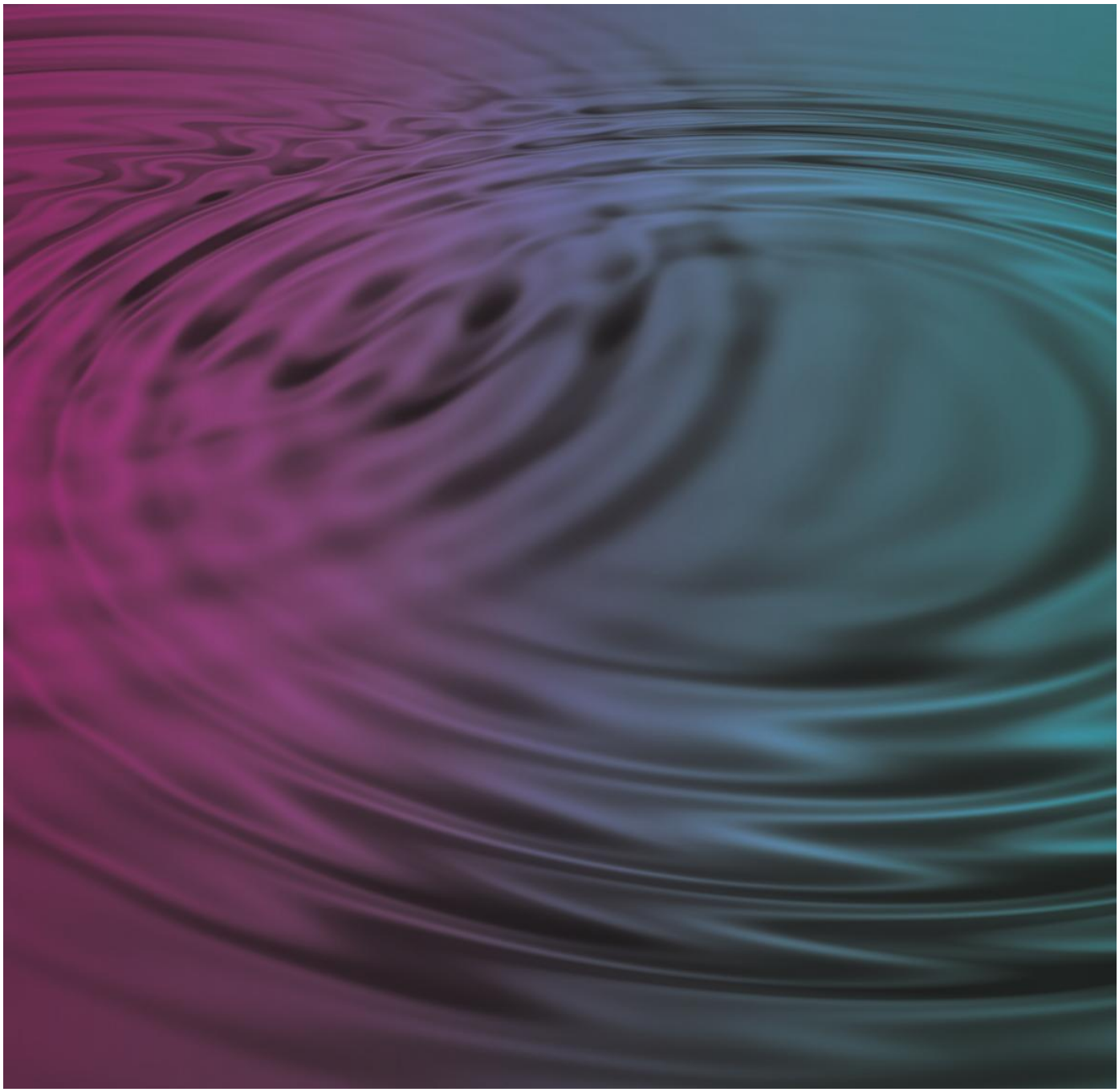
AECOM

Barangaroo
Lend Lease (Millers Point) Pty Limited
23-Jul-2013
Doc No. RPT 066

FINAL

VMP Remediation Extent

VMP Remediation Works Area, (Parts of Barangaroo and Hickson Road), Millers Point, NSW



VMP Remediation Extent

VMP Remediation Works Area, (Parts of Barangaroo and Hickson Road), Millers Point, NSW

Client: Lend Lease (Millers Point) Pty Limited

ABN: 15 127 727 502

Prepared by

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23-Jul-2013

Job No.: 60264796

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Printed on environmentally responsible paper.

Quality Information

Document VMP Remediation Extent

Ref 60264796

Date 23-Jul-2013

Prepared by Andrew Rolfe

Reviewed by Michael Jones

Reviewed by Brad Eismen

Revision History

Revision	Revision Date	Details	Authorised	
			Name/Position	Signature
0	15-Aug-2012	Issued for Lend Lease review	Michael Jones Technical Director	
1	17-Aug-2012	Issued for BDA review	Michael Jones Technical Director	
2	3-Sept-2012	Issued for Site Auditor review	Michael Jones Technical Director	
3	12-Oct-2012	Issued for NSW EPA review	Michael Jones Technical Director	
4	8-Mar-2013	Issued for Lend Lease and BDA review	Michael Jones Technical Director	
5	13-Mar-2013	Issued for Site Auditor review	Michael Jones Technical Director	
6	20-June-2013	Draft issued for Lend Lease review	Michael Jones Technical Director	
7	27-June-2013	Final issued to Lend Lease	Michael Jones Technical Director	
8	11-July-2013	Final Draft issued to Lend Lease, Site Auditor and BDA	Michael Jones Technical Director	
9	23-July-2013	Final issued to Lend Lease, Site Auditor and BDA	Michael Jones Technical Director	

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Glossary of Terms

Term	Description
AECOM	AECOM Australia Pty Limited
AHD	Australian Height Datum
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
ASLP	Australian Standard Leaching Procedure
ASSMAC	New South Wales Acid Sulfate Soils Management Advisory Committee
As	Arsenic
Ba	Barium
BaP/ B(a)P	Benzo(a)pyrene
BDA	Barangaroo Delivery Authority (the Authority)
BH	Borehole location
BTEX	Benzene, Toluene, Ethylbenzene and Xylene
BTOC	Below Top of Casing
Cd	Cadmium
CIM	Confirmed Impacted Material
CLM Act	*Contaminated Land Management Act* (2007)
Co	Cobalt
CoC	Chain of Custody
CO_2	Carbon Dioxide
Cr	Chromium
CoPC	Chemicals of Potential Concern
cPAHs	carcinogenic Polycyclic Aromatic Hydrocarbons
Cu	Copper
CUTEP	Clean Up to the Extent Practicable
DEC	Department of Environment and Conservation NSW (superseded)
DECC	Department of Environment and Climate Change NSW (superseded)
DECCW	Department of Environment, Climate Change and Water NSW (superseded)
DGI	Data Gap Investigation
DoPI	NSW Department of Planning and Infrastructure
DP	Deposited Plan
DQO	Data Quality Objectives
Declaration Area	As defined by the NSW EPA Declaration
DSI	Detailed Site Investigation
EC	electrical conductivity
EMP	Environment Management Plan

Term	Description
ESCO	*Ex situ* Chemical Oxidation
EPA	Environment Protection Authority
ESA	Environmental Site Assessment
ESD	Ecologically Sustainable Development
GDS	Groundwater Discharge Study
GMP	Groundwater Management Plan
Hg	Mercury
HHERA	Human Health and Ecological Risk Assessment
HI	Hazard Index
HIL	Health Investigation Level
ISCO	*In situ* Chemical Oxidation
ISS	*In situ* Solidification / Stabilisation
JBS	JBS Environmental Pty Limited
m bgl	metres below ground level
Mn	Manganese
MW	Monitoring Well Location
MWQC	Marine Water Quality Criteria
LOR	Limit of Reporting
Lend Lease	Lend Lease (Millers Point) Pty Limited
NATA	National Association of Testing Authorities
NEPC	National Environment Protection Council
NEPM	(National Environmental Protection (Assessment of Site Contamination) Measure
Ni	Nickel
NHMRC	National Health and Medical Research Council
NSW	New South Wales
OEH	Office of Environment and Heritage
ORWN	Other Remediation Works (North) Area
ORWS	Other Remediation Works (South) Area
PAH	Polycyclic Aromatic Hydrocarbons
PID	Photoionisation Detector
Pb	Lead
POEO Act	*Protection of the Environment Operations Act* (1997) NSW)
PPE	Personal Protective Equipment
RAP	Remedial Action Plan
RL	Relative Level
SAQP	Sampling Analysis and Quality Plan

Term	Description
SAS	Site Audit Statement
SEPP	State Environmental Planning Policy
SEPR™	Surfactant Enhanced Product Recovery
SHFA	Sydney Harbour Foreshore Authority
SIL	Soil Investigation Level
S-ESCO™	Surfactant Enhanced *Ex situ* Chemical Oxidation
S-ISCO®	Surfactant-enhanced In Situ Chemical Oxidation
SPGWT	Separated Phase Gasworks Waste and Tar
SPOCAS	Suspension Peroxide Oxidation Combined Acidity & Sulfate
SWL	Standing Water Level
SVE	Soil vapour extraction
SVOC	Semi Volatile Organic Compound
TCM	Tar Containing Material
TEQ	Toxicity Equivalency Factor
TOC	Top of Casing
TPH	Total Petroleum Hydrocarbons
VMP	Voluntary Management Proposal
VOC	Volatile Organic Compound
UCL	Upper Confidence Level
US EPA	United States Environment Protection Agency
Zn	Zinc

Units of Measurement			
°C	degrees Celsius	mg	milligrams
cm	Centimetre	mS	milli-Siemens
ha	Hectare	mV	millivolts
kg	Kilogram	ppm	parts per million
km	Kilometre	µg	microgram
m	Metres	%	percent

Executive Summary

AECOM Australia Pty Limited (AECOM) has been commissioned by Lend Lease (Millers Point) Pty Ltd (LL) to prepare this *VMP Remediation Extent* report for the NSW Environment Protection Authority (NSW EPA) Declaration Area (hereafter referred to as 'the Site'), located at Hickson Road, Millers Point, NSW (refer to **Figure F1**). The Site (NSW EPA Declaration Area also known as the "Voluntary Management Proposal (VMP) Remediation Works Area") comprises:

- a section of Hickson Road;
- part of Barangaroo Block 4 (within Barangaroo South); and
- part of Barangaroo Block 5 (within Barangaroo Central).

In May 2009, the NSW EPA, determined that part of the Barangaroo site and part of Hickson Road (corresponding with the location of part of the former gas works) was contaminated in such a way as to present a significant risk of harm (SROH) to human health and the environment. As a consequence, the NSW EPA declared the Site to be a remediation site (Declaration Number 21122; Area Number 3221, here-in referred to as the NSW EPA Declaration) under the then Section 9 of the *Contaminated Land Management (CLM) Act* (1997). The Site coincides with the area of the NSW EPA Declaration.

This report has been prepared to describe:

- The remediation goals, based on the assessment of risk in the *VMP Human Health and Ecological Risk Assessment* (*VMP HHERA*, AECOM, 2012c) and developed to meet NSW EPA policy requirements, that are applicable to remediation of the Site to achieve the nominated remediation objectives; and
- The extent of remediation required to achieve the remediation goals on which the *VMP/Block 4 Remedial Action Plan* (*VMP/Block 4 RAP, AECOM*, 2013b) will be based.

As such, this document represents a link between the *VMP HHERA* (AECOM, 2012c) and the *VMP/Block 4 RAP* (AECOM, 2013b) and should be read in conjunction with these reports.

Remediation Objectives

The key objective of the remediation of the Site is to enable the NSW EPA Declaration to be revoked. Additional objectives of the remediation works are to:

- Ensure that NSW EPA policy requirements are met, specifically:
  - the *Guidelines for the Assessment and Management of Groundwater Contamination* (NSW, DEC, 2007) which incorporate the requirements for removal or treatment of Light[1] or Dense Non-Aqueous Phase Liquids (NAPLs) to the extent practicable and consideration of Clean-up to the extent practicable (CUTEP);
  - the principle of Ecologically Sustainable Development (ESD) as required by Section 9 of the *CLM Act* (1997); and
  - The *Waste Avoidance and Resource Recovery Act* (2001).
- Ensure the remediated Site is protective of human health in the context of its current form and land use;
- Ensure that the remediated Site is, to the extent practicable, protective of the environment (specifically groundwater within fill material at the down hydraulic gradient Site boundary and ultimately surface water in Darling Harbour) by minimising the risk of ongoing contamination; and
- Comply with applicable legislative requirements including the appropriate requirements of the NSW Department of Planning (DoP) and NSW EPA.

AECOM understands that removal of the NSW EPA Declaration would require demonstration that contamination at the Site is not *significant enough to warrant regulation* (as per the *CLM Act*, 1997) under the current land use scenario, or land use scenarios allowable at the Site without a development approval. Based on the current zoning of the developable portion of the Site (Zone B4 Mixed Use under the Environmental Planning Policy (Major Development) Amendment (Barangaroo) 2012)), no development is allowed without planning consent. The

[1] It is noted that LNAPLs have not been identified at the Site and, as such, are not discussed further.

remediation goals developed by this document are therefore 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.

Scope

The scope of work associated with the preparation of this document included:

- Review the Conceptual Site Model for the Site including consideration of available data from previous environmental investigations at the Site to assess the potential for contamination at the Site;
- Development of remediation goals for the protection of human health and the environment based on the recommendations of the *VMP HHERA* (AECOM, 2012c) and to meet NSW EPA policy requirements;
- Consideration of the extent to which the remediation goals can be practicably achieved based on:
    - Comparison of available site data for soil and groundwater to the remediation goals;
    - Identification of areas where contamination has been identified which requires remediation/management as part of the VMP, based on consideration of the remediation goals; and
    - Consideration of the standard and extent of remediation that can be practicably achieved by the remediation technologies that are most likely to be implemented at the Site and as required by:
        - The Guidelines for the Assessment and Management of Groundwater Contamination (NSW, DEC, 2007) which incorporate the principle of Clean-up to the extent practicable (CUTEP) (Section 4.3);
        - The principle of Ecologically Sustainable Development (ESD) as required by Section 9 of the *CLM Act* (1997); and
        - The *Waste Avoidance and Resource Recovery Act* (2001).

Remediation Goals

The remediation goals for the protection of human health and the environment have been developed based on the recommendations of the *VMP HHERA* (AECOM, 2012c) and to meet NSW EPA policy requirements. The remediation goals are:

- As a primary goal, removal / remediation of Separate Phase Gasworks Waste and Tar (SPGWT[2]) 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 Site-Specific Target Criteria (SSTC); and/or
        - Unsaturated or saturated soil concentrations that are considered to be the source of groundwater concentrations exceeding the groundwater SSTCs in fill material; and
    - Such that groundwater quality within fill material leaving the Site (measured in fill at the down hydraulic gradient Site boundary) approaches the Marine Water Quality Criteria (MWQC).

[2] For the purposes of this report, SPGWT refers to:
- Tar Containing Materials (TCM) which are defined as described below; and
- Dense Non Aqueous Phase Liquids (DNAPLs).

The presence or otherwise of TCM is based on comparison of observed site conditions and analytical data to the following criteria:
- 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:
    - Polycyclic Aromatic Hydrocarbons (PAHs): 2,000 mg/kg; or
    - Benzo(a)Pyrene (B(a)P): 150 mg/kg.

Remediation Extent

The extent of remediation in the unsaturated and saturated zones is presented on **Figure F14** and **Figure F15**, respectively.

The lateral extent of remediation has been determined based on consideration of:

- The presence of historic gasworks infrastructure, the distribution of SPGWT and CIM within the respective Site areas; and
- The extent of remediation that can be practicably achieved 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 achieved within the proposed Remediation Extent should 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 within the Remediation Extent fill material is reduced, on average, by 90%, to the extent practicable (calculated based on the estimated mass of naphthalene and TPH C_{10} - C_{14}).

The vertical extent of remediation has been 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 is noted that SPGWT and CIM have been reported in the natural marine sediments both within the Site and in some hydraulically down gradient areas to the west of the Site. However, the negligible contaminant flux from these natural materials is not considered to pose a significant risk to human health or the environment (refer to **Section 2.5**). As such, the proposed extent of remediation works excludes remediation of natural marine sediments which are present below a depth of 10 m bgl.

The proposed extent of remediation is considered to be consistent with the key requirements of the NSW DEC (2007) *Guidelines for the Assessment and Management of Groundwater Contamination,* in particular:

- Source Control and remediation of NAPL to the extent practicable – the proposed extent of remediation includes all of the identified primary contaminant sources (i.e. historical gasworks structures) and the majority 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 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) or the environment. 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 Site: and, groundwater quality discharging to Darling Harbour from residual contamination will be less than the MWQC

- *The value of the groundwater resource* - multiple lines of evidence have been provided to demonstrate 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 achieve the requisite contaminant mass reduction).

1.0 Introduction

AECOM Australia Pty Limited (AECOM) has been commissioned by Lend Lease (Millers Point) Pty Ltd (LL) to prepare this *Voluntary Management Proposal (VMP) Remediation Extent* report for the NSW Environment Protection Authority (EPA) Declaration Area (hereafter referred to as 'the Site'), located at Hickson Road, Millers Point, NSW (refer to **Figure F1**). The Site (NSW EPA Declaration Area also known as the "Voluntary Management Proposal" (VMP) Remediation Works Area") comprises:

- a section of Hickson Road;
- part of Barangaroo Block 4 (within Barangaroo South); and
- part of Barangaroo Block 5 (within Barangaroo Central) (refer to **Figure F2**).

In May 2009, the NSW EPA determined that part of the Barangaroo site and part of Hickson Road (corresponding with the location of part of the former gas works) was contaminated in such a way as to present a significant risk of harm (SROH[3]) to human health and the environment.

As a consequence, the NSW EPA declared the Site to be a remediation site (Declaration Number 21122; Area Number 3221, here-in referred to as the NSW EPA Declaration) under the then Section 9 of the *CLM Act* (1997). The Site coincides with the area of the NSW EPA Declaration.

This report has been prepared to describe:

- The remediation goals, based on the assessment of risk in the *VMP Human Health and Ecological Risk Assessment* (VMP HHERA, AECOM, 2012c) and developed to meet NSW EPA policy requirements, that are applicable to remediation of the Site to achieve the nominated objectives (refer to **Section 1.1**); and
- The extent of remediation required to achieve the remediation goals on which the *VMP/Block 4 Remedial Action Plan* (*VMP/Block 4 RAP*, AECOM, 2013b) is based.

As such, this document represents a link between the *VMP HHERA* (AECOM, 2012c) and the *VMP/Block 4 RAP* (AECOM, 2013b) and should be read in conjunction with these reports.

1.1 Remediation Objectives

The key objective of the remediation of the Site is to enable the NSW EPA Declaration to be revoked. Additional objectives of the remediation works are to:

- Ensure that NSW EPA policy requirements are met, specifically:
  - the *Guidelines for the Assessment and Management of Groundwater Contamination* (NSW, DEC, 2007) which incorporate the requirements for removal or treatment of Non-Aqueous Phase Liquids (NAPLs) to the extent practicable and consideration of Clean-up to the extent practicable (CUTEP);
  - the principle of Ecologically Sustainable Development (ESD) as required by Section 9 of the *CLM Act* (1997); and
  - The *Waste Avoidance and Resource Recovery Act* (2001).
- Ensure the remediated Site is protective of human health in the context of its current form and land use;
- Ensure that the remediated Site is, to the extent practicable, protective of the environment (specifically groundwater within fill material at the down hydraulic gradient Site boundary and ultimately surface water in Darling Harbour) by minimising the risk of ongoing contamination; and
- Comply with applicable legislative requirements including the appropriate requirements of the NSW Department of Urban Affairs and Planning (DUAP), NSW Department of Planning (DoP) and NSW EPA.

AECOM understands that removal of the NSW EPA Declaration would require demonstration that contamination at the Site is not *significant enough to warrant regulation* (as per the *CLM Act*, 1997) under the current land use scenario, or land use scenarios allowable at the Site without a development approval. Based on the current zoning of the developable portion of the Site (Zone B4 Mixed Use under the Environmental Planning Policy (Major

[3] As an amendment to the *CLM Act* on 1 July 2009, reference to SROH was removed. *Significantly contaminated land* is now referred to as *land is contaminated and that the contamination is significant enough to warrant regulation*.

Development) Amendment (Barangaroo) 2012)), no development is allowed without planning consent. The remediation goals developed by this document are therefore 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.

1.2 Scope of Work

The scope of work associated with the preparation of this document included:

- Review the Conceptual Site Model for the Site including consideration of available data from previous investigations at the Site to assess the potential for contamination at the Site;
- Development of remediation goals for the protection of human health and the environment based on the recommendations of the *VMP HHERA* (AECOM, 2012c);
- Consideration of the extent to which the remediation goals can be practicably achieved based on:
    - Comparison of available site data for soil and groundwater to the remediation goals;
    - Identification of areas where contamination has been identified which requires remediation/management as part of the VMP, based on consideration of the remediation goals; and
    - Consideration of the standard and extent of remediation that can be practicably achieved by the remediation technologies that are most likely to be implemented at the Site and as required by:
        - The *Guidelines for the Assessment and Management of Groundwater Contamination* (NSW, DEC, 2007) which incorporate the principle of Clean-up to the extent practicable (CUTEP) (Section 4.3);
        - The principles of ESD as required by Section 9 of the *CLM Act* (1997); and
        - The *Waste Avoidance and Resource Recovery Act* (2001).

1.3 Document Structure

The document structure for this VMP Remediation Extent report is based on the Scope of Work described in **Section 1.2** and is summarised as follows.

- Review of Conceptual Site Model and available soil and groundwater data:
    - Section 2: Conceptual Site Model.
- Development of Remediation Goals based on the recommendations of the *VMP HHERA* (AECOM, 2012c):
    - Section 3: Remediation Goals;
- Recommended Remediation Extent - for the purpose of this document, the remediation extent resulting from application, to the extent practicable, of which of the remediation goals will be considered in turn:
    - Section 4: Contaminant Characterisation for Protection of Human Health;
    - Section 5: Remediation Extent for Protection of Human Health;
    - Section 6: Remediation Extent for Protection of the Environment including assessment of remediation requirements adopting the principles of CUTEP (as provided for by Section 4.3 of the NSW DEC [2007] *Guidelines for the Assessment and Management of Groundwater Contamination*);
- Consolidated remediation requirements for Protection of Human Health and the Environment:
    - Section 7: Conclusions.

2.0 Conceptual Site Model

2.1 Previous Investigations

A Conceptual Site Model (CSM) for the Site has been developed based on the findings of the following reports:

- ERM, 2007. *Environmental Site Assessment, East Darling Harbour, Sydney, NSW*. June 2007;
- Coffey Environments (Coffey), 2008. *Preliminary Environmental Investigation, 30-38 Hickson Road, Millers Point*, NSW 2000. May 2008;
- Coffey. 2010. *Barangaroo Stage 1 Development Geotechnical Report*. 15 October.
- ERM, 2008a. *Additional Investigation Works at Barangaroo, Hickson Road, Millers Point, NSW*. July 2008;
- AECOM, 2010b. *Data Gap Investigation, EPA Declaration Area (Parts of Barangaroo Site and Hickson Road), Hickson Road, Millers Point, NSW*. September 2010;
- AECOM, 2010c. *Data Gap Investigation, Other Remediation Works (North) Area, Hickson Road, Millers Point, NSW*. November, 2010;
- AECOM 2010d. *Groundwater Discharge Study, Stage 1 Barangaroo Development*. 3 November 2010;
- AECOM, 2011. *Declaration Site (Development Works) Remediation Works Area HHERA* (hereafter referred to as the Declaration Site [Development Works] HHERA) – Barangaroo. 9 June.
- AECOM, 2012a. *VMP Supplementary Data Gap Investigation, Site, Millers Point, NSW*, March 2012;
- AECOM, 2012b. *Contaminant Flux and Discharge Estimates for Natural Residual Soil and Marine Sediments, EPA Declaration Area 21122 and adjacent areas of Barangaroo South and Barangaroo Central*, 14 March 2012. Refer to **Appendix C**;
- AECOM, 2012c. HHERA, *VMP Remediation Works Area, (Addressing the NSW EPA Remediation Site Declaration 21122, Millers Point)*. October 2012 (Draft);
- AECOM, 2013a. *Contaminant Flux and Discharge Estimations for natural residual soil and marine sediments, EPA Declaration area 21122 and adjacent areas of Barangaroo South and Barangaroo Central*. 8 March 2013, refer to **Appendix D**; and
- AECOM, 2013b. *VMP/Block 4 RAP, VMP Remediation Works Area, (Parts of Barangaroo and Hickson Road)*. March 2013 (Draft);
- JBS Environmental, 2012. *Barangaroo Central DGI*. August.

A summary of these reports (and others) is presented in Section 2.6 of the *VMP HHERA* (2012c). Summaries of the JBS *Barangaroo Central DGI* report (JBS, 2012), which is not summarised in the *VMP HHERA*, is provided in **Section 2.1.1** below and summaries of AECOM (2010d) and AECOM (2012b) are provided in **Section 2.5.2**.

2.1.1 JBS Barangaroo Central DGI (2012)

JBS Environmental Pty Limited (JBS) was commissioned by the Barangaroo Delivery Authority (the Authority) to undertake the *Barangaroo Central DGI* within the Barangaroo Central site area (comprising parts of Lots 5 and 6 of Deposited Plan 876514). It is understood that the Barangaroo Central area is initially proposed to be developed as the Barangaroo Stage 1 Public Domain (comprising a range of open space land uses and car parking) and, in the future, will be developed for a mixture of high density residential and open space land uses.

The *Barangaroo Central DGI* involved drilling and soil sampling at 52 boreholes across the Barangaroo Central site. Of these boreholes, 24 were converted to either shallow or deep groundwater monitoring wells. None of the JBS groundwater monitoring wells installed down hydraulic gradient of the Site were screened within the natural marine sediments.

The following soil and groundwater sampling locations were located in proximity to the Site (i.e. within 30 metres of the western and northern Site boundaries, refer to **Figure F3**):

- Soil sampling locations:
    - BH539 to BH442 and BH549;

- Groundwater sampling locations:
  - MW539 - screened between 3 and 6 m bgl. Natural clay was reported at 14 m bgl;
  - MW540 (shallow) - screened between 3 and 6 m bgl;
  - MW540 (deep) - screened between 10.7 and 13.7 m bgl. Natural clay was reported at 14 m bgl;
  - MW541 (shallow) - screened between 3 and 6 m bgl;
  - MW541 (deep) - screened between 7.5 and 10.5 m bgl. Bedrock was reported to be present at 10.8 m bgl (natural clays were not encountered during the drilling works); and
  - MW542 - screened between 2.5 and 5.5 m bgl. Natural clay was reported at 14.5 m bgl.

As detailed in Table 7.1.1 of the *Barangaroo Central DGI* report, higher PAH concentrations and BTEX concentrations were reported to be present within the fill materials at depths greater than 6.9 m bgl at BH541 and BH542 (located 10m west of the Site boundary in Block 5). A '*slight hydrocarbon, hydrogen sulphide and methane odour*' was observed in the fill material at BH541 below a depth of 6.9 m bgl and a '*hydrogen sulphide odour*' was observed at a depth of 13 m bgl at BH542. No visual or olfactory evidence of tar was noted in the JBS borehole logs for the sampling locations listed above.

Total PAHs (2,798 mg/kg) were reported to exceed the Tar Containing Material (TCM[4]) criteria (as described in **Section 3.3.1**) at a depth of 9.9-10.0 m bgl at BH541 (refer to **Figure F3**). Benzene and naphthalene groundwater concentrations in fill material also exceeded the Block 4 SSTCs at this location (MW541D, refer to **Table T16**). This well is screened between 7.5 to 10.5 m bgl. The Conclusions section of the *Barangaroo Central DGI* report indicated that impacted material in the south-eastern corner of the Barangaroo Central site was '*considered to be acting as a source of groundwater contamination*'. Based on the finding of the *Barangaroo Central DGI*, it was recommended that '*tar impacted materials as located at depth at the south-east of the site will require remediation/management based on identified impacts to groundwater in this area of the site*'.

No soil CoPC concentrations were reported at concentrations exceeding the SSTC (refer to **Section 3.2**) in the sampling locations detailed above.

The JBS groundwater monitoring results reported adjacent to the Site boundary (i.e. monitoring wells MW539 to MW542) indicated that arsenic, PAHs and ammonia concentrations variably exceeded the MWQC. The results support the *VMP HHERA* (AECOM, 2012c) conclusion that groundwater quality at the Site boundary represents a potential for unacceptable risk to the environment.

2.2 Geology

Lithologic conditions vary across the Site, but generally comprise fill material overlying sandy clays and clays and marine sediments, which in turn overlie weathered Hawkesbury Sandstone bedrock. Sandstone bedrock is generally present underlying natural weathered bedrock soils or in some instances directly under fill materials.

The fill thickness is variable across the Site, ranging from approximately 1 metre below ground level (m bgl) in the east (Hickson Road) to approximately 16 m bgl in the west (in the vicinity of the BH404, refer to **Figure F10** to **Figure F13**). The fill material is generally shallower in the eastern portion of the Site closest to Hickson Road and deeper in the western portion of the Site closest to Darling Harbour. The top of bedrock also varies across the Site from approximately 3 m bgl in the east to greater than 16 m bgl in the west. The natural soil and marine sediments generally thicken from east to west as illustrated in the cross sections presented as **Figure F10** to **Figure F13**.

