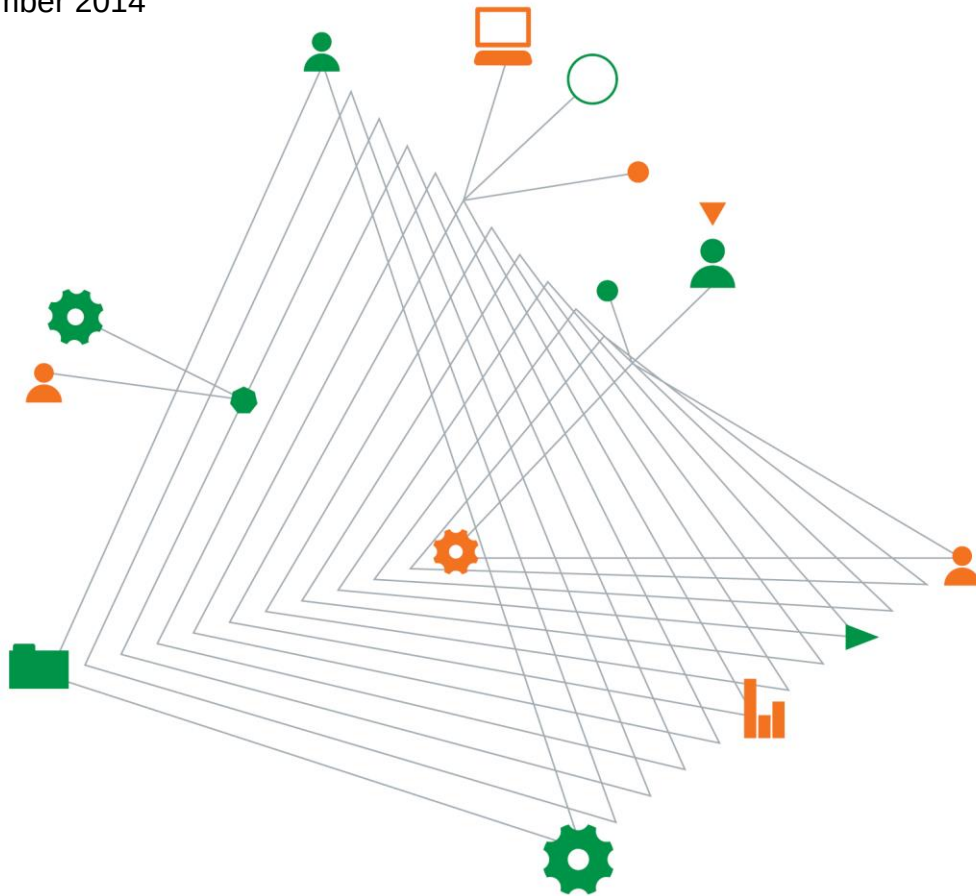


Lend Lease (Millers Point) Pty Ltd

Barangaroo, Hickson Road

Specialist Geotechnical Desktop Report to
Accompany Development Application SSD 6617-
2014 for Hickson Road Remediation

5 November 2014



Experience
comes to life
when it is
powered by
expertise

This page has been left intentionally blank

Barangaroo, Hickson Road

Prepared for
Lend Lease (Millers Point) Pty Ltd

Prepared by
Coffey Geotechnics Pty Ltd
Level 19, Tower B, 799 Pacific Highway
Chatswood NSW 2067 Australia
t: +61 2 9406 1011 f: +61 2 9406 1002
ABN: 93 056 929 483

5 November 2014

Document Authorisation

Our ref: GEOTLCOV24015AL-AE

For and on behalf of Coffey



Pawan Sethi
Principal

Quality information

Revision History

Revision	Description	Date	Author	Reviewer	Signatory
V1	Draft	12 Sep 2014	PS	RJB	PS
V2	Draft	10 Oct 2014	PS	RJB	PS
V3	Final	05 Nov 2014	PS	RJB	PS

Distribution

Report Status	No. of copies	Format	Distributed to	Date
DRAFT 1	1	PDF	Mark Burns (Lend Lease)	12 Sep 2014
DRAFT 2	1	PDF	Mark Burns (Lend Lease)	10 Oct 2014
Final	1	PDF	Mark Burns (Lend Lease)	05 Nov 2014

Table of Contents

1.Introduction	1
2.Project background	2
2.1. The Barangaroo site.....	2
2.2. EPA Declaration Area #21122	2
2.3. Summary site history and key contaminants	3
2.4. Definition of site for Hickson Road Remediation DA	3
2.5. Role of Lend Lease	3
2.6. Remedial action plan and methodology.....	3
3.Available information.....	5
4.Summary of proposed works for the Hickson Road Remediation Area DA	6
4.1. Preferred method – In-situ remediation	6
4.2. Alternative method - Ex-situ remediation	7
5.Geotechnical overview	8
5.1. Geology	8
5.1.1. Hawkesbury Sandstone	8
5.1.2. Pittman LIV Dyke.....	8
5.1.3. Quaternary and Recent Sediments.....	8
5.1.4. Fill	9
5.2. Site history.....	9
6.Interpreted sub-surface conditions within the remediation area.....	10
6.1. Geotechnical model	10
6.2. Hydrogeological model.....	13
6.3. Observations of contamination during previous investigations	14
7.Geotechnical considerations.....	15
7.1. Foundation design parameters	15
7.2. Retaining walls	16
7.3. Ground anchor design parameters	19
7.4. Dewatering and water ingress (Ex-Situ Remediation)	20
7.5. Impacts on Existing Assets	21
7.5.1. Preferred Method – In-Situ Remediation	21
7.5.2. Alternative Method – Ex-Situ Remediation	22

7.5.3.	Impacts to Existing Services	24
7.5.4.	Preferred Method – In-Situ Remediation	24
7.5.5.	Alternative Method – Ex-Situ Remediation	25
7.5.6.	Impacts to Existing Pavements	25
7.6.	Vibration	26
7.6.1.	Vibration limits for structures.....	26
7.6.2.	Vibration limits for historic structures	28
7.6.3.	Vibration limits for underground utilities	28
7.6.4.	Vibration limits for human receptors.....	28
8.	Management of environmental impacts	30
9.	Conclusion.....	31
10.	Limitations	31

Important Information about Your Coffey Report

Tables

Table 6.1 – Summary of typical subsurface conditions

Table 6.2 – Summary of sandstone profile

Table 7.1 - Foundation design parameters

Table 7.2 – Retaining Wall design parameters for soil

Table 7.3 – Retaining Wall design parameters for rock

Table 7.4 – Recommended earth pressure coefficients for preliminary design

Table 7.5 – Recommended bond stresses for ground anchors

Table 7.6 – Assessed volume of dewatering required at Hickson Road

Table 7.7 – Vibration and human perception of motion

Table 8.1 - Geotechnical issues of remediation

Figures

Figure 1 – EPA Plan of Declaration Area

Figure 2 – Location of EPA Declaration Site showing Geotechnical Section Location

Figure 3 – Historic Borehole Location Plan with Inferred Bedrock Contours

Figure 4 – Cross Section A-A'

Glossary

- **Block 4 Remediation Area** – Portion of the Declaration Area situated within Barangaroo South
- **Block 5 Remediation Area** – Portion of the Declaration Area located within Barangaroo Central (including remediation of some land adjacent to the Declaration Area on the west)
- **EPA** – Environment Protection Authority
- **EPA Declaration Area** – Remediation Site Declaration 21122
- **Hickson Road Remediation Area** – Portion of the Declaration Area situated within the Hickson Road reserve
- **Ex-situ Remediation Methodology** – Excavation of contamination and off-site disposal (with off-site pre-treatment, where required)
- **In-situ Remediation Methodology** – Remediation using in-situ chemical oxidation and/or extraction (product recovery). Process would be using SISCO (surfactant enhanced in-situ chemical oxidation) or similar method
- **LLMP** – Lend Lease (Millers Point)
- **RAP** – Remedial Action Plan
- **Site** – area required for the purpose of the Hickson Road Remediation Development Application identified as:
 - Hickson Road Remediation Area
 - Any other areas of Barangaroo or Hickson Road required for staging and undertaking the remediation and stormwater diversion works.
- **Site Remediation Area** – The Hickson Road Remediation Area
- **VMP** – Voluntary Management Proposal

1. Introduction

Coffey Geotechnics Pty Ltd (Coffey) has been engaged by Lend Lease Millers Point (Lend Lease) to prepare a specialist geotechnical desktop assessment report to accompany a Development Application for Remediation of Hickson Road at Barangaroo to be submitted to the Minister for Planning pursuant to the Part 4 of the *Environmental Planning and Assessment Act, 1979*.

The desktop report has been prepared at the request of Lend Lease to address and assess the following geotechnical issues relevant to the Development Application:

- Prepare a summary of available geotechnical information relevant to the scope of the Development Application
- Prepare a geotechnical model for the proposed Remediation Area
- Prepare cross sectional drawings through the proposed Remediation Area
- Prepare a geotechnical assessment of the effect of the preferred *in-situ* remediation techniques and alternative *ex-situ* remediation techniques within the Remediation Area
- Prepare a preliminary groundwater inflow assessment
- Assess the geotechnical impacts (including vibration) of the proposed *in-situ* and *ex-situ* remediation works on the existing services and structures within and directly adjacent to the Remediation Area
- Provide preliminary foundation system design parameters for temporary remediation work area odour control structure supports, groundwater control and retention walls
- Interpret the former Pre-European settlement shoreline of East Darling Harbour within the Remediation Area.

The information contained in this report is based on information gained during recent geotechnical investigations for the adjoining Barangaroo South area, information supplied by Lend Lease and data held in the Coffey archives.

