were reported as 30 µg/L and 44 µg/L in 2008, however concentrations in 2010 had reduced to 2 µg/L.
- Of the remaining exceedances within the fill material, one was reported at IT01 at 19 µg/L (up-gradient of IT05), three were reported at IT05 at 2 µg/L, and two exceedances were within IT04 at 30 µg/L and 24 µg/L.
- With respect to the results from groundwater wells screened within the fill material, as demonstrated by the *GDS* (AECOM, 2010d) (see **Section 2.6.8**), there will be some dilution and attenuation of contamination in groundwater as it approaches the down hydraulic gradient Site boundary (in the order of 5 times). Given that the copper concentrations reported within the fill material and most recent samples are generally within the same magnitude as the adopted MWQC of 1.3 µg/L, consideration of this dilution and attenuation demonstrates that the reported concentrations do not represent an ongoing unacceptable risk to the ecological receptors in Darling Harbour.

7.9.4 Zinc

- Zinc concentrations in 22 of 39 samples were reported at concentrations above the MWQC.
- Of these exceedances, seven were within the marine sediments.
- It is noted that the zinc concentrations reported were higher in those wells screened within the marine sediment (i.e. MW60 and IT05D). Therefore, based on the negligible contaminant flux between the marine sediment and the overlying fill or Darling Harbour, the reported concentrations of copper exceeding the MWQC are not considered to represent an unacceptable risk to ecological receptors in Darling Harbour.

- Zinc concentrations within the fill materials were all reported at concentrations within the same order of magnitude of the MWQC.
- With respect to the results from groundwater wells screened within the fill material, as demonstrated by the *GDS* (AECOM, 2010d) (see **Section 2.6.8**), there will be some dilution and attenuation of contamination in groundwater as it approaches the down hydraulic gradient Site boundary (in the order of 5 times). Given that the zinc concentrations reported within the fill material and most recent samples (max concentration 0.055 mg/L) are generally within the same magnitude of the adopted MWQC of 0.015 mg/L, consideration of this dilution and attenuation demonstrates that the reported concentrations do not represent an ongoing unacceptable risk to the ecological receptors in Darling Harbour.

7.10 Soils Within The Potential Southern Cove Area

In the event that the proposed Southern Cove is created by excavation of existing fill materials, soils within the base of the proposed potential Southern Cove area will be left in place post excavation. Therefore it is considered appropriate that the ISQG published by ANZECC (2000) should apply to the top 0.5 m of soil at the base of the excavated area. These guidelines are summarised in **Table 84** below.

In the absence of a design for the proposed potential Southern Cove, **Table T24** in **Appendix B** presents a comparison of the ISQG (ANZECC, 2000) against the analytical data for all saturated soils within the Site.

Table 84 Interim Sediment Quality Criteria (High; ANZECC, 2000)

Analyte	ISQG High (mg/kg)
Ammonia (as N)	36.4
Lead	220
Arsenic	5.8
Cadmium	10
Cobalt	2.7
Copper	45.5
Nickel	52
Zinc	61
2,4-Dimethylphenol	0.5*
2-Methylnaphthalene	0.9
2-Methylphenol	0.71
3&4-Methylphenol**	0.68
Acenaphthene	0.64
Acenaphthylene	1
Anthracene	1.1
Naphthalene	2.1
Phenanthrene	1.5
TPH C_6 - C_{10}	10***
TPH >C_{10} - C_{16}	50***
Benzene	60
Toluene	9
Ethylbenzene	9
Xylene	554

***Standard LOR adopted in place of ISQG.

7.11 Conclusions

The *VMP Remediation Extent* report (AECOM, 2013b) considers that if the remedial works described by the *VMP / Block 4 RAP* (AECOM, 2013c) are completed, residual gasworks related contamination remaining *in situ* down hydraulic gradient of the Declaration Area (including the Site) will not represent an unacceptable risk to the environment.

The assessment of potential risks to identified ecological receptors has identified the following non-gasworks related CoPCs within groundwater may represent an unacceptable risk to ecological receptors:

- Copper
- Zinc
- Cobalt, and
- Cadmium

The concentrations reported for copper, zinc, cobalt and cadmium are higher in groundwater wells screened within the marine clays. Notwithstanding, given that there will be negligible contaminant flux from within the marine sediments to Darling Harbour, these concentrations are not considered representative of those that may discharge.

Copper, zinc, cobalt and cadmium concentrations reported within groundwater screened within the fill materials are also not considered to present a risk to the environment due to:

- The proposed remedial strategy presented within the *VMP / Block 4 RAP* (AECOM, 2013c) and *VMP Remediation Extent* report (AECOM, 2013b) which includes: (a) historical infrastructure source removal; and, (b) removal of secondary sources of contamination such as SPGWT which are both up-gradient sources of contamination on the Site.
- The groundwater retention wall system to be constructed as part of the proposed Block 4 Development Works will effectively cut off groundwater movement from up-gradient sources to the Site. It is considered that the up-gradient sources are a significant contributor to the groundwater quality within those wells screened within the fill materials.
- The proposed Stage 1C development is likely to incorporate a basement, contained within a groundwater retention wall which will be keyed into bedrock. The presence of this basement will reduce groundwater migration and potential contaminant flux from that area of the Site that in which the basement is constructed.
- Results of the *GDS* (AECOM 2010d), which concludes that there is a five-fold mixing and dilution of groundwater within the unconfined aquifer prior to discharge through the tidal prism to Darling Harbour. The current ERA has not adjusted the groundwater concentrations to reflect dilution, and therefore it is considered that concentrations reported within groundwater at the Site will undergo additional dilution prior to discharge to the nearest environmental receptor, Darling Harbour.
- Additional remediation works (as might be required to achieve a greater degree of environment protection), would be impracticable, cost prohibitive and inconsistent with the principles of Ecologically Sustainable Development (ESD). That is, the net cost to the environment of undertaking the additional works would be greater than the environment benefit realised from the additional work at the Site (AECOM, 2013b).

Soil material which may be re-used within the unsaturated zone (to a depth of 2m) must demonstrate neutral leachate concentrations which are below the adopted MWQC as outlined in **Table 77** above. This requirement is in addition to the requirement that soil concentrations also comply with the relevant human health SSTC (which have not been derived to be protective of the closest down gradient ecological receptor, Darling Harbour, based on the potential for soil leachate to discharge to groundwater). It is noted that the application of the TSC criteria for Suitable Fill within the top 0.5 m (non-Crown areas) or 1.0 m (Crown areas) is considered to be suitably protective of closest down gradient ecological receptor.

Multiple lines of evidence have been provided to demonstrate that residual metals contamination reported within groundwater wells screened with the fill materials will not pose a risk to the environment and that the quality of groundwater in fill within the Site will improve over time following the proposed remedial works in the Declaration Area and Block 4. It is therefore considered that the risks to identified environmental receptors at the Site are low and acceptable.

8.0 Protection of Future Plantings

The HHERA has assumed that areas of the Site to be used for unpaved recreation land uses will be covered in between 0.5 m (Scenario 4) and 1.0 m (Scenario 10) of Suitable Fill. 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 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 the Site.

TSC have been developed in the Declaration Site HHERA (AECOM, 2011a) to define material that is appropriate for use as Suitable Fill.

The TSC developed by the *Declaration Site HHERA* (AECOM, 2011a) are reproduced in **Table 85**.

Table 85 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, NSW Site Auditor Guidelines Appendix II (2006)
Cadmium	3		NEPM (1999) - Interim Urban, NSW Site Auditor Guidelines Appendix II (2006)
Chromium	190		NEPM (draft, 2010) EILs - Public open space – aged, NSW Site Auditor Guidelines Appendix II (2006)
Copper[a]	60		NEPM (draft, 2010) EILs - Public open space – aged, NSW Site Auditor Guidelines Appendix II (2006)
Lead[a]	1100		NEPM (draft, 2010) EILs - Public open space – aged, NSW Site Auditor Guidelines Appendix II (2006)
Mercury	1		NEPM (1999) - Interim Urban, NSW Site Auditor Guidelines Appendix II (2006)
Nickel	30		NEPM (draft, 2010) EILs - Public open space – aged, NSW Site Auditor Guidelines Appendix II (2006)
Zinc[a]	200		NEPM (1999) - Interim Urban, NSW Site Auditor Guidelines Appendix II (2006)
Cyanide (if free)	8		CCME (1999a) coarse soil,
Ammonia	1		Calculated based on an NSW EPA irrigation guideline of 5 mg/L as N (based on protection of plants) and leachability calculation [b].

Key Chemical	Criteria for Protection of Plants and Soil (mg/kg)	Grouped Criteria (mg/kg)	Data Sources/Notes
Petroleum Hydrocarbons			
TPH $C_6 - C_{10}$[a]	210		CCME (2008) coarse soil
TPH $>C_{10} - C_{16}$[a]	150		CCME (2008) coarse soil
TPH $>C_{16} - C_{34}$	-	300	CCME (2008) coarse soil
TPH $>C_{34} - C_{40}$	-		
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			
Acenaphthene[a]		sum - 50[b]	a: CCME (1999b) b: Total PAHs (excluding carcinogenic PAHs), from USEPA Eco SSLs of 48mg/kg rounded to 50mg/kg
Acenaphthylene[a]			
Anthracene			
Fluorene[a]			
Phenanthrene			
Naphthalene[a]	22		
High MWT PAHs			
Benzo[a]anthracene		TEF – 4	Criteria of 4 for total TEF carcinogenic PAHs based on benzo(a)pyrene and applied using the following TEFs from CCME (2010) : - Benzo(a)pyrene (1) - Benzo(a)anthracene (0.1) - Benzo(b)fluoranthene (0.1) - Benzo(g,h,i)perylene (0.01) - Benzo(k)fluoranthene (0.1) - Chrysene (0.01) - Dibenzo(a,h)anthracene (1) - Indeno(1,2,3-cd)pyrene (0.1)
Benzo[a]pyrene			
Benzo[b]fluoranthene			
Benzo[k]fluoranthene			
Benzo[ghi]perylene			
Chrysene			
Dibenz[ah]anthracene			
Indeno[123cd]pyrene			
Fluoranthene		Sum – 18	Total for fluoranthene and pyrene based on USEPA Eco SSL (June, 2007)
Pyrene			
Phenols			
Phenol	3.8		CCME (1999c) coarse soil
2,4-dimethylphenol	3.8		CCME (1999c) coarse soil
2-methylphenol	3.8		CCME (1999c) coarse soil
3&4-methylphenol	3.8		CCME (1999c) coarse soil

9.0 Uncertainties

9.1 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.