A more detailed description of the regional geology and site specific geological conditions, based on the previous investigations listed in **Section 2.1** is presented in Section 2.7 of the *VMP HHERA* (AECOM, 2012c).

[4] The presence of TCM is based on comparison of observed site conditions and analytical data to the following criteria:
- 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:
  - Polycyclic Aromatic Hydrocarbons (PAHs): 2,000 mg/kg; or
  - Benzo(a)Pyrene (B(a)P): 150 mg/kg.

2.3 Hydrogeology

Previous investigation results indicate that groundwater beneath the Site is present as an unconfined, shallow saturated zone within the fill materials and the underlying natural soil and marine sediments. Groundwater is also likely to occur as a deeper bedrock aquifer within the underlying Hawkesbury Sandstone. Groundwater within the sandstone bedrock would occur as a fractured bedrock aquifer, potentially confined by an overlying clay unit in some areas of the Site.

Due to the proximity of the Site to Darling Harbour, the depth to groundwater is shallow and the overall direction of groundwater flow is expected to be towards Darling Harbour. Groundwater at the Site is tidally influenced, resulting in the fluctuation of groundwater levels within the fill materials and natural sediments. The flow direction and gradients change/reverse during the flooding and ebbing tides.

The *Groundwater Discharge Study* (GDS, AECOM, 2010d) (refer to **Section 2.5.1**) indicated that due to tidal influences at the Site there is a discrepancy between the net migration rate and the linear groundwater flow velocity due to the alternation of the hydraulic gradient, which causes water and particles to oscillate rather than move constantly in a single direction (as assumed by the linear groundwater velocity equation). In this instance the oscillation and resultant net migration of contaminant particles can be visualised as a process whereby an individual particle migrates 10 steps eastward during the flood tide and 11 steps westward on the ebb tide (i.e. net migration and therefore net discharge occurs at a rate of one tenth of the estimated linear groundwater flow velocity).

Recharge to the Site is limited to exposed sandstone and soil areas to the immediate east of the Site at Observatory Hill. Since the Site is currently covered by hardstand areas, the majority of potential recharge flows off Site as stormwater outflow.

A more detailed description of the regional hydrogeology and site specific hydrogeological conditions, based on the previous investigations listed in **Section 2.1** is presented in Section 2.8 of the *VMP HHERA* (AECOM, 2012c).

2.4 Contamination

2.4.1 Historic Gasworks Infrastructure

The former AGL (now Jemena) gasworks historically occupied the eastern portions of Block 4 and Block 5 (within the Site) and extended to the area now occupied by Hickson Road (refer to **Figure F3**). It is understood that URS (2001) estimated that the footprint occupied by the former gasworks[5] was approximately 5,420 m^2. The following infrastructure is understood to have been present within this footprint:

- Retort House;
- Meter House;
- Tar tank;
- Engine House;
- Gasholders; and
- Purifier Beds.

Previous investigations and remediation works (undertaken at 30 -34 Hickson Road, refer to **Figure F3**) have identified that existing gasworks infrastructure extends across Hickson Road, including part of the annulus of the former main gasholder, a smaller secondary gas holder and a tar tank (Coffey, 2008).

For the purposes of this document, the remnant historic gas holder annuli and tar tank infrastructure located beneath the Site (which are understood to comprise of excavations cut into the underlying bedrock) will be referred to as described in **Table 1** (refer also to **Figure F3**):

[5] AECOM did not have access to the URS (2001) report and cannot confirm whether this area refers to the entire gasworks site or only the gasworks infrastructure.

Table 1 Historic Gas Works Infrastructure Details

Historic gas works infrastructure	Site area	Relevant sampling location	Approximate depth of cut into bedrock (m bgl)
Main gas holder annulus (part of)	Hickson Road	BH5	10
1870 gas holder annulus	Block 4/Hickson Road	MW10/MW15	9.4
Tar tank	Hickson Road	MW7/BH7 and BH53/MW53	5.5
Small gas holder	Hickson Road	NA (located directly north of the southern tar tank and coinciding with the location of the main gasholder annulus)	Not known

2.4.2 Contaminants of Potential Concern

The Contaminants of Potential Concern (CoPC) for the VMP Remediation Works are presented in **Table 2**. The CoPC are based on those chemicals that the *VMP HHERA* (AECOM, 2012c) determined were present at the Site at concentrations that represented a risk to human health and/or the environment. **Table 2** also identifies, based on the *VMP HHERA*, whether the CoPC represents a risk to human health, the environment or both.

Table 2 CoPCs for VMP Remediation

CoPC	Risk to Human Health	Risk to the Environment
Benzene	✓	✓
Ethylbenzene	×	✓
Toluene	×	✓
Xylenes	×	✓
cPAH [1]	✓	×
Acenaphthene	×	✓
Acenaphthylene	✓	✓
Anthracene	×	✓
Fluorene	×	✓
Naphthalene	✓	✓
Phenanthrene	×	✓
Phenol	×	✓
Ammonia	✓	✓
TPH C6 - C9	×	✓
TPH C10 - C14	✓	✓
TPH C15 – C28	✓	✓
TPH C29 – C36	✓	✓

Notes: [1] cPAH - carcinogenic PAHs. 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-c d)pyrene. The application of cPAH requires adjustment of the individual concentrations for each constituent listed in accordance with the Toxicity Equivalency Factors (TEFs) outlined in Table 2 of PAH toxicity profile, Appendix D in the *VMP HHERA*. The sum of the adjusted TEF concentrations is compared to the cPAH value presented above.

It should be noted that the CoPC considered by the *VMP HHERA* (AECOM, 2012c) were based on those defined by the NSW EPA for the Declaration Area. The complete list of chemicals which have been identified in soil and groundwater at the Site by previous investigations at the Site have been considered separately within the *Declaration Site (Development Works) HHERA* (AECOM, 2011).

2.4.3 Receptors

2.4.3.1 Human Health Receptors

The VMP HHERA (AECOM, 2012c) considered two human receptor groups which may be exposed to Site contaminants based on the current site use:

- Scenario 1 – Recreational Receptors. The paved recreation scenario was assumed to represent areas of the Site which, under current Site use, are used for public open space and which have a hardstand concrete surface covering. No unpaved areas currently exist across the Site; and
- Scenario 2 – Intrusive Maintenance Workers. The intrusive maintenance scenario was considered to account for potential intrusive maintenance activities which may be undertaken at the Site. The intrusive worker considered in this assessment was assumed to only occasionally and/or intermittently conduct intrusive works at the Site (e.g. as required to maintain underground services), but is not assumed to undertake longer term intrusive works, such as construction or redevelopment of the Site.

2.4.3.2 Ecological Receptors

The closest ecological receptor identified by the *VMP HHERA* (AECOM, 2012c) was aquatic ecosystems within the groundwater down hydraulic gradient of the Site boundary, between the Site and Darling Harbour. It is noted that there is little known about the lifecycles and environmental requirements of groundwater dependant ecosystems. Therefore, the precautionary principle was adopted and the ecological receptor (in relation to the assessment of ecological risk) was defined as the down hydraulic gradient boundary of the Site. This approach is consistent with the requirements and polices of the NSW EPA, in particular:

- The *CLM Act* (1997), Section 9, which requires adoption of the precautionary principle where the lack of scientific certainty is not a reason for postponing measures. With respect to the Site, this relates to the protection of groundwater dependant ecosystems down hydraulic gradient of the Site and the requirement for remediation to the extent practicable (even in the absence of data demonstrating the presence, or otherwise, of such ecosystems now, or in the future);
- The NSW DEC (now the NSW EPA, 2007) *Guidelines for the Assessment and Management of Groundwater Contamination*, which reemphasise the requirements of the *CLM Act* (1997) requiring protection of groundwater ecosystems according to the precautionary principle;
- The ANZECC (2000) *Water Quality Guidelines*, Section 1, require that the protection of underground aquatic ecosystems and their novel fauna require the highest level of protection; and
- The *National Environment Protection Measure* Schedule B(6) (NEPC, 1997) which states that determination of the point of use of groundwater is a jurisdictional matter and that the transfer of contaminated groundwater from a contaminated Site is not considered to be acceptable, even if the relevant guidelines are achieved at the point of use / discharge.

It is considered that application of the precautionary approach to protection of aquatic ecosystems in groundwater present within the fill material down hydraulic gradient of the Site will also be protective of the aquatic ecological community in Darling Harbour.

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 Department of Planning, 2007). The terrestrial habitat at the Site is considered to have a low level of environmental sensitivity and was not considered to include ecological receptors which required protection.

2.4.4 Contaminant Migration Pathways

A range of contaminant migration pathways were considered by the *VMP HHERA* (AECOM, 2012c) for each of the identified human health and ecological receptors.

- Human Health:
  - Incidental ingestion of CoPC in soil and/or groundwater;
  - Dermal absorption of CoPC from soil and/or groundwater;
  - Inhalation of CoPC in soil-derived airborne particulates; and
  - Inhalation of groundwater derived vapours.
- Ecological:
  - Off Site migration of Separated Phase Gasworks Waste and Tar (SPGWT) and CoPC impacted groundwater in fill.

2.4.5 Contamination in Bedrock

The conceptual model depicted in Figure 20 of ERM (2008) is generally consistent with the findings of the AECOM site investigations with the exception of deep bedrock contamination. The boreholes constructed by AECOM (2010a), AECOM (2010b) and AECOM (2010c) did not extend more than 0.5 m into bedrock and therefore the contaminated bedrock interpreted by ERM (2008) to be in BH205, BH206 and BH209 was not confirmed.

Review of the ERM (2008) borehole logs and soil analysis data indicates that the most impacted zones of highly gasworks related contamination appear to be in the natural soil at the bedrock interface and decrease with depth into the bedrock. AECOM notes that: the wells installed at BH206 and BH209 are screened across the natural soil and sandstone bedrock suggesting that contamination from the overlying natural soil could be impacting groundwater analysis results; and, the only evidence of bedrock contamination in BH205 is tar reported in the well (which could be related to well completion issues, given the difficult nature of the drilling at the Site, rather than the presence of tar in the bedrock).

Borehole logs from Coffey (2010) reported localised (vertically and horizontally) bedrock impact at the Site.

AECOM considers that the overall Site dataset does not support the presence of significant gasworks related contamination within the bedrock underlying the Site. This opinion is supported by observations noted during excavation of the basement for 30 The Bond (located at 30-34 Hickson Road - directly to the east of the Site, refer to **Figure F3**) which included remediation of the eastern portion of the 1870 gas holder annulus. These remediation works indicated that the movement of gasworks related contaminants into the surrounding bedrock was limited both vertically and horizontally due to the relatively impermeable nature of the natural sandstone and the limited presence of bedrock fracture zones.

2.5 Consideration of Contamination at Depth within Natural Marine Clays and Sediment

2.5.1 Groundwater Discharge Study, AECOM (2010d)

The *GDS* (AECOM 2010d) was prepared to inform the *VMP HHERA* (AECOM, 2012c) 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.

AECOM installed a transect of multilevel piezometers, comprising two arrays of three piezometers, and a stilling well in Darling Harbour (to measure the sea level), immediately adjacent to the multilevel piezometer transect. Instantaneous hydraulic head measurements, groundwater and surface samples were collected from these locations during the investigation.

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 5.12 of the *VMP/Block 4 RAP* (AECOM, 2012c).

2.5.2 Contaminant Mass Flux Study, AECOM (2012b)

AECOM undertook a study to assess the significance of contaminant mass flux and discharge in the natural soil, marine sediments and groundwater underlying the Site. The Contaminant Mass Flux Study (AECOM, 2012b) is provided as **Appendix C**.

Multiple lines of evidence were assessed as summarised following:

- Hydraulic Conductivity and Velocity;
- Tide Effects;
- Hydraulic Head Distribution; and
- Mass Flux and Discharge.

Based on the Conceptual Site Model (refer to **Figure 1**), collation of hydraulic parameters and mass flux/discharge modelling for the Site, the following conclusions were made:

- 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 metre 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;
- The lines of evidence assessed do not indicate there is a significant flux and discharge of contamination from the natural soil and marine sediments underlying the Site into Darling Harbour; and
- Remediation of the deep natural soil and marine sediments is not warranted based on the results presented in the discussed assessment. The cost and potential environmental harm associated with an attempt to remove this material would outweigh any real benefit to the environment, which does not appear to be significantly impacted by the contamination present in the natural soil and marine sediments.

The groundwater analytical results reported at monitoring well IT03 (BH405 in Block 4) confirm the conclusions described above (i.e. that there is negligible flux of CoPCs migrating from the natural sediments into the overlying fill material). In particular, two sampling ports (IT03S and IT03M) were installed in this well at different depths in the fill material (2.5 and 8 m bgl). A third sampling port (IT03D) was installed deeper within the natural sand/silty sandy clay (13.5 m bgl). While elevated groundwater CoPC concentrations were reported in the deep sample port (where elevated soil CoPC concentrations were also reported), CoPCs concentrations in the shallow and middle depth sampling ports were generally non-detect (refer to **Table T10**).

2.5.3 Supplementary Contaminant Mass Flux Study (AECOM, 2013a)

AECOM undertook a supplementary Contaminant Mass Flux study (following on from AECOM [2012b] above) to assess:

- The decrease in contaminant flux that could be expected to result from the proposed remediation extent (refer to **Section 5.0**); and
- potential impacts to water quality in Darling Harbour from the contamination that will remain *in situ* in fill material and marine sediment both within the Site and in off Site areas to the west (i.e. Barangaroo Central and the ORWN area) as an outcome of the proposed remediation extent.

A complete summary of this supplementary study is presented in **Section 6.5.2.1**. However, one of the conclusions from the supplementary study was that less than 0.1% of the contaminant mass flux into Darling harbour (associated with residual contamination to remain *in situ* following the proposed remediation) would be from the marine sediment. This conclusion supports the conclusions of the previous contaminant mass flux study (AECOM, 2102b) and the *GDS* (AECOM, 2010d) that there is not a significant flux and discharge of contamination from the natural soil and marine sediments underlying the Site into Darling Harbour.

2.6 Conclusion

Based on the CSM developed and described in the previous sections, it is concluded that:

- SPGWT and other fill materials contaminated with CoPCs (refer to **Section 2.4.2**) have been identified in a number of locations within the footprint of the former gasworks, indicating these locations are primary source areas of soil and groundwater contamination. The former gasworks infrastructure is identified as follows (refer to **Figure F2** and **Figure F3**):
    - Retort House;
    - Meter House;
    - Tar tank;
    - Engine House;
    - Gasholders including:
        - Main gas holder annulus (part of);
        - 1870 gas holder annulus;
        - Tar tank; and
        - Small gas holder.
    - Purifier Sheds and Beds.
- Contamination, including SPGWT, has been reported in the natural soil underlying fill material in the former gasworks area;
- Analytical soil and groundwater results from locations outside and down hydraulic gradient (west) of the Site indicate that gasworks related contamination has migrated outside the Declaration Area boundary in both soil and groundwater (refer to **Figure F6**);
- Soil and groundwater contamination, including SPGWT, reported at depth, west (down hydraulic gradient) of the Site is typically present in the natural marine sediments immediately underlying the fill material;
- Some localised areas of soil contamination are present in the fill material down hydraulic gradient of the Site (for example sampling locations BH70 and BH74, refer to **Section 4.3.1** and **Figure F6**) which, based on the Site's history, is possibly related to the historic reclamation activities using impacted fill material rather, than the migration of gasworks related contaminants from the former gasworks site; and
- Soil contamination reported at BH60/MW60 and BH191 is also present in the natural material but does not appear to be connected with contamination identified closer to the Site boundary.

The most highly impacted soil is generally present:

- within the footprint of the former gasworks infrastructure or in relatively close proximity to these historic structures; and,
- at the base of the fill material, within the natural marine sediments and at the top of the weathered sandstone.

This is consistent with a Site at which DNAPLs (such as SPGWT) is present and where highly variable and permeable fill material overlies a relatively low permeability natural soil/bedrock. In such circumstances, the DNAPL would generally migrate downwards and pool/adsorb on the less permeable underlying strata. Furthermore, contaminant concentrations in the lower permeability natural soil / marine sediment which has less tidal connectivity would be expected to be comparatively higher than those in the overlying fill material given the:

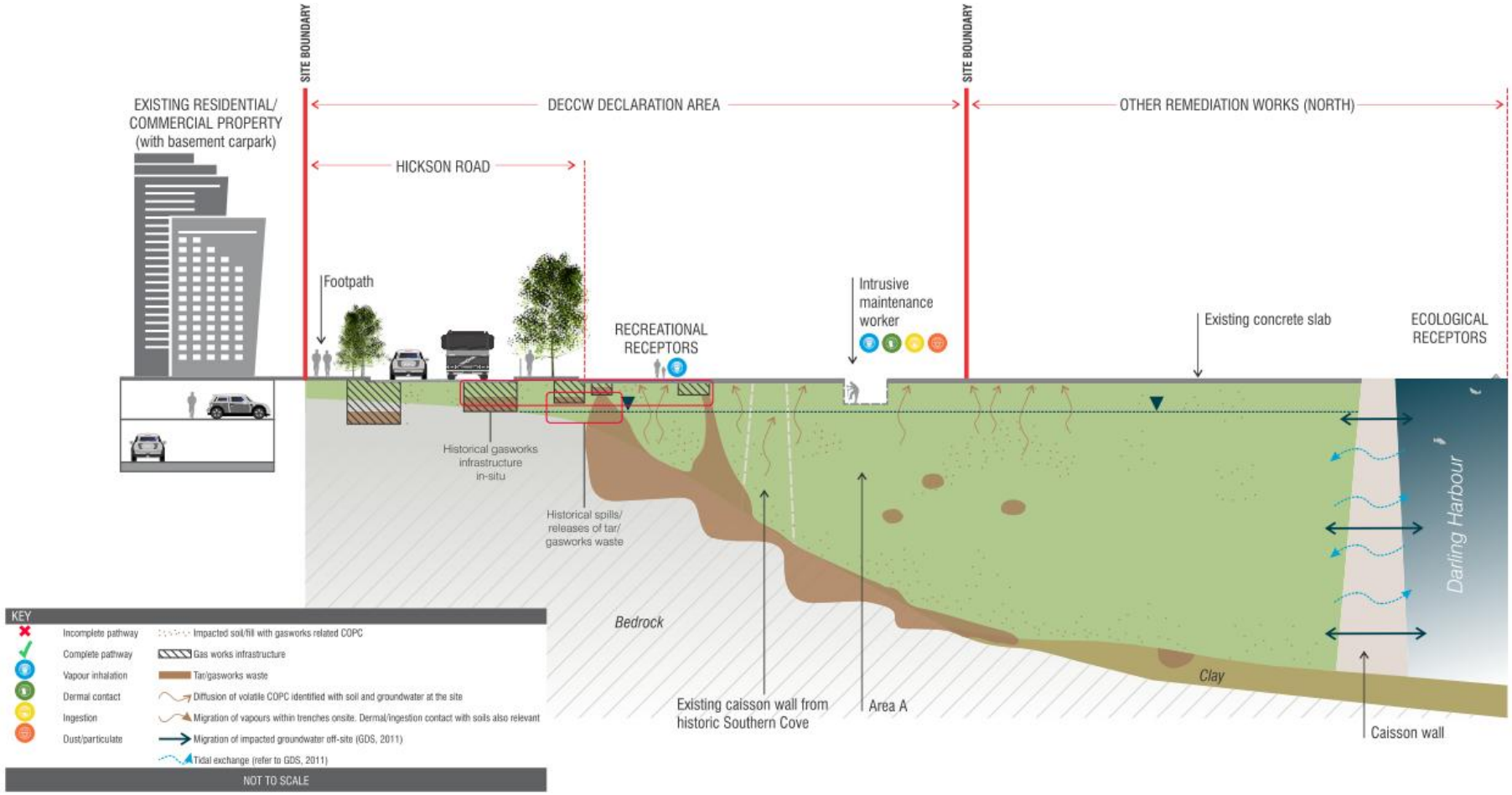
- Age of the contamination: the gasworks ceased operations in the late 1920's;
- Relatively high permeability of the fill; and
- Tidal connectivity of the fill.

It is considered unlikely that contamination from the above mentioned impact would have migrated significantly into the underlying sandstone because the sandstone has a significantly lower bulk hydraulic conductivity and hence lower water transmitting properties than the overlying fill and natural material.

The CSM is shown schematically in **Figure 1** below (the alignment of this schematic cross section is shown in **Figure F3**).

As identified by **Figure 1**, gasworks related contamination has been identified within marine sediments located below the western portions of the Site and in the areas down hydraulic gradient (west) of the Site. Based on the assessment of multiple lines of evidence (refer to **Section 2.5**), there is no significant flux and discharge of contamination from the natural soil and marine sediments underlying the Site (and areas down hydraulic gradient of the Site) into Darling Harbour. As such, remediation of the deep natural soil and marine sediments is not considered warranted. The cost and potential environmental harm associated with an attempt to remove this material would outweigh any real benefit to the environment, which does not appear to be significantly impacted by the contamination present in the natural soil and marine sediments.

Figure 1 **Schematic of the Conceptual Site Model (taken from the *VMP HHERA*)**



3.0 Remediation Goals

3.1 Soil and Groundwater Generic Assessment Criteria

The current Generic Assessment Criteria used in NSW to evaluate possible human health risk from soil analytical results are based on the:

- NSW DEC (2006) *Guidelines for the NSW Site Auditor Scheme*;
- NSW EPA (1994) *Guidelines for Assessing Service Station Sites*; and
- *National Environment Protection (Assessment of Site Contamination) Measure* (National Environment Protection Council [NEPC], 1999).

These guidelines present a range of Health-Based Soil Investigation Levels (SILs), sensitive land use thresholds and expected background concentration ranges for urban redevelopment sites in NSW.

SILs are not available for all CoPCs identified at the Site and are generally considered inappropriate and potentially unnecessarily conservative for remediation works. Therefore, as described by the *VMP HHERA* (AECOM, 2012c) it is necessary and appropriate to adopt a site-specific health-based approach to determining:

- Whether the concentrations of CoPCs identified at the Site represent a risk to human health; and
- Site Specific Target Criteria (SSTC) for soil and groundwater to define the remediation required for the Site to be protective of human health.

3.2 Development of Site-Specific Target Criteria (SSTC)

The following sections summarise development of the soil and groundwater SSTC for the protection of human health at the Site as detailed in the *VMP HHERA* (AECOM, 2012c).

The objective of the *VMP HHERA* (AECOM, 2012c) was to develop SSTC for soil and groundwater for use in defining the remediation end-point for the Site. The remediation end-point is defined as that required to render the Site suitable for continued use based on its current land use with no change to the site conditions. For the purposes of the *VMP HHERA* (AECOM, 2012c), a 'suitable for use' endpoint was considered to be that required to enable the NSW EPA Declaration to be revoked and ensure that unacceptable risks to human health or the environment will not occur.

3.2.1 Key Assumptions

The key assumptions used in the derivation of the soil and groundwater SSTCs are detailed in Section 6.2.4 of the *VMP HHERA* (AECOM, 2012c) and are as follows:

- CoPC considered in the HHERA are limited to those identified within the NSW EPA Declaration (PAHs, BTEX, TPH, ammonia, phenol and cyanide);
- Removal and/or remediation of SPGWT, to the extent practicable, should be undertaken as the primary remediation objective to minimise the risk to human health and the environment;
- 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 the assessment of risk and development of soil SSTC (human health) for the paved areas of the Site, where biodegradation processes are considered to be significant;
- The assessment of threshold risk for each scenario and the development of SSTCs have accounted for the presence of mixtures of chemicals at the Site within the same media;
- The current theoretical estimation of vapour concentrations within indoor and outdoor air is based on partitioning modelling which has been demonstrated to overestimate concentrations between 10-1,000 fold. To account for this conservatism, an adjustment factor of 10 has been applied to all modelled soil results for BTEX, TPH C_6-C_9 and C_{10}-C_{14} for the human health SSTC;
- 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; and

- Chemicals are assumed to be volatile if Henry's Law constant is greater than 1 x 10^{-5} atm-m^3/mole (USEPA, 2004).

3.2.2 Exposure Scenarios

In consideration of risk to human health, the following scenarios were considered for the derivation of SSTCs:

- **Scenario 1:** Paved Recreation (as the entire Site is currently covered with concrete/hardstand paving); and
- **Scenario 2**: Short term ground-intrusive maintenance (for maintenance of utility services).

Table 3 below summarises the land use scenarios and assumptions as discussed in the *VMP HHERA* (AECOM, 2012c).

Table 3 Summary of Land Use Scenarios Considered in the VMP Human Health and Ecological Risk Assessment

Scenario Number	Name and Description	Most Sensitive Human Receptor	General Assumptions
1	Paved Recreation: The entire Site is currently covered with concrete/hardstand paving. This scenario has assumed that contaminated soil may be present directly underlying concrete surface cover.	Recreational Users Assumed to be exposed 2 hrs/day, 365 days/year, for 70 years.	Open Space with Concrete surface covering. Assume that there is significant oxygen movement through the top 2m of the soil based on the oxygen measurements collected during the soil gas sampling (AECOM 2010a and 2010b). Concrete assumed to be minimum 15 cm thick and to have crack fraction of 0.001 (to account for higher cracking possible in surface covering).
2	Intrusive Maintenance: 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 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.	Short term maintenance work or site investigation may be required Assumed not to exceed 3 working weeks per year by same worker. While maintenance work may be expected to be predominantly within existing infrastructure easements and structures, ground-intrusive work may conceivably be planned.

3.2.3 Adopted SSTCs

A summary of the soil and groundwater SSTCs derived for each exposure scenario by the *VMP HHERA* (AECOM, 2012c) is provided in **Table T1** and **T2**, **Appendix B**.

Tables T1 and **T2, Appendix B**, also present the hybrid criteria that are applicable to the Site based on the lowest of the SSTCs for the applicable land use scenarios (that is where more than one SSTC is applicable, the lowest SSTC has been adopted).

It is noted that soil SSTCs have been derived for the unsaturated soils only (assumed based on the depth of groundwater reported across the Site to be soils shallower than 2.0 m bgl). As described by the *VMP* HHERA (AECOM, 2012c), this approach is based on the potential exposure pathways identified for the Scenario 1 and Scenario 2 land uses (refer to **Table 3**).

3.2.4 Implementation of the SSTCs

For the purpose of this document, CIM is considered to be material that represents an unacceptable risk to human health and so warrants remediation. The presence, or absence, of CIM and the resultant extent of remediation will be determined by comparison of soil and groundwater analytical results with the soil and groundwater SSTC developed by the *VMP HHERA* (AECOM, 2012c).

3.3 Remediation Goals for the Protection of Human Health

The remediation goals for the protection of human health, as recommended by the *VMP HHERA* (AECOM, 2012c) are:

- As a primary goal, removal / remediation of SPGWT to the extent practicable; and
- As a secondary goal:
    - Removal/remediation, to the extent practicable, of CIM (that is material containing soil concentrations exceeding the soil SSTCs) from unsaturated soil; and
    - Removal/remediation, to the extent practicable, of CIM (that is material considered to be the source of groundwater concentrations exceeding the groundwater SSTCs).

The process for assessing the extent of remediation based on the identification of SPGWT and CIM is summarised by the following sections.

The outcomes of this process are documented in **Section 4.0** and **5.0**.

3.3.1 Separate Phase Gasworks Waste and Tar

For the purposes of this report, SPGWT refers to:

- Tar Containing Materials (TCM, as described below); and
- Dense Non Aqueous Phase Liquids (DNAPLs).

The presence or otherwise of TCM is based on comparison of observed site conditions and analytical data to the following criteria:

- 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:
    - Polycyclic Aromatic Hydrocarbons (PAHs): 2,000 mg/kg; or
    - Benzo(a)Pyrene (B(a)P): 150 mg/kg.

The above TCM definition was originally proposed by AECOM and adopted by Lend Lease/the Authority to define TCM at the Site, particularly in the context of material that is unsuitable for beneficial reuse (in conjunction with the site-specific risk based criteria which were derived in the *VMP HHERA* [AECOM, 2012c]).

Section 4.2.4 of the *VMP HHERA* (AECOM, 2012c) notes that 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*".

Consequently, in accordance with NSW EPA policy and guidelines, and the remediation goals recommended by the *VMP HHERA* (AECOM, 2012c), all SPGWT identified on the Site and in adjacent off Site areas is required to be remediated to the extent practicable.

3.3.2 CIM based on Soil SSTCs

The decision process for the determination of whether CIM is present based on the soil SSTCs is summarised following.

- Assessment of whether SPGWT is present (refer to **Section 3.2.3**). SPGWT will be removed or remediated to the extent practicable; and
- Assessment of whether soil concentrations between 0 and 2 m bgl exceed the relevant SSTCs for unsaturated soil (refer to **Section 3.2.3**).

3.3.3 CIM based on Groundwater SSTCs

The decision process for the determination of whether CIM is present based on the groundwater SSTCs is summarised following.

- Assessment of whether SPGWT is present (refer to **Section 3.2.2**). SPGWT will be removed or remediated to the extent practicable;
- Assessment of whether groundwater concentrations exceed the relevant SSTCs for groundwater (refer to **Section 3.2.3**); and
- Assessment of soil concentrations considered to be the source of the identified groundwater contamination.

3.3.4 Extent of Remediation

If CIM is identified to be present, the significance of the impacted soils and the corresponding requirement for remediation to the extent practicable will be assessed with due consideration of whether the identified CIM is present in fill material or within marine sediments.

The outcomes of the process are documented in **Section 5.0**.