2. Project background

2.1. The Barangaroo site

Barangaroo is located on the north western edge of the Sydney Central Business District, bounded by Sydney Harbour to the west and north, the historic precinct of Millers Point (for the northern half), The Rocks and the Sydney Harbour Bridge approach to the east; and bounded to the south by a range of new development dominated by large CBD commercial tenants.

The 22 ha Barangaroo site is roughly rectangular in shape and has frontage to the harbour foreshore of 1.4 km. Hickson Road is a public road that is adjacent to the eastern boundary of Barangaroo.

The Barangaroo Concept Plan (as modified) is the statutory planning approval to guide the urban renewal of Barangaroo and currently provides for the development of mixed use precinct comprising commercial, retail, residential and community development and new public open space / public domain.

The Barangaroo Delivery Authority is the state government authority that manages and delivers the development of Barangaroo.

2.2. EPA Declaration Area #21122

In May 2009, the NSW Environment Protection Authority (EPA) determined that a portion of land at Millers Point (part of the Barangaroo Site and an adjacent portion of Hickson Road), was contaminated in such a way as to present a significant risk of harm (SROH) to human health and the environment. As a consequence the EPA declared the area to be a remediation site (Declaration Number 21122; Area Number 3221) under the Contaminated Land Management Act 1997.

The Remediation Site Declaration 21122 indicates that the area of the declaration coincides with the known footprint of the former Millers Point gasworks facilities. This area is located on part of Barangaroo and part of Hickson Road adjacent to Barangaroo.

In accordance with Declaration Number 21122, the Declaration Area comprises:

- Part Lot 5 and Part Lot 3 DP 876514, Hickson Road, Millers Point, NSW 2000
- Part of Hickson Road adjacent to:
 - 30-34 Hickson Road (Lot 11, DP1065410)
 - 36 Hickson Road (Lot 5, DP873158)
 - 38 Hickson Road (SP72797) Millers Point.

Refer to Figure 1 for location of the Declaration Area as gazetted by NSW EPA.

The Barangaroo Delivery Authority has entered into a Voluntary Management Proposal (VMP) with the EPA associated with EPA Declaration Area (Approval No. 20101719). Phase 1 of this VMP involves investigative works and undertaking remedial design to determine and obtain agreement on a proposed remediation methodology. Phase 2 of the VMP will involve the implementation of the agreed remediation works.

An independent, EPA-accredited Site Auditor has been appointed to undertake review of proposed remediation works, and prepare statutory audit statements prior to and following completion of remediation.

For the purposes of planning and staging works, the EPA Declaration Area is divided into three areas as follows:

- Block 4 Remediation Area - the part of the Declaration Area on Barangaroo South
- Block 5 Remediation Area - the part of the Declaration Area on Barangaroo Central (including remediation of some land adjacent to the Declaration Area on the west)
- Hickson Road Remediation Area - the part of the Declaration Area located on Hickson Road.

This DA is for the Hickson Road Remediation Area only. Remediation for the Block 4 and Block 5 Remediation Areas have been subject of separate development applications SSD 5897 and SSD 6533 respectively.

2.3. Summary site history and key contaminants

The Millers Point gasworks operated on the Declaration Area between 1840 and 1921. The site has subsequently been used for various activities, but predominantly a commercial port facility and public road.

When EPA declared parts of Barangaroo and Hickson Road a “Remediation Site”, it described the nature of contamination as gasworks waste, with the following particular substances: polycyclic aromatic hydrocarbons (PAHs); benzene, toluene, ethylbenzene and total xylenes (BTEX); total petroleum hydrocarbons (TPH); ammonia and cyanide.

The AECOM Remedial Action Plan (RAP) provides more specific details regarding the type, magnitude and location of ground contamination as identified in previous site investigations.

2.4. Definition of site for Hickson Road Remediation DA

For the purposes of the Hickson Road Remediation Development Application, the Site includes the area Hickson Road to be remediated (Site Remediation Area), plus any adjacent land used for the staging and undertaking of the proposed remediation.

The Site Remediation Area comprises the part of Hickson Road within the Declaration Area that requires remediation, per RAP.

2.5. Role of Lend Lease

Lend Lease has been contracted by the Barangaroo Delivery Authority to undertake remediation of the Declaration Area, which includes the Hickson Road Remediation Area.

Lend Lease has also been appointed by the Barangaroo Delivery Authority as the Proponent to undertake the development for Barangaroo South.

2.6. Remedial action plan and methodology

The proposed remediation of the Declaration Area is detailed in the AECOM Remedial Action Plan (AECOM 2013).

The RAP included two potential methodology options for Hickson Road Remediation Area:

- Preferred - In-situ remediation (chemical oxidation); or
- Alternative - Ex-situ remediation (excavate, off-site treatment and disposal and backfill).

The Development Application for Hickson Road Remediation includes for undertaking either the preferred or the alternative method above, with final method to be selected following agreement with the NSW EPA.

3. Available information

Supplementary to the previously completed geotechnical investigations undertaken by Coffey for Barangaroo South, we have carried out a review of our project archives for site investigation data and construction records within and adjacent to the proposed development area. This review has identified a number of previous projects where Coffey was involved within the vicinity of the EPA Declaration Area. These projects include:

- The Bond, Hickson Road, Millers Point
- 38 Hickson Road, Miller Point
- Hickson Road Environmental Report for City of Sydney

Coffey has also carried out a review of historical information, which includes:

- Libraries, council records and Goddan Mackay Logan (heritage consultants)
- Published geological mapping resources
- Historical aerial photographs and maps.

Further information related to the Barangaroo development site has been supplied by Lend Lease. This includes the following documents:

- *Environmental Site Assessment, East Darling Harbour, Sydney, NSW* (June 2007), Environmental Resources Management, report reference 0044432RP02 Rev01 Final
- Data Gap Investigation, EPA Declaration Area (Parts of Barangaroo Site and Hickson Road), Millers Point, NSW (July 2010), AECOM, report reference S4150010
- ERM Pty Ltd (ERM) report reference 0080637R03 Revision 01, *Additional Investigation Works at Barangaroo*, dated July 2008
- AECOM report reference M41500, *Groundwater Discharge Study – Stage 1 Barangaroo Development*, prepared for Lend Lease (Millers Point) Pty Ltd, dated 3 November 2010
- Historic Overlay Plans prepared by Rygate and Company on behalf of LLMP
- Jeffery and Katauskas report, Darling Harbour East
- Maritime Services Board, Works as Executed plans.
- Indicative Preliminary Work Plan for In-situ chemical Oxidation Hickson Road Declaration Area, Barangaroo NSW 11 September 2014.

4. Summary of proposed works for the Hickson Road Remediation Area DA

The following summarises the works proposed as part of the Hickson Rd Remediation Area DA, in undertaking the preferred or alternate method as applicable (with final method selected following agreement with the NSW EPA). For both methods, Hickson Rd is to remain open to traffic, with required temporary road closures/diversion in place during remediation works.

4.1. Preferred method – In-situ remediation

Undertaking remediation of required Hickson Road areas (including footpath) using in-situ chemical oxidation / product extraction. The in-situ remediation method will be SISCO/SEPR (Surfactant enhanced In-Situ Chemical Oxidation and Surfactant Enhanced Product Recovery) or similar in-situ oxidation process.

The in-situ remediation process involves the installation of subsurface wells and piping in Hickson Road, and a temporary staging compound in the road reserve, which facilitate controlled injection of chemical mixtures into the ground, to treat required areas of gasworks contamination in-situ.

The in-situ remediation works are summarised as follows:

- a) Localised pruning of street trees where required to facilitate works
- b) Undertake temporary lane / traffic diversion as required during works
- c) Undertake local service diversion or protection as required
- d) Maintain access to 30 and 38 The Bond driveways
- e) Install remediation infrastructure (wells and piping) in Hickson Rd
- f) Install temporary remediation compound/staging area in Hickson Rd reserve
- g) Install boundary groundwater control walls where required
- h) Undertake in-situ chemical oxidation remediation through controlled injection and extraction
- i) Management of extracted fluids and transfer to on-site water treatment plant, or tankering off-site
- j) If required, undertake localised excavation and off-site disposal (under odour control enclosure)
- k) Undertake detailed environmental monitoring (air, noise, water) for duration of works
- l) Validate remediation per RAP, including groundwater monitoring where required
- m) Decommission (cap and leave in-situ) sub-surface well/piping infrastructure
- n) Re-surface required areas of road/pavement to the council's requirements

If the above preferred method is not undertaken, the works for the alternative method below are proposed to be implemented, as part of this DA.

4.2. Alternative method - Ex-situ remediation

Undertaking remediation through selective excavation of required Hickson Road areas (including footpath), followed by off-site disposal (and treatment where required) of material at licensed facilities, backfilling and re-instatement of road/footpath.