9.1.1 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.

There was limited data available with regard to the presence of asbestos within the subsurface of the ORWN Area. Based on information collected to date from within the ORWS Area it is expected that there is significant potential for asbestos to be encountered during excavation of soils in the ORWN Area. Asbestos has been adopted as a CoPC within the current HHERA, and has therefore been included for consideration within the RAP for the ORWN Area to reduce the potential for unacceptable risks to human health under proposed future land use conditions.

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.

9.1.2 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 (2012) and *ASC NEPM* (2013) 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.

9.1.3 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. 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 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 has been considered. Biodegradation effects have been considered for paved areas of the site.
- Steady, well mixed dispersion of emanating vapours within the ambient mixing space is assumed.

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.

9.1.4 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.

Asbestos

Due to the limited available data pertaining to asbestos in the ORWN Area it is difficult to assess the potential for toxic effects as a result of the asbestos that may be present. The available data from within the ORWS Area however indicates that there is limited potential for exposure to asbestos fibres as the asbestos has been observed to be present as bonded ACM. The SSTC adopted within the current HHERA are based on the potential for exposure to asbestos fibres as a result of the degradation of bonded ACM. The following uncertainties have been identified when assessing the potential toxic effects of asbestos fibres as a result of non-occupational exposures:

- Extrapolation of available toxicological data down to levels considered likely to be present in the environment. Environmental levels are predicted to be between 100 – 1000 times lower than occupational exposures (enHealth, 2005).
- It has been accepted that there is no threshold concentration below which exposure to asbestos fibres is acceptable. However, more recent scientific information indicates there is some potential that assessment of threshold exposures may be relevant to asbestos fibres (enHealth, 2005).
- The toxicity and carcinogenic potential of asbestos fibres is dependent upon various properties such as chemical composition of respirable particles in air, bio-persistence of inhaled particles, fibre/particle type and fibre/particle size.
- The type and size distribution of asbestos fibres found in soil and ambient air is highly variable, therefore the composition and mixture of fibres to which receptors may be exposed can vary depending on the location and duration of exposure.
- The presence of asbestos fibres alone has been considered to result in adverse effects, however this does not account for the effects of natural biological defence mechanisms which are likely to prevent deposition of asbestos fibres in lung tissue in a large proportion of environment exposure scenarios. This is because general environmental exposures involve significantly lower concentrations of fibres as compared to occupational exposures (enHealth, 2005).
- The toxicity of various asbestos fibres has been shown to vary considerably, with a number of fibre types shown to have minimal or low carcinogenic potential.

9.1.4.1 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 it is not 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 **Appendix V**.

Table 86 Sensitivity Analysis – Dermal Slope Factor for Carcinogenic PAHs (Scenario 4 only)

Carcinogenic PAH	Groundwater SSTC (mg/L)	
	Based on NHMRC (2011) 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 (2011) cancer slope factor. While the difference in SSTCs is significant (a 60 fold reduction), it is considered unnecessarily conservative considering the limited proportion of the Site where intrusive maintenance works could be undertaken.

9.1.4.2 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, 2012; *ASC NEPM*, 2013). Background intakes were accounted for in accordance with *ASC NEPM* (2013) and Friebel, E. and Nadebaum, P. (2011). Adjustment of RfCs and RfDs are discussed in the toxicity profiles presented within **Appendix L**.

9.1.5 Sensitivity Analysis

Table 87 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 m bgl (relative to existing ground level)	2.0 m bgl (relative to existing surface level) 3.0 m bgl (relative to proposed future surface level within the Crown Site)	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/cm^3	1.66 g/cm3	Value will increase with decreased bulk density.	Conservative assumption with higher of the range adopted resulting in a lower SSTC.
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	Value will increase with a higher biodegradation rate.	Conservative assumption to account for over-estimation for derived soil SSTC.

9.1.6 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.

9.2 Ecological Uncertainties

Risk assessments based soil and groundwater criteria involve a number of assumptions regarding Site conditions, potential ecological 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 ecological changes or conditions at a site for the exposure periods or durations considered in the risk assessment. The assumptions adopted for this ERA have, therefore, been selected to be conservative, in order to evaluate an assumed reasonable maximum exposure scenario over time and to provide a deliberate margin of safety.

9.2.1 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 and has been the subject of further data gap analysis and verification over a significant area of the site and of a separate tidal discharge study and report.

The identification of CoPC in groundwater has used nationally and internationally recognised MWQC that are based on conservative environment protection endpoints. The approach adopted is considered appropriate for the identification of key chemicals that warrant detailed assessment.

9.2.2 Leachability

Leachability testing was performed on samples where either the soil concentrations exceeded the adopted screening guidelines and or on field observations.

The majority of the samples collected for leachate sampling reside within the fill, and it is therefore expected that some variation of leach concentrations will occur.

9.2.3 Toxicity Considerations

In addition to the uncertainty considerations detailed above for human health with respect to toxicity the following is noted to be relevant for ecological endpoints.

The adoption of the MWQC as the toxicological endpoint is considered to be conservative as the majority of the guidelines are based of single species studies. Single species studies often are over simplified and consider unrealistic routes of environmental exposure. It is understood that often, only single species studies are available, and therefore a number of conservative arbitrary factors are usually applied to the developed value in order to apply a single species value to field data.

There is also limited data which accounts for potential synergistic and antagonistic effects which may occur within the ecosystem when it is exposed to more than one chemical. If any of the constituents of concern at a Site act by a similar mode of action, total risks could be higher than estimated. Conversely, if the constituents of concern at the site act antagonistically, total risks could be lower than estimated.

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

This may introduce several types of uncertainty, as follows:

- those related to extrapolating from laboratory to field conditions;
- those related to extrapolating from one species to another; and
- those related to extrapolating from the high exposure doses, usually used in laboratory studies, to the lower doses usually estimated for environmental exposure situations.

In order to adjust for these uncertainties, water quality guidelines and species protection approaches incorporate safety factors and ranges.

Adverse effects to individuals do not necessarily imply adverse effects at the population or community level. In general, the goal of ERA is to protect communities and populations (except in the case of rare species) and not each individual in that population. There may be interspecies differences in chemical absorption, metabolism, excretion and toxic response including developmental and habitat-related effects. There may also be uncertainties concerning the specific relevance of a general water quality guideline to a specific species or habitat situation. In addition, the frequent necessity to extrapolate results of short-term or sub-chronic animal studies to environmental exposures and over a lifecycle or prolonged time has inherent uncertainty. Most toxicity water quality guidelines or reference values for dose-based evaluations are based on individual-level adverse effects. Risk estimates based on individual risk may overestimate risk at the appropriate population level.

Toxicity guidelines predominantly are derived from studies of the adverse effects of a single constituent. Exposures to ecological receptors may involve multiple constituents, where additive, synergistic, or antagonistic interactions could occur. Data generally are not adequate to permit any quantitative adjustment in toxicity values or risk calculations based on inter-chemical interactions.

10.0 Conclusions and Recommendations

10.1 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, unacceptable human health risks are generally not expected at the Site following redevelopment, with the exception of the following locations and/or situations:

- **Scenario 6 (Intrusive Maintenance) – potential contact with groundwater**: The highest reported concentrations of naphthalene and TPH C_{10}-C_{14} fraction in groundwater within the ORWN Area have the potential to result in unacceptable health risks to intrusive maintenance workers.

  The predominant risk driving pathway was identified as dermal contact of intrusive maintenance workers with groundwater. Locations where reported concentrations may result in a potential risk are near the northern edge of the Site, and based on the proposed Crown Hotel Development, the location of these exceedances would be within the proposed Crown Basement. It is considered unlikely that services installed in this area would be constructed at a depth where groundwater contact was probable (that is, the depth to groundwater is approximately 2.5 m (outside of the Crown Hotel Development) and the groundwater is saline which would be corrosive to below ground services). In addition, it is likely that the reported elevated groundwater concentrations are representative of groundwater quality within marine sediments which are present at depths significantly greater than 2.5 m and from which contaminant flux has been shown to be minimal.

  Consequently, under the assumed exposure scenarios presented in the HHERA it is considered unlikely that the reported groundwater concentrations in the ORWN would result in an unacceptable health risk for the intrusive maintenance worker. It is also considered that all intrusive maintenance works will be undertaken in accordance with state occupational health and safety requirements and personal protective equipment will be worn.