3.4 Remediation Goals for the Protection of the Environment

The remediation goals for the protection of the environment, as recommended by the VMP HHERA (AECOM, 2012c) are:

- As a primary 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 quality within fill material leaving the Site (measured in fill at the down hydraulic gradient Site boundary) approaches the Marine Water Quality Criteria (MWQC).

The process for assessing the extent of remediation based on the identification of SPGWT will be as described for the protection of human health (refer to **Section 3.3.1**).

The process for assessing the extent of remediation that can be practicably achieved with a view to ultimately improving groundwater quality in fill material at the Site such that it approaches the MWQC (measured in fill at the down hydraulic gradient Site boundary) is summarised by the following sections.

The outcomes of the process are documented in **Section 6.0**.

3.4.1 Separate Phase Gasworks Waste and Tar

As per **Section 3.3.1**, in accordance with NSW EPA policy and guidelines, and the remediation goals recommended by the *VMP HHERA* (AECOM, 2012c), SPGWT identified on the Site and in adjacent off Site areas is required to be remediated to the extent practicable.

3.4.2 Marine Water Quality Criteria (MWQC)

The selection of MWQC relevant to protection of aquatic ecological receptors is described by Section 8.4 of the *VMP HHERA* (AECOM, 2012c). The MWQC have been selected, in consultation with the NSW EPA, as suitable screening criteria that are protective of the environment including: groundwater dependant ecosystems which may be present down hydraulic gradient of the Site boundary currently or in the future; and, Darling Harbour.

The MWQC are based on:

- Groundwater and 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
- Groundwater and surface water: *ANZECC* (2000) trigger values for marine water (99% protection level) for chemicals with the potential to have bioaccumulative impacts. Low reliability trigger values have been adopted where no other value is available.

In addition, where the ANZECC (2000) *Water Quality 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 4** below.

Table 4 Marine Water Quality Criteria

Analyte	Criteria (µg/L)	Source
Low MW PAHs		
Acenaphthene	5.8	CCME (1999) Freshwater Guideline
Acenaphthylene	5.8	Adopted criteria for Acenaphthene as surrogate
Anthracene	0.1 [a]	ANZECC (2000) 99% Marine Water Trigger Value (0.01 µg/L) identified to be lower than LOR.
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
Other Organics		
Phenol	400	ANZECC (2000) 95% Marine Water Trigger Value
Petroleum Hydrocarbons		
Benzene	700	ANZECC (2000) 95% Marine Water Trigger Value, moderate reliability
Ethylbenzene	80	ANZECC (2000) 95% Fresh Water Trigger Value, low reliability
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	Adoption of the ANZECC (2000) 95% Marine Water Trigger Value, low reliability for xylene (o).
TPH C_6 - C_9	110	CCME (2008a 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_{14}	40	CCME (2008a) Canada-Wide Standard for Petroleum Hydrocarbons (PHC) in Soil – Table B-9 values for TPH C>10 to C12 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 C15-C28	100	No guidelines values available, therefore the standard laboratory Limit of Reporting (LOR) has been adopted.
TPH C29-C36	50	No guidelines values available, therefore the standard LOR has been adopted.

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.

3.4.3 Extent of Remediation

As described in Section 8.1 of the *VMP HHERA* (AECOM, 2012c), the determination of potential risks to the environment required consideration of the potential for risks posed to underground aquatic ecosystems and their novel fauna (as required by Section 1 of the ANZECC [2000] *Water Quality Guidelines*). This is in accordance with the requirements of the NSW EPA which require that the level of protection of groundwater within fill material

at the down hydraulic gradient boundary of the Site is based on the level of protection required for the nearest surface water receptor, Darling Harbour (that is the MWQC).

The current groundwater monitoring wells are not located immediately on or 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 and depending on the location or 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. Therefore, it is not considered appropriate to rely solely on the existing (limited) groundwater monitoring data set from groundwater monitoring wells located near the down hydraulic gradient Site boundary. Consequently, groundwater concentrations within fill material both at the down hydraulic gradient Site boundary and across the Site were compared by the *VMP HHERA* (AECOM, 2012c) to the MWQC to assess risk to the environment.

Widespread exceedances of the MWQC have been identified in groundwater both within the Site and at the Site boundary, indicating an unacceptable risk to the environment. The distribution of exceedances is described on Figure F7 of the *VMP HHERA* (AECOM, 2012c). In summary:

- The exceedances are most concentrated in the vicinity of the former gasworks infrastructure within Hickson Road and the eastern portion of Block 4; but
- Exceedances are also evident within Block 5, the western portion of Block 4 and beyond the down hydraulic gradient Site boundary within Block 5 and Block 4.

Based on the identified MWQC exceedances remediation, to the extent practicable, of soil contamination that is considered to be the source of the groundwater MWQC exceedances within fill material, is required to minimise the risk of adverse impact to the environment.

The assessment of the extent of remediation that can be practicably achieved will be based on consideration of the requirements of the:

- NSW DEC (2007) *Guidelines for the Assessment and Management of Groundwater Contamination*.

As part of this process, consideration will also be given to the principles of:

- ESD, as required by Section 9 of the *CLM Act* (1997); and
- the *Waste Avoidance and Resource Recovery Act* (2001).

3.5 Other Contaminants

3.5.1 Asbestos in Soil

Asbestos in soils was not included in the NSW EPA Declaration and the *VMP HHERA* (AECOM, 2012c) did not consider that asbestos was a CoPC for which specific risk based criteria were required to be calculated. Rather, the *VMP HHERA* (AECOM, 2012c) recommended that the risk of asbestos was most appropriately managed through implementation of appropriate management tools in the *VMP/Block 4 RAP*.

As such, the risk of asbestos in soil is not considered further by this document.

3.5.2 Acid Sulfate Soils

The previous investigations undertaken at the Site have included analysis of samples for Suspension Peroxide Oxidation Combined Acidity & Sulfur (SPOCAS) to evaluate the potential for potential acid sulphate soils (PASS) or actual acid sulfate soils (AASS) to be present.

The *VMP/Block 4 RAP* will consider the results of this analysis and whether, or not, they indicate there is a potential that AASS or PASS are present at the Site.

4.0 Contaminant Characterisation for Protection of Human Health

The remediation goals for the protection of human health, as described by **Section 3.3**, are:

- As a primary goal, removal / remediation of SPGWT to the extent practicable; and
- As a secondary goal:
  - Removal / remediation, to the extent practicable, of CIM (that is material containing soil concentrations exceeding the soil SSTCs) from unsaturated soil; and
  - Removal / remediation, to the extent practicable, of CIM (that is material considered to be the source of groundwater concentrations exceeding the groundwater SSTCs within fill material).

The following Sections compare the Site's soil and groundwater analytical data to these remediation goals to identify materials at the Site which may be representative of SPGWT or CIM and therefore may require remediation.

Soil analytical data beyond the Site boundary has also been assessed. This assessment has been included because the Site Auditor is required by NSW DEC (2006) to include in his/her site audit an assessment off Site impacts and the risk of cross contamination of onsite areas from off Site areas. The off Site analytical data considered as part of this assessment are limited to gasworks related impacted material that is considered to be directly related to the Site. Contamination that may be present in areas beyond the Site boundary but that is not considered to be related to the gasworks previously located on the Site (for example as a result of historical filling activities) will be assessed separately as part of the respective HHERA and RAP prepared in relation to the Other Remediation Works North (ORWN) Area (Block 4) and Barangaroo Central (Block 5).

The process for assessing the extent of remediation based on the identification of SPGWT and CIM is summarised by **Section 3.3**. It is proposed that remediation of the Site may be undertaken in stages, depending on final logistical and other requirements associated with the broader Barangaroo development. This may require that key Site areas be remediated and validated separately, such that the EPA Declaration is removed progressively. In consideration of this, the following Site areas have been addressed individually:

- Block 4 and 5;
- Hickson Road;
- Off Site areas west of the Site (i.e. down-gradient of the Site within the ORWN and Barangaroo Central areas); and
- Off Site areas east of the Site.

The soil and groundwater analytical data for the Site is compared to the applicable soil and groundwater SSTCs in **Table T3** to **T13, Appendix B**.

The off-Site soil and groundwater analytical data, for the area west of the Site within Block 5 and the ORWN area, is compared to the relevant SSTCs and presented in **Table T14** to **T16, Appendix B**.

4.1 Block 4 and 5

The presence of CIM within Block 4 and Block 5 was assessed using soil and groundwater analytical data from the investigations detailed in **Section 2.1**.

4.1.1 Separate Phase Gasworks Waste and Tar (Block 4 and Block 5)

As detailed in **Table 4**, based on consideration of both field observations (i.e. during soil and groundwater sampling activities) and soil analytical results, SPGWT has primarily been identified in the following areas (refer to **Figure F6**):

- Across most of the eastern portion of Block 4, in areas where the depth of bedrock is generally shallower than 10 m bgl (approximately Relative Level [RL] -7.5 m Australian Height Datum [AHD]), and in association with former gasworks infrastructure;
- Across part of the western portion of Block 4, down gradient from the former gasworks infrastructure in the vicinity of BH49 and BH119; and
- In relatively isolated locations, either associated with the migration of SPGWT from former gasworks infrastructure or with historical filling practices in:
    - The southern portion of Block 4, in the vicinity of BH42/BH408; and
    - The eastern portion Block 5 (as described below), in areas where the depth of bedrock is generally shallower than 10 m bgl.

Observations from bulk samples collected as part of the ex-situ stabilisation trial (EPS, 2012) indicate that SPGWT is likely to be present in the eastern part of Block 5 (refer to TP02 on **Figure F3**) adjacent to the former gasworks infrastructure. Based on the reported analytical results, it is likely that SPGWT is present at a depth of approximately 4.2 m bgl at TP02. Bedrock was not encountered at this location to the maximum depth of 4.8 m bgl. SPGWT was also encountered at TP05 and TP06 at depths ranging between 2.9 and 4.0 m bgl (refer to **Table 5** below).

Table 5 SPGWT Identified within Block 4 and Block 5

Site Area	Approximate SPGWT Depth Range (m bgl)	TCM identified in fill or natural material?
Eastern Block 4		
BH49	9.2 - 12.7 (depth of bedrock) [2]	Fill and natural sandy clay
BH52	4.2 - 4.4 (bedrock present at 5.2) [1]	Fill
BH54	1.0 - 1.8 (bedrock present at 3.0) [1]	Fill
BH55	1.0 - 2.9 (depth of bedrock) [3]	Fill
BH59	3.4 - 4.4 (depth of bedrock) [3]	Fill
BH087	1.5 -7.5 (depth of bedrock?) [3]	Fill
BH019	2.5 - 3.6 (depth of bedrock) [3]	Fill
BH141	3.0 – 4.1 (depth of bedrock) [3]	Fill
BH204S	1.0 (bedrock present at 1.3) [1]	Fill
BH204D	1.5 - 5.0 (natural clayey sand present at 4.1) [3]	Fill and natural sandy clay
BH205/MW205	DNAPL observed in groundwater (bedrock present at 11.0) [2]	Natural clayey sand
BH206/MW206	DNAPL observed in groundwater (bedrock present at 8.0) [2]	Bedrock
TP05	3.1 - 4.0 (bedrock present at 4.0) [2]	Fill
TP06	2.9 - 3.1 (bedrock present at 3.1) [2]	Fill

Site Area	Approximate SPGWT Depth Range (m bgl)	TCM identified in fill or natural material?
TP07	2.0 – 4.3 (depth of bedrock now known) [2]	Fill
Eastern Block 5		
TP02	4.2 - 4.8 (bedrock present at 4.8) [2]	Fill
Southern Block 4		
BH42	3.2 - 3.5 (depth of bedrock) [3]	Fill
BH408	8.0 - 9.4 (depth of bedrock) [2]	Natural silty sandy clay
Western Block 4		
BH119	7.5 - 10 (depth of bedrock not known) [3]	Fill
BH405	14 - 14.45 (within natural silty sandy clay, bedrock at 14.45 m bgl) [1]	Natural silty sandy clay

Notes: The distribution of SPGWT described above is based on a review of the analytical results and field observations as denoted below:
1 based on laboratory analytical data
2 based on field observations (i.e. greater than 10% tar noted to be present in observed fill/soil)
3 based on laboratory analytical data and field observations

It is noted that, based on observations from previous investigations, it is likely that SPGWT is present in other areas where former gasworks infrastructure that was not intersected by the previous investigations is present.

With the exception of some isolated areas of SPGWT, possibly related to historical filling practices, the distribution of SPGWT appears to be principally related to:

- Proximity to former gasworks related infrastructure (specifically the main gas holder annulus, the tar tank and the 1870 gas holder);
- Location relative to former gasworks related infrastructure (i.e. SPGWT is generally present down gradient of the former gasworks related infrastructure); and
- The reduced permeability of the underlying marine sediments and the sandstone bedrock profile which generally dips to the west (i.e. SPGWT is generally contained within the marine sediments but has generally not penetrated the underlying bedrock).

Consequently, the distribution of SPGWT is typically shallower in the eastern portion of Block 4 (generally 1.0 to 4.0 m bgl) and deeper in the western portion (approximately 7.5 to 15.0 m bgl) where it has been reported within the underlying marine sediments.

As discussed in **Section 3.3.1**, DNAPL is included within the definition of SPGWT. DNAPL has been identified at the following Block 4 borehole locations (refer to **Figure F6**):

- BH87/MW15;
- BH204D/MW204D;
- BH205/MW205; and
- BH206/MW206.

4.1.2 Soil Analytical Results (Block 4 and Block 5)

The analytical results from soil samples collected across the Block 4 and Block 5 Area are presented in **Table T5** to **T7** (for unsaturated and saturated soils respectively).

A summary of the Block 4 and Block 5 Area unsaturated soil analytical data (i.e. shallower than 2 m bgl) reported at concentrations exceeding the soil SSTC is presented in **Table 6** below. All other analytes were reported at concentrations below the soil SSTC.

Table 6 Block 4 and Block 5 – Soil Concentrations exceeding the Unsaturated Soil SSTC

CoPC (SSTC, mg/kg)	EQL	Number		Concentration Range (mg/kg)		Mean (SD)	Number of Results > SSTC	Exceed.
		Results	Detections	Min	Max			
cPAH [1] (67)	-	60	42	0.06	921.56	56 (166)	10	BH001_1.0 BH200/1.0 BH204S/1.0 BH204D/1.5 BH145_0.3-0.5 BH073_1.5-1.95 BH087_1.5-1.95 BH55_1.0-1.2 BH64_1.0-1.2 BH54_1.0-1.4
TPH C_{10} - C_{14} (54,000)	50	63	17	<50	54,200	1,286 (6,597)	1	BH204D/1.5
TPH C_{15}-C_{28} (72,000)	100	63	38	<100	72,400	2,471 (9,539)	1	BH204D/1.5

NOTE: EQL – Estimated Quantitation Limit

[1] Soil results have been compared to the cPAH SSTC using the relevant Toxicity Equivalency Factors (TEF, as required by Appendix D of the *VMP HHERA* (AECOM, 2012c).

4.1.3 Groundwater Analytical Results (Block 4 and 5)

Recent groundwater analytical results for the monitoring wells located across the Block 4 and Block 5 Area are presented in **Table T10** (taken from either 2010 or 2011 sampling events). Historic groundwater results are presented in **Table T11**.

A summary of the Block 4 and Block 5 groundwater analytical data reported at concentrations above the relevant groundwater SSTCs is presented in **Table 7** below. All other analytes were reported at concentrations below the groundwater SSTCs.

Table 7 Block 4 and Block 5 - Groundwater Concentrations exceeding the Groundwater SSTC

CoPC (SSTC, µg/L)	EQL	Number		Statistics (Concentrations)			Number of Results > SSTC	Exceedances
		Results	Detects	Min	Max	Mean (SD)		
Naphthalene (1,300) [1]	0.1	18	11	<1	283,000	18,148 (66,207)	7	MW15 MW54 IT03D MW200 MW204S MW205 MW206
cPAH (1000)	-	18	7	0.32	11,556	672 (2,718)	1	MW205
TPH C_{10}-C_{14} (17,000) [1]	50	18	10	<50	1,730,000	107,171 (405,521)	5	MW200 MW205 MW206 MW54 MW15
TPH C_{15}-C_{28} (220,000)	100	18	12	<100	1,520,000	91,259 (356,958)	1	MW205
TPH C_{29}-C_{36} (250,000)	50	18	9	<50	332,000	19,396 (78,092)	1	MW205
Benzene (2,100) [1]	1	17	9	<1	17,900	2,233 (5,230)	3	MW200 MW206 MW15

NOTE: [1] SSTC presented are based on those in Appendix C of the *VMP HHERA* (AECOM, 2012c) which have been confirmed to be correct. It is noted that as a result of a transcription error, these values are different to those presented within the body of the *VMP HHERA* (AECOM, 2012c).

4.1.4 Block 4 and Block 5 – Identification of CIM

The results of soil and groundwater analysis from the Block 4 and Block 5 Area indicate that the following CoPCs were reported at concentrations above the relevant SSTCs:

- Benzene;
- TPH C_{10}-C_{28};
- naphthalene; and
- cPAHs.

SPGWT was also identified in the Block 4 and Block 5 Area.

4.1.4.1 Benzene

Overall assessment of the soil and groundwater results for benzene indicates the following:

- benzene concentrations reported in the unsaturated soil did not exceeded the soil SSTC in any of the sampled analysed; and
- benzene concentrations reported in groundwater exceeded the groundwater SSTC in 3 of the 15 Block 4 and Block 5 monitoring wells, with a maximum concentration of 17,900 µg/L reported in MW200.

The 3 wells (MW15, MW200 and MW206) that reported groundwater concentrations exceeding the groundwater SSTCs are all located in areas identified as containing SPGWT. Based on the groundwater results, some benzene concentrations in groundwater are considered representative of CIM and, as such, are discussed further in **Section 5.1.1**.

4.1.4.2 Total Petroleum Hydrocarbons

Overall assessment of the soil and groundwater results for TPH (C_{10}-C_{36}) indicates the following:

- TPH concentrations reported in soil exceeded the soil SSTC for:
  - TPH C_{10}-C_{14}, TPH C_{15}-C_{28} and TPH C_{29}-C_{36} in 1 of the 63 soil samples analysed (BH205D/1.5);
- TPH concentrations reported in groundwater exceeded the relevant groundwater SSTC for:
  - TPH C_{10}-C_{14} in five of the 15 Block 4 and 5 monitoring wells MW200, MW205, MW206, MW54 and MW15);
  - TPH C_{15}-C_{28} in one of the 15 Block 4 and 5 monitoring wells (MW205); and
  - TPH C_{29}-C_{36} in one of the 15 Block 4 and 5 monitoring wells (MW205).

The discussed TPH exceedances were predominantly located in areas identified as containing SPGWT. Based on the soil and groundwater concentrations, some TPH concentrations in unsaturated soil and groundwater are considered representative of CIM and, as such, are discussed further in **Section 5.1.1**.

4.1.4.3 Polycyclic Aromatic Hydrocarbons

Overall assessment of the soil and groundwater results for PAHs indicates that naphthalene exceeded the relevant groundwater SSTC in 7 of the 15 Block 4 and 5 monitoring wells (refer to **Table T10**).

Based on the discussed naphthalene concentrations in groundwater, naphthalene is considered representative of CIM and, as such, is discussed further in **Section 5.1.1**.

4.1.4.4 Carcinogenic PAHs

Overall assessment of the soil and groundwater results for cPAHs indicates the following:

- cPAH concentrations reported in soil exceeded the relevant SSTC in 10 of 60 unsaturated soil samples analysed. These locations are all located in the area of the former gasworks infrastructure (refer to **Figure F4**); and
- cPAH concentrations reported in groundwater exceeded the relevant SSTC in 1 of the 15 monitoring wells (MW205).

The exceedances of soil and groundwater SSTC were predominantly located in areas identified as containing SPGWT. Based on the concentrations in unsaturated soil and groundwater, some cPAH concentrations are considered representative of CIM and, as such, are discussed further in **Section 5.1.1**.

4.2 Hickson Road

The presence of CIM within Hickson Road was assessed using soil and groundwater analytical data from the investigations detailed in **Section 2.1**.

4.2.1 Separate Phase Gasworks Waste and Tar (Hickson Road)

As detailed in **Table 8**, based on consideration of both field observations and soil analytical results, SPGWT has been identified beneath parts of Hickson Road, primarily:

- associated with the historic tar tank structures that have been excavated into the bedrock (i.e. sampling locations BH7/MW7, BH10 and BH53);
- at BH15/MW15 (located down hydraulic gradient of the main gas holder annulus and historic tar tank structures); and
- in the northwest area of Hickson Road at BH61.

Table 8 SPGWT Identified in Hickson Road

Site Area	Approximate SPGWT Depth Range (m bgl)	TCM identified in fill or natural material?
BH7/MW7	4.6 – 5.5 (depth of bedrock within historic tar tank) [3]	Fill
BH53	4.0 - 5.45 (depth of bedrock within historic tar tank) [3]	Fill
BH10/MW10	4.9 – 9.4 (depth of bedrock within gas holder annulus) [3]	Fill
BH61	2.0 - 3.45 (depth of bedrock) [3]	Fill and natural clayey sand(?)
BH15/MW15	DNAPL observed in groundwater (bedrock at 1.9 m bgl)	Fill
BH6/MW6	Sheen observed in groundwater (bedrock at 4.5 m bgl)	Fill

NOTES: The distribution of SPGWT described above is based on a review of the analytical results and field observations as denoted below:
[1] based on laboratory analytical data
[2] based on field observations (i.e. greater than 10% tar noted to be present in observed fill/soil)
[3] based on laboratory analytical data and field observations

It is noted that, based on observations from previous investigation, it is likely that SPGWT is present in other areas where former gasworks infrastructure that was not intersected by the previous investigations is present.

As discussed in **Section 3.3.1**, DNAPL is included within the definition of SPGWT. DNAPL has been identified at the following Hickson Road locations (refer to **Figure F6**):

- BH7/MW7;
- BH10/MW10;
- BH15/MW15; and
- BH53/MW53.

4.2.2 Soil Analytical Results (Hickson Road)

The analytical results from soil samples collected from the Hickson Road area are presented in **Table T8**. and **T9** (for unsaturated and saturated soils respectively). All CoPC concentrations were reported at concentrations less than the unsaturated soil SSTCs.

4.2.3 Groundwater Analytical Results (Hickson Road)

Recent groundwater analytical results for the monitoring wells located in Hickson Road are presented in **Table T13** (taken from 2008 and 2010 sampling events).

A summary of the Hickson Road groundwater data reported at concentrations above the relevant groundwater SSTCs is presented in **Table 9** below. All other analytes were reported at concentrations below the groundwater SSTCs.

Table 9 Hickson Road Groundwater Concentrations exceeding the Groundwater SSTC

CoPC (SSTC, µg/L)	EQL[1]	Concentration				Number of Results > SSTC	Exceedances
		Min	Max	Average	Median (SD)		
Naphthalene (1,300) [1]	0.1	<2	192,000	35,575	2749.5 (76,868)	3	MW7 MW10 MW15
cPAH (1000)	-	3.88	11,162	2,041	11,157 (4,488)	2	MW10 MW15
TPH C_{10}-C_{14} (17,000) [1]	50	<50	830,000	309,298	248,450 (357,138)	3	MW10 MW7 MW15
TPH C_{15}-C_{28} (220,000)	100	<100	754,000	159,525	24,840 (297,032)	1	MW15
Benzene (2,100) [1]	1	<1	40,200	11,813	2733 (16,991)	3	MW10 MW7 MW15

NOTE: [1] SSTC presented are based on those in Appendix C of the *VMP HHERA* (AECOM, 2012c) which have been confirmed to be correct. It is noted that as a result of a transcription error, these values are different to those presented within the body of the *VMP HHERA* (AECOM, 2012c).

4.2.4 Hickson Road – Identification of CIM

The results of groundwater analysis from the Hickson Road area indicate that the following CoPCs were reported at concentrations above the relevant SSTCs:

- Benzene;
- TPH C_{10}-C_{28};
- naphthalene; and
- cPAHs.

Note that all concentrations in unsaturated soil samples collected within Hickson Road were below the relevant SSTC.

SPGWT was also identified in the Hickson Road Area.

4.2.4.1 Benzene

Overall assessment of the groundwater results for benzene indicates that benzene concentrations reported in groundwater exceeded the groundwater SSTC in 3 of the 6 Hickson Road monitoring wells (MW10, MW7 and MW15).

The three wells that reported groundwater concentrations exceeding the groundwater SSTCs are located in areas identified as containing SPGWT (refer to **Figure F6**). Based on the groundwater concentrations, some benzene concentrations are considered representative of CIM and, as such, are discussed further in **Section 5.1.1**;

4.2.4.2 Total Petroleum Hydrocarbons

Overall assessment of the groundwater results for TPH (C_{10}-C_{36}) indicates that the groundwater SSTCs were exceeded as follows:

- TPH C_{10}-C_{14} in 3 of the 6 Hickson Road monitoring wells (MW10, MW7 and MW15); and
- TPH C_{15}-C_{28} in 1 of the 6 Hickson Road monitoring wells (MW15).

The three wells that reported groundwater concentrations generally exceeding the groundwater SSTCs are located in areas identified as containing SPGWT (refer to **Figure F6**). Based on the reported groundwater concentrations, some TPH concentrations are considered representative of CIM and, as such, are discussed further in **Section 5.1.1**.

4.2.4.3 Polycyclic Aromatic Hydrocarbons

Overall assessment of the groundwater results for PAHs indicates that naphthalene concentrations exceeded the relevant SSTCs in 3 of the 15 Hickson Road monitoring wells (MW7, MW10 and MW15) at which SPGWT has also been identified (refer to **Figure F6**).

Based on the discussed groundwater concentrations, naphthalene concentrations are considered representative of CIM and, as such, are discussed further in **Section 5.1.1**.

4.2.4.4 Carcinogenic PAHs

Overall assessment of the groundwater results for cPAHs indicates that cPAH concentrations reported in groundwater exceeded the SSTC in 2 of the 6 Hickson Road monitoring wells (MW10 and MW15) at which SPGWT has also been identified (refer to **Figure F6**).

Based on the cPAH groundwater concentrations, some total cPAH concentrations are considered representative of CIM and, as such, is discussed further in **Section 5.1.1**.

4.3 Off Site Areas - West

The presence of CIM in areas off Site to the west of Block 4 and Block 5 was assessed using soil and groundwater analytical data from the investigations detailed in **Section 2.1**.

The following sections assess impacted soil that is located west of the Site boundary, but that is considered to be directly related to the Site and the Site's historical use as a gasworks.

4.3.1 Separate Phase Gasworks Waste and Tar (Off Site Areas – west)

As detailed in **Table 9** and presented in **Figure F6,** SPGWT has been identified in off-Site areas within the ORWN Area and Block 5. The identified SPGWT is predominantly present in the underlying marine sediments at the interface with the underlying bedrock. The only exception to this is localised areas of SPGWT reported in the fill material at BH70 and BH74.

Table 10 SPGWT Identified in Off Site Areas (west of the Site in Block 5 and ORWN)

Site Area	Approximate SPGWT Depth Range (m bgl)	TCM identified in fill or natural material?
Off Site (Block 5 and Barangaroo Central)		
BH70	2.5 m bgl in fill material (bottom of fill at 16 m bgl) and natural clayey sand (16-16.2 m bgl) [3]	Fill and natural clayey sand
BH74	1.0 - 2.5 m bgl in fill material (bottom of fill at 16 m bgl) [2]	Fill
BH400	16.8 m bgl at the natural clayey sand/bedrock interface (bottom of fill at 12.4 m bgl) [3]	Natural clayey sand
BH402	14.0 - 19.8 m bgl in the silty/sandy clays (bottom of fill at 14.0 m bgl) [3]	Natural silty/sandy clays
BH403	9.0 - 17.0 m bgl in the silty/sandy clays (bottom of fill at 8.0 m bgl) [3]	Natural clays
BH541	9.9-10.0 m bgl in fill material (bedrock present at 10.8 m bgl, refer to **Section 2.1.1**) [1]	Fill material

Site Area	Approximate SPGWT Depth Range (m bgl)	TCM identified in fill or natural material?
Off Site (Block 4 and ORWN)		
BH48	14.5 m bgl on bedrock [2]	Upper surface of the natural bedrock (no marine sediment present)
BH60	16 - 17.5 m bgl in sandy clay (bottom of fill at 16 m bgl) [2]	Natural sandy clay
BH404	15.0 - 16.0 m bgl in 'silty clay' (bedrock at 16.0 m bgl) [2]	Natural silty clay
BH406	14.30 - 14.50 m bgl – tar band in fill material and tar noted from 15.0 - 16.8 m bgl in silty clay and silty sand (bedrock at 16.8 m bgl) [3]	Fill and natural clays

NOTES: The distribution of SPGWT described above is based on a review of the analytical results and field observations as denoted below:
[1] based on laboratory analytical data
[2] based on field observations (i.e. greater than 10% tar noted to be present in observed fill/soil)
[3] based on laboratory analytical data and field observations

The borehole log for BH404 actually reported the SPGWT to be present within fill at 15.0 to 16.0 m bgl. However, based upon further review, it is considered more likely that the SPGWT is actually present within marine sediments. In particular, while no marine sediments or residual material was reported in the BH404 borehole log:

- the description of the 'fill material' between 15-16 m bgl (described as 'Silty Clay, very pale grey to white, very stiff, very moist, medium plasticity', refer to **Table 10**) is consistent with the description of natural clays in boreholes advanced to bedrock in the surrounding area (i.e. BH403, BH406 and BH63); and
- significant depths of marine sediments were reported in boreholes advanced to bedrock in the surrounding area (i.e. BH403, BH406 and BH63).