The ex-situ remediation works are summarised as follows:

- a) Removal of street trees where required to facilitate excavation works
- b) Undertake temporary lane / traffic diversion as required during works
- c) Undertake local service diversion or protection as required
- d) Maintain access to 30 and 38 The Bond driveways
- e) Undertake remediation in 2 main stages (east and west)
- f) Temporarily close one half and undertake remediation, while traffic is diverted to other half
- g) Following 1st stage, re-instate remediated half, and re-divert traffic to complete remaining stage
- h) Install boundary groundwater control walls, and walls to facilitate staged excavation, where required
- i) Install odour control structures over excavation area (in stages as required)
- j) Excavate gasworks contamination in stages where required, from beneath road/footpath
- k) Excavate rock, if required, to facilitate access to deep contamination within annulus trench
- l) Transfer excavation water to Barangaroo water treatment plant, for treatment or be transported off site using licensed liquid waste contractors
- m) Transfer excavated material directly off-site to licensed facility for treatment/disposal
- n) Undertake detailed environmental monitoring (eg. air, noise) for duration of works
- o) Validate remediation per RAP
- p) Backfill excavations with suitable imported fill or suitable excavated material
- q) Decommission odour tents
- r) Re-surface road / pavement to the council's requirements
- s) Plant new street trees to replace those removed
- t) Remove temporary traffic diversions

5. Geotechnical overview

5.1. Geology

The Sydney 1:100,000 Scale Geological Sheet indicates that the site locality is underlain by Fill and Quaternary age alluvium overlying Triassic age Hawkesbury Sandstone bedrock. An igneous dyke inferred to be of Jurassic Age is also shown passing through the southern extent of Hickson Road and Block 4 of the site.

5.1.1. Hawkesbury Sandstone

The Hawkesbury Sandstone is described as a fine to coarse grained quartzose sandstone deposited in 1 m to 3 m thick beds and lenses that exhibit either massive or sheet facies. Shale breccia is common at the contacts between beds, with siltstone/shale interbeds forming a minor part of the unit. In some cases these minor shale bands weather preferentially to form softer bands.

The Hawkesbury Sandstone is inferred to represent fluvial deposition in a large braided river system, with massive and cross beds representing deposition from waning flood events and shale interbeds representing overbank and swamp type deposits.

Structurally, there are two main joint sets within the Hawkesbury Sandstone in the Sydney CBD region: one set trending north north east and an orthogonal set trending west north west. The joints are typically sub-vertical, relatively widely spaced and may not be continuous through the sandstone beds. Vertical joints often terminate in shale bands. There are a number of sub-vertical fault zones and joint swarms that have been identified trending roughly north east across the Sydney CBD that can result in more closely spaced jointing and may impact on excavation stability to a greater extent than the more widely spaced joints of the main joint sets.

5.1.2. Pittman LIV Dyke

Igneous dykes and breccia diatremes of Jurassic Age are sparsely distributed throughout the Sydney Region. The dykes within the Sydney region generally consist of linear basaltic rock bodies, typically less than 3m wide intruded into the surrounding country rock. The preferred strike direction is west north west, sub-parallel to the regional joint pattern within the sandstone and shale. The dykes are generally observed extremely weathered and altered to white kaolinitic clay to a depth of between 10m to 20m below ground level.

One of these dykes, a dolerite intrusion, numbered LIV on the Pittman numbering system, is known to trend in a general east west direction within the vicinity of Block 4 of Barangaroo. There are limited sub-vertical joints associated with this intrusion. Experience from nearby projects which have intersected this dyke, including the excavations for development at 38 Hickson Road, indicates that the feature is generally vertical, approximately 3m wide and completely weathered to clay in its upper part. The permeability of the rock mass in the vicinity of the dyke has been found to be relatively high. The rock around the dyke may be more weathered and of lower strength of differing (higher or lower) permeability from the rock further afield.

5.1.3. Quaternary and Recent Sediments

Quaternary and recent alluvial and estuarine sediments occur as channel infills and coastal/marginal marine deposits within the Barangaroo area. The deeper Quaternary sediments are inferred to have been deposited during the last glacial period, or Pleistocene (approximately 120,000 years before present to 10,000 years before present) when sea level oscillation of between -20 m AHD and -120 m AHD occurred. It was during the periods of lower sea level that river systems incised into the underlying bedrock.

In terms of sedimentary stratigraphy, the clay dominated deposits represent the broad lagoon/estuarine type environments associated with elevated sea levels, with the sand units representing higher energy fluvial deposits associated with lower sea levels. Periods of low sea level during the Pleistocene allowed sediments to become exposed and oxidised and thus Pleistocene sediments often exhibit red and orange hues associated with aerial exposure.

During the Holocene Epoch, from approximately 10,000 years ago to the present, the sea level rose to the present level, submerging the eroded land surface and incised river valleys. Recent Holocene sediments are generally normally consolidated, typically soft or loose and are often dark grey in colour owing to their lack of aerial exposure.

5.1.4. Fill

Filling of the site to its current day application was undertaken sporadically throughout the last 150 years (refer Section 5.2 below) leading to the Fill material on site being highly variable in nature and in thickness. By its very nature, fill material is heterogeneous, typically uncontrolled and cannot be easily characterised.

5.2. Site history

The original undeveloped natural shoreline at Barangaroo through the early 1800s comprised rocky outcrops and mangrove swamps. A prominent headland, Cockle Bay Point (later to become known as Millers Point), was present at the northern part of the Barangaroo site with a second, smaller headland known as Soldier's Point located at the northern extent of the present day King Street Wharf development. The natural shoreline to the south of Millers Point ran approximately parallel to, and just east of the existing Hickson Road. The location of the original shoreline, as shown on an 1836 map of the area, is shown on Figure 2.

Substantial amounts of reclamation in the area took place during the mid to late 19th Century, with various wharves constructed perpendicular to the natural coastline (City of Sydney, 1889). A gas works constructed in 1840 on the coastline of the time, was located at the present day location of The Bond on Hickson Road. Historic maps indicate of up to four gas holders were located within the gasworks site during its operation. The largest gas holder, shown located at the south western corner of the present day The Bond, is estimated to have been approximately 45 m in diameter. A smaller 'tar tank' is shown below the present day Hickson Road, approximately mid way between The Bond and 38 Hickson Road, approximately 15 m in diameter. The location of both the former below ground and above ground gasworks infrastructure is presented on Figure 2. It must be noted that the locations of the previous structures is based on interpretation of historic maps of the area and are indicative only.

Construction of Hickson Road was undertaken following the demolition of the gasworks in the mid 1920's. Information suggests that Hickson Road was typically founded on sandstone bedrock where the road passes through the EPA declared area. The present day seawall and wharf structures were constructed typically by sinking concrete caissons approximately 150 m west of the original timber seawall and backfilling.

6. Interpreted sub-surface conditions within the remediation area

6.1. Geotechnical model

A limited number of boreholes have been drilled in the Hickson Road area and these have typically been undertaken to assess the subsoil environmental conditions and generally do not extend to bedrock. Therefore, Coffey has developed the geotechnical model for the site based on geotechnical boreholes drilled for the adjacent Stage 1B site, as well as archive information in the vicinity of the Hickson Road site. We have attempted to classify the sandstone within Hickson Road based on the available data, though it should be noted that weaker rock layers could be present within Hickson Road that could influence the rock classification and may possibly downgrade the assessed rock class.

The subsurface conditions typically comprise the following:

- Asphalt concrete pavement overlying a heterogeneous fill of highly variable thickness (Unit 1), overlying
- Residual soils (Unit 3) and sandstone bedrock (Unit 4).

Table 6.1 presents a summary of the subsurface conditions across Hickson Road Remediation Area.

Table 6.1 – Summary of typical subsurface conditions

Unit	Approx. depth to top of Unit (m)	Approx. thickness (m)	Description
1. Fill	0	Typically 0.9 to 5.5 (between 9 and 10 close to the former gas holders)	An asphalt concrete pavement surfacing observed typically 0.35m to 0.4m thick along the road and footpath. Pavement thickness is found to be up to 0.75m thick close to the previous tar tank and south western gas holder locations. Underlying fill is typically observed between 0.5m and 3.7m in thickness below the pavement layer. Fill generally consists of a mixture of sand and gravel with lesser quantities of clay. The sand and gravel is inferred to have been derived from crushed and/or ripped sandstone. The fill has been identified at greater depths in a number of boreholes, typically at the locations of the former gas holders, including the main gas holder annulus. It is anticipated that buried services may be positioned within pockets of deeper fill not encountered in the boreholes
3. Residual Soil	1.0 to 4.0 (where encountered)	Generally absent to 0.9	Generally a dense sand or stiff sandy clay where encountered. Due to the position of Hickson Road adjacent to a

Unit	Approx. depth to top of Unit (m)	Approx. thickness (m)	Description
			historic cliff line it is likely that much of the residual soils were either eroded or removed during road construction.
4. Sandstone	0.9 to 5.5, (up to 9.75 close to the former gas holders)	Not measured	Typically highly weathered to fresh and medium to high strength from surface, likely due to the excavation of more weathered bedrock during construction of the road. Very low strength and highly weathered sandstone is found in boreholes close to the western boundary and adjacent to the dolerite dyke. Within this zone a small amount of cementitious grout was observed within the upper fractured zone, possibly indicating previous grouting works have been undertaken within the dyke area. For further information regarding the sandstone bedrock refer to Table 6.2.
5. Dolerite Dyke	Unknown but may be close to surface	Not measured	The extension of a known dolerite dyke passes through the southern section of Hickson Road, encountered in Barangaroo investigations and excavations for construction of 38 Hickson Road basement. Extremely to highly weathered near vertical dolerite dyke, approximately 3m wide. Where extremely weathered occurs as very stiff to hard pale grey/white kaolinitic clay. Where highly weathered, typically very low strength pale green with relic fine grained crystalline texture. May have associated weathered/fractured 'dyke-affected zone' within sandstone immediately adjacent to dyke.

The sandstone bedrock has been further sub-divided into a number of separate units based on the Pells *et al.* (1998) rock classification system. These sub-divisions are presented within Table 6.2.