- **Scenario 8 (Multistorey Commercial Slab on Ground, with Advection)**: The highest reported concentrations of naphthalene in soil and benzene, TPH C_6-C_{10} and TPH $>C_{10}$-C_{16} in groundwater within the ORWN Area have the potential to result in unacceptable health risks to commercial employees working in a building where advection vapour intrusion processes occur. Locations where reported concentrations may result in a potential risk are near the eastern and northern edges of the Site, and the potential health risk assumes that the future multi-storey commercial slab-on-ground building is on top of these impacted areas. Based on the proposed Crown Hotel Development, the location of these exceedances would be within the proposed Crown Basement and therefore this exposure scenario would not be relevant.

Based on proposed future land use at the Site, there is also potential for intrusive maintenance workers (only) to encounter asbestos in soils during intrusive works. There is currently insufficient data to determine the potential for risks associated with asbestos in soil within the Site. However, available data collected during excavation of the ORWS Area indicates that there is a significant potential for asbestos containing material to be present. In order to address the potential for future exposures to asbestos at the Site, the current HHERA presents risk based SSTC for asbestos in soils. The future ORWN RAP will be required to consider these SSTCs to minimise the potential for unacceptable risks to intrusive maintenance workers.

Human health risks are not expected to be associated with Scenarios other than 6 and 8. This is because SSTC for these scenarios were not exceeded by reported Site contaminant concentrations, or reported exceedances are not considered to pose a health risk based on consideration of their location, nature and/or extent.

Furthermore it is considered that remediation works undertaken in the NSW EPA Declaration Area (including the Block 4 Development Works Area) will result in an overall reduction in groundwater contaminant concentrations within the ORWN Area.

A separate assessment of potential risks to human health from exposure to sediments and surface water within the potential Southern Cove has not been undertaken. This is because, in the event that construction of the potential Southern Cove requires excavation of existing fill, the material at the new surface of the potential Southern Cove will be required to meet the ANZECC (2000) ISQG, which are considered to be suitably protective for recreational exposures for humans and the surface water will be of the same composition and makeup of Darling Harbour.

With respect to potential human health risks associated with material which may be reused within the Site, it is expected that material which meets criteria for Scenarios 3 through 6 and Scenario 8 would be suitable for reuse from a human health perspective in areas/locations where respective land use and human exposure assumptions are met. It is understood that the proposed Crown Hotel Development specifically excludes the reuse material.

Odour Risks

Comparison of Site data to derived odour SSTC indicates one exceedance for 2-methylnaphthalene within the Site, at BH40 at 16.5 m bgl. It is considered that remedial activities at the Site are not likely to extend to this depth. It should be noted, however, observations during intrusive Site investigations have indicated that relatively small scale excavations or intrusive works have potential to result in localised odour issues.

Locations where odour issues may occur are likely to be a result of 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 gasworks waste that cannot be specifically identified and which may contribute to odour); and
- 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 to mitigate risks to human health and excavation of the proposed basement will remove contamination with the potential to generate odour and therefore result in a reduction in the potential for odour generation. It should also be noted that areas of the Site that will not be the subject of remediation or basement excavation and in which potentially odorous material may remain *in situ* will be covered by clean fill (referred to as 'Suitable Fill') and/or concrete paving / hardstand which will further reduce the potential for odour generation (**Figure F14** of **Appendix A**).

Visual Amenity Risks

Limited visual amenity impacts as a result of sheen or tar (particularly within the potential Southern Cove) are expected to occur at the Site. Furthermore, the remediation work described by the future ORWN RAP will make consideration of the potential negative impacts from fill, tar or sheen on visual amenity.

As required by the *ASC NEPM* (2013), all surface soils, including Suitable Fill in areas subject to paved and unpaved recreational land uses (refer to **Section 5.5.6.2**), must contain 'no visible asbestos'.

Ecological Risks

The *VMP Remediation Extent* report (AECOM, 2013b) considers that if the *VMP / Block 4 RAP* (AECOM, 2013c) is implemented, residual gasworks related contamination remaining *in situ* down hydraulic gradient of the Declaration Area will not represent an unacceptable risk to the environment.

With respect to non-gasworks related contamination, ecological screening criteria were exceeded within the Site for copper, zinc, cobalt and nickel within the groundwater wells screened within both the fill and marine sediment.

The concentrations reported for copper, zinc, cobalt and nickel are higher in groundwater wells screened within the marine clays. Notwithstanding, given that there will be negligible contaminant flux from within the marine sediments to Darling Harbour, these concentrations are not considered representative of those that may discharge to the environment.

Copper, zinc, cobalt and nickel concentrations reported within groundwater screened within the fill materials are also not considered to present a risk to the environment due to:

- The proposed remedial strategy presented within the *VMP / Block 4 RAP* (AECOM, 2013c) and *VMP Remediation Extent* report (AECOM, 2013b) which includes: (a) historical infrastructure source removal; and, (b) removal of secondary sources of contamination such as SPGWT which are both up-gradient sources of contamination on the Site.
- The groundwater retention wall system to be constructed as part of the proposed Block 4 Development Works will limit groundwater movement from up-gradient sources to the Site. It is considered that the up-gradient sources are a significant contributor to the groundwater quality within those wells screened within the fill materials.
- The proposed Stage 1C development is likely to incorporate a basement, similar to that proposed as part of the Block 4 Development Works, contained within a groundwater retention wall which will be keyed into bedrock. While the extent of the basement has not yet been confirmed, it will reduce groundwater migration and potential contaminant flux from that area of the Site that in which the basement is constructed.

- Results of the *GDS* (AECOM 2010d), which concludes that there is a five-fold mixing and dilution of groundwater within the unconfined aquifer prior to discharge through the tidal prism to Darling Harbour. The current ERA has not adjusted the groundwater concentrations to reflect dilution, and therefore it is considered that concentrations reported within groundwater at the Site will undergo additional dilution prior to discharge to the nearest environmental receptor, Darling Harbour.
- Additional remediation works (as might be required to achieve a greater degree of environment protection), would be impracticable, cost prohibitive and inconsistent with the principles of Ecologically Sustainable Development (ESD). That is, the net cost to the environment of undertaking the additional works would be greater than the environment benefit realised from the additional work at the Site (AECOM, 2013b).

Soil material which may be re-used within the unsaturated zone (to a depth of 2m) must demonstrate neutral leachate concentrations which are below the adopted MWQC as outlined in **Table 77**. This requirement is in addition to the requirement that soil concentrations also comply with the relevant human health SSTC (which have not been derived to be protective of the closest down gradient ecological receptor, Darling Harbour, based on the potential for soil leachate to discharge to groundwater). It is noted that the application of the TSC criteria for Suitable Fill is considered to be suitably protective of the closest down gradient ecological receptor.

Multiple lines of evidence have been provided to demonstrate that residual metals contamination reported within groundwater wells screened with the fill materials will not pose a risk to the environment and that the quality of groundwater in fill within the Site will improve over time following the proposed remedial works in the Declaration Area and Block 4. It is therefore considered that the risks to identified environmental receptors at the Site are low and acceptable.

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:

1) A RAP (or RAPs if staged remediation and development is required) should be prepared to determine the extent and need for remediation at the Site.
2) Soil and groundwater remaining within the Site should be remediated and/or validated to meet relevant health/odour criteria (SSTC) (**Table T19**and **Table T20** and **Table 70**), as follows:
   a) The specific health/odour SSTC to be met in different Site locations will depend on the land use(s) relevant to the area.
   b) In the event that the proposed Southern Cove is created by excavation of existing fill materials, soils within the base of the proposed potential Southern Cove from 0 to 0.5 m bgl will meet the ISQG (High) Criteria (**Table 84**). .
3) Material reused within the Site should meet relevant health/odour criteria (SSTC) and TSC (**Table T20** and **Table 70** and **Table 85**), as follows:
   a) The specific health/odour SSTC to be met will depend on the exact location of material relative to the proposed land use(s).
   b) Soil re-used in locations above the current ground level should also demonstrate neutral leachate concentrations which are below are below the adopted MWQC.
4) Basement design plans must include engineering controls to ensure that contaminated groundwater does not accumulate in compartments which are ventilated to basement airspaces. The following is also recommended:
   a) Basement levels should be maintained at a lower pressure than occupied areas above in accordance with AS 1668.2 (Standards Australia, 2002).
   b) Sump rooms should be placed as far as possible from lift wells.
   c) Engineering controls must be in place restricting dermal contact by general public and commercial workers (i.e. car park attendants and loading dock workers) to groundwater which may ingress through basement walls.

5) SPGWT should not be present in the immediate vicinity of outer basement walls (to the extent practicable), and basement design and engineering controls should ensure that SPGWT seepage into basements does not occur.

6) Soil to be placed in Headland Park will be required to meet the criteria defined in the separate Headland Park RAP prepared by the Authority.

7) To address potential visual impacts (tar or sheen) to the potential Southern Cove, a suitable cover thickness over any residual tar or visually impacted material should be present in order to ensure that tidal and wave induced movement of sediment does not result in exposed tar at the base of the cove. A suitable cover thickness should be determined in the future ORWN RAP.

8) The ORWN RAP(s) should include consideration of mitigation measures for the appropriate management of asbestos that may be potentially encountered during the remediation works.

9) The ORWN RAP(s) will describe the validation of groundwater following remediation which will be undertaken by comparison of:

   a) individual groundwater monitoring results with the lowest of the derived SSTC (presented in **Table T19**); and

   b) groundwater monitoring results at the down-hydraulic gradient Site boundary with the MWQC (presented within **Table T21**), to the extent practicable.

10) The ORWN RAP(s) will describe the validation of soil following remediation (as applicable) which will be undertaken in accordance with the following:

   a) use of systematic sampling patterns;

   b) collection of an appropriate number of samples for estimation of the arithmetic average concentration of contaminant(s) within relevant environmental media and exposure areas; and

   c) estimation of the 95% UCL of the arithmetic average concentration.