The lateral distribution of identified SPGWT impacts within the underlying natural marine sediments is presented in **Figure F6**. The extent of SPGWT impact within the marine sediments immediately west of the Site is considered to have been appropriately delineated (both laterally and vertically) by field observations and soil analytical data obtained from the following sampling locations (in order from north to south, refer to **Figure F6**):

- **Block 5**:
  - BH71 – no odour or staining from 15 m bgl (upper surface of marine sediments) to the depth of bedrock (23.5 m bgl);
  - BH63 – slight to moderate tar odours noted from 13 m bgl to the depth of bedrock (22 m bgl). No staining noted;
  - BH550 – no odour or staining between 13.8 and 15.0 m bgl within the weathered sandstone (clayey sand); and
  - BH73 – slight to strong chemical odours noted from 12.8 m bgl to the depth of bedrock (19 m bgl). No staining noted.
- **Block 4 and ORWN**:
  - BH57 – no odour or staining from 15.8 m bgl to 18.3 m bgl (target depth drilling reached);
  - BH56 – natural sand present at 17.5 m bgl. Moderate tar odour noted from 19 m bgl to the depth of bedrock (21.4 m bgl). No staining noted;
  - BH47 – slight hydrocarbons odours noted from 16 m bgl to the depth of bedrock (18.6 m bgl). No staining noted;
  - BH46 – very strong chemical odour noted from 19 m bgl to 23.7 m bgl (target drilling depth reached). No staining noted;
  - BH39 – no odour or staining from 23.5 m bgl to the depth of bedrock (25 m bgl); and
  - BH38 – no odour or staining from 17.5 m bgl to 20.7 m bgl (target drilling depth reached).

It is noted that SPGWT has been identified in the natural marine sediments in BH60/BH191 located in northern portion of the off Site ORWN area (refer to **Figure F6**). Based on adjacent sampling locations these impacts appear to be localised and are not likely related to impacts in the off Site BH70 and BH541 area due to the presence of shallower bedrock levels between BH60/BH191 and BH70 / B541. Based on the modelled bedrock contours it is considered that impacts from the BH70 and BH541 area would be expected to have migrated to the northwest (refer to **Figure F6**).

4.3.2 Gasworks Related Impacts (Off Site Areas – West)

The following tasks were undertaken to assess the distribution of other gasworks related impacts in the off Site areas west of the Site (i.e. down-gradient of the Site within the ORWN and Barangaroo Central areas).

- Borehole logs were reviewed to assess whether gasworks related impacts were observed either within the fill material, marine sediments or bedrock. Field observations (either olfactory [odour] or visual evidence) of either hydrocarbon or tar based odours have been summarised from the borehole data and noted in **Table T17**; and
- A review of key contaminant concentrations (naphthalene and TPH C_{10-14}) which exceeded an arbitrary value of 20 and 50 mg/kg respectively (refer to **Figure F7** and **Figure F8** respectively). It is noted that 50 mg/kg was generally the level of detection for the TPH C_{10}-C_{14} analysis. A review of the off Site soil analytical data indicated that the selected arbitrary criteria was appropriate for defining less significant gasworks related impacts in the off Site area to the west of the Site.

Review of off Site field observations

A summary of field observations where tar or hydrocarbon impacted soils were reported to be greater than 'slightly' impacted in the off Site fill material and natural marine sediments is detailed in **Table T17** and illustrated in **Figure F7** and **Figure F8**, respectively. As detailed in **Table 10** and illustrated in **Figure F6**, SPGWT was identified to be present in off Site areas generally within 20 m from the western Site boundary with the exception of the BH60/BH191 area (marine sediments), and BH48 (marine sediments) and BH74 (shallow fill material). The distribution of minor gasworks related impacts (based on field observations) indicates that these off Site impacts are generally sporadic and not indicative of a continuous plume of impacted fill material or marine sediments emanating from historic gasworks activities at the Site.

Review of off Site naphthalene and TPH C_{10-14} concentrations

The distribution of naphthalene and TPH C_{10-14} concentrations exceeding the arbitrary criteria in the off Site areas indicates that there is a relatively strong correlation between the two contaminants in both the fill material and natural marine sediments (refer to **Figure F7** and **Figure F8** respectively). This is expected given naphthalene is typically reported in the TPH C_{12} fraction range and therefore would be included in reported TPH C_{10-14} concentrations. The minor gasworks related impacts are generally located within approximately 20 m of the Site boundary with some more localised impacts also in the vicinity of BH60/BH191 where SPGWT has also been reported (as discussed in **Section 4.3.1**).

Based on the above off Site field observations and reported low naphthalene and TPH C_{10-14} impacts, it can be concluded that the minor gasworks related impacts present in the off Site fill material and marine sediments:

- are sporadic and not indicative of continuous migration of gasworks related impacts from the Site;
- are, based on the horizontal and vertical distribution of the identified impacts, likely to be the result of historic landfilling of impacted fill materials within the Barangaroo Central and ORWN area, as opposed to impacts which have migrated directly from the contaminated materials present on the Site; and
- are, based on the off Site groundwater results within fill materials (refer to **Table T16**), unlikely to be acting as a significant contaminant source to groundwater within the fill material. Consequently, the minor gasworks related impacts are not considered to represent a significant adverse risk to off Site groundwater quality within fill material and ultimately Darling Harbour.

4.3.3 Soil Analytical Results (Off Site Areas - West)

The analytical results from soil samples collected west of the Site (in Block 5 and the ORWN) are presented in **Table T14** and **T15** (for unsaturated and saturated soils respectively). The results indicated that all CoPC concentrations in the unsaturated soils were less than the relevant SSTCs.

4.3.4 Groundwater Analytical Results (Off Site Areas - West)

Groundwater analytical results (2006 to 2011) for the monitoring wells located in the off Site areas (including in Block 5 and the ORWN Area) are presented in **Table T16**. All CoPC concentrations were reported to be less than the relevant SSTCs, with the exception of the following:

- MW60 (ORWN Area) -TPH C_{10-14} (18,500 µg/L) and naphthalene (1,500 µg/L);
- MW69 (Block 5) - naphthalene (1,920 µg/L); and
- MW541D (Block 5) - benzene (4,300 µg/L) and naphthalene (1,900 µg/L).

The groundwater results for monitoring wells located on or adjacent to the western Site boundary are also compared to the MWQC in **Table T12**.

4.3.5 Off Site Areas (West) – Identification of CIM

The results of soil and groundwater analysis from the off Site areas west of the Site did not identify CoPC groundwater concentrations in fill material above the relevant SSTCs with the exception of benzene and naphthalene reported at MW541 (as discussed in **Section 2.1.1**).

The groundwater concentrations exceeding the SSTCs reported at MW60 and MW69 (refer to **Section 4.3.4**) are not considered to be representative of CIM as the groundwater impacts are present within either natural marine sediments or within the natural bedrock. As described by **Section 2.5,** there is negligible contaminant flux from these natural materials into the overlying fill.

As such, CIM has only been identified at MW541 and is discussed further in **Section 5.3**.

SPGWT has been identified in the off Site area west of the Site and, as such, is discussed further in **Section 5.3**.

4.4 Off Site Areas – East

The following sections assess impacted soil that is located east of the Site boundary, but that is considered to be directly related to the Site and the Site's historical use as a gasworks.

It is understood that the area east of the Site has been the subject of a series of previous investigation, remediation and construction works. In particular (refer to **Figure F3**):

- 36 Hickson Road, which includes the south east quarter of the main gas holder annulus and (potentially) the eastern edge tar tank, has been the subject of a series of previous intrusive soil and groundwater investigations;
- 30-34 Hickson Road was the subject of basement excavation and construction works which included excavation and remediation of the north east portion of the main gasholder. Based on experience from the 30-34 Hickson Road remediation program, SPGWT is likely to be present at the base of the main gasholder annulus within 36 Hickson Road (and within the Site);
- 38 Hickson Road was the subject of basement excavation and construction works which are likely to have effectively removed residual contamination that may have been present;

As an outcome of the above mentioned work at 30-34 Hickson Road, 36 Hickson Road and 38 Hickson Road, Site Audit Statements were prepared confirming that the sites are suitable for their current land use (refer to **Appendix E**). Therefore, it is considered unlikely that the soil and groundwater contamination that may be present in these off Site areas warrants remediation.

It should also be noted that prior to declaration of the Site as a Remediation Site (under the then Section 9 of the CLM Act) a larger area (that included the Site and 36 Hickson Road) had been declared an Investigation Site. It is understood that on the basis of the results of additional soil and groundwater investigations, 36 Hickson Road was not included as part of the subsequent declaration of a Remediation Site. This observation is considered to further support the conclusions that it is unlikely that soil and groundwater contamination that may be present in these off Site areas warrants remediation.

The following sections specifically assess the potential for SPGWT that is likely to be contained within historic gasworks structures present east of the Site boundary to impact on remediation works within the Site.

4.4.1 Separate Phase Gasworks Waste and Tar (Off Site Areas – East)

As above, remediation works undertaken during construction of the basement for 'The Bond' (located at 30-34 Hickson Road directly to the east of the Site, refer to **Figure F3**) indicated that there is potential for residual SPGWT to be present in the south eastern portion of the main gasholder annulus within 36 Hickson Road. Further, more recent investigations of the tar tank (sampling locations BH7 and BH53), which potentially extends over the Site boundary into 36 Hickson Road, have identified SPGWT within this structure (refer to **Section 4.2.1**).

Given that the proposed remediation works will involve remediation, of SPGWT present within those sections of the main gasholder annulus and tar tank within the Site (refer to **Section 3.3**), to the extent practicable, the risk of residual contamination from beneath 36 Hickson Road impacting on the future remediated Site warrants consideration (refer to **Section 5.3.1**).

4.4.2 Off Site Areas (East) – Identification of CIM

SPGWT has been identified in the off Site area east of the Site (specifically within the eastern portion of the main gasholder annulus and tar tank present beneath 36 Hickson Road) and, as such, is discussed further in **Section 5.4**.

5.0 Remediation Extent for the Protection of Human Health

The remediation goals for the protection of human health are described by **Section 3.3**. The contamination identified within the Site (and in areas adjacent to the Site) have been characterised in the context of these remediation goals (i.e. in terms of the presence of SPGWT and CIM) in **Section 4.1**.

The following Sections present the recommended remediation extent for each of the following Site areas:

- Block 4 and 5;
- Hickson Road;
- Off Site areas: west of the Site; and
- Off Site areas: east of the Site.

5.1 Human Health Remediation Extent (Block 4 and 5)

Based on the analytical data and findings presented in **Section 4.1**, both SPGWT and CIM have been identified in Block 4 and Block 5. The CIM has generally been identified at locations that correspond to the presence of SPGWT, the footprint of historic gas works infrastructure and based on concentrations of the following CoPCs which exceed the unsaturated soil and groundwater SSTCs:

- Benzene;
- TPH C_{10}-C_{28};
- naphthalene; and
- cPAHs.

5.1.1 Contaminant Distribution (Block 4 and Block 5)

5.1.1.1 Separate Phase Gasworks Waste and Tar

As discussed in **Section 4.1.1** and detailed in **Table 5**, SPGWT has been identified in areas of Block 4 and 5 which will require remediation to be protective of human health.

5.1.1.2 Contamination (non-SPGWT) in Unsaturated Soil

As shown in **Figure F4** exceedances of the unsaturated SSTC for non SPGWT contamination (i.e. concentrations of cPAHs exceeding the SSTCs) are generally distributed across the eastern part of Blocks 4 and 5, in the middle of the Site.

No exceedances of the SSTCs were reported in the unsaturated soil in the southern portion of Block 4.

Remediation of unsaturated soil in areas where CIM has been reported (predominantly based on cPAH concentrations) is required to be protective of human health.

5.1.1.3 Contamination (non-SPGWT) in Groundwater

As shown in **Figure F5** exceedances of the groundwater SSTC for non-SPGWT contamination (i.e. TPH, benzene and PAHs exceeding the groundwater SSTCs) are generally limited to those parts of Block 4 where SPGWT has been identified to be present (i.e. the northeast part of Block 4, refer to **Figure F6**).

The groundwater monitoring results for CoPCs detailed in **Section 4.1.3** indicate that groundwater concentrations which exceed the groundwater SSTC are generally present in the eastern and central portion of Block 4. There were no exceedances of the groundwater SSTC present in Block 5.

Remediation of saturated soil contamination considered to represent the source of the groundwater CIM identified within fill material, is required to be protective of human health. That is, remediation of soil contamination, to the extent practicable, in areas of groundwater CIM identified within fill material, will result in the removal of the contaminant source and, ultimately, a reduction in groundwater CoPC concentrations within fill material to less than the relevant groundwater SSTCs.

5.1.2 Recommended Remediation Extent (Block 4 and Block 5)

Based on the distribution of SPGWT and CIM discussed above, the extent of remediation works in Block 4 and Block 5 is recommended to include the following Site areas, which generally correspond with the location of

historic gasworks structures. The extent of remediation required in the unsaturated and saturated zones is also presented on **Figure F14** and **Figure F15**, respectively.

- Unsaturated zone (i.e. between 0 and 2 m bgl):
  - All Block 4 areas where SPGWT has been identified (refer to **Table 5** and **Figure F6**).
- Saturated zone (i.e. greater than 2 m bgl):
  - All Block 4 areas where SPGWT has been identified (refer to **Table 5** and **Figure F6**);
  - The western portion of the 1870 gasholder annulus (Block 4);
  - The eastern portion of Block 4 and 5 (i.e. east of the 10 m bgl bedrock contour);
  - The south east portion of Block 4 in the vicinity of BH42/BH408; and
  - The western portion of Block 4 in the vicinity of BH49 and BH119.

The vertical extent of remediation will be to the depth of the underlying natural bedrock or to a maximum depth of 10 m bgl. The vertical extent of remediation is based on consideration of:

- locations where SPGWT has been reported (refer to **Section 4.1.1**);
- locations where exceedances of the groundwater SSTC and unsaturated soil SSTC have been reported (refer to **Section 4.1.2** and **4.1.3**);
- the footprint of historical gasworks structures and infrastructure (refer to **Section 2.4.1**); and
- the depth to bedrock (noting the depth to bedrock steadily increases to the west beyond the 10 m bgl rock contour, such that remediation to the depth of underlying natural bedrock would steadily increase beyond this point, refer to the cross sections provided in **Figure F10** to **Figure F13**).

It is noted that SPGWT and CIM have been reported in the natural marine sediments in some Site areas outside the recommended remediation extent. As described by **Section 2.5,** there is negligible contaminant flux from these natural materials into the overlying fill. Therefore, SPGWT and CIM that may be present within the natural marine sediments are not considered to pose a significant risk to human health. As such, the proposed extent of remediation works excludes remediation of natural marine sediments which are present below a depth of 10 m bgl.

5.1.2.1 Recommended Remediation Extent (Block 4 and Block 5) - Depth to Bedrock

As illustrated in cross sections A-A' to C-C' (**Figure F10** to **Figure F12**), the vertical extent of remediation for protection of human health includes remediation to bedrock across the majority of Block 4 and 5. Based on the modelled bedrock contours, two localised areas where fill material is likely to remain below 10 m bgl:

- BH65/BH197 (Block 5, as illustrated in cross section A-A', **Figure F10**) - the following field observations were made:
  - BH65 - tar was observed within the marine sediments at a depth of 9.5 m bgl. As such, the depth of remediation in this area would be expected to extend into the marine sediments (to a depth of 10 mbgl) to facilitate removal, to the extent practicable, of this material; and
  - BH197 - no tar was observed to be present below a depth of 10 m bgl and bedrock was recorded at a depth of 12.8 m bgl.
- BH49 to BH119 (the western portion of Block 4, as illustrated in cross section C-C', **Figure F12**) - The following field observations were made:
  - BH49 - tar was observed at and below 10 m bgl within the fill material. Marine sediments (a very stiff, sandy clay) were reported at 11.2 m bgl. The depth of remediation in this area may be required to locally extend below 10 m bgl to facilitate removal of SPWGT to the extent practicable. Over excavation, if required, would be undertaken in accordance with the requirements of the RAP; and
  - BH119 - no tar was observed within the fill material at this borehole (drilling was terminated within fill material at 10 m bgl).

5.2 Human Health Remediation Extent (Hickson Road)

Based on the analytical data and findings presented in **Section 4.2**, both SPGWT and CIM have been identified in Hickson Road. The CIM has generally been identified at locations that correspond to the presence of SPGWT, the footprint of historic gas works infrastructure and based on concentrations of the following CoPCs which exceed the unsaturated soil and groundwater SSTCs:

- Benzene;
- TPH C_{10}-C_{28};
- naphthalene; and
- cPAHs.

5.2.1 Contaminant Distribution (Hickson Road)

5.2.1.1 Separate Phase Gasworks Waste and Tar

As discussed in **Section 4.2.1** and detailed **Table 8**, SPGWT has been identified in areas of Hickson Road which will require remediation to be protective of human health.

5.2.1.2 Contamination (non-SPGWT) in Unsaturated Soil

As discussed in **Section 4.2.2** and detailed in **Table 6**, CoPCs were not reported at concentrations exceeding the relevant SSTCs in unsaturated soil within Hickson Road.

5.2.1.3 Contamination in (non-SPGWT) Groundwater

As shown in **Figure F5**, exceedances of the groundwater SSTC for non-SPGWT contamination (i.e. TPH C_{10}-C_{28}, naphthalene, benzene - and cPAHs exceeding the SSTCs) are generally located in the southern portion of Hickson Road and are considered likely to be related to SPGWT within the main gasholder annulus and tar tank structures. Relatively high CoPC concentrations at MW15 are possibly related to contamination associated with nearby historical gas works infrastructure located to the west (i.e. the main gasholder annulus and tar tank).

Remediation of saturated soil contamination (CIM) considered to represent the source of the groundwater CIM, is required to be protective of human health. That is, remediation of soil contamination, to the extent practicable, in areas of groundwater CIM, will result in the removal of the contaminant source and, ultimately, a reduction in groundwater CoPC concentrations within fill material to less than the relevant groundwater SSTCs.

5.2.2 Recommended Remediation Extent (Hickson Road)

Based on the distribution of SPGWT and CIM discussed above, the extent of remediation works in Hickson Road is recommended to include the following historic gas works structures and site areas. The extent of remediation required in the saturated zones (i.e. greater than 2 m bgl) is also presented on **Figure F15**:

- All areas where SPGWT has been identified (refer to **Table 8** and **Figure F15**):
    - The BH7/MW7 and BH53 area – the southern tar tank;
    - The BH10/MW10 area - eastern portion of the 1870 gas holder;
    - The western portion of the main gas holder annulus;
    - The northern tar tank; and
    - The BH6, BH15 and BH61 area - located west and down gradient of the main gas holder annulus and northern/southern tar tanks.

As described by **Section 5.1.2**, the depth of remediation will be to the depth of the underlying natural bedrock or to a maximum depth of 10 m bgl. It is noted that the depth of natural bedrock, even within the historic gasworks structures, is not expected to extend below 10 m bgl. If the depth to bedrock within the historic gasworks structures is greater than 10 m bgl, the depth of remediation will be extended to the depth of bedrock, to the extent practicable.

5.3 Off Site Areas (West) - Extent of Remediation

Based on the analytical data and findings presented in **Section 4.3.1**, SPGWT and CIM have been identified both within the fill material and within marine sediments in areas west of the Site (specifically in the vicinity of BH70 and BH541/MW541).

5.3.1 Contaminant Distribution (Off Site Areas – West)

5.3.1.1 Separate Phase Gasworks Waste and Tar

As discussed in **Section 4.3.1** and detailed in **Table 10**, SPGWT has been identified in localised off Site areas both within the fill material (specifically in the vicinity of BH70 and potentially BH541) and within the underlying marine sediment. Remediation of SPGWT within fill material is required to be protective of human health.

As detailed in **Table 10** and presented in **Figure F6**, while SPGWT has been identified at depth within the natural marine sediments in areas to the west of the Site (i.e. typically within 30 m of the western Site boundary with the exception of BH60), remediation of these materials is not considered to be warranted for the following reasons:

- the contaminant flux from the natural marine sediments is negligible (refer to **Section 2.5**); and
- SPGWT that may be present within the natural marine sediments is not considered to pose a significant risk to human health.

5.3.1.2 Contamination in (non SPGWT) Groundwater

As discussed in **Section 4.3**, in addition to the SPGWT identified in the vicinity of BH70 and potentially BH541, the benzene and naphthalene groundwater concentrations in fill material at MW541 exceeded the groundwater SSTC and is considered to be representative of CIM.

5.3.2 Recommended Remediation Extent (Off Site Areas - West)

Based on the distribution of SPGWT and CIM, the extent of remediation works in the off Site areas west of the Site (in Block 5 or Barangaroo Central) is recommended to include the following (refer to **Figure F15**):

- SPGWT in the vicinity of BH70 (located west of the Block 5 portion of the Site) to a depth of approximately 2 to 3 m bgl in fill material (potential SPGWT); and
- SPGWT and CIM in the vicinity of BH541 (located west of the Block 5 portion of the Site) to a depth of approximately 9.9-10 m bgl in fill material.

As described by **Section 5.1.2**, the vertical extent of remediation will be to the depth of the underlying natural bedrock or to a maximum depth of 10 m bgl.

It is noted that SPGWT and CIM have been reported in the natural marine sediments in some hydraulically down gradient areas to the west of the Site (outside the recommended extent of remediation). As described by **Section 2.5,** there is negligible contaminant flux from these natural materials into the overlying fill. Therefore, SPGWT and CIM that may be present within the natural marine sediments is not considered to pose a significant risk to human health. As such, the proposed vertical extent of remediation works excludes remediation of natural marine sediments which are present below a depth of 10 m bgl.

It is noted that potential SPGWT observed in the fill material at BH74[6] (located 70 m west of the western Site boundary) may also require remediation for the protection of human health. However, this material is not directly related to the Site and the Site's historical use as a gasworks, and due to the proximity of BH74 from the Site's western boundary does not represent a risk of cross contamination of the Site. Therefore, the requirement for remediation of this material will be assessed separately as part of the Barangaroo Central RAP (to be prepared by the Authority).

[6] Not to be mistaken for the ERM sampling location BH074 (located on the western Site boundary, Block 5).

5.4 Off Site Areas (East) – Extent of Remediation

Based on the analytical data and findings presented in **Section 4.4.1**, SPGWT may be present in isolated areas immediately east of the Site (specifically in the vicinity of BH70 and BH541).

5.4.1 Contaminant Distribution (Off Site Areas – East)

5.4.1.1 Separate Phase Gasworks Waste and Tar

As discussed in **Section 4.4.1**, there is potential for SPGWT to be present in the south east portion of the main gasholder annulus and the eastern edge of the tar tank which extend beyond the Site boundary to the east (i.e. into 36 Hickson Road). Given that the proposed remediation works will involve remediation, to the extent practicable, of SPGWT from within the Site, there is a risk that SPGWT from the structures remaining beneath 36 Hickson Road could migrate back onto the future remediated Site.

Management measures are required to be protective of human health and to prevent the migration of contamination onto the future remediated Site.

5.4.1.2 Non SPGWT Contamination

As discussed in **Section 4.4**, with the exception of SPGWT identified in the former gasworks structures, non SPGWT contamination requiring remediation for the protection of human health (CIM) has not been identified in unsaturated soil or groundwater in the area immediately east of the Site.

However, as noted in **Section 4.4.2**, management measures are required to be protective of human health and to prevent the migration of groundwater contamination within fill material onto the future remediated Site from the identified SPGWT.

5.4.1.3 Recommended Remediation Extent (Off Site Areas - East)

There is potential SPGWT to be present within the historical gasworks structures east of the Site that may impact on remediation works within the Site. Therefore, the *VMP/Block 4 RAP* will consider management measures (likely engineering controls) that will mitigate the risk of the remediated Site being re contaminated. Such engineering controls may include the construction of a perimeter cutoff wall on the eastern Site boundary in the areas adjacent to the eastern portions of the main gasholder annulus and tar tank.

The SPGWT potentially present in the area directly east of the Site (i.e. in the south east portion of the main gasholder annulus and the eastern edge of the tar tank) is not considered to require remediation for the protection of human health based on the following reasons:

- The existing Site Audit Statement for 36 Hickson Road indicates the site is suitable for its current land use in its current form. This site is not included within the Declaration Area;
- Remediation of Site will include remediation of approximately half of the main gasholder annulus and the majority (if not all) of the tar tank. Therefore, the mass of contamination remaining within the two structures following remediation of the Site will be significantly reduced; and
- It is considered likely that the residual SPGWT remaining within the south east portion of the main gasholder annulus and eastern edge of the tar tank (if it extends across the Site boundary) will be limited in extent (both vertically and laterally) and effectively contained within the gasworks structures. Evidence supporting this conclusion includes:
    - the depth of groundwater within the tar tank has been observed to be higher than groundwater in the surrounding bedrock, suggesting that migration of groundwater out of the structures is limited (i.e. the tar tank is able to hold water); and
    - observations from the remediation works at 30-34 Hickson Road (which included remediation of a portion of the gasholder annulus) indicated that the extent of SPGWT (tar) migration into the bedrock mass is relatively limited (refer to **Section 2.4.5**).

6.0 Remediation Extent for Protection of the Environment

The remediation goals for the protection of the environment, as described by **Section 3.3**, are:

- As a primary 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 quality leaving the Site (measured at the down hydraulic Site boundary) approaches the MWQC.

Sections 4.0 and **5.0** include a comparison of the Site's soil and groundwater analytical data to these remediation goals to identify materials at the Site which may be:

- representative of SPGWT and therefore may require remediation; and
- contaminated such that groundwater leaving the Site (measured at the down hydraulic Site boundary) approaches the MWQC.

The following Sections present the outcome of the process adopted for development of the remediation extent for the protection of the environment.

An iterative approach has been adopted based on consideration of multiple lines of evidence. In summary, the outcome is that the proposed remediation extent (refer to **Section 5.0**) corresponds with the extent of remediation required for protection of the environment to the extent practicable. The proposed extent of remediation is considered consistent with the principles of 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.*

6.1 Regulatory Policy Requirements

As described by **Section 2.4**, the closest ecological receptor identified by the *VMP HHERA* (AECOM, 2012c) was the potential groundwater aquatic ecosystem down hydraulic gradient of the Site boundary, between the Site and Darling Harbour. As such, in the context of protection of the environment, the protection of groundwater quality is the key contaminant migration pathway that requires consideration.

The NSW DEC (2007) *Guidelines for the Assessment and Management of Groundwater Contamination* describe a best-practice framework for the assessment and management of contaminated groundwater in NSW. The guidelines have been made under section 105 of the *CLM Act* (1997) and therefore must be taken into account by the NSW EPA and site auditors accredited under the *CLM Act* (1997)when relevant. The relevant requirements of NSW DEC (2007) are summarised in the following Sections.

Other regulatory considerations that are relevant to development of the proposed remediation extent are also summarised following:

- Ecological Sustainable Development; and
- Waste Avoidance and Resource Recovery.

6.1.1 *Guidelines for the Assessment and Management of Groundwater Contamination* (NSW DEC, 2007)

Section 3.2 of NSW DEC (2007) prescribes the following management responses to identification of groundwater contamination. In considering the appropriate management responses, NSW DEC (2007) requires that focus first be on the greatest threats and that the benefits of groundwater clean-up must outweigh any incidental negative impacts that could arise.

- Control short-term threats arising from the contamination - acute risks relating to contamination have not been identified based on the current land use. The NSW EPA Declaration and conclusions from the *VMP HHERA* (AECOM, 2012c) are based on the requirement to mitigate long-term or chronic risks;
- Restrict groundwater use - groundwater within the Site is saline and therefore not suitable for use as described by **Section 6.6**);
- Prevent or minimise further migration of contaminants from source materials to groundwater: specifically source control to the extent practicable; and

- Clean up groundwater to protect human and ecological health: as described by **Section 5.1** and **5.2**, in the case of human health and described by **Section 6.5**, in the case of the environment.

6.1.1.1 Source Control

Section 3.5 of NSW DEC (2007) considers that the control of all known and suspected sources of groundwater contamination is an important element for minimising contaminant release to the environment and remediation of groundwater contamination. In the case of the Site, primary contaminant sources are considered to be historical gasworks infrastructure (which has been found to contain SPGWT) and secondary sources are considered to be SPGWT observed in groundwater and soil. Source control can include contaminant removal, *in situ* treatment and containment.

NSW DEC (2007) acknowledges that complete source removal or treatment may not be possible, particularly in cases where: treatment is not technically feasible; the volume of materials or complexity of the Site make it impracticable; or, where severe adverse effects on other aspects of the environment would result.

6.1.1.2 Remediation of NAPL to the extent practicable

Section 3.5.1 of NSW DEC (2007) specifically requires that non-aqueous phase liquids (NAPLs) (which represent a subset of materials considered to be SPGWT) must be cleaned up to the extent practicable. As above, NSW DEC (2007) acknowledges that complete removal or treatment of NAPL may: be impracticable, for example as a result of complex geological conditions; and/or may have high costs with uncertain benefits. If this is the case, ongoing monitoring and management of the contamination is required to ensure protection of human health and the environment.

The objectives of any strategy for the control of NAPL contamination should be:

- Ensuring the protection of human health and the environment;
- Controlling further migration of contaminants from NAPLs; and
- Reduction in the NAPL mass to the extent practicable (through either removal or treatment).