Table 6.2 – Summary of sandstone profile

Unit ⁽¹⁾	Depth to top of unit below bedrock surface (m)	Description
4A. Class V Sandstone	0 (typically less than 1 m thick where present)	Extremely low to low strength, extremely to highly weathered, frequent zones of clay seams, highly fractured or fragmented. At most locations, Unit 4A has been eroded and no longer exists, with the stronger Units 4B or 4C directly below the eroded bedrock surface.
4B. Class IV Sandstone	0 to 0.5 (typically 1 m to 1.5 m thick where present)	Low strength, highly weathered, significant clay seams, fractured. Typically highly permeable. May also occur within Unit 4C as more weathered and fractured sandstone or sandstone containing shale and laminite lenses. Unit 4B may also have been eroded in some locations so that Unit 4C occurs directly below the eroded bedrock surface. Unit 4B is likely to occur close to the margins of the igneous dyke, observed as highly fractured, highly weathered sandstone.
4C. Class III Sandstone	Typically 0.5 to 2	Medium to very high strength, slightly to moderately weathered, fractured. May occur as more fractured/weathered zones within the lower Unit 4D successions. Unit 4C is generally found closer to the bedrock surface within the vicinity of Hickson Road and deeper towards Darling Harbour.
4D. Class II Sandstone or better	Typically 1 to 4	Medium to very high strength, fresh to slightly weathered, slightly fractured to unbroken. Unit 4D is generally found closer to the bedrock surface within the vicinity of Hickson Road and deeper towards Darling Harbour.

Note: (1) Rock classes were assessed based on the Pells et al (1998) rock classification system

Generally, the subsurface information indicates that the buried rock profile is consistent with the original natural shoreline geometry, with bedrock levels generally dropping away from the Hickson Road alignment. Buried cliff lines have been inferred from cored boreholes across Barangaroo South. It is likely that these buried cliff lines extend through the Site, however, due to the limited amount of cored boreholes within Hickson Road of the Barangaroo site confidence in positioning of these features is low.

Figure 3 presents an inferred contour plot of the top of the sandstone bedrock below the Remediation Area based on the historical borehole information. Figure 4 present a cross sectional interpretation of the subsurface conditions across the Hickson Road Remediation Area.

Bedrock levels are found as deep as –17 m AHD along the western extent of Block 5, whereas below the Hickson Road area the bedrock level is observed generally be close to the surface.

6.2. Hydrogeological model

Hydrogeological information has been gained from the following sources:

- ERM Pty Ltd (ERM) report reference 0080637R03 Revision 01, Additional Investigation Works at Barangaroo, dated July 2008
- AECOM report reference M41500, Groundwater Discharge Study – Stage 1 Barangaroo Development, prepared for Lend Lease (Millers Point) Pty Ltd, dated 3 November 2010
- Coffey report reference GEOTLCOV24015AB-AQ, Barangaroo Stage 1 Development – Geotechnical Report, prepared for Bovis Lend Lease, dated 15 October 2010
- Diaphragm Wall Baseline Groundwater Report – Version 1, prepared for Lend Lease Project Management and Construction, dated 27 January 2012
- Coffey report reference GEOTLCOV24015AO-BI, Barangaroo South Stage 1B Geotechnical Investigation and Testing, prepared for Lend Lease Building Pty Ltd, dated 5 February 2014
- Coffey report reference GEOTLCOV24015AO-BP, Barangaroo South Pitman LIV Dyke Hydraulic Testing Report, prepared for Lend Lease Building Pty Ltd, dated 12 May 2014.

On the Stage 1A site, located to the south of the Site, groundwater tidal fluctuations were recorded by Coffey as part of construction monitoring for Stage 1A. Groundwater variation in the soil profile (fill or estuarine sediments) varied from near 100% of tidal variation for piezometers installed near the northern limit of the Stage 1A area within 40m of the harbour wall to 14% in the south east corner of the Stage 1A area near Hickson Road.

Similar results were obtained for the Stage 1B site adjacent to Block 5. Groundwater levels in fill recorded in piezometer BH103 (some 90 m from the waters of Darling Harbour) showed approximately 90% of tidal variation during periods of inactivity on the site while the groundwater levels in fill recorded in piezometer BH101 (near the north east corner of the Stage 1B site) showed little response to tides.

Information held by Coffey indicates that within the area the existing Highest Astronomical Tide (HAT) is 1.175 m AHD and the existing Mean High Water Springs (MHWS) is 0.67 m AHD.

6.3. Observations of contamination during previous investigations

Investigations within the surrounding area have encountered visual and olfactory evidence of hydrocarbon contamination which has been reported in a number of previous reports. Coffey has observed evidence of hydrocarbon contamination during the recent investigations associated with Barangaroo South, within the fill, natural soils and sandstone bedrock. Additionally, Coffey was engaged by Lend Lease to map excavations for the basement to 38 Hickson Road in 2002 in which observations of tar like contamination was noted along a number of rock defects such as major joints and bedding partings. The principal source of tar seepage into the excavation was found to be at approximately -7.7 m AHD, permeating along a thin “stringer” igneous dyke, found to the north of the main Pittman LIV dyke body, and an associated joint swarm. As stated in the RAP, the purpose of remediation in Hickson Road area is to target the primary sources of tar within the fill material and that Remediation within the rock is not required.

The investigations undertaken by Coffey on the Barangaroo South site were designed to assess the geotechnical conditions across the site and were not intended to assess possible contamination. The drilling methods adopted did not provide a method of assessing contamination levels nor penetration depth of contamination.

7. Geotechnical considerations

7.1. Foundation design parameters

Services diversion, groundwater control, installation of a perimeter retention wall and construction of excavation odour control structures adjacent to and within the Hickson Road Remediation Area are proposed to facilitate the remediation works for the ex-situ remediation method. A retaining wall shall also be required for the in-situ option. Pells *et al* (1998) rock mass classification system provides guidance as to ultimate and serviceability end bearing pressure and shaft adhesion available for each rock class. The allowable pressures for serviceability considerations are based on the amount of test hole and proving data available and a settlement not exceeding 1% of the footing width. Due to the temporary, and likely flexible nature of the odour control structure, higher bearing pressures may be able to be adopted if required using a limit state approach combined with an assessment of possible ground movements.

Based on the information supplied it is unlikely that strip or pad footings are to be adopted for the temporary remediation work area odour control structure (ex-situ remediation option only) due to the requirement to subsequently excavate beneath the structures and the possible large amount of contaminated spoil generation. Therefore, as a guide, bored piles founded on sandstone may be designed in accordance with the serviceability or limit state design parameters given in Table 7.1.

Table 7.1 - Foundation design parameters

Unit	Working Stress Design Values		Limit State Design Values		
	Allowable End Bearing (MPa)	Allowable Shaft Adhesion (kPa)	Ultimate End Bearing (MPa)	Ultimate Shaft Adhesion (kPa)	Elastic Modulus (MPa)
4A	1	50	3	150	100
4B	1.5	150	10	500	500
4C	3.5	400	20	800	800
4D	8	800	80	1500	1600

Notes:

- Bearing pressure values assume a minimum embedment of 0.5 m into the relevant bearing stratum.
- Shaft adhesion values assume minimum embedment of 3 pile diameters into the relevant stratum
- Bearing pressure values are dependent on level of assessment carried out during construction.
- Nominated values are appropriate for the modulus provided. Higher values may be possible but a lower modulus would apply and higher settlements may occur.

To adopt the parameters in the Table 7.1, piles should have a minimum embedment of 0.5 m into the relevant class of rock and bases cleaned of debris and a clean socket of roughness category R2 or better is required. Shaft adhesion values may have to be reduced if wall smear or polish is present.

Geotechnical strength reduction factors for piled footings should be based on guidance found within AS2159-2009 Piling – Design and Installation. Based on the existing ground information a site risk rating of 2.5 - 3 and a design risk rating of 1.5 may be adopted. These risk ratings should be combined with an installation risk rating, to be assessed by the foundation designer, to produce an overall risk category and overall geotechnical strength reduction factor. Serviceability Limit State deflections should be checked using the elastic properties presented in Table 7.1.

Due to the large size and likely lightweight nature of the temporary remediation odour control structures, piles should be checked for uplift capacity. For uplift capacity the shaft adhesion values given in Table 7.1 should be multiplied by 0.6. In addition to shaft adhesion, the uplift capacity should be checked for a cone pull-out failure mode assuming a cone angle of 70° considering the submerged weight of the rock, following complete excavation of soil, and adopting a factor of safety of 1 against pull out. Uplift capacity for groups of piles will need to take into account interaction between piles which will lead to lower individual pile capacities.

Advice on the amount of excavation of bedrock required during remediation is currently unavailable, however, it is not anticipated to extend significantly beyond the existing top of bedrock levels. Where excavations into bedrock are required it is recommended that piled supports for temporary remediation work area odour control structures be closely co-ordinated with excavation levels as bearing pressures may need to be downgraded should rock be excavated close to footings.

Dependant on allowable bearing pressure requirements of piled footings, a number of piles should be inspected by a geotechnical engineer or engineering geologist to assess the sandstone. Bored piles would be suitable for the temporary odour control structure supports. Either open bored, continuous flight auger or displacement type piles may be adopted. Displacement piles are likely to minimise spoil generation within the Remediation Area. The choice of piled footing should be made taking into consideration of the retention wall options.

7.2. Retaining walls

It is expected that perimeter retention structures to gas structures at 36 Hickson Road are required to facilitate both the preferred *in-situ* and alternate *ex-situ* remediation works. Secant piles or soldier piles with jet grout column could be considered at this location.

Additional temporary retention walls may need to be constructed within Hickson Road to facilitate excavation in controlled stages for the *ex-situ* method.

Along the Hickson Road Remediation Area the retention systems are likely to consist of relatively shallow (<5m) walls retaining fill, except at discrete positions where service trenches, former gas works structures and buried infrastructure extend to greater depths.