11.0 Limitations

This document was prepared by AECOM Australia Pty Ltd (AECOM) for the sole use of Lend Lease (Millers Point) Pty Ltd, the only intended beneficiary of our work. Any advice, opinions or recommendations contained in this document should be read and relied upon only in the context of the document as a whole and are considered current to the date of this document. Any other party should satisfy themselves that the scope of work conducted and reported herein meets their specific needs before relying on this document. AECOM cannot be held liable for any third party reliance on this document, as AECOM is not aware of the specific needs of the third party. No other party should rely on the document without the prior written consent of AECOM, and AECOM undertakes no duty to, nor accepts any responsibility to, any third party who may rely upon this document.

This document was prepared for the specific purpose described in our proposal dated 23 May 2014 and as agreed to by Lend Lease (Millers Point) Pty Ltd. From a technical perspective, the subsurface environment at any site may present substantial uncertainty. It is a heterogeneous, complex environment, in which small subsurface features or changes in geologic conditions can have substantial impacts on water and chemical movement. Uncertainties may also affect source characterisation assessment of chemical fate and transport in the environment, assessment of exposure risks and health effects, and remedial action performance.

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

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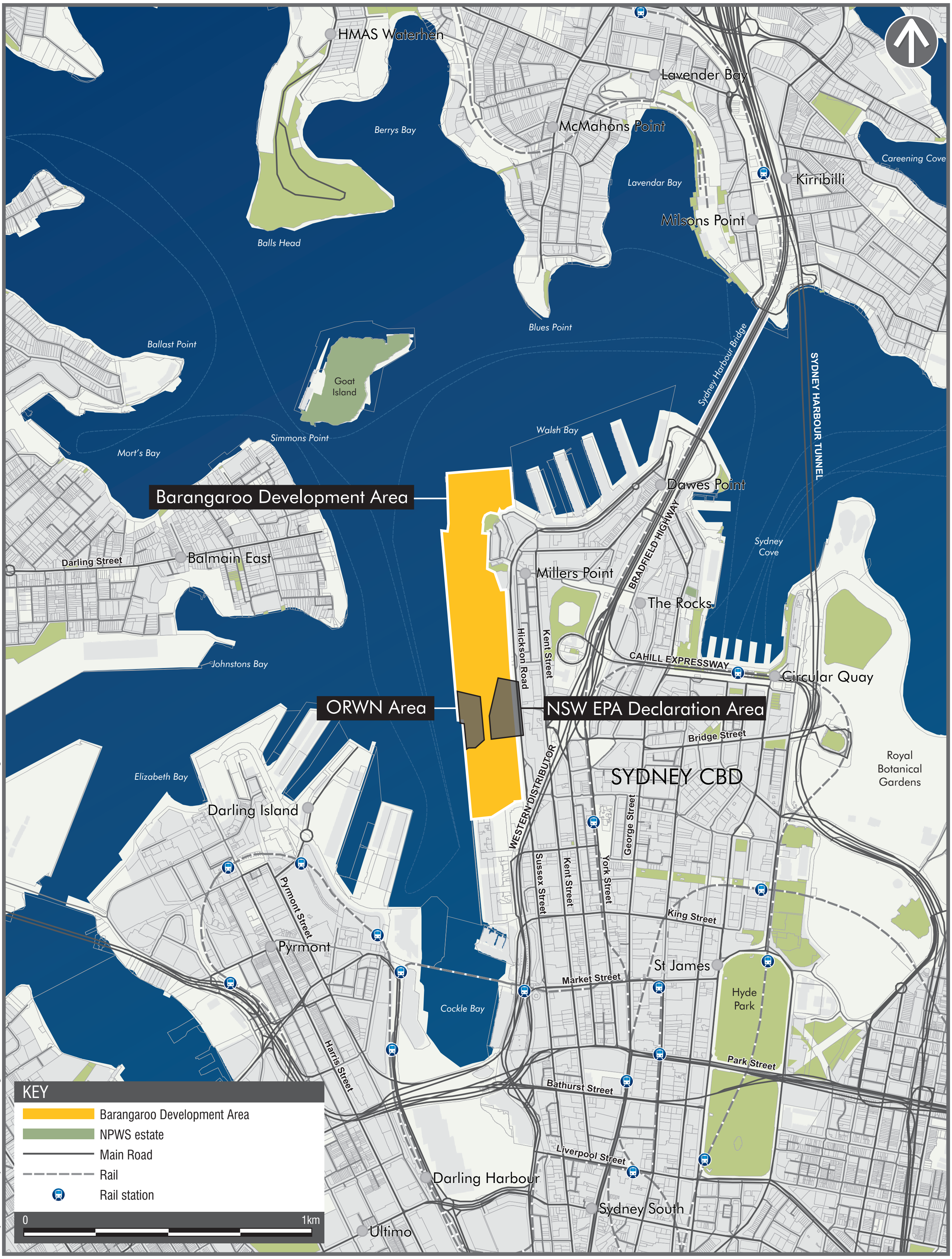
Appendix A

Figures



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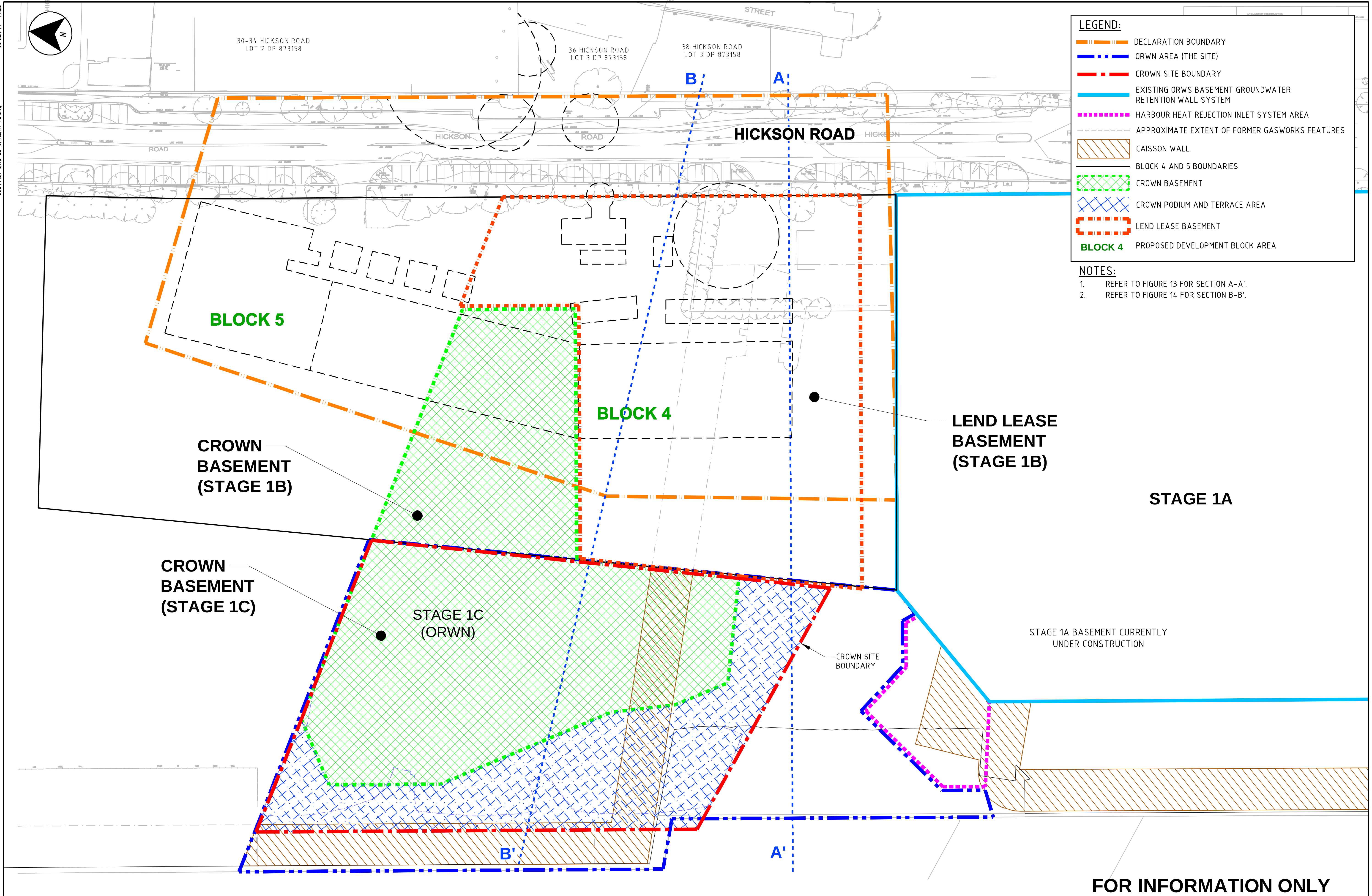
BARANGAROO SITE LOCATION

HHERA - Future Stage 1c, (ORWN Area)
Barangaroo
Hickson Road, Millers Point NSW

FIGURE F1



NOTES:
1. REFER TO FIGURE 13 FOR SECTION A-A'.
2. REFER TO FIGURE 14 FOR SECTION B-B'.