The remediation goals for the protection of human health and the environment established for the Site are described in **Sections 3.3** and **3.4**, respectively, and are consistent with the policy requirements described above. In particular: numerical criteria (SSTCs) have been developed for the Site for the protection of human health; and, the primary goal for protection of the environment is remediation of SPGWT within fill material (which includes NAPL) to the extent practicable.

6.1.2 Clean Up to the Extent Practicable (CUTEP)

Section 4 of NSW DEC (2007) establishes the following clean-up objectives for contaminated groundwater:

1) Clean up so natural background water quality is restored;

2) Clean up to protect the relevant environmental values of groundwater, and human and ecological health.

3) *Clean up to the extent practicable*.

The clean up objectives for the protection of human health and the environment established for the Site are described in **Sections 3.3** and **3.4**, respectively, and are consistent with this hierarchy. In particular: numerical criteria (SSTCs) have been developed for the protection of human health; and, long-term numerical criteria (MWQC at the down hydraulic gradient Site boundary) have been developed, in consultation with the NSW EPA, for the protection of the environment.

Section 4.3 of NSW DEC (2007) acknowledges that it may not be practicable to clean up groundwater to the point where all long-term environment goals are achieved. In such instances, the NSW EPA may consider interim clean-up goals. In evaluating the remediation extent that is practicable, the following factors must be considered:

- *technical capability to achieve the clean-up;*
- *threats the contamination poses to human or ecological health;*
- *the value of the groundwater resource; and*
- *clean-up costs*.

The proposed remediation extent is considered in the context of each of these factors in **Sections 6.3** to **6.7**.

Section 4.3 of NSW DEC (2007) also requires that any proposal for CUTEP must include consideration of ongoing management and monitoring of groundwater to ensure the protection of human and ecological health. In particular, any proposal for CUTEP should be accompanied by:

- A commitment to ongoing monitoring and evaluation of clean-up practicability - ongoing groundwater monitoring and evaluation is prescribed by Section 17.4 and 19.8 of the *VMP/Block 4 RAP* (AECOM, 2013b);
- A groundwater management plan (GMP) - Section 17.4 of the *VMP/Block 4 RAP* (AECOM, 2013b) includes a requirement for preparation of and implementation of a GMP;
- Acknowledgement that future management may be required if necessary to ensure protection of human and ecological health - Section 20.5 of the *VMP/Block 4 RAP* (AECOM, 2013b) describes the potential for a Site Management Plan to be implemented in the event that future land owners plan to re-develop the Site. Section 23.0 of the *VMP/Block 4 RAP* (AECOM, 2013b) also describes contingency management actions that may be implemented to ensure the protection of human and ecological health; and
- Provision of long-term resourcing and responsibility for implementation of any ongoing management strategy - implementation of any ongoing management strategy (if required) will be the responsibility of the future land owner.

6.1.3 Ecological Sustainable Development

The National Strategy for ESD, endorsed by all Australian jurisdictions in 1992, defines the goal of ESD as *development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends*.

In considering the application of ESD to remediation, E.K. Hocking (2001) *Intergenerational Equity and Environmental Restoration Cleanup Levels* observed that while low remediation clean-up criteria could be perceived as this generation's efforts to remediate sites to benefit future generations, the significant resources required to undertake such works may in fact divert funding from other activities that could have a greater beneficial impact on future generations.

Section 9 of the *CLM* Act (1997) references the principles of inter-generational equity which can be can be defined as the fairness of access to resources across generations. The key ESD principles set out in Section 9 of the *CLM Act* (1997) are:

- *If there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation (the 'precautionary principle');*
- *The principle of inter-generational equity – that the present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations (the 'intergenerational principle');*
- *The conservation of biological diversity and ecological integrity should be a fundamental consideration in decision-making (the 'biodiversity principle');*
- *Improved valuation, pricing and incentive mechanisms should be promoted (the 'valuation principle').*

One of the objectives of the *Protection of the Environment Operations Act* (the POEO Act, 1997) is also:

- '*to protect, restore and enhance the quality of the environment in New South Wales, having regard to the need to maintain ecologically sustainable development'*.

Section 4.4 of NSW DEC (2007) also requires that the benefits from undertaking groundwater clean-up must outweigh any incidental negative impacts to human health or the environment that could arise from the clean-up.

6.1.4 Waste Avoidance and Resource Recovery Act (2001)

The *Waste Avoidance and Resource Recovery Act* (2001) includes the following objectives:

- *to encourage the most efficient use of resources and to reduce environmental harm in accordance with the principles of ecologically sustainable development,*
- *to ensure that resource management options are considered against a hierarchy of the following order:*
    - *avoidance of unnecessary resource consumption,*

- *resource recovery (including reuse, reprocessing, recycling and energy recovery),*
- *disposal,*

- *to provide for the continual reduction in waste generation;* and
- *to minimise the consumption of natural resources and the final disposal of waste by encouraging the avoidance of waste and the reuse and recycling of waste.*

Any potential remediation works required at the Site to provide additional protection to the receiving environment need to appropriately consider the *Waste Avoidance and Resource Recovery Act* (2001).

6.2 DNAPL Removal to the Extent Practicable (as per the NSW DEC 2007 Guidelines)

As described by **Section 6.1.1**, contaminated groundwater in NSW is managed in accordance with the NSW DEC (2007) *Guidelines for the Assessment and Management of Groundwater Contamination*. The guideline requires that where NAPLs (DNAPLs in the case of this Site which are included as part of the materials referred to as SPGWT by this document) are present on sites, they must be removed or treated as much as practicable. This requirement is consistent with the primary remediation goal for protection of the environment; which is to the remediation of SPGWT within fill material to the extent practicable (refer to **Section 3.4**).

As illustrated in **Figure F6**, the presence of SPGWT, or indications that SPGWT may be present (as evidenced by the presence of a sheen in groundwater or observations of DNAPL), has been documented at the locations summarised in **Table 11**.

Table 11 Identified Area of SPGWT or Sheen and Confirmation of Remediation Requirements

Location		SPGWT identified?	Sheen identified in groundwater?	Located within proposed remediation area?
Block 4				
1.	BH52	Yes	No	Yes*
2.	BH54	Yes	No	Yes*
3.	BH55	Yes	No	Yes*
4.	BH59	Yes	No	Yes*
5.	BH087/MW15	Yes	Yes	Yes*
6.	BH019	Yes	No	Yes*
7.	BH141	Yes	No	Yes*
8.	BH200/MW200	No	Yes	Yes*
9.	BH204S/MW204S	Yes	Yes	Yes*
10.	BH204D/MW204D	Yes	Yes	Yes*
11.	BH205/MW205	Yes	Yes	Yes*
12.	BH206/MW206	Yes	Yes	Yes*
13.	BH209/MW209	No	Yes	Yes*
14.	TP05	Yes	Yes	Yes*
15.	TP06	Yes	Yes	Yes*
Southern Block 4				
16.	BH42	Yes	No	Yes*
17.	BH408	Yes	No	Yes

Location		SPGWT identified?	Sheen identified in groundwater?	Located within proposed remediation area?
Western Block 4				
18.	BH49	Yes	No	Yes*
19.	BH119	Yes	No	Yes
20.	BH405/IT03	Yes	Yes within marine sediments (IT03D)	No
Block 5				
21.	BH198/MW198	No	Yes	Yes*
22.	TP02	Yes	Yes	Yes*
Hickson Road				
23.	BH7/MW7	Yes	Yes	Yes*
24.	BH53/MW53	Yes	Yes	Yes*
25.	BH10/MW10	Yes	Yes	Yes*
26.	BH61	Yes	Yes	Yes
27.	BH15/MW15	Yes	Yes	Yes
28.	BH6/MW6	Yes	Yes	Yes
Off Site (Block 5 and Barangaroo Central)				
29.	BH69/MW69	No	Yes	No
30.	BH70	Yes	No	Yes
31.	BH74	Yes	No	No
32.	BH400	Yes	No	No
33.	BH402	Yes	No	No
34.	BH403	Yes	No	No
35.	BH541/MW541D	Yes	No	Yes
Off Site (Block 4 and ORWN)				
36.	BH48	Yes	No	No
37.	BH60	Yes	No	No
38.	BH404	Yes	No	No
39.	BH406	Yes	No	No

NOTE: * Borehole location is likely to be located within or directly adjacent to the former gasworks infrastructure.

Of the 39 locations at which SPGWT has been observed, or indications that SPGWT may be present have been recorded, 29 locations are located within the proposed remediation extent required for the protection of human health.

Of the 10 locations which are outside the proposed remediation extent:

- 1 location (BH74) is within fill materials:
  - BH74 (depth 1 to 2.5 m bgl) – is located approximately 70 m from the western Site boundary.
- 2 locations (BH48 and BH69) relate to observations of SPGWT within bedrock underlying fill in off Site areas. As noted in **Section 2.4.5**, contaminant flux from the bedrock is likely to be negligible at this location given the relatively impermeable nature of the natural sandstone and the limited presence of bedrock fracture zones:

- BH48 – the SPGWT identified at this borehole is located within the bedrock at greater than 14 m bgl;
- BH69/MW69 - is located adjacent to the northern Site boundary within Barangaroo Central. The impacted groundwater at this location is located within the bedrock. Consequently, the assessment of whether remediation is required at this location will be included in the Barangaroo Central RAP.

- 1 location (BH405) relates to observations from within marine sediments underlying fill at the Site. As noted in **Section 2.5**, contaminant flux from the marine sediments is likely to be negligible given the comparatively low hydraulic conductivity of the marine sediment:
  - BH405/IT03D (located in the western portion of Block 4) the presence of SPGWT at this location was based on soil contaminant concentrations exceeding the TCM criteria at depth of 14 m bgl within marine sediments. No tar was observed at this location. A sheen was also noted within the deep sampling port within the marine sediments. No sheen was observed in the groundwater within the shallow and middle sampling ports (IT03S and IT03M) which were both installed within the fill material. BTEX, TPH and PAH concentrations in groundwater within the shallow and middle sampling ports (IT03S and IT03M) were also generally reported to be non-detect and significantly less than the relevant groundwater SSTCs. As discussed in **Section 2.5.2**, the field observations and analytical results reported at the three IT03 sampling ports confirm the Conceptual Site Model (i.e. there is negligible contaminant flux from the marine sediments to groundwater present in the overlying fill materials, refer to **Section 2.5**).
- 6 locations (BH60, BH400, BH402, BH403, BH404 and BH406) relate to observations from within marine sediments underlying fill within off Site areas. As noted in **Section 2.5**, contaminant flux from the marine sediments is likely to be negligible given the comparatively low hydraulic conductivity of the marine sediment:
  - BH60 – the SPGWT identified at this location is within the marine sediments at a depth of 16 to 17.5 m bgl. BH60 is located approximately 85m west of the western Site boundary;
  - BH400, BH402 and BH403 – the SPGWT identified at these boreholes is located within the marine sediments at generally greater than 10 m bgl;
  - BH404 - the SPGWT identified at this borehole is located within the marine sediments at greater than 15 m bgl;
  - BH406 - the SPGWT identified at this borehole is located within the fill material and marine sediments at greater than 14 m bgl.

Based on the above information, it is considered that the proposed remediation extent is consistent with the requirements of the NSW DEC (2007) guidelines for: (a) source removal; and (b) remediation of NAPL to the extent practicable. In particular, the proposed remediation extent includes:

- All of the known historic gasworks structures, which are considered to be representative of primary contaminant sources; and
- The majority of locations (i.e. 29 out of 30 locations both within the Site and off Site) at which NAPL has been recorded in fill by previous investigations, which are considered to be representative of secondary contaminant sources. It is noted that this calculation excludes the impact reported at:
  - BH48 and BH69 where SPGWT was reported in bedrock;
  - BH405 were SPGWT was reported in marine sediments below the Site; and
  - BH400, BH402, BH403, BH404, BH405, BH406 were SPGWT was reported in marine sediments off Site.

It should also be noted that the contaminant mass calculations presented in **Section 6.4**, are based on sample results that include samples that are considered representative of SPGWT. Therefore, the reduction in contaminant mass that is anticipated will be realised from the proposed remediation extent incorporates a similar reduction in the mass of NAPL.

Removal of the residual pockets of NAPL that have been reported outside the proposed extent of remediation is considered neither practicable nor necessary because:

- The contaminant flux from the underlying bedrock or marine sediment is negligible, such that contaminants present within the marine sediment and bedrock is largely being contained and controlled from further migration;
- The proposed remediation extent is predicated on achieving the remediation goals for protection of human health (refer to **Section 3.3**);
- Contaminant flux modelling (AECOM, 2013a), which includes the presence of residual SPGWT at depth within fill and marine sediments, demonstrates that the residual SPGWT following completion of the proposed remediation will not represent an unacceptable impact to the environment (refer to **Section 6.5.2**);
- The benefit of treating or removing the residual SPGWT does not outweigh the cost in terms of negative impact to the environment (refer to **Section 6.7**).

6.3 CUTEP - Technical Capability to Achieve the Clean-up

As required by Section 4.3 of the NSW DEC (2007) *Guidelines for the Assessment and Management of Groundwater Contamination*, one of the key factors that must be considered to assess whether CUTEP has been achieved is the technical capability to achieve the clean-up.

The following Sections consider the technical capability to achieve the clean-up as follows:

1) Identification of the most likely remediation technologies to be adopted (refer to **Section 6.3.1**);
2) Consideration of the standard of remediation that can be practicably achieved by the identified most likely remediation technologies (refer to **Section 6.3.2**);
3) Consideration of the practicability limitations associated with the most likely remediation technologies and the implications of remediating to greater depths or across larger areas than proposed (refer to **Section 6.3.3**); and
4) Consideration of the contaminant mass reduction that will be achieved by implementation of the most likely remediation technologies (refer to **Section 6.4**).

6.3.1 Likely Remediation Strategy

Section 10 of the *VMP/Block 4 RAP* (AECOM, 2013b) describes the process adopted for selection of the preferred remedial technology. Importantly, the process adopted for selection of an appropriate remediation strategy was undertaken based on the nature and distribution of contamination reported within the Site and areas adjacent to the Site. As such, the process was not based on the outcomes of this remediation extent document.

A three stage process was adopted:

- **Identification of Remedial Technology Options** – based on review of the primary information sources to identify potential treatment technologies for the Site;
- **Screening of Remedial Technology Options** –based on an initial comparison of all identified technologies to assess their suitability for implementation at the Site; and
- **Assessment of Remedial Technology Options** – based on a more detailed review of the highest rating technologies from the screening stage, against the key remediation objectives.

Seven remediation technologies were selected based on the first two stages of the technology assessment process (refer to **Table T18**). The seven technologies were:

- **Ex-situ Remediation Technologies:**
    - Excavation and Ex Situ Thermal Desorption (on Site): Desorption and/or destruction of organic contaminants in excavated soil by heating, usually by a direct heating thermal unit. Treated material could be disposed off Site or re used on site;
    - Excavation and ex Situ Thermal Desorption (off Site): Desorption and/or destruction of organic contaminants in excavated soil by heating, usually by direct heating thermal unit. Requires transport of materials to an off-site thermal desorption facility. Treated material would likely be disposed off Site;

- Excavation and ex situ stabilisation (on Site): Encapsulation of contaminant by ex situ blending with chemical binders to immobilise contaminants of concern. Stabilised material could be disposed off Site or re used on Site; and
- Excavation and Surfactant enhanced ex situ chemical oxidation (S-ESCO™): Ex situ treatment of excavated soils using strong oxidants, such as hydrogen peroxide, permanganate or persulphate, to degrade a wide range of organic contaminants. Treated material could be disposed off Site or re used on Site.

- **In situ Remediation Technologies:**
  - Surfactant enhanced *in situ* chemical oxidation (S-ISCO®): Injection of strong oxidants, such as hydrogen peroxide, permanganate or persulphate in the presence of a surfactant, into the subsurface to degrade a wide range of organic contaminants;
  - *In Situ* Stabilisation or Solidification (ISS): Encapsulation of contaminant by *in situ* blending with chemical binders to immobilise contaminants of concern. This could be achieved by large drilling of large diameter borehole and mixing of fly ash, lime, cement with the contaminated soil; and
  - Physical Containment: Containment or capping of contaminated soil to prevent or significantly reduce contaminant migration and to prevent human and environmental exposure. It is considered unlikely that physical containment alone would be considered acceptable by regulators nor would containment alone satisfactorily address the NSW EPA Declaration. Therefore, physical containment has not been considered further by this document.

In considering the most likely remediation strategies, consideration should be given to the proposed phased approach to remediation of the respective areas of the Site. In particular:

- Block 4: excavation of Block 4 is likely required as part of the Barangaroo South development for a potential future basement , so ex situ remediation technologies are appropriate;
- Block 5: planning of the Block 5 development (which is part of Barangaroo Central) is in a preliminary stage and the nature of the development has not yet been defined, therefore *in situ* remediation technologies are appropriate; and
- Hickson Road: this public roadway contains a high density of below ground services and utilities. Therefore, *in situ* remediation technologies that do not necessitate relocation of these services and will minimise disturbance of pedestrian and vehicular traffic are appropriate.

The preferred remediation strategies will be further developed and confirmed as part of the *VMP/Block 4 RAP*. While the details of the preferred remediation strategies will be subject to confirmation in the *VMP/Block 4 RAP*, the approaches nominated above are considered to be representative of the remediation technologies (both *in situ* and ex situ) that are likely to be implemented at the Site and are therefore are appropriate for assessment of the technical capability of potential remediation technologies.

6.3.2 Remediation Technology Capability

As described by **Section 6.3.1**, the most likely remediation strategies that have been considered by the following sections for the purpose of assessing remediation technology capability are a combination of:

- Ex-situ Remediation – specifically excavation of contaminated materials, followed by treatment (either on-site or off Site) and beneficial reuse (as appropriate) or off-site disposal to landfill; and/or
- In situ Remediation – either:
  - S-ISCO® and SEPR™ remediation (contingent on the successful completion of a Pilot Trial);
  - ISS remediation (if selected by the *VMP/Block 4 RAP* as the preferred strategy ISS would be contingent on successful bench scale testing and a Pilot Trial).

It is noted that the preferred remediation strategies will be assessed further and final recommendations made as part of the *VMP/Block 4 RAP*. As above, the following sections consider the standard of remediation (or remediation technology capability) that can be practicably achieved by these remediation strategies only.

6.3.2.1 Ex situ Remediation

The extent of remediation that can be practicably achieved through excavation (and subsequent treatment) is linked not to the destruction efficiency of the remediation technology but to the practicability of actual physical excavation. In terms of contamination removal efficiency, excavation can be expected to remove 100% of the contaminant mass from excavated areas.

6.3.2.2 *In* situ Remediation

A key advantage of *in* situ remediation technologies is that they are designed to manage contaminants *in situ.* Such an approach will:

- Provide for the efficient use of resources and will avoid potentially unnecessary resource consumption, and as such is consistent with the principles of ESD (refer to **Section 6.7.3**);
- Mitigate the requirement to dispose of materials to landfill and, as such is consistent with the *Waste Minimisation Act* (2001) (refer to **Section 6.7.4**); and
- Promotes the destruction or treatment of contamination *in situ* and so is consistent with the remediation hierarchy promoted by the NEPC (1999a) and DEC (2006).

S-ISCO® and SEPR™

VeruTek Technologies Inc. (VeruTEK) has been responsible for development and implementation of the S-ISCO® and SEPR™ for remediation of similar former gasworks and tar impacted sites in the United States. A series of case studies are provided Appendix J of the *Revised Work Plan and Trial Management Plan, Surfactant Enhanced In Situ Chemical Oxidation (S-ISCO) & Surfactant Enhanced Product Recovery (SEPR)* (VeruTEK, 2011).

VeruTEK's project experience implementing S-ISCO® in the United States indicates that the S-ISCO® and SEPR™ process is most efficient when targeting the destruction of between 90% and 95% of the organic contaminant mass. Destruction rates above this level, while possible, become progressively less practicable given the increased quantities of oxidant, surfactant and catalyst required to achieve the relatively small incremental benefit to the environment. VeruTEK project experience also indicates that CoPC contaminant concentrations continue to reduce in the medium to long term after completion of the S-ISCO® injections.

***In situ* Solidification / Stabilisation**

ISS reduces the mobility of contaminants through both physical and chemical means. Contaminants are physically or chemically bound to the medium to produce a non-leachable material. Importantly, the process does not destroy the contaminants but alters the conditions of the material such that risks are significantly reduced. The main soil changes are reduced permeability of the treated mass and decreased mobility of the contaminants.

As such, it is not appropriate to measure the effectiveness of ISS as a function of a particular mass reduction or destruction. An effective decrease in the hydraulic conductivity of the solidified mass in relation to the surrounding media is the benchmark check on performance of the solidification process to ensure long-term protection of groundwater by preventing groundwater contact with contaminants. In the absence of relevant NSW EPA and/or Australian guidelines, United States Environment Protection Agency guidelines (USEPA, 1993 *Resource Document Solidification/Stabilization and its Application to Waste Materials*) are typically adopted for defining the success criteria for ISS. Based on these guidelines, solidified soils are typically required to achieve:

- A hydraulic conductivity of less than 10^{-5} centimetres per second (cm/s); and
- A compressive strength of 50 pounds per square inch (psi) (350 kilo Pascals [kPa]).

Notwithstanding, for the purpose of assessing the technical capability of ISS, it is considered that, in terms of preventing the migration of contamination from soil to groundwater to impacting ecological receptors, implementation of ISS would be at least equivalent to a contaminant mass reduction of at least 90%.

The quantity and type of chemical additives used as part of ISS are typically optimised to achieve the required hydraulic conductivity and compressive strength for a given site through bench scale and pilot scale testing. As such, further reductions in hydraulic conductivity or increases in compressive strength are considered neither practicable nor warranted in terms of increasing the level of protection to the environment (that is use of additional chemical additives will not result in an appreciable improvement in environmental protection).

6.3.3 Remediation Practicability Limitations

6.3.3.1 Ex situ Remediation

Considerations that can limit the practicability of the actual physical excavation and that are pertinent to the Site include:

- The depth of the excavation – deep excavations require shoring. The complexity and cost of shoring increases with increasing excavation depth;
- The nature of the material to be excavated – fill often contains oversize materials that require additional processing. Rock can be time consuming and expensive to excavate;
- The presence of groundwater – that will necessitate dewatering and groundwater treatment (if required) to facilitate disposal. The presence of groundwater can also affect the stability of the excavation (requiring additional shoring);
- The presence of below ground infrastructure – such has historic gasworks structures or seawalls (for example the caisson wall associated with the historic Southern Cove) that may currently be containing or restricting the migration of contamination; and
- The presence of underground services – which typically would require relocation to facilitate excavation of the underlying materials (as would be the case in Hickson Road).

In the case of the Site, it is considered that while remediation through excavation may be possible, extensive excavation extending to significant depths over a wide area may not be consistent with the principles of ESD. That is, the reduction in risk to the environment from excavation of all contaminated material may not be commensurate with the additional cost and time and resource usage required to excavate materials from significant depths, material containing comparatively low contaminant concentrations, and material from below existing underground services.

6.3.3.2 *In situ* Remediation

Considerations that can limit the practicability of in-situ remediation technologies that are pertinent to the Site include:

- The depth of the contamination – ISS is limited in effectiveness to 12 m bgl. S-ISCO® is more difficult to implement in the unsaturated zone due to difficulties in controlling the even distribution of the oxidising chemicals. The quantity of chemical additives required for treatment also increases with the depth (and resulting mass) of contamination requiring treatment;
- The nature of the material to be treated – ISS is not suitable for treatment of fill containing oversize materials or fine grained material (for example marine sediment). S-ISCO® and SEPR™ in fine grained material requires an increased density of injection (and extraction) locations and increases in associated costs;
- The presence of groundwater – can inhibit the effectiveness of ISS but is beneficial to the implementation of S-ISCO® and SEPR™;
- The presence of below ground infrastructure – as above, ISS is not suitable for treatment of fill surrounding or within historic gasworks structures or seawalls ; and
- The presence of underground services – which typically would require relocation to facilitate ISS (as would be the case in Hickson Road).

6.4 CUTEP - Contaminant Mass Calculations

As required by Section 4.3 of the NSW DEC (2007) *Guidelines for the Assessment and Management of Groundwater Contamination*, one of the key factors that must be considered to assess whether CUTEP has been achieved is the technical capability to achieve the clean-up. Within this context, this section considers the contaminant mass reduction that will be achieved by implementation of the most likely remediation technologies.

6.4.1 Introduction

The estimated mass of CoPC currently present at the Site and in off Site areas (i.e. down-gradient of the Site within the ORWN and Barangaroo Central areas) was estimated based on statistical analysis of the soil analysis results within fill material at the Site. Separate contaminant mass calculations were estimated for the following material types:

- Upper fill material - fill material extending from the ground surface to either:
    - The depth of bedrock (for example in the eastern portions of the Site in which marine sediments are not present or are inconsistent); and
    - Approximately 2 m above the surface of the natural marine sediments underlying the fill (in the case of the western portions of the Site and the areas west of the Site);
- Lower fill material - fill material located within the horizon 2 m above the upper surface of the natural marine sediments (where present in the western portions of the Site and the areas west of the Site); and
- Natural marine sediments (where present). While it has been demonstrated that there is minimal contaminant flux from the marine sediments (refer to **Section 2.5**), they have been included in this analysis in order to provide a conservative assessment of the contaminant mass that will remain following remediation.

The statistical analysis was based on the following data sets (refer to **Table F3**, **Appendix F**):

- **Zone 1 (human health remediation extent – refer to Figure F15)** – includes all soil analytical results from the materials across Block 4 and Block 5 and Hickson Road (within the Site) that are within the extent of remediation for the protection of human health (including off Site locations BH70 and MW541D, refer to **Figure F15**). It is noted that natural marine sediments reported within Zone 1 are not continuous and where present generally range between 0 and 0.3 m (refer to the cross sections presented in **Figure F10** to **Figure F13**). In consideration of this all material within Zone 1 is assumed to comprise of fill;
- **Zone 2 (western Declaration Area – refer to Figure F15)** – includes all soil analytical results from the materials across Block 4 and Block 5 and Hickson Road (within the Site) outside Zone 1 - that is, generally west of the extent of remediation for the protection of human health. Zone 2 materials correspond with that portion of the Site that is outside the extent of remediation shown on **Figure F15;**
- **Zone 3 (off Site within 20m of the Declaration Area – refer to Figure F15)** - includes all soil analytical results from the materials located off Site, within the corridor 20 m west of the western Site boundary (i.e. down hydraulic gradient of the Site within the ORWN and Barangaroo Central areas); and
- **Zone 4 (off Site beyond 20m of the Declaration Area – refer to Figure F15)** – includes all soil analytical results from the materials located off Site, beyond or west of the corridor 20m west of the western Site boundary (i.e. down hydraulic gradient of the Site within the ORWN and Barangaroo Central areas).

The on Site and off Site mass calculations were undertaken to:

- Estimate the distribution of gasworks related contaminant mass present within in and in association with the Site for:
    - The three material types described above, which broadly corresponding to depth; and
    - The proposed remediation extent for the protection of human health (Zone 1, which was sub-divided into Block 4, Block 5 and Hickson Road), the Declaration Area / Site (Zone 2) and the areas outside the Site (Zones 3 and 4);
    - The proposed extent of remediation for the protection of human health (Zone 1, which was again sub-divided into Block 4, Block 5 and Hickson Road) after completion of remediation using the most likely remediation technologies.
- Facilitate consideration of whether contaminant mass located outside the proposed extent of remediation for the human health remediation area (and outside the Site) has the potential to impact the environment.

6.4.2 Calculation Approach

Statistical analysis of the soil CoPC concentrations was undertaken because the remediation strategy for the Site is focussed on the remediation of the soil contamination that is either identified at concentrations above the

relevant SSTC or is considered to represent an ongoing source of groundwater contamination within fill material. For the purpose of the statistical analysis, non-detectable concentrations were assumed to be 50% of the EQL.

The calculation of contaminant mass based on the average CoPC concentration is considered suitable for providing an assessment of the distribution of the contamination. It is noted that the average calculated CoPC concentration may overestimate or underestimate the total mass of contaminant present. The variables which would affect the accuracy of these estimates include the density of the fill material and the analytical data set obtained during the site investigations; which is typically biased toward the laboratory analysis of samples observed (based on field observations and field screening of soil samples) to be more heavily impacted. Thus it is considered likely that the analysis of selected samples based on field observations of contamination will skew the analytical results and overestimate contaminant concentrations at the Site and in off Site areas. As such, the contaminant mass estimates presented would represent a conservative estimate of the contaminant mass.

Notwithstanding these limitations, the mass calculations are intended to assist in providing a preliminary assessment of the relative Site contamination status (and contaminant mass) pre- and post-remediation (based on the proposed human health remediation extent). As such, the precision of the calculated mass is less important than the relative proportions of the pre- and post-remediation estimated masses.

Only data in the upper 5 m of the off Site marine sediments was included in the statistical analysis for the following reasons:

- the analytical results reported within the off Site marine sediments indicated that significant gasworks related impacts did not extend vertically greater than 5 m into the marine sediments (as illustrated by the BH60 and BH191 soil analytical data, refer to **Table T15**, **Appendix B**); and
- based on a review of the borehole logs and as shown in the cross sections (refer to **Figure F10** to **Figure F12**), the thickness of marine sediments is generally less than 5 m thick in the off Site areas with the exception of the western most parts of Barangaroo Central and the ORWN area where the depth to bedrock increases significantly while the depth to the marine sediments increases only gradually to the west (towards Darling Harbour). For example, the depth to bedrock adjacent to Darling Harbour (BH212, BH213, BH411 and BH412, refer to **Figure F3**) has been observed to be greater than 32 m bgl and the overlying marine sediments are approximately 15 m thick at these boreholes.