The depth of remediation appears to be in the range of 2 m to 3 m below existing ground level, with the exception of a localised zone located at north western corner of the Hickson Road Remediation Area and at the Tar tank location.

The following options (or equivalent) could be considered for the temporary groundwater control and retaining wall:

- Secant piled wall
- Sheet piles installed within a slurry trench
- Bored soldier piles with jet grout infill (grout infill would need to extend to the top of the bedrock)

Regardless of which retaining wall type is adopted, the temporary wall would need to be temporarily supported to enable excavation and remediation works to be carried out safely.

The design of the retaining walls will require specific consideration of the staging of excavations, particularly where excavations on either side of retention structures are required, such as along the western boundary of Hickson Road.

Temporary wall support systems along Hickson Road warrant careful consideration. Steeply inclined anchors could be provided to minimise interaction with the remediation works in the western part of Hickson Road.

It is anticipated that some over excavation in sandstone along the annulus trench might be required to facilitate access to the contamination within the trench.

Ground anchors may be installed through the retaining walls using design parameters presented in Table 7.5. The following design parameters may be adopted for the design of temporary retention walls:

Table 7.2 – Retaining wall design parameters for soil

Unit	Description	Bulk Unit Weight (kN/m ³)	Effective Cohesion (kPa)	Effective Friction Angle (degrees)	Undrained Shear Strength (kPa)	Elastic Modulus (MPa)	Poisson's Ratio
1	Fill*	18-20	0	30	-	5-15	0.35
2B	Alluvium	18	0	25	25	5-10	0.35
3	Residual Soil	20	5	25	75	60	0.35
4A	Class V Sandstone	23	20	35	250	80	0.3

* Fill parameters are based on existing in-situ material, alternate parameters may be more suitable for engineered fill placed during *ex-situ* remediation.

Table 7.3 – Retaining wall design parameters for rock

Unit	Bulk Density (kN/m ³)	UCS (MPa)	Mass Modulus E (MPa)	Poisson's Ratio	Geological Strength Index, GSI ⁽¹⁾	Material Constant, m _i ⁽¹⁾	Disturbance Factor, D ⁽¹⁾
4B	23	8	500	0.3	40	14	0.15
4C	24	14	1500	0.3	55	15	0.1
4D	24	22 – 25	2500 - 3000	0.2	70 - 80	16 - 17	0

(1) As defined by Hoek *et al.* (1995)

The GSI, m_i and D values given in Table 7.3 can be used to obtain effective cohesion (c') and friction angle (φ') parameters using the generalised Hoek-Brown failure criterion (Hoek, *et al.*, 2002). It should be noted that these parameters are dependent upon the in-situ stress. It should also be noted that the equivalent c', φ' values computed from the above approach are likely to be conservative for

the rock mass in general. For the design of retaining walls the impacts of the potential occurrence of large scale, low strength and adversely oriented defects should be considered. The potential for such conditions to occur locally will need to be carefully assessed by experienced geotechnical personnel during construction and the design reviewed and modified (if necessary) to suit the site conditions.

The design of retention systems is geotechnically complex, and best carried out using soil-structure interaction analysis methods. For preliminary design purposes, we have provided some recommended earth pressure coefficients for the various units in Table 7.4 below. However, it must be pointed out that these values are based on empirical methods and may not provide satisfactory solutions in some cases.

Table 7.4 – Recommended earth pressure coefficients for preliminary design

Unit	Description	'Active' Earth Pressure Coefficient, K_a	'At Rest' Earth Pressure Coefficient, $K_0^{(1)}$
1	Fill	0.35	0.5
2B	Alluvium	0.35	0.5
3	Residual Soil	0.35	0.5
4A	Class V Sandstone	0.27	0.5

(1) Values provided assume a lateral movement of the wall of about 0.2% of the wall height is allowed to occur. *In situ* "at rest" earth pressure coefficient may be significantly higher for Units 3 and 4A.

Active earth pressure coefficients should be adopted where wall movements of about 1% of the wall height can be tolerated. At rest pressure coefficients should be adopted where less movement can be tolerated. However, it should be understood that a well-constructed wall will still undergo movements of the order of 0.1% to 0.3% of the wall height where at rest pressures are adopted.

Retaining walls should be designed for hydrostatic pressures unless permanent and effective drainage can be provided. Applicable surcharge loads should be added to earth pressures.

The earth pressure coefficients for Class IV or better sandstone are variable and dependent on global effects of defects. Variability also occurs due to the *in situ* stress environment and geometry of the excavation.

Due to the presence of Class III or better sandstone close to the bedrock surface, typically directly below the shallow fill materials along the Hickson Road boundaries, together with the risk of unacceptable impacts to buried structures and local residents, driven steel sheet pile retaining walls are considered unsuitable. The design and choice of retention systems adjacent to Hickson Road should take into consideration the relatively shallow depth of the fill, the presence of good quality rock near bedrock surface and the variability of retained fill material for anchoring of walls.

7.3. Ground anchor design parameters

Dependant on the type of retention system adopted during design and the tolerances of possible wall movement during remediation temporary ground anchors may be required. The capacity of the anchors in the fill will vary significantly and it is recommended that each anchor would have to be tested to confirm the capacity achieved. Reduction in anchor capacity may be required to allow for group effects. Anchors should also be checked for an anchor pull out failure mechanism assuming a 45° failure cone in addition to bond strength.

Due to the shallow bedrock levels along the Hickson Road alignment it may be possible to install anchors into the sandstone.

Due to the high groundwater table within the vicinity of the remediation works care must be taken to fully support the saturated soil materials during drilling and installation of the anchors to avoid loss of ground and consequential surface settlement.

For the preliminary design of anchors, the following allowable and ultimate bond stresses are recommended:

Table 7.5 – Recommended Bond Stresses for Ground Anchors

Unit	Allowable (Working) Bond Stress (kPa) ⁽¹⁾	Ultimate Bond Stress (kPa) ⁽¹⁾
4A	75	150
4B	250	500
4C	600	1200
4D	1000	2000

Notes

1) For bond lengths not less than 3 m and not more than 7m

The recommended values are given on the provision that each anchor is proof loaded to 1.3 times maximum working load prior to locking off at the required working load. As discussed above, anchoring of retention systems should take into consideration the requirement of possible excavation on either side of the retaining wall during *ex-situ* remediation.

The lengths and inclination of anchoring of retention systems should take into consideration the presence of existing buried services, basements and retention staging. Where existing services or structures may preclude the installation of ground anchors, alternative options of either a cantilevered wall or internal propping may be more suitable.

7.4. Dewatering and water ingress (Ex-Situ Remediation)

An assessment of inflow to the excavation for the ex-situ remediation method has been made based on the following assumptions:

- Impermeable cut off walls for the soils enclose the site and penetrate into sandstone bedrock
- The effects of individual high permeability features, such as igneous dykes, sheared zones etc., are not taken into account – inflows associated with such features, if present, would be additional
- Sandstone permeability within Barangaroo South site has been assessed based on the results of packer testing to be in the order of 5×10^{-6} m/s
- Hydraulic connection is present between the sandstone and waters of Darling Harbour.

The above assumptions are considered reasonable based on the information available but it must be recognised that groundwater inflow prediction is strongly dependant on ground conditions. As a result inflows may depart significantly from the assessment presented herein.

An assessment of the volume of water which would need to be removed from the fill materials within Hickson Road to achieve dewatering to the top of bedrock is presented in the following table.

Table 7.6 – Assessed volume of dewatering required at Hickson Road Remediation Area

Remediation Area	Approximate Size of Area (m ²)	Average Thickness of Saturated Sediments (m)	Estimated Volume of Water (ML)
Hickson Road	5000	0.50	0.75

The above calculations do not allow for seepage beneath the cut off wall, which would need to be considered when calculating dewatering rates. Seepage below the individual cut off walls for Hickson Road Remediation Area is likely to be limited to less than 5L/s, however, localised high permeability features such as the igneous dyke may produce higher flows.

The volumes of water to be removed from Hickson Road may be achieved through conventional groundwater pumping from extraction wells. Where groundwater extraction is required for remediation on site treatment of possible contamination will be required.

It is likely that some surface settlement may occur during the dewatering process. It is unlikely that the structures along the Hickson Road Remediation Area will be affected by settlement during dewatering activities as sandstone foundations are unlikely to experience movement. Buried services and roadways constructed in/on saturated soils may experience some settlement during dewatering activities. The positioning of the dewatering points and staging of dewatering should be managed to minimise disruption to those services to remain in place during remediation.

It is recommended that further assessment of the zone of influence of dewatering activities, and the potential effect on buried services in undertaken prior to execution of the alternate *ex-situ* remediation methods.

Sewer and stormwater services are known to be present across the Hickson Road Area, however, we understand that during the remediation works these services shall need to be protected in-situ or temporarily diverted. Appropriate diversions of SWC stormwater servicing Hickson Road and Millers Point would be provided prior to remediation.

7.5. Impacts on Existing Assets

7.5.1. Preferred Method – In-Situ Remediation

The In-situ method will involve the injection of chemical fluids at controlled rates into the underlying soils. Due to the permeable nature of the fill materials within the Hickson Road Remediation Area, and the typically unconfined nature of the material it is unlikely that injection of fluids within this area will have a significant effect on groundwater levels in surrounding areas. However, localised pore pressure increase will occur in response to the injection of fluids. The magnitude of this pressure increase will vary from location to location in accordance with the variable nature of the fill materials and buried structures and services.