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HHERA - FUTURE STAGE 1C (ORWN AREA)

FIGURE 2:
SITE LAYOUT AND SURROUNDING AREAS

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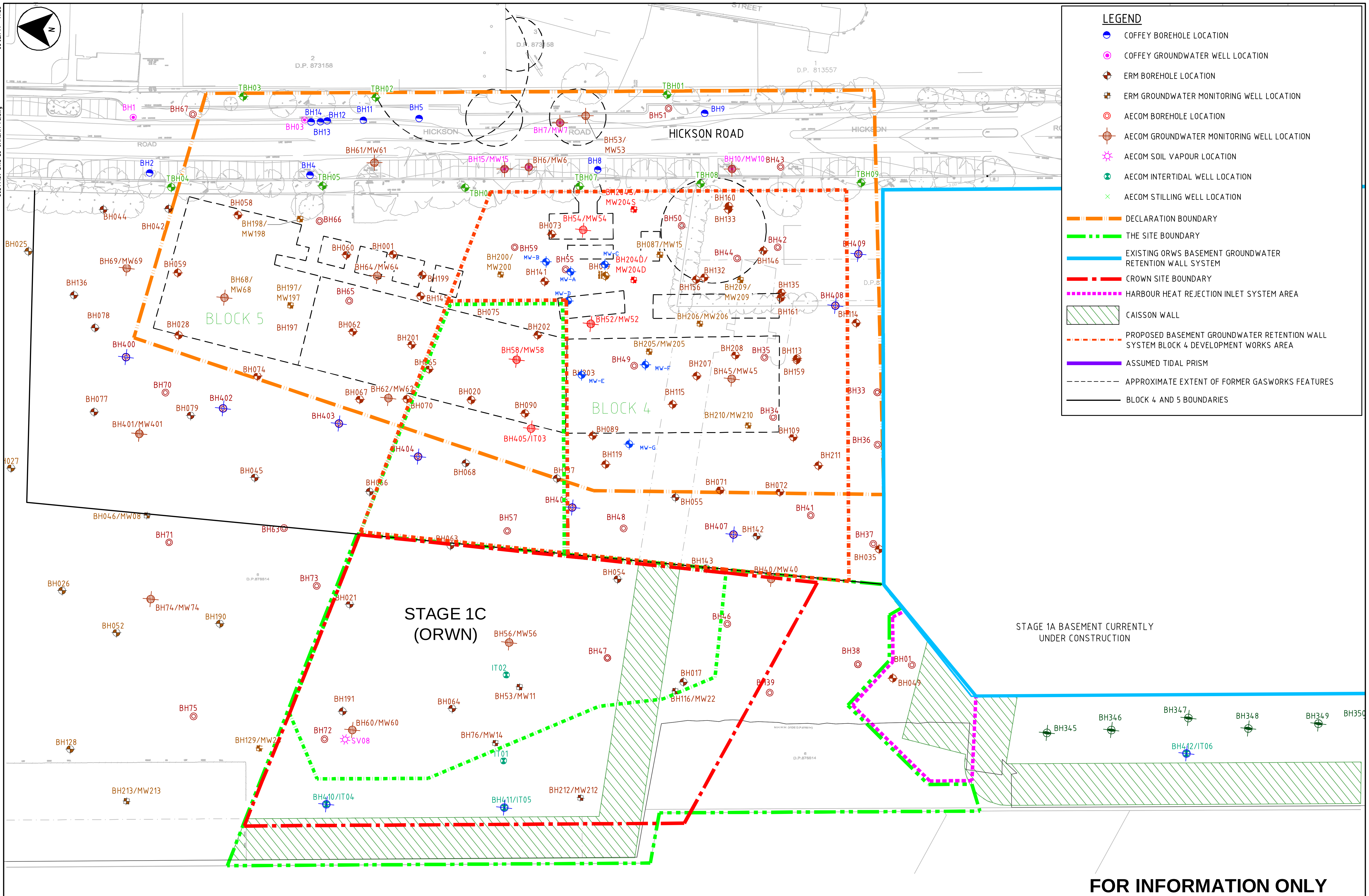

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FIGURE 3:
SITE DEVELOPMENT PLAN
AND SAMPLING LOCATIONS

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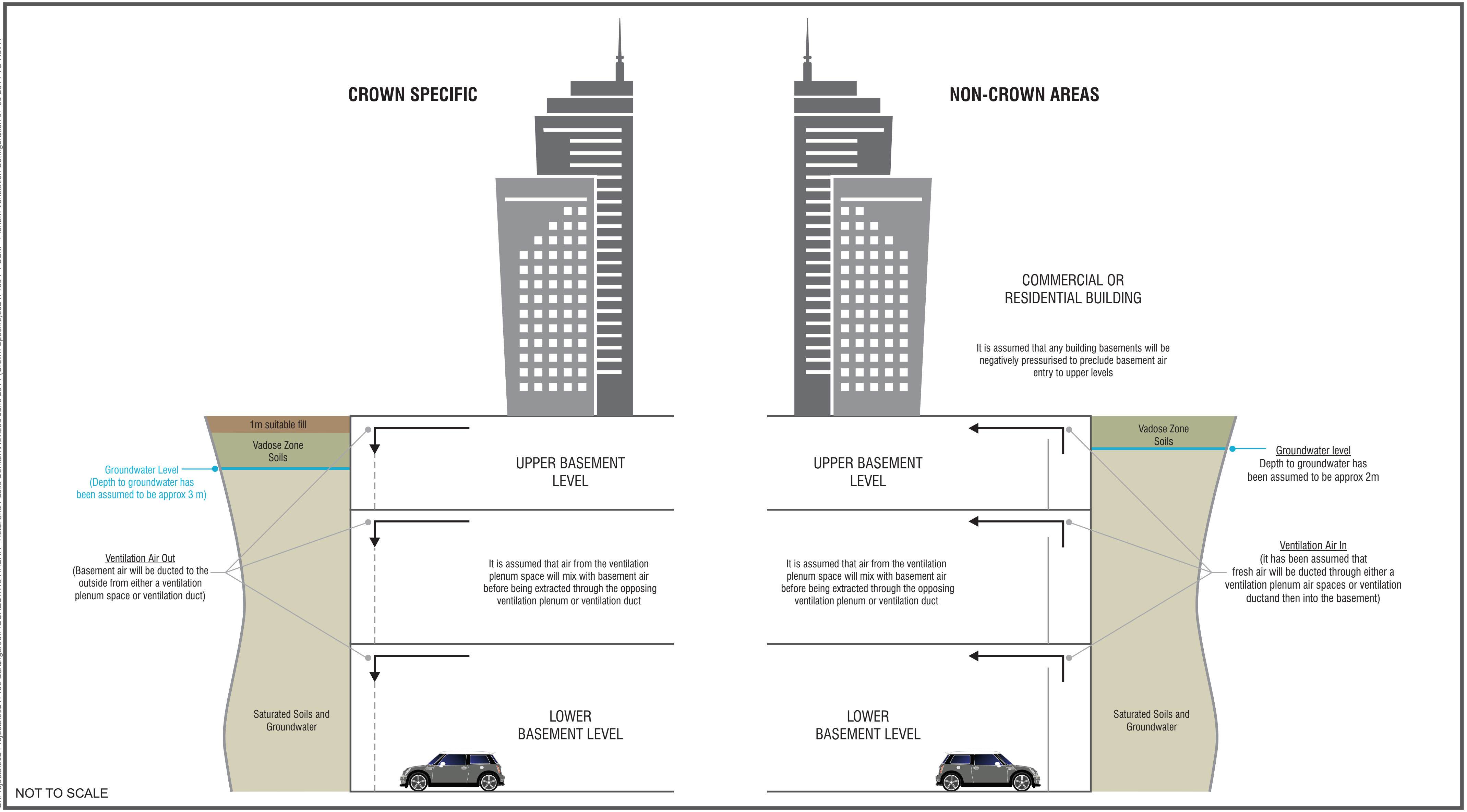