It is considered that the above assumptions will improve the accuracy of the average CoPC concentrations estimated in areas of marine sediment (particularly Zone 4) and therefore provide a more accurate estimation of contaminant mass. In terms of Zone 3 and 4, it should also be noted that the identified SPGWT and CIM identified off Site in the vicinity of BH70 and BH541 were included in the Zone 1 calculations and therefore excluded from the Zone 3 calculations.

The separation of the fill material into upper and lower fill strata will also improve the accuracy of the contaminant mass calculations by minimising the potential for elevated localised CoPC concentrations present in the lower fill material to bias (overestimate) the contaminant mass estimates present within the significantly larger volume of upper fill materials.

The estimation of CoPC contaminant masses was also based on consideration:

- the average CoPC concentrations within each zone (noting that Zone 1 was further sub-divided into Block 4, Block 5 and Hickson Road) and material type as detailed in **Table F3**, **Appendix F**;
- a typical fill density of 2,000 kg/m^3 based on the results of geotechnical analysis presented in AECOM (2012d); and
- the estimated fill material volumes in **Table 12** overpage (refer to **Table F3**, **Appendix F** for further detail regarding calculation of these volumes).

Table 12 Zone 1 to 4 Material Volume Estimates (m^3)

Area	Upper Fill Material	Lower Fill Material	Marine Sediments
Zone 1 (total):	82,000		-
- Block 4	(43,000)		-
- Block 5	(23,200)		-
- Hickson Road	(15,800)		-
Zone 2	51,600	11,200	10,100
Zone 3	53,900	8,800	10,000
Zone 4	309,900	50,400	99,400

In addition to estimating the current mass of CoPC, the estimated post remediation mass of CoPC within Zone 1 (that is the area proposed to be remediated for the protection of human health) was also estimated according to the same approach as described above.

6.4.3 Key Gasworks Related CoPC

Table 13 presents a summary of the estimated total contaminant mass (including upper fill, lower fill and marine sediment, as relevant) calculated in Zone 1 and Zone 2. Details of these calculations are presented in **Table F1**, **Appendix F**.

Table 13 Zone 1 and 2 Estimated Mass Balance Calculations (Current Site Conditions)

CoPC	Zone 1 (Current Conditions)		Zone 2 (Current Conditions)	
	Average (mg/kg)	Contaminant Mass (kg)	Average (mg/kg)	Contaminant Mass (kg)
Acenaphthene	26	4,264	0.33	41
Acenaphthylene	145	23,780	0.83	104
Anthracene	109	17,876	0.99	124
Fluorene	127	20,828	0.52	65
Naphthalene[1]	**801**	**131,364**	**0.82**	**103**
Phenanthrene	357	58,548	2.6	327
TPH C10 - C14[1]	**3,163**	**518,732**	**27**	**3,391**
TPH C6 - C9	327	53,628	3.4	427
Total Xylene	87	14,268	0.37	46
Benzene	66	10,824	0.1	13
Ethylbenzene	11	1,804	0.19	24
Toluene	81	13,284	0.19	24

NOTE: 1. Naphthalene and TPH C_{10}-C_{14} average concentrations for Zone 1 are based on the analytical data across the entire Zone 1 fill material (i.e. individual averages have not been calculated for Block 4, Block 5 and Hickson Road). This has been undertaken to facilitate comparison of the Zone 1 average concentration to the Zone 2 average concentrations for the purpose of identifying key gasworks related CoPC. It is noted that the average concentrations adopted for Zone 1 in the following sections are based on the individual data sets for those parts of Block 4, Block 5 and Hickson Road that fall within Zone 1.

Table 13 indicates that that the two CoPCs with the largest volume of contaminant mass within the Site are naphthalene and TPH C_{10}-C_{14}. Further, the groundwater analysis results presented in **Table T10** and **T13** also indicate that naphthalene and TPH C_{10}-C_{14} concentrations generally exceed the MWQC by the largest order of magnitude across the Site.

As such, these two CoPCs are considered to be the key gasworks related contaminants with the potential to represent an ongoing risk to the environment. Further, remediation of these two CoPCs would be expected to result in remediation of the other CoPCs listed in **Table 13**.

It is noted that TPH as reported by environmental laboratories is a complex mixture of over 100 compounds which are quantified as unresolved mass peaks on the laboratory gas chromatograph fitted with a specific detector. As such, TPH C_{10}-C_{14} analysis is likely to be overestimated as TPH is a broad analytical measure and is likely to include other gasworks related contaminants (including naphthalene). TPH C_6-C_9 analysis is also likely to include the reporting of benzene impacts.

Based on these findings, only naphthalene and TPH C_{10}-C_{14} are considered in further detail by the following contaminant mass analysis.

6.4.4 Current Contaminant Mass Estimates (Zone 1 to 4)

Table 14 below presents the estimated gasworks related contaminant mass calculations for the current conditions across Zones 1 to 4. Details of the contaminant mass calculations are presented in **Table F3**, **Appendix F**.

Table 14 Zone 1 to 4 Current Contaminant Mass Calculations

Zone Area	CoPC	Ave conc (mg/kg)	Estimated volume (m^3)	Total contaminant mass (kg)	% of Total mass (Zone 1 to 4)
Zone 1 - Onsite within Remediation Area					
Block 4	Naphthalene	809	43,000	69,574	53.5%
	TPH C_{10} - C_{14}	2,621	43,000	225,406	42.6%
Block 5	Naphthalene	64	23,200	2,970	2.3%
	TPH C_{10} - C_{14}	262	23,200	12,157	2.3%
Hickson Road	Naphthalene	1,190	15,800	37,604	28.9%
	TPH C_{10} - C_{14}	5,956	15,800	188,210	35.6%
Zone 1 total	***Naphthalene***	***-***	***82,000***	***110,148***	***84.8%***
	TPH C_{10} - C_{14}	***-***	***82,000***	***425,772***	***80.5%***
Zone 2 - Onsite within upper fill outside Remediation Area					
	Naphthalene	0.8	51,600	83	0.1%
	TPH C_{10} - C_{14}	26	51,600	2,683	0.5%
Zone 2 – Onsite within lower fill outside Remediation Area					
	Naphthalene	9.3	11,200	208	0.2%
	TPH C_{10} - C_{14}	79	11,200	1,770	0.3%
Zone 2 - Onsite within marine sediments outside Remediation Area					
	Naphthalene	120	10,120	2,429	1.9%
	TPH C_{10} - C_{14}	394	10,120	7,975	1.5%
Zone 3 - Off Site upper fill within 20m of Declaration Area					
	Naphthalene	5.5	53,920	593	0.5%
	TPH C_{10} - C_{14}	61	53,920	6,578	1.2%
Zone 3 - Off Site lower fill within 20m of Declaration Area					
	Naphthalene	41	8,800	722	0.6%
	TPH C_{10} - C_{14}	38	8,800	669	0.1%

Zone Area	CoPC	Ave conc (mg/kg)	Estimated volume (m^3)	Total contaminant mass (kg)	% of Total mass (Zone 1 to 4)
Zone 3 - Off Site marine sediments within 20m of Declaration Area					
	Naphthalene	474	9,960	9,442	7.3%
	TPH C_{10} - C_{14}	2,502	9,960	49,840	9.4%
Zone 4 - Off Site upper fill outside 20m of Declaration Area					
	Naphthalene	1.2	309,920	744	0.6%
	TPH C_{10} - C_{14}	30	309,920	18,595	3.5%
Zone 4 - Off Site lower fill outside 20m of Declaration Area					
	Naphthalene	22	50,400	2,218	1.7%
	TPH C_{10} - C_{14}	25	50,400	2,520	0.5%
Zone 4 - Off Site marine sediments outside 20m of Declaration Area					
	Naphthalene	17.0	99,400	3,380	2.6%
	TPH C_{10} - C_{14}	64.0	99,400	12,723	2.4%

The following observations can be made based on comparison of the estimated contaminant masses presented in **Table 14**:

- Between 80% and 85% (naphthalene and TPH C_{10} - C_{14} concentrations, respectively) of the total gasworks related contaminant mass is currently located within Zone 1 (the human health remediation extent) and will be remediated as part of the proposed remediation works;
- Between 0.3% and 0.8% (naphthalene and TPH C_{10} - C_{14}, respectively) of the total gasworks related contaminant mass is currently located within the fill materials (both upper fill and lower fill) within Zone 2 (i.e. within the Site but outside Zone 1);
- Between 3.3% and 5.3% (naphthalene and TPH C_{10} - C_{14}, respectively) of the total gasworks related contaminant mass is currently located within the fill materials (both upper and lower fill) within Zones 3 and 4 (i.e. off Site); and
- Between 9.8% and 11.8% (naphthalene and TPH C_{10} - C_{14}, respectively) of the total gasworks related contaminant mass is currently located within the natural marine sediments within Zones 3 and 4 (i.e. off Site) which are generally present at depths of between approximately 13 m bgl and 32 m bgl.

Based on the observations above, it is evident that the majority (between 80% and 85%) of the gasworks related contaminant mass will be remediated by the proposed Zone 1 extent of remediation. Of the residual gasworks related contamination that will remain *in situ* following the proposed remediation works, the majority (approximately half of the residual or between 9.8% and 11.8% of the total) of the contaminant mass is present within the marine sediments of Zone 3 and 4. As discussed in **Section 2.5**, there is considered to be a negligible potential for contaminant flux and discharge from the natural marine sediments underlying the Site and off Site areas into Darling Harbour.

6.4.5 Post Remediation Contaminant Mass Estimate

Table 15 presents an estimate of the TPH C_{10}-C_{14} and naphthalene contaminant mass that will remain within Zones 1 to 4 following remediation to the extent practicable within Zone 1. Details of the contaminant mass calculations are presented in **Table F4**, **Appendix F**. The Zone 1 post remediation contaminant mass estimates presented in **Table 15** are based on the following assumptions.

- **Block 4** – it is assumed that a 100% reduction in contaminant mass will be achieved within the extent of remediation by ex-situ remediation of contamination within Block 4. Ex situ remediation is considered to be the most likely remediation technology for Block 4 given the proposed construction of a basement (including a basement groundwater retention wall system) as part of the Barangaroo South Development;

- **Block 5** – a 90% reduction in the contaminant mass within the extent of remediation is likely to be achieved by S-ISCO® and SEPR™ remediation works (refer to **Section 6.3.2.2**). While it is possible that a basement (possibly incorporating a basement groundwater retention wall system system) will be constructed within Block 5 as part of the Barangaroo Central development, the timing of this development is not yet understood. Therefore a 90% reduction in contaminant mass has been conservatively adopted; and
- **Hickson Road** – a 90% reduction in the contaminant mass is likely to be achieved within the extent of remediation by S-ISCO® and SEPR™ remediation works (refer to **Section 6.3.2.2**).

It is noted that the contaminant mass estimates for Zones 2, 3 and 4 (i.e. the unremediated areas) presented in **Table 15** are unchanged from those in **Table 14**.

Table 15 Zone 1 and 4 Estimated Mass Balance Calculations (Post-Remediation)

Zone Area	CoPC	Ave conc (mg/kg)	Estimated volume (m^3)	Total contaminant mass (kg)	% of Residual Mass (post remediation) (Zone 1 to 4)
Zone 1 - Onsite within Remediation Area					
Block 4	Naphthalene	-	-	-	-
	TPH C_{10} - C_{14}	-	-	-	-
Block 5	Naphthalene	6.4	23,200	297	1.2%
	TPH C_{10} - C_{14}	26.2	23,200	1,216	1.0%
Hickson Road	Naphthalene	119.0	15,800	3,760	15.8%
	TPH C_{10} - C_{14}	595.6	15,800	18,821	15.3%
Zone 1 total	***Naphthalene***	***-***	***39,000***	***4,057***	***17.0%***
	TPH C_{10} - C_{14}	***-***	***39,000***	***20,037***	***16.2%***
Zone 2 - Onsite within upper fill outside Remediation Area					
	Naphthalene	0.8	51,600	83	0.3%
	TPH C_{10} - C_{14}	26	51,600	2,683	2.2%
Zone 2 – Onsite within lower fill outside Remediation Area					
	Naphthalene	9.3	11,200	208	0.9%
	TPH C_{10} - C_{14}	79	11,200	1,770	1.4%
Zone 2 - Onsite within marine sediments outside Remediation Area					
	Naphthalene	120	10,120	2,429	10.2%
	TPH C_{10} - C_{14}	394	10,120	7,975	6.5%
Zone 3 - Off Site upper fill within 20m of Declaration Area					
	Naphthalene	5.5	53,920	593	2.5%
	TPH C_{10} - C_{14}	61	53,920	6,578	5.3%
Zone 3 - Off Site lower fill within 20m of Declaration Area					
	Naphthalene	41	8,800	722	3.0%
	TPH C_{10} - C_{14}	38	8,800	669	0.5%
Zone 3 - Off Site marine sediments within 20m of Declaration Area					
	Naphthalene	474	9,960	9,442	39.5%
	TPH C_{10} - C_{14}	2,502	9,960	49,840	40.4%

Zone Area	CoPC	Ave conc (mg/kg)	Estimated volume (m^3)	Total contaminant mass (kg)	% of Residual Mass (post remediation) (Zone 1 to 4)
Zone 4 - Off Site upper fill outside 20m of Declaration Area					
	Naphthalene	1.2	309,920	744	3.1%
	TPH C_{10} - C_{14}	30	309,920	18,595	15.1%
Zone 4 - Off Site lower fill outside 20m of Declaration Area					
	Naphthalene	22	50,400	2,218	9.3%
	TPH C_{10} - C_{14}	25	50,400	2,520	2.0%
Zone 4 - Off Site marine sediments outside 20m of Declaration Area					
	Naphthalene	17.0	99,400	3,380	14.2%
	TPH C_{10} - C_{14}	64.0	99,400	12,723	10.3%

Based on percentages of the residual (post remediation) contaminant mass presented in **Table 15**, it is evident that following remediation:

- the majority of the residual gasworks related contaminant mass will remain within:
  - Fill within Zone 1 – the remediation extent for the protection of human health (between 17.0% and 16.2% of the residual contaminant mass for naphthalene and TPH C_{10} - C_{14}, respectively). Notwithstanding, Zone 1 will have been remediated to the extent practicable based on the technical capability of the most likely remedial technologies (refer to **Section 6.3**); and
  - Marine Sediment within Zones 3 and 4 (between 53.7% and 50.7% of the residual contaminant mass for naphthalene and TPH C_{10} - C_{14}, respectively). As discussed in **Section 2.5**, there is considered to be a negligible potential for contaminant flux and discharge from the natural marine sediments underlying the Site and off Site areas into Darling Harbour and therefore this residual contamination would not be considered to represent a risk to the environment;
- Between 1.2% and 3.6% (naphthalene and TPH C_{10} - C_{14}, respectively) of the residual gasworks related contaminant mass will remain within the fill materials (both upper fill and lower fill) within Zone 2 (i.e. within the Site but outside Zone 1);
- Between 17.9% and 23% (naphthalene and TPH C_{10} - C_{14}, respectively) of the residual gasworks related contaminant mass will remain within the fill materials (both upper and lower fill) within Zones 3 and 4 (i.e. off Site). It is noted that these fill materials will be the subject of a separate HHERA and RAP as part of the proposed future development works in the ORWN and Barangaroo Central areas.

Table 16 summarises, for naphthalene and TPH C_{10}-C_{14} contaminant mass, the estimated percent reduction in contaminant mass achieved by the proposed remediation works in Zone 1 as a function of:

- the total contaminant mass within Zones 1 to 4, including upper fill, lower fill and marine sediments; and
- the total contaminant mass within Zones 1 to 4 within fill material only (i.e. upper fill and lower fill) based on the observation that there is a negligible potential for contaminant flux and discharge from the natural marine sediments underlying the Site and off Site areas into Darling Harbour and therefore residual contamination within the marine sediment would not be considered to represent a risk to the environment (refer to **Section 2.5**).

Table 16 Zone 1 to 4 - Comparison of Estimated Current and Post-Remediation Contaminant Masses (Zone 1 to 4)

	Zone 1 to 4 (Current Conditions)	Zone 1 to 4 (Post Remediation)	
CoPC	Estimated Contaminant Mass (kg)	Estimated Contaminant Mass (kg)	Zone 1 to 4 % contaminant reduction
Within fill material and marine sediments			
Naphthalene	129,965	23,875	81.6%
TPH C10 - C14	529,125	123,389	76.7%
Within fill material only			
Naphthalene	114,715	8,666	92.4%
TPH C10 - C14	458,587	53,044	88.4%

In summary, remediation of Zone 1 to the extent practicable (which is assumed to be equivalent to removal of approximately 90% of the contaminant mass in the case of in-situ remediation technologies and approximately 100% of the contaminant mass by ex-situ remediation in Block 4) will result in a reduction in gasworks related contaminant mass of between 88-92% within fill materials. As described by **Section 2.5**, there is a negligible potential for contaminant flux and discharge from the natural marine sediments underlying the Site and off Site areas into Darling Harbour and therefore contamination within the marine sediment would not be considered to represent a risk to the environment.

It is reasonably expected that a reduction in gasworks related contaminant mass of this magnitude will improve groundwater quality within fill material at the down hydraulic gradient Site boundary and in off Site areas such that the risk to the environment is effectively mitigated. Further assessment of the improvement in groundwater quality that may be realised as a result of the calculated reduction in gasworks related contaminated mass is provided in **Section 6.5**.

6.4.6 Conclusion

The gasworks related contaminant mass estimates described above demonstrate that:

- The majority (between 80% and 85%) of the gasworks related contaminant mass is present within the proposed extent of remediation and will, therefore, be subject to remediation.
- Of the residual gasworks related contamination that will remain *in situ* following the proposed remediation works, more than half (between approximately 57% and 64%) of the residual contaminant mass is present within the marine sediments of Zone 3 and 4. As discussed in **Section 2.5**, there is considered to be a negligible potential for contaminant flux and discharge from the natural marine sediments underlying the Site and off Site areas into Darling Harbour.
- Remediation of Zone 1 to the extent practicable (which is assumed to be equivalent to removal of approximately 90% of the contaminant mass in the case of in-situ remediation technologies for Block 5 and Hickson Road and approximately 100% of the contaminant mass in the case of ex situ remediation of Block 4) will result in a reduction in gasworks related contaminant mass of between 88-92% within fill materials. As described by **Section 2.5**, there is a negligible potential for contaminant flux and discharge from the natural marine sediments underlying the Site and off Site areas into Darling Harbour and therefore contamination within the marine sediment would not be considered to represent a risk to the environment.
- A reduction in gasworks related contaminant mass of this magnitude would be expected to improve groundwater quality within fill material at the down hydraulic gradient Site boundary and in off Site areas such that the risk to the environment is effectively mitigated. Further assessment of the improvement in groundwater quality that may be realised as a result of the calculated reduction in gasworks related contaminated mass is provided in **Section 6.5**.

6.5 CUTEP - Threats the Contamination Poses to Human or Ecological Health

As required by Section 4.3 of the NSW DEC (2007) *Guidelines for the Assessment and Management of Groundwater Contamination*, one of the key factors that must be considered to assess whether CUTEP has been achieved is the threats that the contamination poses to human or ecological health.

The following Sections consider the threat to human and ecological health posed by contamination remaining *in situ* following completion of the proposed remediation extent as follows:

- Consideration of post remediation risk to human health based on the outcomes of the VMP HHERA and resultant remediation extent (refer to **Section 6.5.1**);
- Consideration of the post remediation risk to the environment (refer to **Section 6.5.2**), including assessment of:
    - The improvement in contaminant mass flux that will be realised by the proposed remediation; and
    - 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.
- Consideration of how works to be undertaken as part of the subsequent development of the Site (for example construction of a basement groundwater retention wall as part of the Barangaroo South development) will further minimise the threat to the environment posed by residual contamination remaining *in situ* following completion of the proposed remediation.

6.5.1 Threat to Human Health

As detailed in **Section 5.1** (for Block 4 and 5), **Section 5.2** (for Hickson Road) and **Section 5.3** (for areas west of the Site) the proposed remediation extent is based on remediation of SPGWT and CIM to the extent practicable.

In addition to being the primary remediation goal for the protection of human health (refer to **Section 3.3**), the remediation of SPGWT to the extent practicable is a requirement of the NSW DEC (2007) *Guidelines for the Assessment and Management of Groundwater Contamination* (refer to **Section 6.2**). The distribution of SPGWT identified at the Site and in off Site areas is detailed in **Figure F6**. As described by **Section 6.2**, the proposed remediation extent (refer to **Figure F14** and **Figure F15**) is considered to constitute remediation of a SPGWT to the extent practicable and is therefore considered to be protective of human health.

CIM is defined as soil containing CoPC concentrations that either: exceed the SSTC (i.e. site-specific health based criteria) for unsaturated soil; or, are considered the source of groundwater contamination that exceeds the SSTC for groundwater. The secondary remediation goal for protection of human health (refer to **Section 3.3**) is remediation of CIM to the extent practicable. The distribution of soil and groundwater concentrations that exceed the SSTCs and so are considered representative of CIM is detailed in **Figure F4** and **Figure F5**. As described by **Section 5.1** (for Block 4 and 5), **Section 5.2** (for Hickson Road) and **Section 5.3** (for areas West of the Site), the proposed remediation extent (refer to **Figure F14** and **Figure F15**) is considered to constitute remediation of SPGWT to the extent practicable and is therefore considered to be protective of human health.

It is noted that SPGWT and CIM have been reported in the natural marine sediments in some Site areas outside the proposed remediation extent. As described by **Section 2.5,** there is negligible contaminant flux from these natural materials into the overlying fill. Therefore, SPGWT and CIM that may be present within the natural marine sediments is not considered to pose a significant risk to human health.

In conclusion if the remediation proposed for protection of human health is completed, as described by **Section 5.0**, there will not be an unacceptable ongoing risk to human health under current land uses.

6.5.2 Threats to the Environment

As described in **Section 6.4.5**, the proposed remediation extent for the protection of human health will result in a comparatively minor quantity of residual contamination remaining *in situ.* The majority of the residual contamination (in the order of 45% will remain within in the Zone 2 to Zone 4 marine sediments (i.e. the western portion of the Site and the areas down hydraulic gradient [west] of the Site). Refer to **Table F4**, **Appendix F**.

As detailed in **Section 2.5**, AECOM has undertaken a series of studies (AECOM 2010d and 2012b) to assess the potential for contaminant mass flux from the marine sediments into the overlying fill and Darling Harbour.

Based on the assessment of multiple lines of evidence (refer to **Section 2.5**), it is concluded there is no significant flux and discharge of contamination from the natural soil and marine sediments underlying the Site (and areas down hydraulic gradient of the Site) into Darling Harbour. As such, remediation of the deep natural soil and marine sediments is not considered warranted for the protection of human health or the environment.

6.5.2.1 Supplementary Contaminant Flux and Discharge Estimations, AECOM (2013a)

Approximately 55% of the residual gasworks related contaminant mass that will remain *in situ* (based on the proposed remediation extent) will be within the fill material. In consideration of this, AECOM undertook a supplementary Contaminant Mass Flux study (following on from AECOM [2012b] - refer to **Section 2.5.2**) to assess:

- The decrease in contaminant flux that could be expected to result from the proposed remediation extent (refer to **Section 5.0**); and
- potential impacts to water quality in Darling Harbour from the contamination that will remain *in situ* in fill material and marine sediment both within the Site and in off Site areas to the west (i.e. Barangaroo Central and the ORWN area) as an outcome of the proposed remediation extent (refer to **Section 5.0**).

The supplementary mass flux discharge modelling was based on the conceptual model, geology, hydrogeology, extent of contamination, aquifer parameters, tidal effects and mass flux and discharge modelling which were presented in AECOM (2012b) (refer to **Section 2.5.2**). The contaminant mass flux was calculated based on groundwater monitoring results from the Site and off Site areas along the following transects:

- Transect A-A' - monitoring wells located within the footprint of the former gasworks and the middle of the proposed remediation area (Block 4 and 5); and
- Transect B-B' – monitoring wells located in off Site areas and in proximity to Darling Harbour (Barangaroo Central and the ORWN area).

The supplementary contaminant mass flux study (AECOM, 2013a) is provided as **Appendix D**.

Based on the proposed remediation extent (refer to **Section 5.0**), the Conceptual Site Model (refer to **Figure 1**, **Section 2.6**), the available hydraulic parameters and the supplementary mass flux/discharge modelling, the following conclusions were made:

- Improvement in contaminant mass flux that will be realised by the proposed remediation:
    - the groundwater quality in fill at the down hydraulic gradient of the Site would be expected to improve by in the order of 250% to 380% (measured in terms of a reduction in contaminant mass flux) as a result of the proposed remediation extent.
- 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:
    - Less than 1% of the contaminant mass flux at Transect B-B' (associated with residual contamination to remain *in situ* following the proposed remediation) is associated with the marine sediment. This conclusion supports the conclusions of the previous contaminant mass flux study (AECOM, 2102b) and the *GDS* (AECOM, 2010d) that there is not a significant flux and discharge of contamination from the natural soil and marine sediments underlying the Site into Darling Harbour;
    - Groundwater quality estimated from the contaminant mass flux at Transect B-B' (associated with residual contamination to remain *in situ* following the proposed remediation) entering Darling Harbour is less than the MWQC; and
    - Groundwater quality in fill discharging into Darling Harbour will improve over time because better quality groundwater (that is a lower contaminant mass flux) from Transect A-A' will slowly migrate towards Transect B-B'.

6.5.2.2 Additional Mitigation Resulting from Proposed Future Works

Part of the Site (specifically that part of Barangaroo Block 4 that is within the Declaration Area) and part of the area located down hydraulic gradient of the Site (specifically that part of Barangaroo Block 4 that is outside the Declaration Area and the ORWN Area) are located within the Barangaroo South development (refer to **Figure F3**). As such, these areas will be subject to future proposed development works.

Of particular note, is that the proposed Block 4 development works (to be undertaken as part of the Barangaroo South development) will include construction of a basement groundwater retention wall system around the perimeter of Block 4 (including those parts of Block 4 within and outside the Declaration Area). The basement groundwater retention wall system will extend to and be keyed into bedrock. This will effectively eliminate the pathway for the migration of contamination from Block 4 to the environment.

It should be noted that these potential works are associated with the future development and will be subject to receipt of development consent.

For clarity, the Block 4 development works are not required as part of the VMP Remediation Works contemplated by this document. Further, construction of the above mentioned basement groundwater retention wall system is not required to demonstrate that the proposed remediation extent is protective of the environment in accordance with the principles of CUTEP. However, as mentioned above, the proposed Block 4 development works will include construction of the basement groundwater retention wall system which will further minimise the threat to the environment of residual contamination remaining within Block 4.

6.5.2.3 Conclusion

In conclusion if the proposed remediation is completed, there will not be an unacceptable ongoing risk to the environment.

6.6 CUTEP - The Value of the Groundwater Resource

As required by Section 4.3 of the NSW DEC (2007) *Guidelines for the Assessment and Management of Groundwater Contamination*, one of the key factors that must be considered to assess whether CUTEP has been achieved is the value of the groundwater resource.

The EPA requires the point of compliance for the purpose of assessing ecological risk from the Site is the down hydraulic gradient boundary of the Site. In the absence of any other information, the level of protection of groundwater at the down hydraulic gradient boundary of the Site has been based on the level of protection required for the nearest surface water receptor, Darling Harbour. This approach is consistent with the policies of the NSW EPA, in particular:

- The *CLM Act* (1997), section 9, which requires adoption of the precautionary principle where the lack of scientific certainty is not a reason for postponing measures. With respect to the Site, this relates to the protection of groundwater dependant ecosystems down hydraulic gradient of the Site and the requirement for remediation to the extent practicable (even in the absence of data demonstrating the presence, or otherwise, of such ecosystems now, or in the future);
- The Department of Environment and Conservation NSW (now the NSW EPA) *Guidelines for the Assessment and Management of Groundwater Contamination*, March 2007, section 1, which reemphasise the requirements of the *CLM Act* (1997) requiring protection of groundwater ecosystems according to the precautionary principle;
- The *ANZECC 2000 Water Quality Guidelines*, section 1, which require that the protection of underground aquatic ecosystems and their novel fauna require the highest level of protection; and
- The *National Environment Protection Measure Schedule B(6)* (NEPC, 1999) which states that determination of the point of use of groundwater is a jurisdictional matter and that the transfer of contaminated groundwater from a contaminated Site is not considered to be acceptable, even if the relevant guidelines are achieved at the point of use / discharge.

As described by Section 8.2 of the *VMP HHERA* (AECOM, 2012c), guidance from the NSW EPA indicates that although Darling Harbour is classified as a waterway affected by urban development, the applicable aquatic ecosystem management objectives (and so the value of the groundwater resource) as:

- 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.

It is noted that due to the proximity of the Site to Darling Harbour (which is located approximately 100 metres to the west), the Site groundwater is saline and is not considered to be a valuable in terms of providing a water resource (for humans or stock).

The long term remediation goal for protection of the groundwater resource (and ecological health) is compliance with the MWQC at the down hydraulic gradient Site boundary. As described by **Section 3.4.2**, the MWQC have been developed in consultation with the NSW EPA and is considered to be reflective of the value of the groundwater resource.

As described by **Section 6.5.2**, AECOM has demonstrated through consideration of multiple lines of evidence 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.