Due to the proximity of the basement structures to the harbour and the generally low lying area of Hickson Road it is likely that retention structures associated with The Bond and the two adjacent pumping stations will have been designed to consider groundwater surcharge to ground level. In order to reduce the likelihood of adverse structural affects to the adjacent existing basements the injection remediation methodology should not allow the groundwater levels to reach the ground surface. The remediation methodology should incorporate water level monitoring measures during the works. Potential for uplift of lightly loaded foundations, such as those found within the public domain area, street furniture and lighting should be assessed.

An increase in hydrostatic pressure caused by raised groundwater levels at the structure boundaries may cause an increase in seepage of groundwater into the basement structures. It is expected that the existing groundwater storage and treatment facilities would have capacity to accommodate localised and short term increases in groundwater seepage, however, this should be confirmed prior to operation. The pre-remediation pilot trial shall also be used to assess potential groundwater fluctuations.

The use of a cavitating fluid can, in some cases, cause localised pressure build up during injection. It is possible that this localised pressure concentration will materialise at the ground surface, typically taking the path of least resistance. It is unlikely that potential pressure build up would have an adverse impact on the nearby concrete buried structures, however, the potential for uplift of lightly loaded foundations should be assessed and addressed as appropriate.

An assessment of the chemical impacts of the injection materials or by-products on the structural elements of the buildings is outside the scope of this desk top study. A review of literature associated with the chemical injection remediation technologies indicates that the use of agents such as hydrogen peroxide together with catalytic compounds, have the potential to generate heat and gas. It is recommended that an assessment of these and other chemical impacts on structural units is performed prior to operation.

In summary, it is anticipated that the impacts expected to arise from chemical reactions will be minor, however the impacts on substructures and services should be verified prior to commencement of the works.

7.5.2. Alternative Method – Ex-Situ Remediation

During the excavation of the Hickson Road Remediation Area the retaining structures for the following will be temporarily exposed:

- The Bond
- Existing pumping station to the west
- A historic decommissioned pump station to the east.

Information provided by Lend Lease indicates that during construction of The Bond a low height (<2m) temporary soldier pile wall was installed along the Hickson Road boundary. Anecdotal evidence provided by Lend Lease suggests that lateral restraint was provided during construction with the installation of two rows of anchors. Structural drawings of The Bond supplied by Lend Lease suggest that a 300mm thick reinforced concrete wall was constructed internally of the temporary soldier pile wall, which in turn was covered with a blockwork wall. The reinforced concrete wall is shown to extend to a point below the lowest basement floor level along the Hickson Road boundary. A site inspection of The Bond basement structure was undertaken on 11 November 2010 which confirmed the presence of a blockwork wall covering a concrete wall to the Hickson Road boundary.

During excavation and construction of the basement to The Bond the former main gas holder annulus was intersected. The gas holder annulus was originally excavated as a trench into the sandstone bedrock approximately 1.5m wide to approximately -6.6m AHD. Where the basement wall intersected the annulus a series of secant piles with temporary ground anchors were installed. Two rows of ground anchors were installed at approximately 0.75m AHD and -2.70m AHD during bulk excavation of the annulus and surrounding rock. The following Plate 7.1 presents the position of the secant pile wall and the upper anchored waler beam within the annulus prior to bulk excavation of the building basement.



Plate 7.1 Photograph showing main gas holder annulus, secant pile wall and upper waler beam and ground anchors (Source: Lend Lease)

Structural drawings supplied by Lend Lease of the basement construction to 38 Hickson Road indicate temporary soldier pile shoring of the near surface soils was undertaken prior to bulk excavation for the four level basement. The drawings show up to 13 temporary ground anchors were installed at the soldier locations, close to the base of the shoring wall. No information is provided as to the constructed height of the soldier pile wall, however, it may be assumed that the wall was founded within the sandstone bedrock, likely to be less than 3m below ground level. The drawings indicate that basement excavation was taken to approximately -8.7m AHD within the sandstone bedrock, with the sandstone face covered with a blockwork wall.

Additional buried structures known to exist along the Hickson Road alignment include the decommissioned pumping station, located immediately south of The Bond, and Sydney Water Hickson Road Pumping Station, SP1129, located directly opposite The Bond. No information has been supplied as to the construction of the decommissioned pumping station, however, we understand the structure extends to approximately -6.5m AHD, within the footprint of the former main gas holder. SWC stamped drawings supplied by Lend Lease indicate the current pumping station, located on the western boundary of Hickson Road within Block 5 of Barangaroo, is housed within a reinforced concrete structure founded at approximately -8m AHD. A 450mm diameter gravity fed sewer line is shown entering the pumping station at approximately -5.2m AHD within sandstone bedrock. A 400mm diameter rising main exits the pumping station, initially supported on a mass concrete support. Supplementary drawings suggest the rising main was directionally drilled below Hickson Road generally between -1m AHD and -2m AHD. No drilling records have been supplied from the rising main construction, however, it is assumed that much of the alignment will have been constructed within the sandstone bedrock. The supplied drawings indicate the sewer rising main

passes through the gas holder annulus at two locations. No information is available to suggest the method of support to the service at these two locations.

It is understood that remediation by Ex-Situ methods along Hickson Road will involve the excavation of the near surface soils, likely to include fill and residual soils, in part. It is not expected that significant excavation of sandstone bedrock is to be undertaken as part of the remediation works. However, it is understood that some localised 'chasing' of contamination into the sandstone bedrock may be required but the extent of chasing of contamination would practically be confined to the extent outlined in the RAP. Furthermore, some over excavation in rock around the annulus trench may be required to facilitate access to contamination within this trench.

With careful excavation adjacent to the temporary shoring walls to the top of sandstone bedrock we believe that structural impacts can be limited to superficial damage of the wall panels of both buildings. Information on the drawings supplied indicates the retention systems were temporary and as such are likely to be providing no structural support to the buildings. Removal of the soil materials adjacent to the wall panels may cause some lateral movement of the shoring, though it is unlikely that this movement will affect the buildings or surrounding ground.

Excavation adjacent to the decommissioned and existing pumping stations is likely to cause minimal damage, if undertaken in a careful manner. It is unlikely that Ex-Situ remediation will lead to structural damage. No information has been supplied to indicate the construction methods of either pumping station walls, therefore care should be employed during excavation to assess whether ground anchors or temporary shoring may be damaged.

Where excavation of the sandstone bedrock close to the neighbouring buried structures is required it is recommended that an excavation method be chosen to limit vibration and potential structural damage. The use of low vibration and noise excavation techniques, such as rock saws or splitting, may be necessary where bedrock excavations close to sensitive structures. Where excavation of sandstone bedrock is required directly adjacent to existing buried structures further detailed assessment of the unloading effects of material removal is recommended.

It is considered that with careful planning and by adopting industry standard construction methods the groundwater control, retention and remedial works staging walls, together with material removal, associated with Ex-Situ remediation may be executed without adversely impacting the adjoining structures.

7.5.3. Impacts to Existing Services

A number of existing services are present below ground generally running parallel to Hickson Road including sewerage, water, storm water and electricity. Additionally, a number of services also pass across the road reserve, most notably the 400mm diameter rising main and 450mm diameter sewer which crosses the road between The Bond and 38 Hickson Road at depth.

Coffey understands that existing services will either be protected in place or diverted.

7.5.4. Preferred Method – In-Situ Remediation

This option involves the controlled injection of fluid chemicals into the contaminated soils whilst monitoring groundwater levels.

Introduced chemical agents have potential to migrate into groundwater (and surface) drainage systems associated with nearby structures (particularly building basements). In addition, chemical agents have potential to be introduced into leaks in service pipes (stormwater, sewer, water and communication conduits etc.) Potential for such fugitive emissions and their impacts should be considered prior to execution of the works.

Where injection levels are controlled such that they do not affect the natural groundwater fluctuations of the site it is unlikely that the presence of injection fluid will have an adverse effect on the buried services on site. Where groundwater levels are allowed to increase above those naturally occurring within the area, corresponding to a point above the mean spring tide, saturation of the service trenches may occur and possibly cause a reduction in the bearing capacity of the trench backfill.

Trench backfill to shallow buried services is likely to comprise material of higher permeability than that of the surrounding ground. Where injection of fluids into the ground occurs close to service trenches movement of this fluid is likely to occur along the trench. The impacts on the remediation process, such as additional loss of remediation chemicals, of these possible groundwater conduits should be considered during design stage.

The presence of certain remediation chemicals plus catalysts within the ground has a potential to generate heat and pressure. An assessment of the effects of heat on the buried services should be undertaken during design as well as assessment of the effects of corrosion or chemical attack.

Where differential settlement of buried assets occurs during remediation there is a risk of damage and disruption to services. The tolerance levels of buried assets are a measure of the age and condition of the services. An empirical criterion for limiting differential settlement of utilities at which damage would occur has been developed by Bracegirdle et al (1996). The criteria was developed specifically for cast iron piped services, but has been used as a preliminary method of distinguishing utility types that are more at risk of damage than others. The following induced slope limitation may be applied to the services that are to remain in place during the ex-situ remediation:

- Relatively rigid pipes, >200mm diameter less than 1/140
- Relatively flexible pipes, >200mm diameter 1/140 to 1/40

7.5.5. Alternative Method – Ex-Situ Remediation

Information supplied by Lend Lease indicates that prior to commencing excavation during remediation all shallow buried services within the Hickson Road alignment are proposed to be supported in-situ or diverted.

Limits on vibration as summarised in Section 7.6 should be taken into consideration during retention wall construction and material excavation. Piled retaining structures should be designed to maintain a minimum of 1m clearance between the service obvert and pile toe, additionally, the temporary cut-off wall should avoid vertical loading of the service. Permanent support, such as mass concrete footings, should be provided to the SWC rising sewer main where it passes through the main gas holder annulus following removal of annulus infill.