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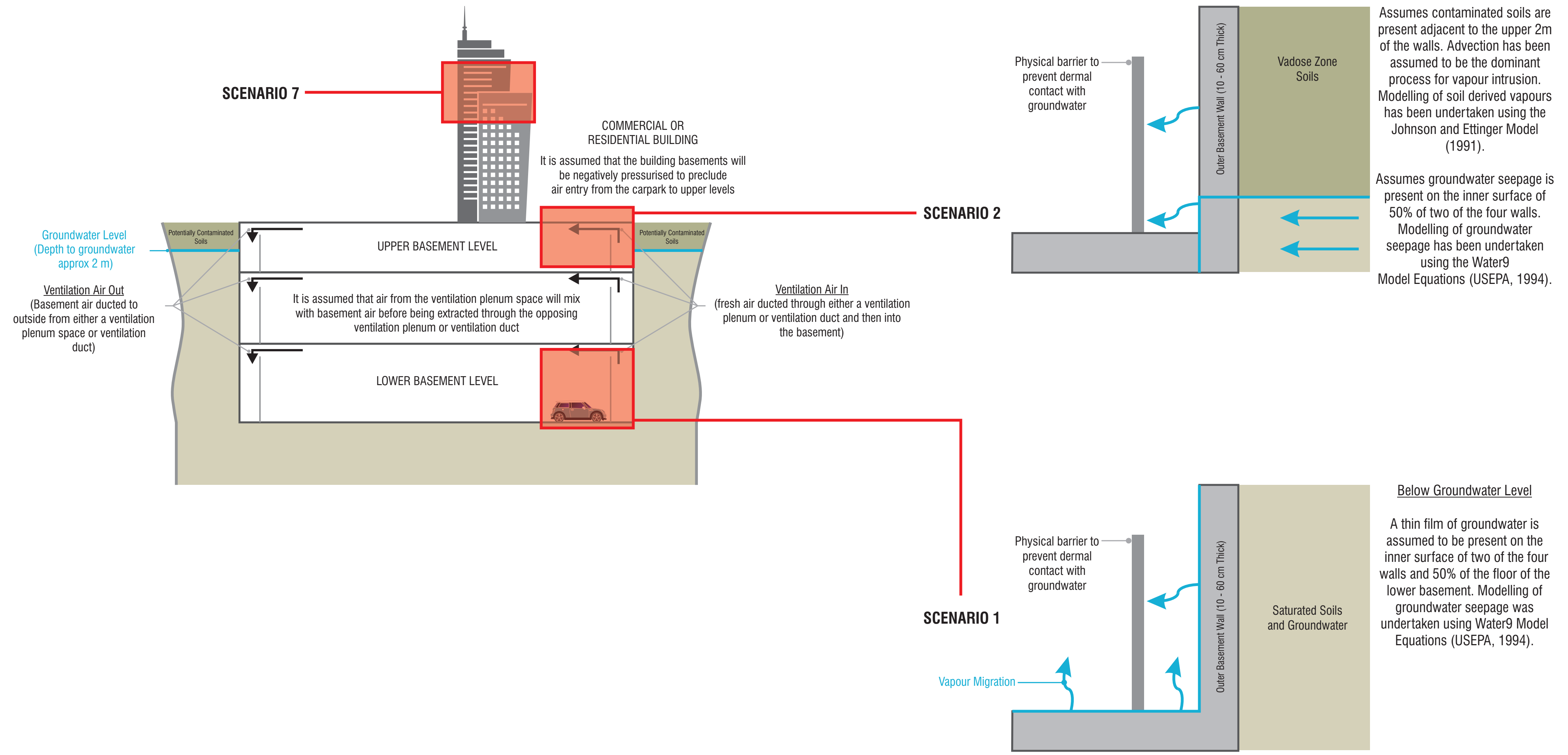
CONCEPTUAL SITE MODEL - VENTILATION CONFIGURATION

HHERA - Future Stage 1c, (ORWN Area)
Barangaroo
Hickson Road, Millers Point NSW

FIGURE F4



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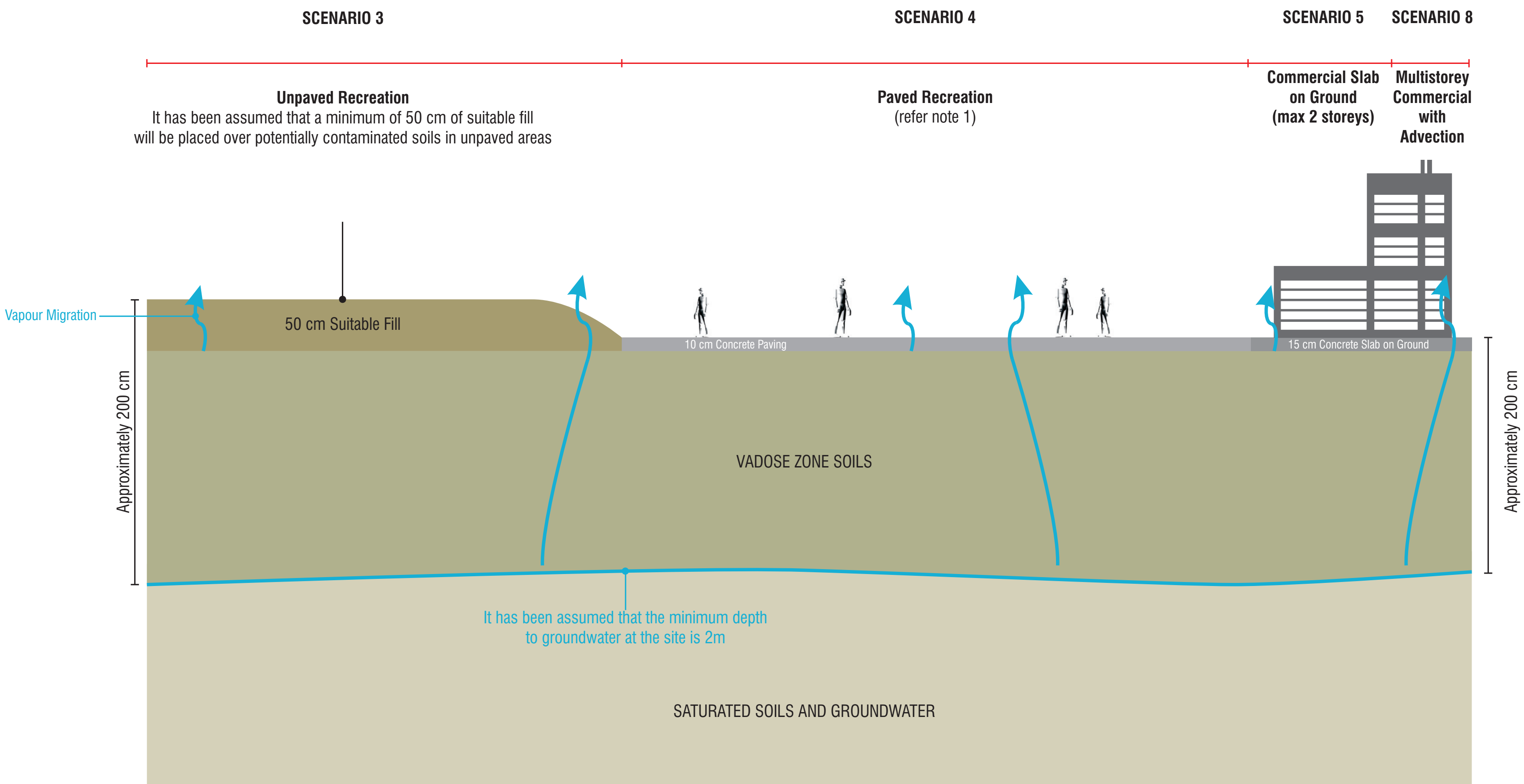
CONCEPTUAL SITE MODEL - SCENARIO 1 (LOWER BASEMENT), SCENARIO 2 (UPPER BASEMENT) AND SCENARIO 7 (HIGH DENSITY RESIDENTIAL)

HHERA - Future Stage 1c, (ORWN Area)
Barangaroo
Hickson Road, Millers Point NSW

FIGURE F5



Note 1: It has been assumed that paved recreation areas will be covered by 10cm thick concrete/hardstand.
It is noted however that future paved recreation areas may become unpaved, so it is recommended that at least 50cm of suitable fill be placed below paved recreation areas also.

NOT TO SCALE

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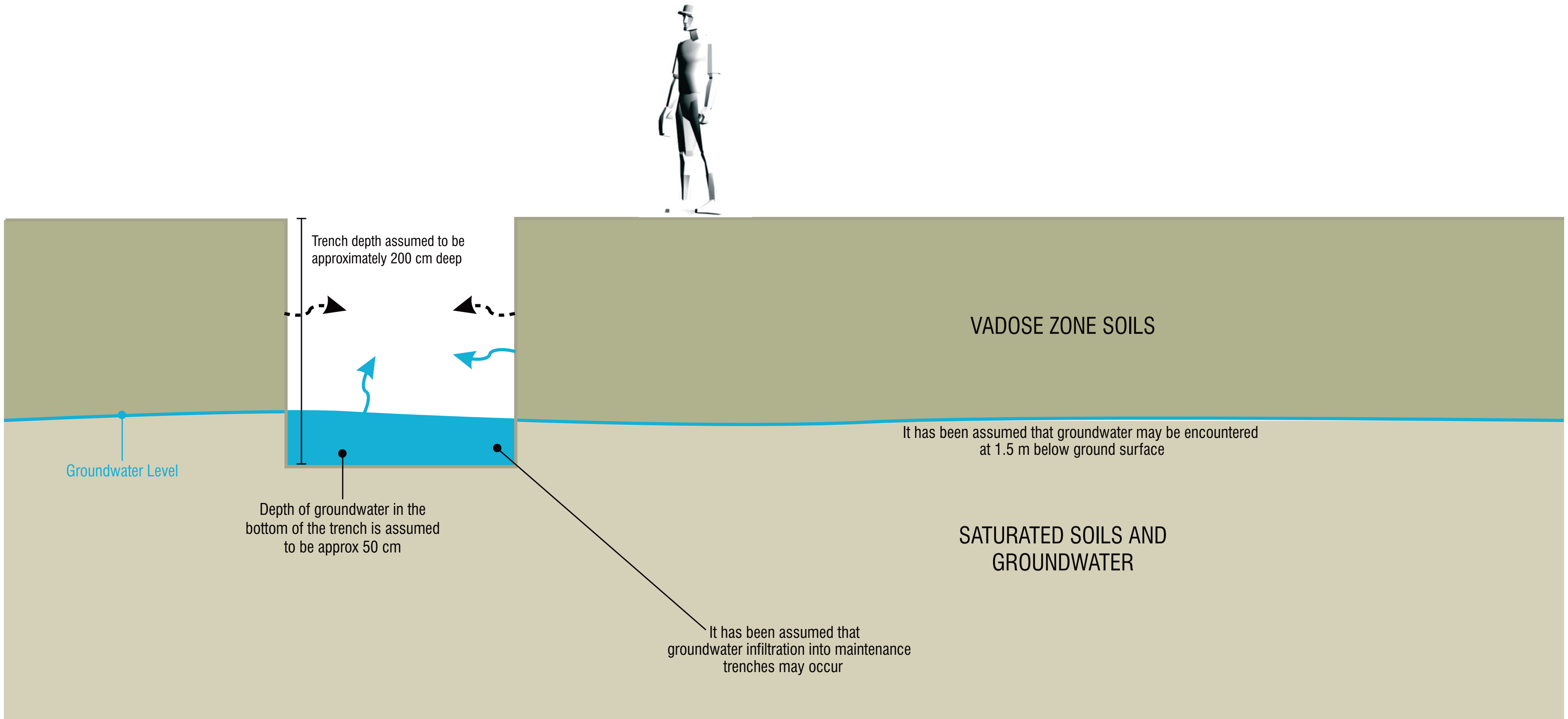
CONCEPTUAL SITE MODEL - SCENARIO 3 (UNPAVED RECREATION), SCENARIO 4 (PAVED RECREATION), SCENARIO 5 (COMMERCIAL SLAB ON GROUND) AND SCENARIO 8 (COMMERCIAL WITH ADVECTION)