6.7 CUTEP - Clean-up Costs

As required by Section 4.3 of the NSW DEC (2007) *Guidelines for the Assessment and Management of Groundwater Contamination*, one of the key factors that must be considered to assess whether CUTEP has been achieved is the consideration of clean-up costs.

If it is assessed that the proposed extent of remediation does not represent CUTEP and additional remediation is required for protection of the environment, additional remediation of soil beyond the proposed extent of remediation (refer to **Figure F14** and **Figure F15**) would be required. Additional remediation would necessitate the ex-situ and/or *in situ* remediation of soil across an increased area and over an increased depth than currently proposed.

The following Sections consider the additional clean-up costs (expressed in terms of remediation volumes) versus the environmental benefit (expressed in terms of a reduction in contaminant mass) that might be realised from the remediation of additional areas within and adjacent to the Site.

Within this context, the following sections also consider:

- practicality limitations and cost implications of additional remediation;
- the principles of ESD; and
- the principles of waste avoidance and resource recovery.

6.7.1 Remediation Cost verses Benefit

If it was proposed to achieve a higher level of protection for the environment than currently proposed, a substantial increase in remediation works would be required to realise any substantial increase in the contaminant mass reduction. In particular:

- the depth of contamination and so the depth and volume of remediation increases rapidly with increasing distance to the west of the Site, in the direction of Darling Harbour (refer to **Figure F10** to **Figure F13**);
- the estimated mass of gasworks related contamination present within the Zone 2 fill materials within the Site (outside the Remediation Area) and within Zone 3 (20m west of the Site) is small (refer to **Section 6.4**). Fill materials are generally present from the ground surface to between 12 to 16 m bgl in this area. As such, they represent the most accessible material in terms of remediation practicability. However, the benefit, in terms of reduced contaminant mass would be small and in some cases negligible as illustrated by the following data (refer to **Table 14**):
    - Only 0.1% and 0.5% (naphthalene and TPH C_{10} - C_{14}, respectively) of the total gasworks related contaminant mass is present within the upper fill in Zone 2; and
    - Only 0.5% and 1.2% (naphthalene and TPH C_{10} - C_{14}, respectively) of the total gasworks related contaminant mass is present within the upper fill in Zone 3.
- The majority of the estimated mass of gasworks related contamination that will remain *in situ* on completion of the proposed remediation is present at substantial depth and within the marine sediments (refer to **Table 14**):
    - Only 1.9% and 1.5% (naphthalene and TPH C_{10} - C_{14}, respectively) of the total gasworks related contaminant mass is present within the marine sediment in Zone 2 (at a typical depth of 12-14 m bgl);
    - between 7.3% and 9.4% (naphthalene and TPH C_{10} - C_{14}, respectively) of the total gasworks related contaminant mass (or approximately half of the residual contaminant mass) is present within the marine sediment in Zone 3 (at a typical depth of 14 to 16 m bgl; and

- between 2.6% and 2.4% (naphthalene and TPH C_{10} - C_{14}, respectively) of the total gasworks related contaminant mass is present within the marine sediment in Zone 4 (at a typical depth of 14 to 18 m bgl);

As discussed in **Section 6.7.2**, remediation of marine sediments would be difficult and subject to significant practicability constraints including, but not limited to: the thickness of overburden, the presence of fine grained material; and the depth below the groundwater table. Further, there is a negligible potential for contaminant flux and discharge from the natural marine sediments underlying the Site and off Site areas into Darling Harbour and therefore contamination within the marine sediment does not represent a risk to the environment (refer to **Section 2.5**).

As outlined in **Table 17** the following Scenarios are illustrative of the significant cost (expressed in terms of remediation volumes) in comparison to the comparatively small benefit (expressed in terms of a percent reduction in gasworks related contaminant mass).

- Scenario 1 - expansion of the proposed remediation extent to incorporate the entire Site (i.e. including upper fill, lower fill and marine sediment with Zone 2);
- Scenario 2 - expansion of the proposed remediation extent to incorporate the entire Site and Zone 3 (including upper fill, lower fill and marine sediment).

Table 17 Scenario 1 to 2 Mass Volume Estimations

Zone Area	Estimated Remediation volume (m3)	Increase in Remediation Volume (%)	Contaminant mass (% of total)		Reduction in contaminant mass (% of total)	
			Naphtha - lene	TPH C10 - C14	Naphtha - lene	TPH C10 - C14
Proposed Remediation: Zone 1 (proposed remediation area) only						
Zone 1	82,000		84.8%	80.5%		
Total	**82,000**	**-**	84.8%	80.5%	**-**	**-**
Scenario 1: Zone 1 (proposed remediation area) + Zone 2 (On Site outside remediation area)						
Zone 1	82,000		84.8%	80.5%		
Zone 2 - upper fill	51,600		0.1%	0.5%		
Zone 2 - lower fill	11,200		0.2%	0.3%		
Zone 2 - marine sediments	10,120		1.9%	1.5%		
Total	**154,920**	**88.9%**	87.0%	82.8%	**2.5%**	**2.8%**
Scenario 2: Zone 1 (proposed remediation area) + Zone 2 (On Site outside remediation area) + Zone 3 (within 20m of the Site)						
Zone 1	82,000		84.8%	80.5%		
Zone 2 - upper fill	51,600		0.1%	0.5%		
Zone 2 - lower fill	11,200		0.2%	0.3%		
Zone 2 - marine sediments	10,120		1.9%	1.5%		
Zone 3 - upper fill	53,920		0.5%	1.2%		
Zone 3 - lower fill	8,800		0.6%	0.1%		
Zone 3 - marine sediments	9,960		7.3%	9.4%		
Total	**227,600**	**177.6%**	95.4%	93.5%	**12.4%**	**16.1%**

In the case of Scenario 1 (proposed remediation extent expanded to incorporate the entire Site):

- The estimated volume of remediation required would increase by approximately 72,920 m^3 (which equates to an 89% increase in remediation volume); but

- The corresponding reduction in contaminant mass (assuming 100% removal) would be between 2.5% and 2.8% (naphthalene and TPH C_{10} - C_{14}, respectively) of the total gasworks related contaminant mass.

In the case of Scenario 2 (proposed remediation extent was expanded to incorporate the entire Site and Zone 3):

- The estimated volume of remediation required would increase by approximately 145,600 m^3 (which equates to a 178% increase in remediation volume). It should be noted that of this remediation volume, approximately 20,080 m^3 relates to marine sediments; but
- The corresponding reduction in contaminant mass (assuming 100% removal) would be between 12.4% and 16.1% (naphthalene and TPH C_{10} - C_{14}, respectively) of the total gasworks related contaminant mass. It should be noted that of this reduction, the majority (between 81% and 85% [naphthalene and TPH C_{10} - C_{14}, respectively]) relates to contaminant mass that is present within the marine sediment and which is not considered to require remediation for protection of the environment (refer to **Section 2.5**).

It is therefore considered that the cost and potential environmental harm associated with expansion of the proposed remediation extent would substantially outweigh any real benefit to the environment.

This conclusion is consistent with Section 4.4 of NSW DEC (2007) which requires that the benefits from undertaking groundwater clean-up must outweigh any incidental negative impacts to human health or the environment that could arise from the clean-up.

6.7.2 Practicability Limitations

As described by **Section 6.7.1**, if it was proposed to achieve a higher level of protection for the environment than currently proposed, a substantial increase in the remediation extent, remediation depth and/or remediation volume would be required to realise any substantial increase in the contaminant mass reduction. The following discussion considers practicability limitations and resultant additional costs that would be incurred should the extent, and in particular, the depth of remediation be increased.

6.7.2.1 Ex situ Remediation (Block 4)

- The strength and complexity of the shoring system required to facilitate the excavation would increase significantly with increasing depth. In particular, increasing the depth below the groundwater table that an excavation is required to progress, substantially increases the loads imposed on the shoring system and therefore the strength required to support the excavation;
- The presence of below ground infrastructure – such as historic seawalls present at depth (for example the caisson wall associated with the historic Southern Cove) that would need to be removed prior to construction of the shoring system;
- The extent and quantity of dewatering required to facilitate excavation to increasing depths below the groundwater table will substantially increase. Additional costs would increase the density of required dewatering points (particularly if the excavation was to extend into lower permeability saturated marine sediments), operation of a water treatment plant (including ongoing operation and maintenance); and disposal of treated water (if required);
- The extent and complexity of the excavation enclosure and associated emissions control system (including ongoing operation and maintenance) would require expansion and additional cost;
- The logistical requirements associated with the physical removal of material from a larger and deeper excavation become more complex with increasing depth of excavation. These logistical considerations would be amplified by the required for conduct of much of the excavation within an excavation enclosure;
- Increased volumes of material requiring treatment will result in increased treatment and/or stabilisation costs required as a precursor to off-site disposal of material in accordance with the DECCW (2009) *Waste Classification Guidelines.*
- The treatment of saturated marine sediments, as will be realised from deeper excavations in the west of the Site and in the ORWN and Barangaroo South areas, will also incur additional costs associated with spadability limitations within the excavation pre-treatment requirements (including reduction in moisture content and increasing the granular content of the feed stock) prior to treatment or stabilisation. These considerations are less onerous for granular materials as would generally be recovered from shallower excavations in fill;

- Increased remediation volumes will result in increased excavation, handling, haulage and waste disposal costs for off Site disposal to landfill of additional excavated materials; and
- Targeting of more significant contamination that is present at depth within marine sediments (for example) would necessitate excavation and management of significant volumes of overburden that would not otherwise require excavation.

6.7.2.2 *In situ* Remediation (Block 5 and Hickson Road)

- In the case of S-ISCO® and SEPR™, additional drilling costs would be realised to facilitate installation of additional infrastructure (including groundwater monitoring wells, injection wells, extraction wells and soil vapour extraction wells) to cover:
  - an increased remediation area - the additional wells would be constructed in areas of the Site where drilling conditions have proven difficult during the previous site investigations;
  - an increased depth of remediation – marine sediments present at depth would require an increased density of injection wells to facilitate adequate distribution of the S-ISCO® chemistry.
- In the case of ISS, additional drilling costs would be realised to cover:
  - Treatment of an increased remediation area – noting that ISS is reliant on construction of overlapping and continuous piles, a relative modest increase in remediation area can result in a substantial increase in the number of piles required; and
  - An increased depth of remediation – noting that ISS is limited to remediation to a maximum depth of 12 m bgl.
- Increased volumes of remediation would necessitate increased volumes of treatment agents including:
  - In the case of S-ISCO® - oxidants, surfactants and catalyst; and
  - In the case of ISS – cement, lime, flyash and cement kiln dust.
- Increased volumes of remediation would result in an increase to the duration for operation, maintenance and monitoring costs associated with the selected *in situ* remediation strategy.

6.7.3 Ecologically Sustainable Development

In considering the extent of remediation that can be achieved practicably for the protection of the environment, it is appropriate to consider the principles of ESD. The regulatory framework support application of ESD is described in **Section 6.1.3**.

The ESD principles set out in Section 9 of the *CLM Act* (1997) are detailed in **Table 18** along with a description of how the proposed remediation works are consistent with the requirements of the Act.

Table 18 Consideration of the ESD Principles (CLM Act, 1997)

ESD Principles (CLM Act, 1997)	How the proposed remediation works are consistent with the ESD Principles
a) *If there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation (the 'precautionary principle');*	- The soil and groundwater analytical data set for the Site is considered to be appropriate to draw conclusions regarding the risk of current soil and groundwater conditions to human health and the environment; - The *VMP HHERA* (AECOM, 2012c) and this document have been prepared to develop remediation goals and determine the remediation extent required at the Site to mitigate risks to the environment (and human health); - As directed by the NSW EPA, the precautionary principle has been applied to protection of a potential groundwater ecosystem down hydraulic gradient from the Site (refer to **Section 6.6**); and - As described by **Section 6.5.2**, while the proposed remediation works will result in residual contamination being left *in situ*, the residual contamination will not represent a serious of irreversible threat of environmental

ESD Principles (CLM Act, 1997)	How the proposed remediation works are consistent with the ESD Principles
	damage.
The principle of inter-generational equity – that the present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations (the 'intergenerational principle');	- The proposed remediation works will enhance the environment to the benefit of future generations by significantly reducing the contaminant mass within the Site (refer to **Section 6.4**) and improving the quality of groundwater migrating from the Site and ultimately to Darling Harbour (refer to **Section 6.5.2**); - The avoidance of off Site disposal of low level contaminated material (which is not necessary to be protective of the environment) will preserve limited landfill space providing for future intergenerational equity; - The use of *in situ* remediation technologies will minimise the required for off Site disposal of contaminated material and therefore preserve limited landfill space providing for future intergenerational equity; - S-ISCO, if adopted by as the *in situ* remediation technology will effectively destroy target contamination, degrading it to other less toxic compounds which do not represent a risk to the environment or human health providing for future intergenerational equity; - S-ISCO, if adopted as the remediation works will result in a lower rate of natural resource usage thereby improving the overall environmental performance of the Barangaroo project.
The conservation of biological diversity and ecological integrity should be a fundamental consideration in decision-making (the 'biodiversity principle'); and	- A key remediation goal for protection of the environment is remediation of the soil within the unsaturated and saturated zones, to the extent practicable, such that groundwater quality leaving the Site (measured at the down hydraulic gradient Site boundary) approaches the MWQC. - As directed by the NSW EPA, the biodiversity principle has been applied to protection of a potential groundwater ecosystem down hydraulic gradient from the Site (refer to **Section 6.6**) and protection of the surface water ecosystem within Darling Harbour.
Improved valuation, pricing and incentive mechanisms should be promoted (the 'valuation principle').	- Remediation of the Site to enable removal the Declaration is first required to facilitate the proposed Barangaroo development. The development will improve economic efficiency for the CBD and utilise currently vacant land located close to transport hubs; - Use of innovative *in situ* remediation technologies will provide cost effective alternatives to conventional ex situ remediation technologies; - Appropriate commercial arrangements will be provided to contractors to encourage competitive tendering and pricing for the remediation works.

It is considered that the proposed remediation extent is consistent with the principles of ESD. In particular:

- The proposed remediation works will, notwithstanding a lack of scientific certainty regarding the presence or otherwise of a groundwater ecosystem in the are down hydraulic gradient of the Site, mitigate against serious or irreversible environmental damage – in accordance with the precautionary principle;
- The proposed remediation works substantially enhance the environment through removal of a substantial mass of gasworks related contaminant mass – in accordance with the intergenerational principle;

- The proposed remediation works, including leaving residual contamination on the Site and down hydraulic gradient of the Site, will be protective of ecological health within Darling Harbour and ultimately will be protective of ecological health within the areas down hydraulic gradient of the Site – in accordance with the biodiversity principle; and
- The proposed remediation works contemplate use of innovative *in situ* remediation technologies designed, among other things, to promote efficient pricing of the required remediation works – valuation principle.

Should the proposed remediation extent be required to be increased, the associated cost and potential environmental harm would substantially outweigh any real benefit to the environment and would be inconsistent with the principles of ESD.

6.7.4 *Waste Avoidance and Resource Recovery Act* (2001)

In considering the extent of remediation that can be achieved practicably for the protection of the environment, it is appropriate to consider the principles of waste avoidance and resource recovery. The objectives and principles encompassed by the *Waste Avoidance and Resource Recovery Act* (2001) are described in **Section 6.1.4**. In summary, the *Act* seeks to avoid generation of wastes by avoidance (including action to reduce the amount of waste created), resource recovery (including reuse, recycling and reprocessing) and, where required/unavoidable, disposal in the most environmentally responsible manner.

If it was proposed to achieve a higher level of protection for the environment than currently proposed, a substantial increase in remediation works would be required to realise any substantial increase in the contaminant mass reduction. Such an increase would also be likely to generate large volumes of excavation spoil which may be unsuitable for beneficial reuse at Barangaroo and, therefore, require disposal to landfill in accordance with the DECCW (2009) *Waste Classification Guidelines*. Minimising the quantity of material deposited in landfills, through the beneficial reuse of material (where possible) is of key importance in terms of sustainability and intergenerational equity. Where beneficial reuse of excavated material is option the potential for Resource Recovery Exemptions can also be considered.

Given that any potential additional remediation works over and above the proposed remediation extent is likely to have only a small incremental benefit to protection of the environment, but as above, result in a substantial increase in the volume of material required disposal to landfill. Such a modification to the proposed remediation extent would therefore be inconsistent with the principles of the *Waste Avoidance and Resource Recovery Act* (2001)

6.8 Conclusions

The assessment of the extent of remediation that can be practicably achieved for protection of the environment was based on consideration of the requirements of the NSW DEC (2007) *Guidelines for the Assessment and Management of Groundwater Contamination*. As part of this process, consideration was also given to the principles of: (a) ESD, as required by Section 9 of the *CLM Act* (1997); and, (b) the *Waste Avoidance and Resource Recovery Act* (2001).

6.8.1 Recommended Remediation Extent for Protection of the Environment

Based on the assessment described above, the recommended remediation extent for protection of the environment to the extent practicable is:

- Remediation of SPGWT within fill material to the extent practicable (as described by **Section 6.2**);
- Remediation of contaminated soil within the proposed remediation extent recommended for protection of human health – Zone 1 (refer to **Section 5.0** and **Figure F15**) – to the extent practicable such that:
    - the contaminant mass is reduced, on average, by 90% within the Remediation Extent (calculated based on the estimated mass of naphthalene and TPH C_{10} - C_{14}); and
    - the contaminant concentrations in unsaturated soil and groundwater are less than the relevant SSTCs (for the projection of human health).

6.8.2 Regulatory Compliance

The NSW DEC (2007) *Guidelines for the Assessment and Management of Groundwater Contamination* describe a best-practice framework for the assessment and management of contaminated groundwater in NSW. The recommended remediation extent for protection of the environment (refer to **Section 6.8.1**) is considered to be consistent with the key requirements of this guideline as follows.

Source Control

Source control is a primary objective of the proposed remediation extent. In particular, the primary remediation goal for protection of the environment is removal of SPGWT to the extent practicable (as discussed following). The primary contaminant sources at the Site are considered to be historical gasworks infrastructure (which has been found to contain SPGWT). Secondary contaminant sources are considered to be areas where SPGWT has been observed in groundwater and soil. As such, achievement of the primary remediation goal will substantially satisfy the requirement of this guideline requirement.

Other secondary contaminant sources may be considered to include areas where CIM (that is soil and groundwater concentrations exceeding the SSTCs for the protection of human health) has been identified. The secondary remediation objective for protection of human health is the remediation of CIM to the extent practicable as described by **Section 5.0**.

The proposed remediation extent is considered to be consistent with the requirement for source control for protection of the environment.

Remediation of NAPL to the Extent Practicable

The proposed remediation extent is consistent with the guideline requirement for remediation of NAPL to the extent practicable (as well as the requirement for source removal) because the proposed remediation extent includes:

- All of the known historic gasworks structures, which are considered to be representative of primary contaminant sources; and
- The majority of locations (i.e. 29 out of 30 locations both within the Site and down hydraulic gradient of the Site) at which NAPL has been recorded in fill by previous investigations, which are considered to be representative of secondary contaminant sources. It is noted that this calculation excludes the impact reported at:
    - BH60/MW60 and BH74 which will be addressed by the ORWN and Barangaroo Central RAPs; and
    - BH48, BH69/MW69, BH400, BH402, BH403, BH404, BH405, BH406 were SPGWT was reported in either marine sediments or bedrock.

Removal of the residual pockets of NAPL that have been reported outside the proposed remediation extent is considered neither practicable nor necessary because:

- The majority of these locations are within marine sediment or bedrock. Contaminant flux from the underlying bedrock or marine sediment is negligible, such that contaminants present within the marine sediment and bedrock is largely being contained and does not represent a risk to the environment;
- Contaminant flux modelling (AECOM, 2013a), which includes the presence of residual SPGWT at depth within fill and marine sediments, demonstrates that the residual SPGWT following completion of the proposed remediation will not represent an unacceptable impact to the environment; and
- The benefit of treating or removing the residual SPGWT does not outweigh the cost in terms of negative impact to the environment.

Clean Up to the Extent Practicable

As required by Section 4.3 of the NSW DEC (2007) *Guidelines for the Assessment and Management of Groundwater Contamination*, the key factors that must be considered to assess whether CUTEP has been achieved are:

- **Technical capability to achieve the clean-up**:
    - A range of remediation technologies have been considered as an outcome of the remediation technology assessment presented in the *VMP/Block 4 RAP* (AECOM, 2013b). Importantly, the process

adopted by the *VMP/Block 4 RAP* (AECOM, 2013b) for selection of an appropriate remediation strategy was based on the nature and distribution of contamination reported within the Site and areas adjacent to the Site and was not based on the outcomes of this remediation extent document.

- The technical capability of the most likely remediation technologies range from:
  - 90% for potential *in situ* remediation technologies; to
  - 100% for potential ex situ remediation technologies;
- The technical capability of the most likely remediation technologies applied to the proposed remediation extent will result will result in a reduction in gasworks related contaminant mass of between 88-92% within fill materials.
- Of the residual gasworks related contamination that will remain *in situ* following the proposed remediation works, the majority (approximately half of the residual) of the contaminant mass is present within the marine sediments down hydraulic gradient of the Site.
- There is considered to be a negligible potential for contaminant flux and discharge from the natural marine sediments underlying the Site and off Site areas into Darling Harbour and remediation of the marine sediments is not considered to be warranted for the protection of the environment (or human health).

- **Threats the contamination poses to human or ecological health**:
  - If the remediation proposed for protection of human health is completed, as described by **Section 5.0**, there will not be an unacceptable ongoing risk to human health under current land uses.
  - If the remediation proposed for protection of human health is completed, as described **Section 5.0**, and to the technical capability of the most likely remediation technologies (i.e. a 90% on average reduction in contaminant mass) there will be no unacceptable ongoing risk to the environment. This conclusion is supported by contaminant flux modelling undertaken by AECOM that demonstrated:
    - The groundwater quality in fill at the down hydraulic gradient boundary of the Site would be expected to improve by between 250% and 380% (measured in terms of a reduction in mass flux) as a result of the proposed remediation; and
    - Less than 1% of the contaminant mass flux discharging to Darling Harbour is associated with the marine sediment;
    - Groundwater quality estimated from the contaminant mass flux discharging to Darling Harbour from residual contamination that will remain *in situ* following the proposed remediation will be less than the MWQC and therefore not represent an unacceptable risk to the environment; and
    - Groundwater quality discharging from fill into Darling Harbour will improve further over time because better quality groundwater (that is with a lower contaminant mass flux) from the Site will slowly migrate towards Darling Harbour.

- **The value of the groundwater resource:**
  - Groundwater at the down hydraulic Site boundary is required by the EPA to be protective of both potential groundwater ecosystems that may be present down hydraulic gradient of the Site (as required by the precautionary principle) and Darling Harbour.
  - AECOM has demonstrated through consideration of multiple lines of evidence 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**:
  - If it was proposed to achieve a higher level of protection for the environment than currently proposed, a substantial increase in remediation works would be required to realise any substantial increase in the contaminant mass reduction
  - It is considered that the cost and potential environmental harm associated with expansion of the proposed remediation extent would substantially outweigh any real benefit to the environment, which

would be minimal at best, particularly considering that contamination within the marine sediments does not appear to be significantly impacting the environment under current conditions.

- The practicability of implementing the most likely remediation technologies would be reduced as a consequence of increasing the proposed remediation extent and in particular, the depth of remediation including the requirement to remediate saturated marine sediments.
- It is considered that the 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 ESD (in particular providing for intergenerational equity). 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.
- Additional remediation works would be inconsistent with the principles of the *Waste Avoidance and Resource Recovery Act* (2001) which seeks to avoid generation of wastes by avoidance (including action to reduce the amount of waste created), resource recovery (including reuse, recycling and reprocessing) and, where required/unavoidable, disposal in the most environmentally responsible manner.

Additional remediation works would be inconsistent with 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 achieve the requisite contaminant mass reduction).

7.0 Summary

This VMP Remediation Extent report has been prepared to describe:

- The remediation goals, based on the assessment of risk in the *VMP Human Health and Ecological Risk Assessment* (*VMP HHERA*, AECOM, 2012c) and developed to meet NSW EPA policy requirements, that are applicable to remediation of the Site to achieve the nominated remediation objectives; and
- The extent of remediation required to achieve the remediation goals on which the *VMP/Block 4 RAP* (AECOM, 2013b) will be based.

Remediation Goals

The remediation goals for the protection of human health and the environment have been developed based on the recommendations of the *VMP HHERA* (AECOM, 2012c) and to meet NSW EPA policy requirements. The remediation goals are:

- As a primary goal, removal / remediation of Separate 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 Site-Specific Target Criteria (SSTC); and/or
        - Unsaturated or saturated soil concentrations that are considered to be the source of groundwater concentrations exceeding the groundwater SSTCs in fill material; and
    - Such that groundwater quality within fill material leaving the Site (measured in fill at the down hydraulic gradient Site boundary) approaches the Marine Water Quality Criteria (MWQC).

Remediation Extent

The extent of remediation in the unsaturated and saturated zones is presented on **Figure F14** and **Figure F15**, respectively.

The lateral extent of remediation has been determined based on consideration of:

- The presence of historic gasworks infrastructure, the distribution of SPGWT and CIM within the respective Site areas; and
- The extent of remediation that can be practicably achieved 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 achieved within the proposed Remediation Extent should 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 within the Remediation Extent fill material is reduced, on average, by 90%, to the extent practicable (calculated based on the estimated mass of naphthalene and TPH C_{10} - C_{14}).

The vertical extent of remediation has been 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 is noted that SPGWT and CIM have been reported in the natural marine sediments both within the Site and in some hydraulically down gradient areas to the west of the Site. However, the negligible contaminant flux from these natural materials is not considered to pose a significant risk to human health or the environment (refer to **Section 2.5**). As such, the proposed extent of remediation works excludes remediation of natural marine sediments which are present below a depth of 10 m bgl.

The extent of remediation works at the Site is recommended to include the following site areas.

Block 4 and Block 5

- Unsaturated zone (i.e. between 0 and 2 m bgl):
  - All Block 4 areas where SPGWT has been identified (refer to Table 3 and Figure F6).
- Saturated zone (i.e. greater than 2 m bgl):
  - All Block 4 areas where SPGWT has been identified (refer to Table 3 and Figure F6);
  - The western portion of the 1870 gasholder annulus (Block 4);
  - The eastern portion of Block 4 and 5 (i.e. east of the 10 m bgl bedrock contour);
  - The south east portion of Block 4 in the vicinity of BH42/BH408; and
  - The western portion of Block 4 in the vicinity of BH49 and BH119.

Hickson Road

- All areas where SPGWT has been identified (refer to Table 6 and Figure F8):
  - The BH7/MW7 and BH53 area – the southern tar tank;
  - The BH10/MW10 area - eastern portion of the 1870 gas holder;
  - The western portion of the main gas holder annulus;
  - The northern tar tank; and
  - The BH6, BH15 and BH61 area - located west and down gradient of the main gas holder annulus and northern/southern tar tanks.

Off-site Areas (West of the Block 5 portion of the Site)

- BH70 at a depth of approximately 2 to 3 m bgl in fill material (where SPGWT has been potentially identified); and
- BH541 at a depth of approximately 9.9-10 m bgl in fill material (where SPGWT has been potentially identified and the groundwater is considered to be CIM based on benzene concentrations).

Off Site Areas (East)

- The *VMP/Block 4 RAP* must consider management measures to mitigate against the risk of the remediated Site being re contaminated by contaminant migration from SPGWT likely to remain in situ within the portions of the main gasholder annulus and tar tank located east of the Site.

The proposed extent of remediation is considered to be consistent with the key requirements of the NSW DEC (2007) *Guidelines for the Assessment and Management of Groundwater Contamination,* in particular:

- Source Control and remediation of NAPL to the extent practicable – the proposed extent of remediation includes all of the identified primary contaminant sources (i.e. historical gasworks structures) and the majority 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 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) or the environment. 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 Site: and, groundwater quality discharging to Darling Harbour from residual contamination will be less than the MWQC.
    - *The value of the groundwater resource* - multiple lines of evidence have been provided to demonstrate 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 in this document 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 achieve the requisite contaminant mass reduction).