Care will need to be exercised in the design and installation of temporary anchors to avoid damage to services to be retained and in particular the sewers tunnelled into rock along Hickson Road.

Some settlement of the buried services and authority pits located above the bedrock surface can be anticipated where dewatering activities are required prior to excavation. The differential settlement limits presented in the earlier section should be used in detailed design as a guide to assess the likelihood of damage during dewatering.

7.5.6. Impacts to Existing Pavements

The in-situ remediation option requires traffic diversions during installation of the injection wells, with sections of the Hickson Road and footpaths stripped of asphalt to allow positioning of injection lines, monitoring equipment and ancillary equipment. Following installation of the injection equipment it is anticipated that these sections of road and footpath will be temporarily restored to provide unimpeded traffic flow during remediation.

To provide protection of existing pavements particular attention should be given to monitoring of the following areas during injection:

- The ground surface, in particular, in the immediate area surrounding the injection well any line on a heterogeneous ground surface (concrete joints or cracks, base of a wall, outer limits of a road box), or the ground surface itself for any deformation (e.g. bitumen bulging, concrete lifting).
- Monitoring wells in the vicinity of the injection area should act as ‘sentinels’ for warning signs of imminent surfacing of fluids and gaseous emissions, and should be monitored for increases in water level and vapour concentrations. Injection rates should be controlled if an unsustainable increase is noted in these parameters.

Where, through additional injection of fluids during remediation, groundwater levels are anticipated to rise above those occurring naturally there is a risk that saturation of pavement sub-base may cause loss of foundation material or strength and lead to settlement and/or pavement deterioration, such as surface rutting, cracking or asphalt delamination. Groundwater monitoring piezometers should be installed to assess the fluctuations in the groundwater level, supplemented by regular visual surveys of the pavement surface in the vicinity of the remediation works to observe potential signs of distress.

7.6. Vibration

Structures that are likely to be sensitive to construction induced vibrations would include but not be limited to the following:

- Structures founded on relatively shallow footings
- Water retaining structures, such as the Sydney Water sewer pump station SP1129, existing service pits and sewers
- Masonry structures and structures with movement sensitive finishes such as rendered or tiled walls
- Structures that are in poor condition, with pre-existing damage
- Buried services close to excavations
- Retained services, either above or below bedrock level.

Additionally, during remediation the following receptors may be affected by construction noise and vibration:

- Construction site accommodation
- Residents of 38 Hickson Road
- Commercial occupants of neighbouring buildings.

7.6.1. Vibration limits for structures

Currently there is no Australian Standard for assessment of structural building damage caused by vibrational energy. In terms of the most recent relevant vibration damage goals, Australian Standard AS 2187: Part 2- 2006 *‘Explosives - Storage and Use - Part 2: Use of Explosives’* recommends the frequency dependent guideline values and assessment methods given in BS 7385 Part 2-1993 *‘Evaluation and measurement for vibration in buildings Part 2’* as they “are applicable to Australian conditions”.

The British Standard sets guide values for building vibration based on the lowest vibration levels above which damage has been credibly demonstrated. These levels are judged to give a minimum risk of vibration-induced damage, where minimal risk for a named effect is usually taken as a 95% probability of no effect. Sources of vibration that are considered in the standard include demolition, blasting (carried out during mineral extraction or construction excavation), piling, ground treatments (e.g. compaction), construction equipment, tunnelling, road and rail traffic and industrial machinery.

The British Standard discusses levels at which 'cosmetic', 'minor' and 'major' categories of damage might occur. The suggested limits (guide values) are for transient vibration to ensure minimal risk of cosmetic damage to residential and industrial buildings. The Standard recommends that the peak particle velocity is used to quantify vibration and specifies damage criteria for frequencies within the range 4 Hz to 250 Hz, which is the range usually encountered in buildings.

For most construction activities involving intermittent vibration sources such as rock breakers, piling rigs, vibratory rollers, excavators and the like, the predominant vibration energy occurs at frequencies greater than 4 Hz (and usually in the 10 Hz to 100 Hz range).

The peak vibration limits set for minimal risk of 'cosmetic' damage for frequencies above 4 Hz, which are most common and relevant to buildings, are:

- 15mm/s for un-reinforced or light framed structures (e.g. residential or light commercial buildings)
- 50mm/s for reinforced or framed structures (e.g. industrial or commercial buildings, such as The Bond or 38 Hickson Road)

'Minor' damage is considered possible at vibration magnitudes which are twice those given and 'major' damage to a building structure may occur at levels greater than four times those values.

The values relate to transient vibrations and to low rise buildings. Continuous vibration can give rise to dynamic magnifications due to resonances. Rock breaking/hammering and sheet piling activities are considered to have the potential to cause dynamic loading and it may be appropriate to reduce the transient values by 50%.

Both The Bond and 38 Hickson Road structures are reinforced concrete structures and vibratory impacts on these buildings should be assessed as such. Buried structures such as the SWC SP1129 and the decommissioned pumping station adjacent to The Bond may also be assessed under the reinforced or framed structures limits.

Installation of the groundwater control and retention walls involved with the ex-situ remediation may cause vibrations. It is recommended that a full assessment of the type of construction necessary, together with the type of construction plant available is undertaken with regard to vibratory impacts. This analysis should take into consideration the building structure, vibration source, dominant frequencies and dynamic characteristics of the structure to assess an applicable 'safe' vibration level.

It is likely that low impact groundwater control and retention wall construction methods such as bored piles and jet grouting are anticipated to be employed.

Bulk excavation of the soil units is unlikely to cause vibration beyond that of vehicle movements, however, where excavation of the sandstone bedrock is required careful consideration of the excavation methods should be undertaken prior to removal. Bulk excavation of the soils during ex-situ remediation is likely to be undertaken using a track mounted excavator equipped with a toothed bucket. Where excavation of the underlying sandstone bedrock is required excavation methods should be chosen to limit vibrations. The use of impact hammers and rock breakers should be avoided adjacent to sensitive receptors, where possible, within the vicinity of vibration sensitive receptors, instead the use of rock saws or splitting may be more appropriate.

Dilapidations surveys should be carried out on neighbouring buildings prior to commencing excavation, with vibration monitoring carried out prior to and during excavation assess likelihood of damage to nearby sensitive structures.

7.6.2. Vibration limits for historic structures

The German standard DIN 4150 – Part 3 – “Structural Vibration in Buildings – Effects on Structures” provides recommended maximum levels of vibration that reduce the likelihood of building damage caused by vibration. In particular the standard presents minimum ‘safe limits’ of vibration at low frequencies for sensitive structures, such as historical structures with preservation orders, of 3 mm/s (at frequencies less than 10 Hz). The limits increase as the frequency content of the vibration increases, with limits of between 3 to 8mm/s at frequencies between 10 and 50 Hz, and up to 10mm/s at 100 Hz.

In line with the recommendations in the previous section, a more detailed analysis of the building structure, vibration sources, dominant frequencies and dynamic characteristics of the structure would be required to assess the applicable safe vibration level.

7.6.3. Vibration limits for underground utilities

Installation of cut off walls and excavation during remediation adjacent to buried services to be preserved should take into consideration the effects of vibration. As such the underground services, such as the sewer rising main and the gravity sewers, may be considered to be particularly sensitive to vibration. Vibration limits close to these buried services may be more stringent than those presented for structures.

For each buried service that is to be retained during remediation the acceptable vibration limits will be based on a number of factors, including, but not limited to, service age, service condition, service construction. The vibration limits for these underground services should be assessed on a case by case basis in consultation with the asset owner following dilapidation surveys.

7.6.4. Vibration limits for human receptors

Structural vibration in buildings can be detected by and affect occupants of buildings adjacent to and at distance from construction sites in many ways. Australian Standard AS 2670.2—1990 Evaluation of human exposure to whole-body vibration Part 2: Continuous and shock induced vibration in buildings (1 to 80 Hz) presents mechanisms for assessing limits of vibration on human receptors, whereby annoyance or complaints may be received. The Standard should be used to assess threshold values for the human receptors that may be impacted during remediation of Block 5.

The following Table 7.8 presents an indication of typical human perception of vibration based on frequency content between 8 Hz and 80 Hz.

Table 7.7 – Vibration and human perception of motion

Approximate vibration level (mm/s)	Degree of perception
0.10	Not felt
0.15	Threshold of Perception
0.35	Barely Noticeable
1.0	Noticeable
2.2	Easily Noticeable
6.0	Strongly Noticeable

8. Management of environmental impacts

Coffey is satisfied that the proposed remediation works being considered, if undertaken in a carefully planned and managed manner, can be executed without unacceptable environmental impacts on adjacent landowners and stakeholders.

Where geotechnical impacts as a result of the remedial works arise, Coffey has provided recommendations in Table 8.1 to mitigate such impacts to within acceptable limits.

Table 8.1 - Geotechnical issues of remediation

Potential Geotechnical Issues	Possible Mitigation Strategies
Structural impacts associated with cut off wall installation	Careful consideration of the type of groundwater control and retention wall should be undertaken to assess the most suitable retention with respect to performance, effect on adjacent buried structures, and effect on adjacent building users and spoil generation. Suitable monitoring plan to be developed prior to commencement of excavation. A monitoring plan is to address the requirements of survey monitoring of adjacent structures and infrastructure that may be impacted to assess potential movements during excavation.

9. Conclusion

Coffey has been engaged by Lend Lease to prepare a specialist geotechnical desktop assessment report to accompany a Development Application for Remediation of Hickson Road at Barangaroo to be submitted to the Minister for Planning pursuant to the Part 4 of the *Environmental Planning and Assessment Act, 1979*.