HHERA - Future Stage 1c, (ORWN Area)
Barangaroo
Hickson Road, Millers Point NSW

FIGURE F6



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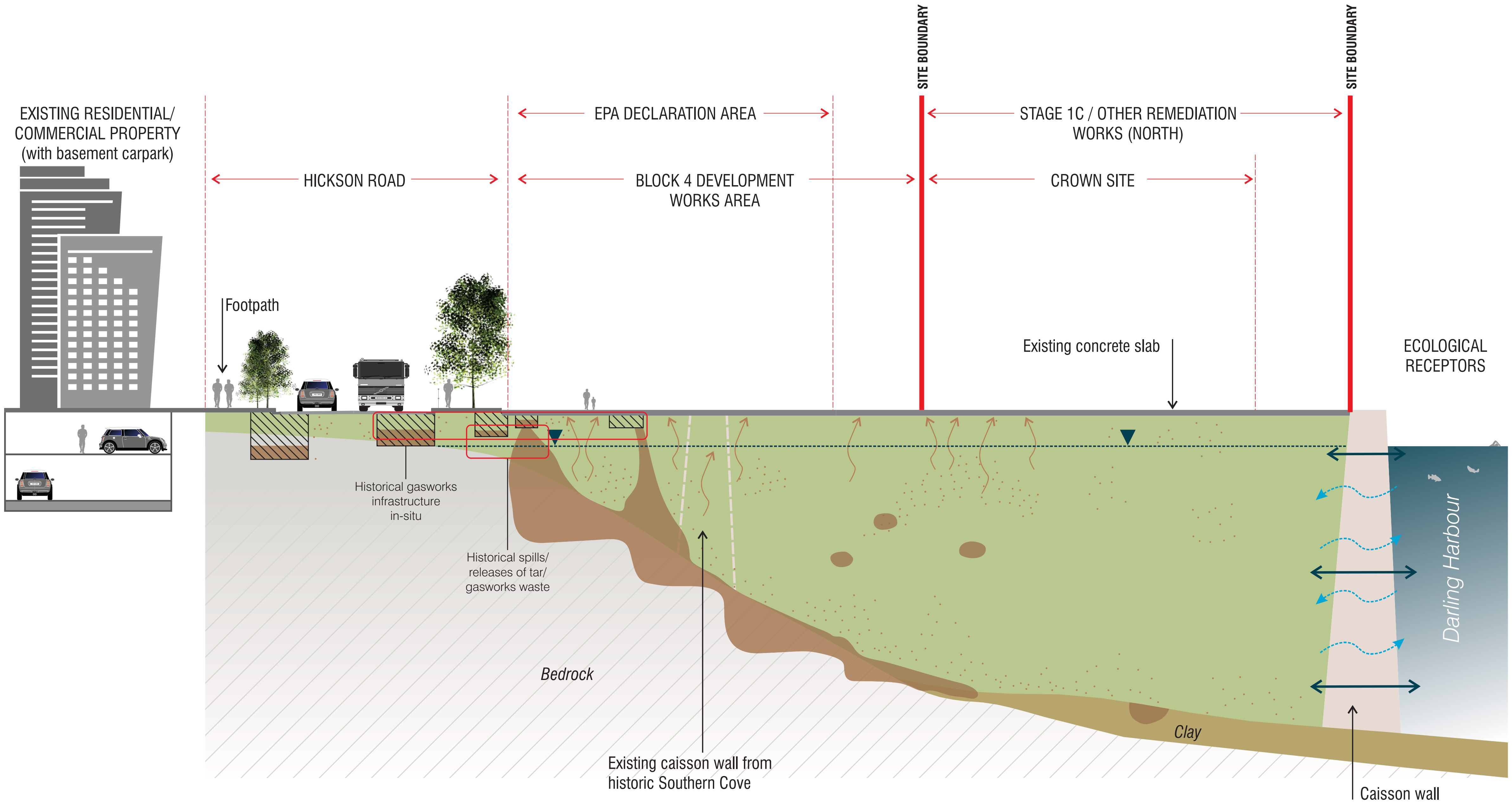
CONCEPTUAL SITE MODEL - SCENARIO 6 (INTRUSIVE MAINTENANCE - CONTACT WITH GROUNDWATER)

HHERA - Future Stage 1c, (ORWN Area)
Barangaroo
Hickson Road, Millers Point NSW

FIGURE F7



KEY

- Impacted soil/fill with gasworks related COPC
- Gas works infrastructure
- Tar/gasworks waste
- Diffusion of volatile COPC identified with soil and groundwater at the site
- Migration of vapours within trenches onsite. Dermal/ingestion contact with soils also relevant
- Migration of impacted groundwater off-site (GDS, 2011)
- Tidal exchange (refer to GDS, 2011)

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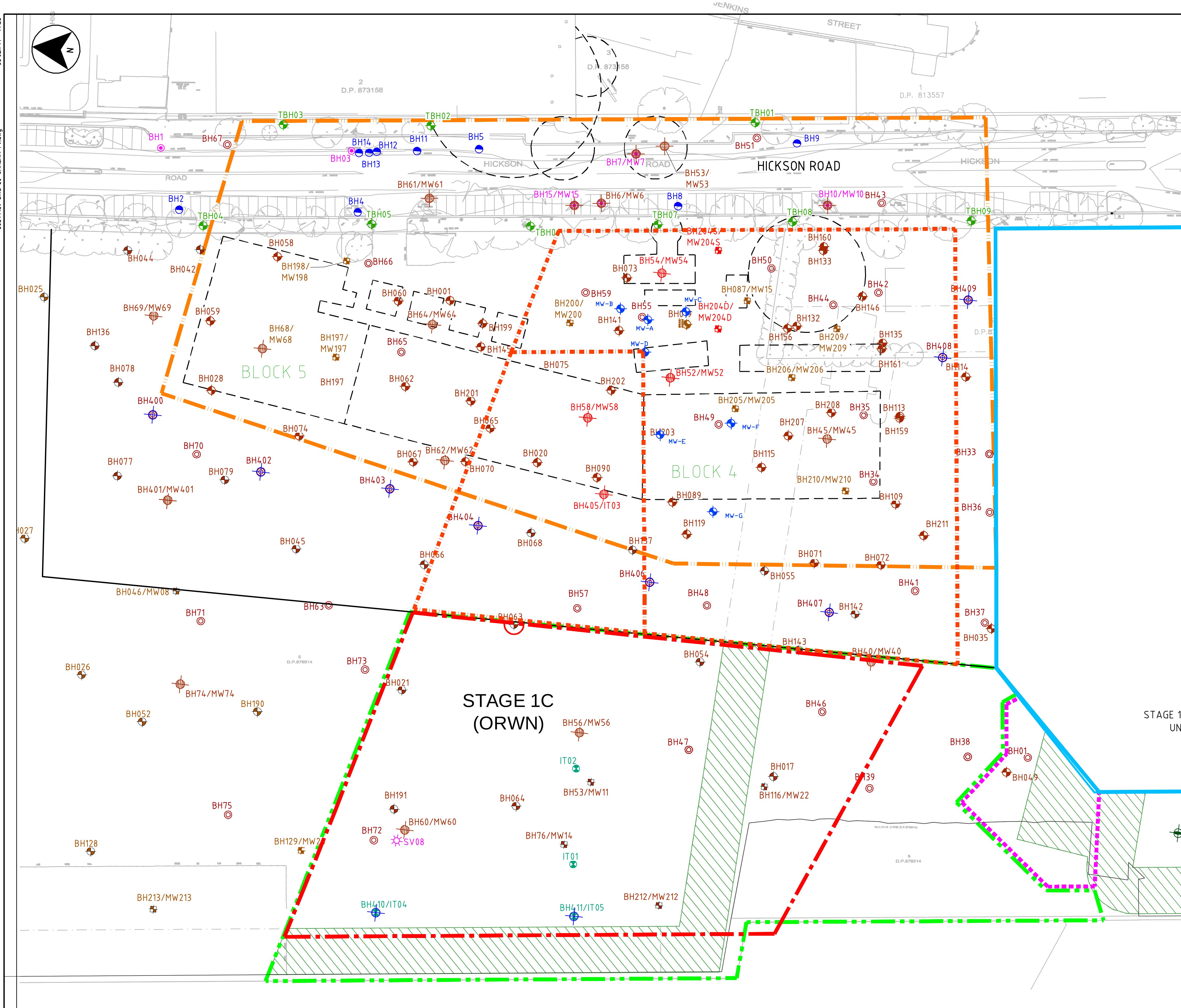
OVERALL CONCEPTUAL SITE MODEL

HHERA - Future Stage 1c, (ORWN Area)
Barangaroo
Hickson Road, Millers Point NSW

FIGURE F8



LEGEND

- COFFEY BOREHOLE LOCATION
- COFFEY GROUNDWATER WELL LOCATION
- ERM BOREHOLE LOCATION
- ERM GROUNDWATER MONITORING WELL LOCATION
- AECOM BOREHOLE LOCATION
- AECOM GROUNDWATER MONITORING WELL LOCATION
- AECOM SOIL VAPOUR LOCATION
- AECOM INTERTIDAL WELL LOCATION
- AECOM STILLING WELL LOCATION
- DECLARATION BOUNDARY
- THE SITE BOUNDARY
- EXISTING ORWS BASEMENT GROUNDWATER RETENTION WALL SYSTEM
- CROWN SITE BOUNDARY
- HARBOUR HEAT REJECTION INLET SYSTEM AREA
- CAISSON WALL
- PROPOSED BASEMENT GROUNDWATER RETENTION WALL SYSTEM BLOCK 4 DEVELOPMENT WORKS AREA
- ASSUMED TIDAL PRISM
- APPROXIMATE EXTENT OF FORMER GASWORKS FEATURES
- BLOCK 4 AND 5 BOUNDARIES

NAPHTHALENE EXCEEDS SITE SPECIFIC CRITERIA

NOTE:
LOCATION OF COFFEY GROUNDWATER WELLS ARE APPROXIMATE ONLY.