8.0 References

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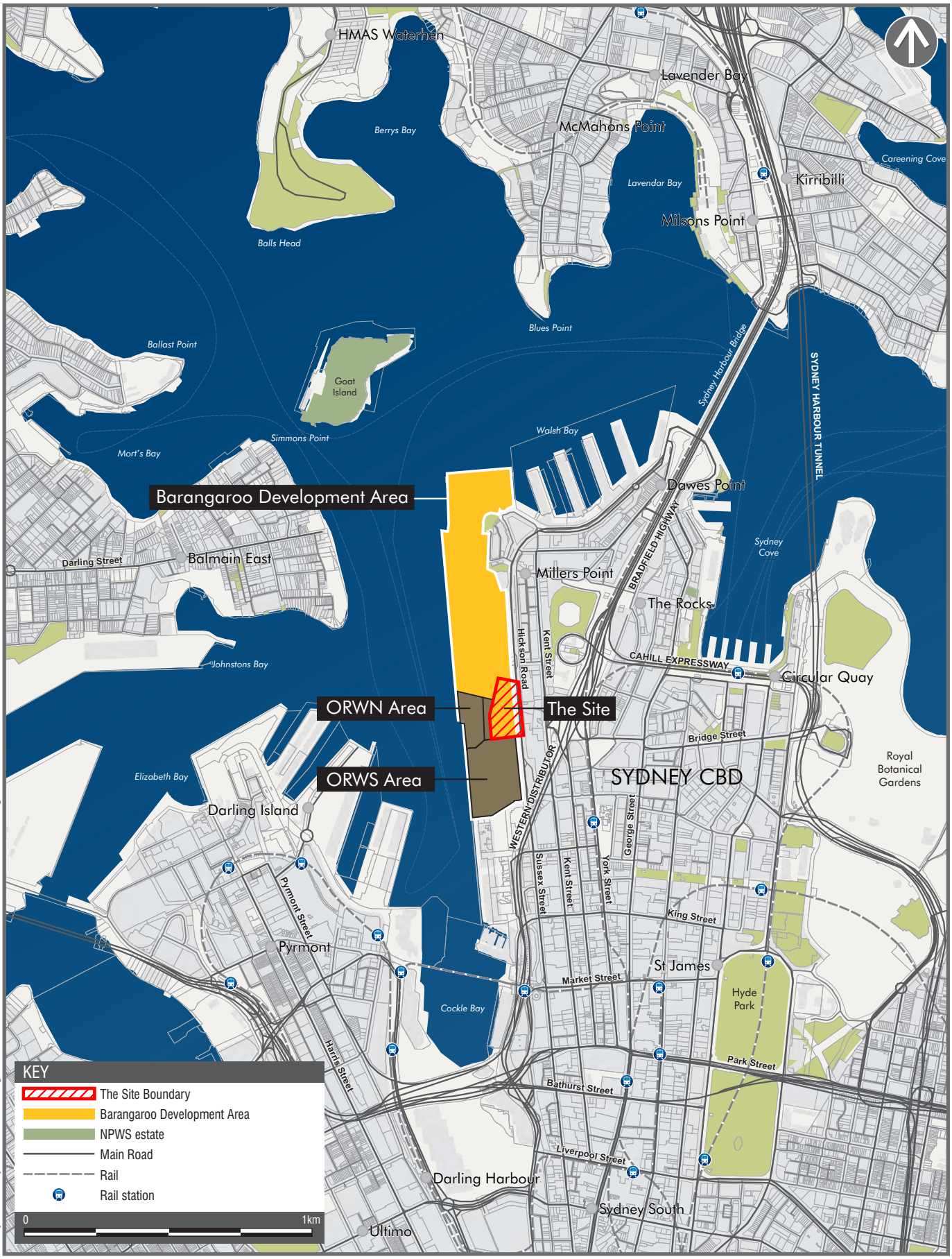
Appendix A

Figures

Appendix A Figures



G:\Projects\602 Projects\60247139 Barangaroo\FIGURES\1.03 VMP Remediation Extent\60247139 F1 Barangaroo Site Location 20 06 2013 TO Rev A

AECOM

BARANGAROO SITE LOCATION

VMP Remediation Extent

FIGURE F1

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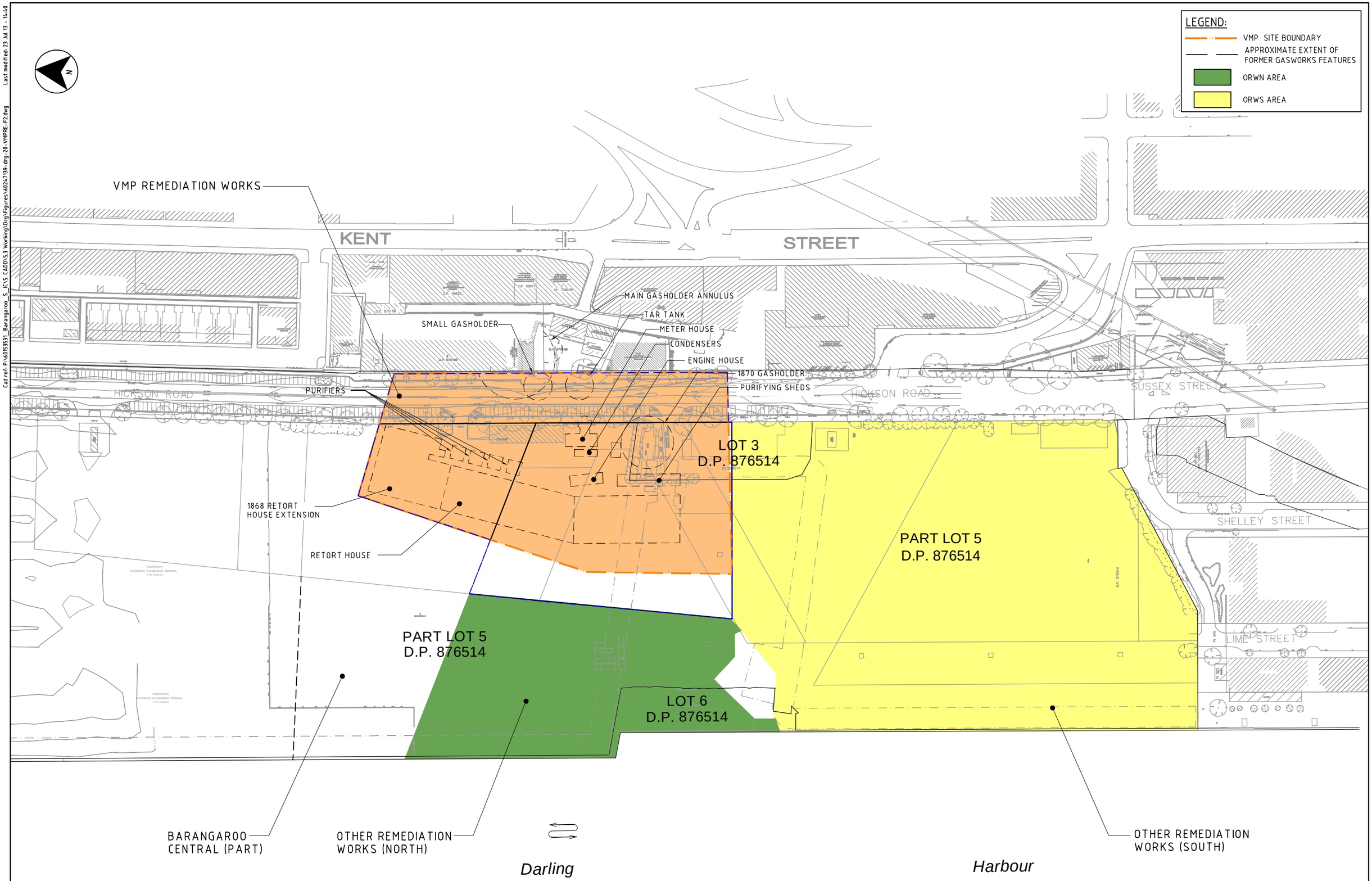

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02	PAS	06.03.13	DRAFT ISSUE	AR
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APPROVED	AR	DATE	23.07.13

CONTRACTOR:

DESIGNER:

AECOM

AECOM Australia Pty Ltd A.B.N. 20 093 846 925

CLIENT:

VMP REMEDIATION EXTENT, BARANGAROO

FIGURE F2:
SITE LAYOUT AND SAMPLING LOCATIONS

STATUS: FINAL

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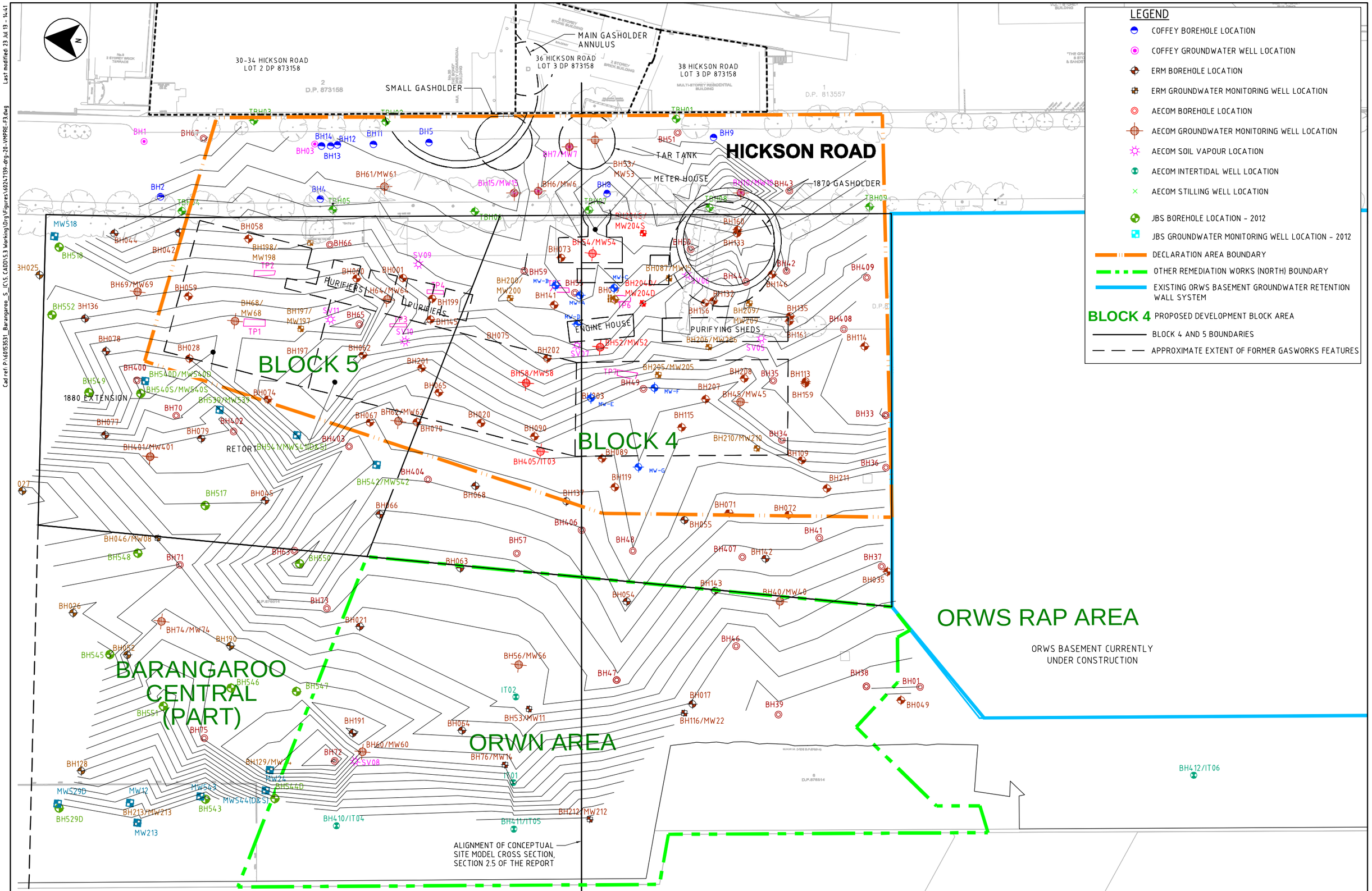

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DESIGNER:

AECOM

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CLIENT:

VMP REMEDIATION EXTENT, BARANGAROO

FIGURE F3:
SITE PLAN AND SAMPLING LOCATIONS

STATUS: FINAL

DRAWING NO: 60247139-DRG-20-VMPRE-F3

REV: 05

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HICKSON ROAD

BLOCK 5

BLOCK 4

BARANGAROO CENTRAL (PART)

ORWN AREA

ORWS RAP AREA

ORWS BASEMENT CURRENTLY UNDER CONSTRUCTION

BH204S_1	18/03/2008
CPAH (TEF)	119.4

BH54_1-1.4	23/02/2010
CPAH (TEF)	842.6

BH073_1.5-1.95	2/05/2006
CPAH (TEF)	140.1

BH001_1	1/05/2006
CPAH (TEF)	67.0

BH200_1	7/04/2008
CPAH (TEF)	166.0

BH087_1.5-1.95	8/06/2006
CPAH (TEF)	114.5

BH64_1-1.2	1/03/2010
CPAH (TEF)	108.0

BH55_1-1.2	25/02/2010
CPAH (TEF)	372.1

BH204D_1.5	7/04/2008
TPH C10-C14	54200.0
TPH C15-C28	72400.0
CPAH (TEF)	921.6

BH145_0.3-0.5	1/05/2006
CPAH (TEF)	110.0

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
- JBS BOREHOLE LOCATION - 2012
- JBS GROUNDWATER MONITORING WELL LOCATION - 2012
- DECLARATION AREA BOUNDARY
- OTHER REMEDIATION WORKS (NORTH) BOUNDARY
- EXISTING ORWS BASEMENT GROUNDWATER RETENTION WALL SYSTEM

BLOCK 4 PROPOSED DEVELOPMENT BLOCK AREA

BLOCK 4 AND 5 BOUNDARIES

APPROXIMATE EXTENT OF FORMER GASWORKS FEATURES

NOTE:

LOCATION OF COFFEY GROUNDWATER WELLS ARE APPROXIMATE ONLY.

TPH C10-C14 EXCEEDS SITE SPECIFIC CRITERIA

TPH C15-C28 EXCEEDS SITE SPECIFIC CRITERIA

CPAHs EXCEEDS SITE SPECIFIC CRITERIA

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DESIGNER: AECOM

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CLIENT:

VMP REMEDIATION EXTENT, BARANGAROO

FIGURE F4:
SOIL SSTC EXCEEDENCES (UNSATURATED)

STATUS: FINAL

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HICKSON ROAD

MW7/BH7	26/03/2008
TPH C10-C14	830000
Benzene	25200
Ammonia as N	294
Naphthalene	4800

MW15/BH15	1/05/2008
TPH C10-C14	494000
TPH C15-C28	754000
Naphthalene	192000
Benzene	40200
CPAH (TEF)	11162

MW10/BH10	26/03/2008
CPAH (TEF)	1054.69
TPH C10-C14	528000
Benzene	5450
Ammonia as N	348
Naphthalene	15800

MW204S/BH204S	25/02/2011
Naphthalene	8580

MW15/BH087A	15/03/2010
TPH C10-C14	41000
Benzene	13100
Naphthalene	7800

MW54/BH54	19/03/2012
TPH C10-C14	28000
Naphthalene	8640

MW69/BH69	19/03/2010
Naphthalene	1920

MW206/BH206	19/03/2010
TPH C10-C14	68000
Benzene	5450
Naphthalene	10600

MW200/BH200	28/02/2011
TPH C10-C14	47400
Benzene	17900
Naphthalene	5450

MW541D	25/05/2012
Benzene	4300
Naphthalene	1900

IT03D/BH405	25/02/2011
Naphthalene	2560

MW205/BH205	17/03/2010
CPAH (TEF)	11556
Naphthalene	283000
TPH C10-C14	1730000
TPH C15-C28	1520000
TPH C29-C36	332000

MW60/BH60	18/03/2010
TPH C10-C14	18500
Naphthalene	1500

BLOCK 5

BLOCK 4

ORWS RAP AREA

ORWS BASEMENT CURRENTLY UNDER CONSTRUCTION

ORWN AREA

BARANGAROO CENTRAL (PART)

LEGEND

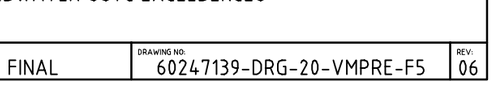
- COFFEY BOREHOLE LOCATION
- COFFEY GROUNDWATER WELL LOCATION
- ERM BOREHOLE LOCATION
- ERM GROUNDWATER MONITORING WELL LOCATION
- AECOM BOREHOLE LOCATION
- AECOM GROUNDWATER MONITORING WELL LOCATION
- AECOM SOIL VAPOUR LOCATION
- AECOM INTERTIDAL WELL LOCATION
- AECOM STILLING WELL LOCATION
- JBS BOREHOLE LOCATION - 2012
- JBS GROUNDWATER MONITORING WELL LOCATION - 2012
- DECLARATION AREA BOUNDARY
- OTHER REMEDIATION WORKS (NORTH) BOUNDARY
- EXISTING ORWS BASEMENT GROUNDWATER RETENTION WALL SYSTEM

BLOCK 4 PROPOSED DEVELOPMENT BLOCK AREA

- BLOCK 4 AND 5 BOUNDARIES
- APPROXIMATE EXTENT OF FORMER GASWORKS FEATURES

NOTE:

COLOURED CIRCLES REPRESENT LOCATIONS AT WHICH CONTAMINANTS WERE REPORTED AT CONCENTRATIONS ABOVE THE APPLICABLE SSTCS. CONTAMINANT CONCENTRATIONS REPORTED ABOVE THE LABORATORY LIMIT OF REPORTING IS PRESENTED IN THE DATA BOXES FOR EACH LOCATION.



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APPROVED	AR	DATE	23.07.13

CONTRACTOR:

DESIGNER: AECOM

AECOM Australia Pty Ltd A.B.N. 20 093 846 925

VMP REMEDIATION EXTENT, BARANGAROO

FIGURE F5:
GROUNDWATER SSTC EXCEEDENCES

STATUS: FINAL

DRAWING NO: 60247139-DRG-20-VMPRE-F5

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HICKSON ROAD

BLOCK 5

BLOCK 4

BARANGAROO CENTRAL (PART)

ORWN AREA

ORWS RAP AREA

ORWS BASEMENT CURRENTLY UNDER CONSTRUCTION

D.P. 873158

D.P. 813557

D.P. 878814

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
- JBS BOREHOLE LOCATION - 2012
- JBS GROUNDWATER MONITORING WELL LOCATION - 2012
- DECLARATION AREA BOUNDARY
- OTHER REMEDIATION WORKS (NORTH) BOUNDARY
- EXISTING ORWS BASEMENT GROUNDWATER RETENTION WALL SYSTEM

BLOCK 4 PROPOSED DEVELOPMENT BLOCK AREA

- BLOCK 4 AND 5 BOUNDARIES
- APPROXIMATE EXTENT OF FORMER GASWORKS FEATURES

1.0 - 2.0 DEPTH OF IMPACT (M BGL)

- PRESENCE OF DNAPL NOTED
- PRESENCE OF TCM NOTED IN FILL MATERIAL
- PRESENCE OF SHEEN NOTED
- PRESENCE OF TCM NOTED IN MARINE SEDIMENTS

NOTE:
LOCATION OF COFFEY GROUNDWATER WELLS ARE APPROXIMATE ONLY.

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04	PAS	20.06.13	DRAFT ISSUE		AR
03	PAS	12.03.13	DRAFT ISSUE		AR
02	PAS	06.03.13	DRAFT ISSUE		AR
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DESIGNER: AECOM

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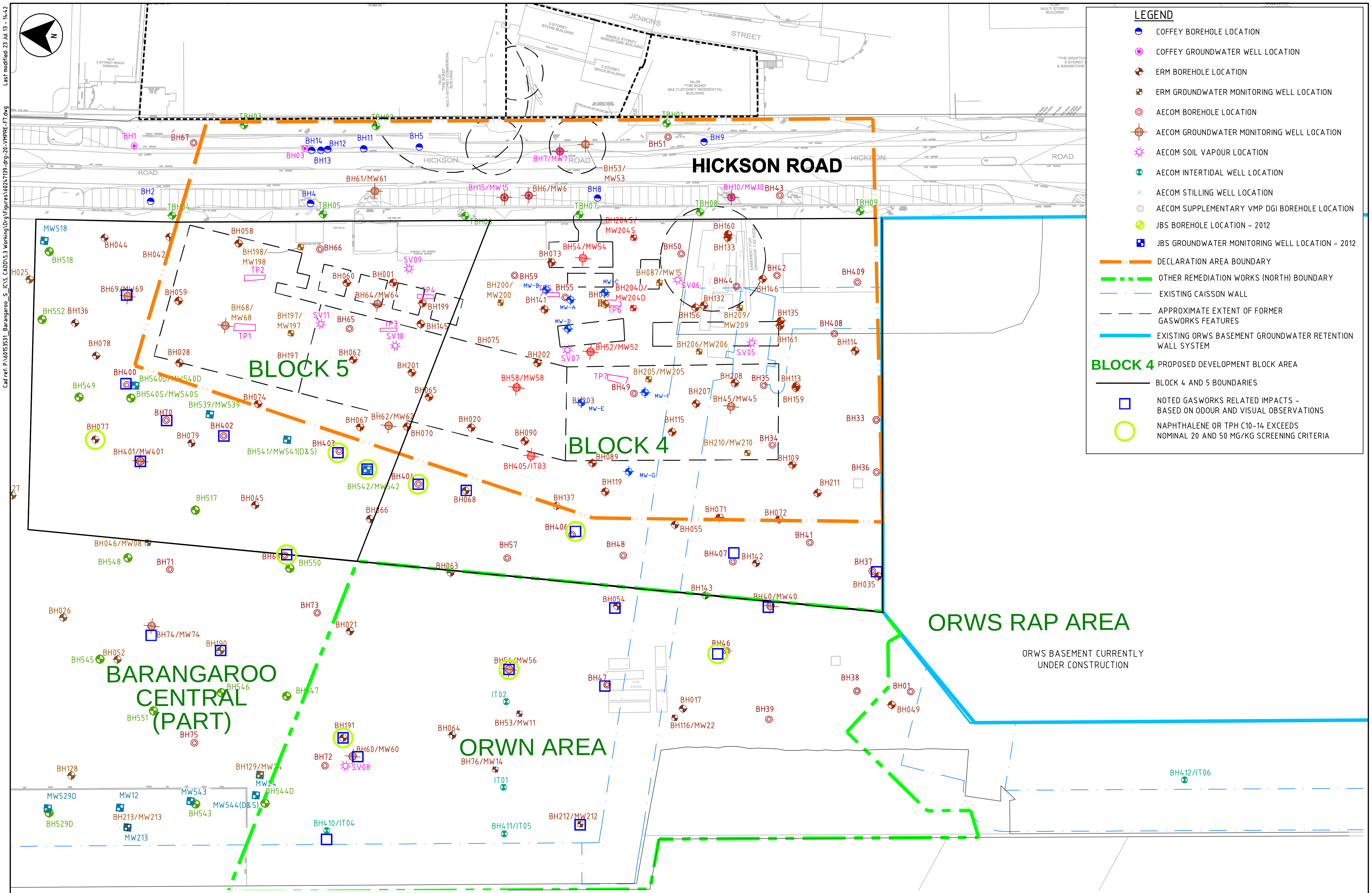
VMP REMEDIATION EXTENT, BARANGAROO

FIGURE F6:
LOCATIONS OF SEPARATED PHASE GASWORKS RELATED WASTES AND TAR (SPGWT)

STATUS: FINAL

DRAWING NO: 60247139-DRG-20-VMPRE-F6

REV: 05



This drawing is confidential and shall only be used for the purposes of this project.

REVISIONS

No.	BY	DATE	DESCRIPTION	APPD
05	PAS	23.07.13	FINAL ISSUE	AR
04	PAS	20.06.13	DRAFT ISSUE	AR
03	PAS	12.03.13	DRAFT ISSUE	AR
02	PAS	06.03.13	DRAFT ISSUE	AR
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CLIENT:

VMP REMEDIATION EXTENT, BARANGAROO

FIGURE F7:
OFFSITE GASWORKS RELATED IMPACTS
IN FILL MATERIAL

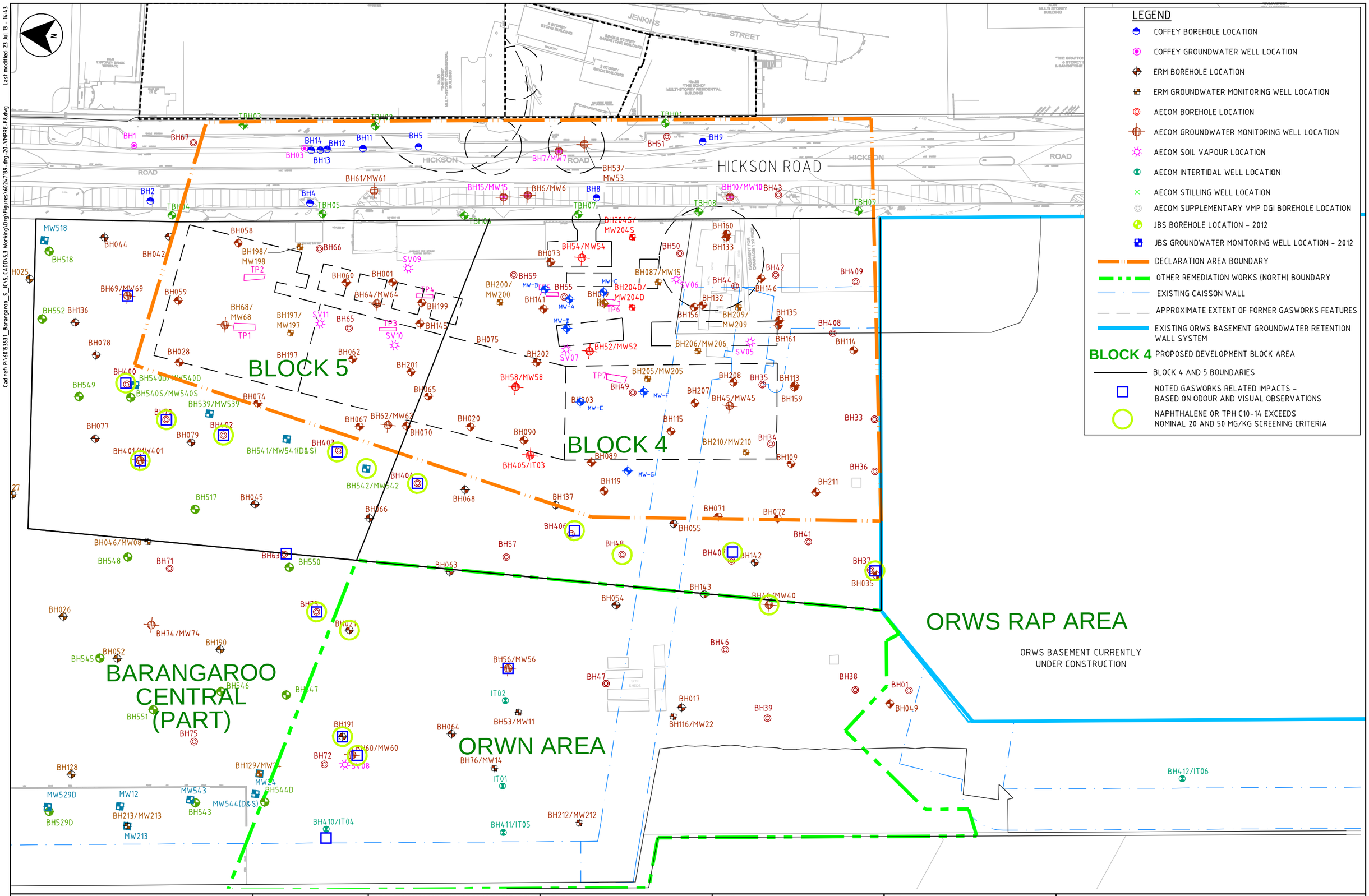
STATUS: FINAL

DRAWING NO: 60247139-DRG-20-VMPRE-F7

REV: 05

Last modified: 23 Jul 13 - 14:43

Cad ref: P:\60153531_Barangaroo_S_(CS_CAD)\S3 Working\Drg\Figures\60247139-drg-20-VMPRE-F8.dwg



REVISIONS

No.	BY	DATE	DESCRIPTION	APPD
06	PAS	23.07.13	FINAL ISSUE	AR
05	PAS	20.06.13	DRAFT ISSUE	AR
04	PAS	12.03.13	DRAFT ISSUE	AR
03	PAS	06.03.13	DRAFT ISSUE	AR
02	TT	13.02.13	DRAFT ISSUE	AR
01	TT	06.10.12	DRAFT ISSUE	DM

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VMP REMEDIATION EXTENT, BARANGAROO

FIGURE F8:
OFFSITE GASWORKS RELATED IMPACTS IN MARINE SEDIMENTS

STATUS: FINAL

DRAWING NO: 60247139-DRG-20-VMPRE-F8

REV: 06

Last modified: 23 Jul 13 - 14:44

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30-34 HICKSON ROAD
LOT 2 DP 873158

MAIN GASHOLDER ANNULUS

36 HICKSON ROAD
LOT 3 DP 873158

38 HICKSON ROAD
LOT 3 DP 873158

SMALL GASHOLDER

HICKSON ROAD

TAR TANK

METER HOUSE

1870 GASHOLDER

ENGINE HOUSE

PURIFYING SHEDS

PURIFIERS

1880 EXTENSION

RETORT

BLOCK 5

BLOCK 4

ORWS RAP AREA

ORWS BASEMENT CURRENTLY UNDER CONSTRUCTION

BARANGAROO CENTRAL (PART)

ORWN AREA

A A'

B B'

C C'

D D'

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
- JBS BOREHOLE LOCATION - 2012
- JBS GROUNDWATER MONITORING WELL LOCATION - 2012
- DECLARATION AREA BOUNDARY
- BLOCK 4 AND 5 BOUNDARIES
- OTHER REMEDIATION WORKS (NORTH) BOUNDARY
- EXISTING ORWS BASEMENT GROUNDWATER RETENTION WALL SYSTEM
- BLOCK 4 PROPOSED DEVELOPMENT BLOCK AREA
- A' A CROSS SECTION ALIGNMENT (REFER TO FIGURE F10 TO F13)
- MARINE SEDIMENT CONTOURS mAHD
- BEDROCK CONTOURS mAHD

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02	PAS	06.03.13	DRAFT ISSUE	AR
01	TT	13.02.13	DRAFT ISSUE	DM

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CLIENT:

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FIGURE F9:
INDICATIVE BEDROCK AND MARINE SEDIMENT CONTOURS

STATUS: FINAL

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REV: 05