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FIGURE 9:
SOIL SSTC EXCEEDANCES - SCENARIO 8
COMMERCIAL SLAB ON GROUND WITH ADVECTION

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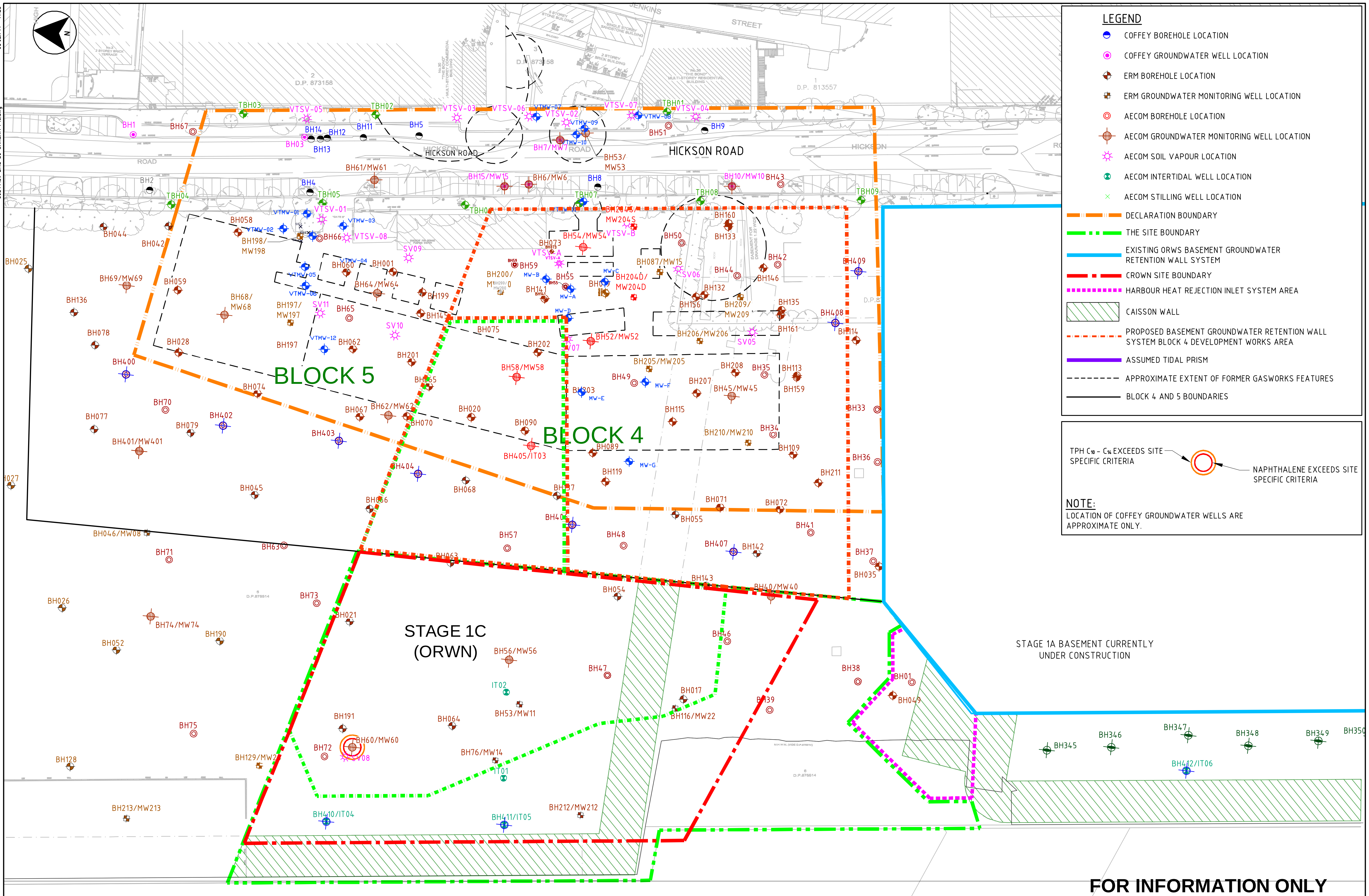

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FIGURE 10:
GROUNDWATER SSTC EXCEEDENCES - SCENARIO 6:
INTRUSIVE MAINTAINANCE

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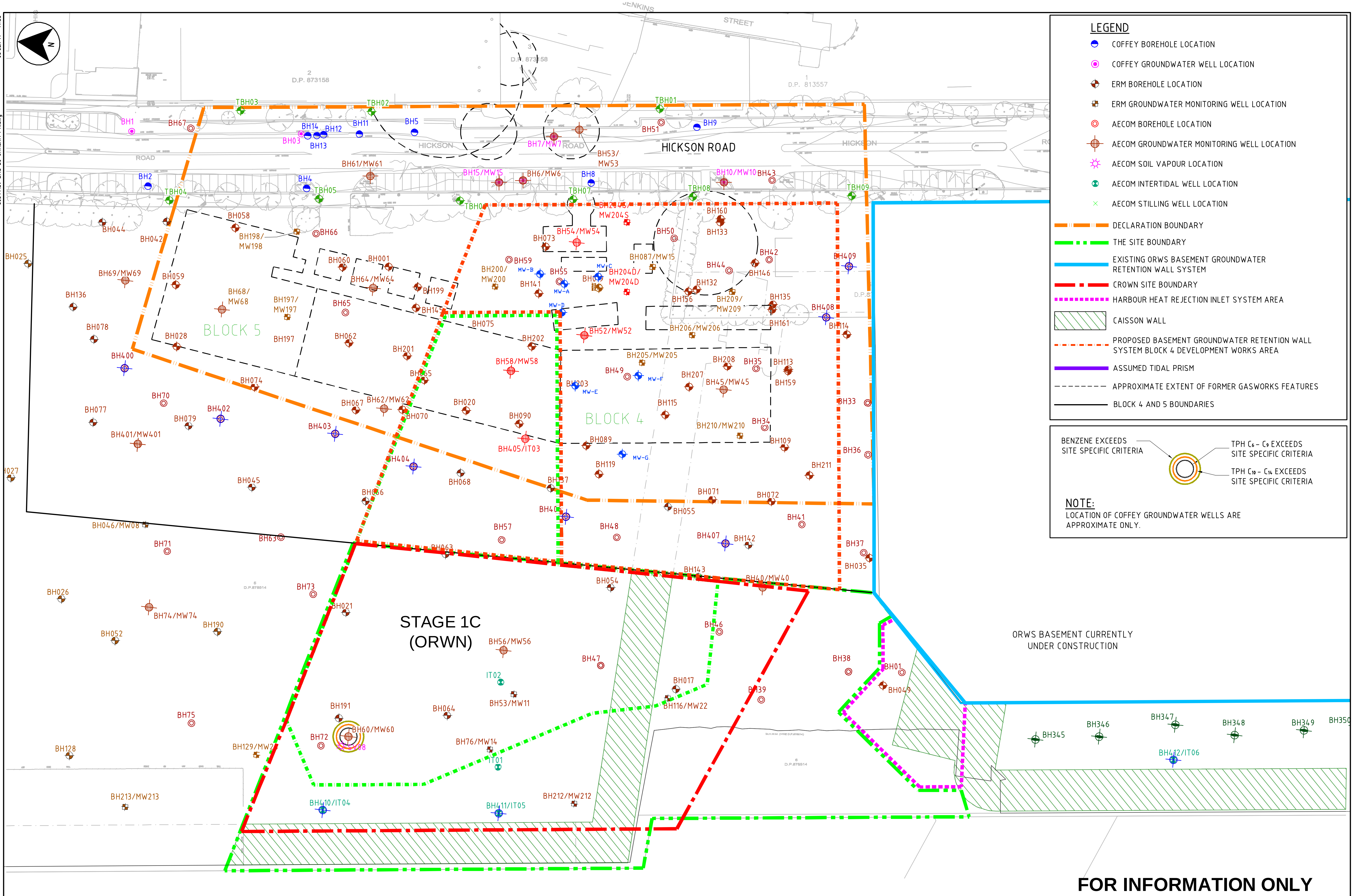

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FIGURE 11:
GROUNDWATER SSTC EXCEEDENCES - SCENARIO 8:
COMMERCIAL SLAB ON GROUND WITH ADVECTION

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