Coffey has undertaken a geotechnical assessment of the proposed works contemplated and is satisfied that the proposed remediation works being considered, if undertaken in a carefully planned and managed manner, can be executed without unacceptable geotechnical impacts on adjacent landowners and stakeholders.

Where significant geotechnical impacts are expected to arise, Coffey has provided advice as to how these impacts can be managed and mitigated to acceptable levels.

10. Limitations

The assessments provided herein are based on discrete/specific geotechnical and environmental investigation data typically gathered from external sources. No assurances can be given as to the accuracy and reliability of this information. As more information becomes available during the remediation process, the geotechnical interpretation and recommendations presented within this report should be reviewed.

In addition, subsurface conditions can change over relatively short distances and the subsurface conditions encountered at the test locations may not be representative of subsurface conditions across the site. We recommend that a geotechnical engineer/engineering geologist be engaged during the remediation to confirm that subsurface conditions are consistent with design assumptions.

The attached document entitled “Important Information about Your Coffey Report” presents additional information on the uses and limitations of this report.



Important information about your **Coffey** Report

As a client of Coffey you should know that site subsurface conditions cause more construction problems than any other factor. These notes have been prepared by Coffey to help you interpret and understand the limitations of your report.

Your report is based on project specific criteria

Your report has been developed on the basis of your unique project specific requirements as understood by Coffey and applies only to the site investigated. Project criteria typically include the general nature of the project; its size and configuration; the location of any structures on the site; other site improvements; the presence of underground utilities; and the additional risk imposed by scope-of-service limitations imposed by the client. Your report should not be used if there are any changes to the project without first asking Coffey to assess how factors that changed subsequent to the date of the report affect the report's recommendations. Coffey cannot accept responsibility for problems that may occur due to changed factors if they are not consulted.

Subsurface conditions can change

Subsurface conditions are created by natural processes and the activity of man. For example, water levels can vary with time, fill may be placed on a site and pollutants may migrate with time. Because a report is based on conditions which existed at the time of subsurface exploration, decisions should not be based on a report whose adequacy may have been affected by time. Consult Coffey to be advised how time may have impacted on the project.

Interpretation of factual data

Site assessment identifies actual subsurface conditions only at those points where samples are taken and when they are taken. Data derived from literature and external data source review, sampling and subsequent laboratory testing are interpreted by geologists, engineers or scientists to provide an opinion about overall site conditions, their likely impact on the proposed development and recommended actions. Actual conditions may differ from those inferred to exist, because no professional, no matter how qualified, can reveal what is hidden by earth, rock and time. The actual interface between materials may be far more gradual or abrupt than assumed based on the facts obtained. Nothing can be done to change the actual site conditions which exist, but steps can be taken to reduce the impact of unexpected conditions. For this reason, owners should retain the services of Coffey through the development stage, to identify variances, conduct additional tests if required, and recommend solutions to problems encountered on site.

Your report will only give preliminary recommendations

Your report is based on the assumption that the site conditions as revealed through selective point sampling are indicative of actual conditions throughout an area. This assumption cannot be substantiated until project implementation has commenced and therefore your report recommendations can only be regarded as preliminary. Only Coffey, who prepared the report, is fully familiar with the background information needed to assess whether or not the report's recommendations are valid and whether or not changes should be considered as the project develops. If another party undertakes the implementation of the recommendations of this report there is a risk that the report will be misinterpreted and Coffey cannot be held responsible for such misinterpretation.

Your report is prepared for specific purposes and persons

To avoid misuse of the information contained in your report it is recommended that you confer with Coffey before passing your report on to another party who may not be familiar with the background and the purpose of the report. Your report should not be applied to any project other than that originally specified at the time the report was issued.

Interpretation by other design professionals

Costly problems can occur when other design professionals develop their plans based on misinterpretations of a report. To help avoid misinterpretations, retain Coffey to work with other project design professionals who are affected by the report. Have Coffey explain the report implications to design professionals affected by them and then review plans and specifications produced to see how they incorporate the report findings.



Important information about your **Coffey** Report

Data should not be separated from the report*

The report as a whole presents the findings of the site assessment and the report should not be copied in part or altered in any way. Logs, figures, drawings, etc. are customarily included in our reports and are developed by scientists, engineers or geologists based on their interpretation of field logs (assembled by field personnel) and laboratory evaluation of field samples. These logs etc. should not under any circumstances be redrawn for inclusion in other documents or separated from the report in any way.

Geoenvironmental concerns are not at issue

Your report is not likely to relate any findings, conclusions, or recommendations about the potential for hazardous materials existing at the site unless specifically required to do so by the client. Specialist equipment, techniques, and personnel are used to perform a geoenvironmental assessment. Contamination can create major health, safety and environmental risks. If you have no information about the potential for your site to be contaminated or create an environmental hazard, you are advised to contact Coffey for information relating to geoenvironmental issues.

Rely on Coffey for additional assistance

Coffey is familiar with a variety of techniques and approaches that can be used to help reduce risks for all parties to a project, from design to construction. It is common that not all approaches will be necessarily dealt with in your site assessment report due to concepts proposed at that time. As the project progresses through design towards construction, speak with Coffey to develop alternative approaches to problems that may be of genuine benefit both in time and cost.

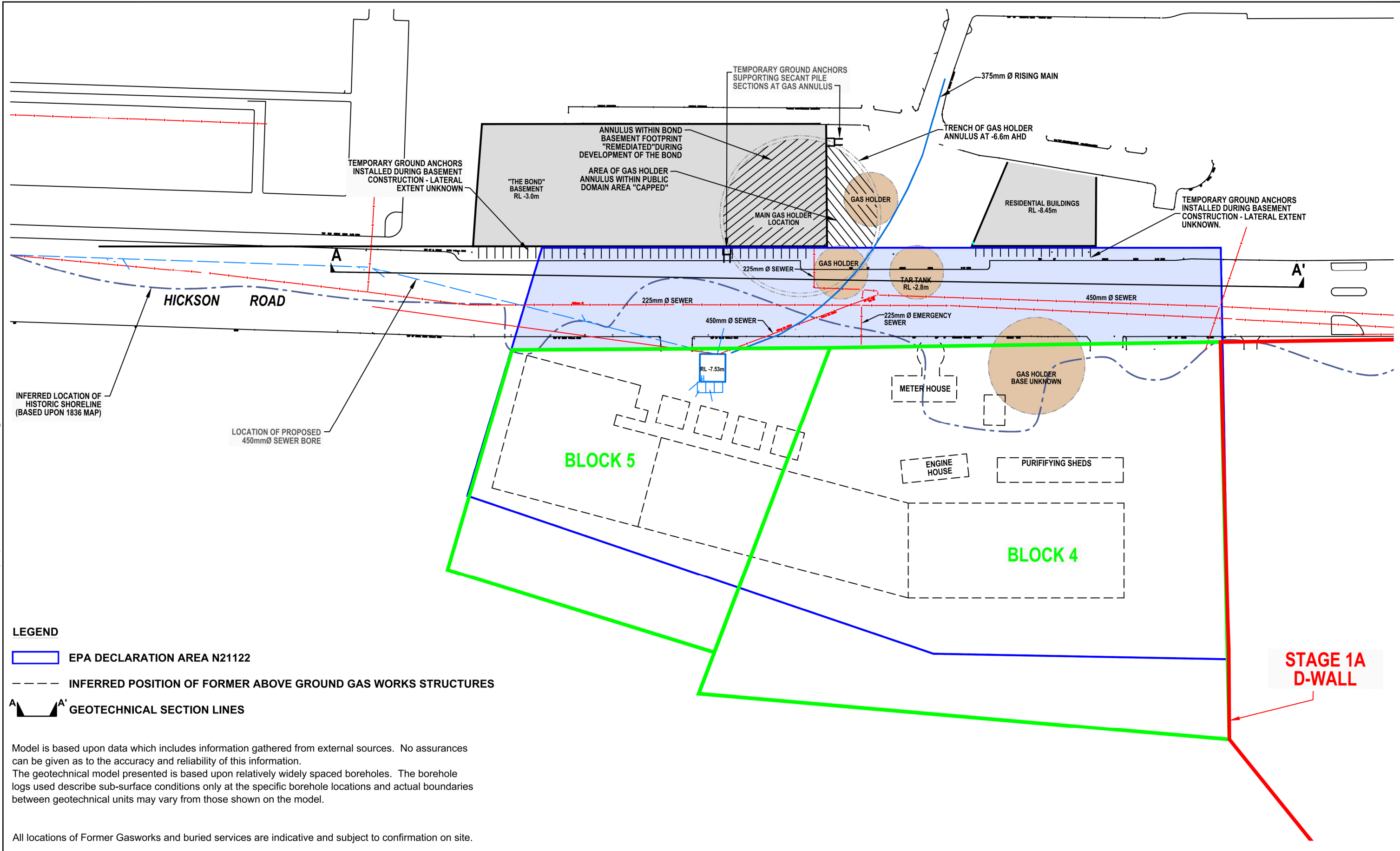
Responsibility

Reporting relies on interpretation of factual information based on judgement and opinion and has a level of uncertainty attached to it, which is far less exact than the design disciplines. This has often resulted in claims being lodged against consultants, which are unfounded. To help prevent this problem, a number of clauses have been developed for use in contracts, reports and other documents. Responsibility clauses do not transfer appropriate liabilities from Coffey to other parties but are included to identify where Coffey's responsibilities begin and end. Their use is intended to help all parties involved to recognise their individual responsibilities. Read all documents from Coffey closely and do not hesitate to ask any questions you may have.

* For further information on this aspect reference should be made to "Guidelines for the Provision of Geotechnical information in Construction Contracts" published by the Institution of Engineers Australia, National headquarters, Canberra, 1987.

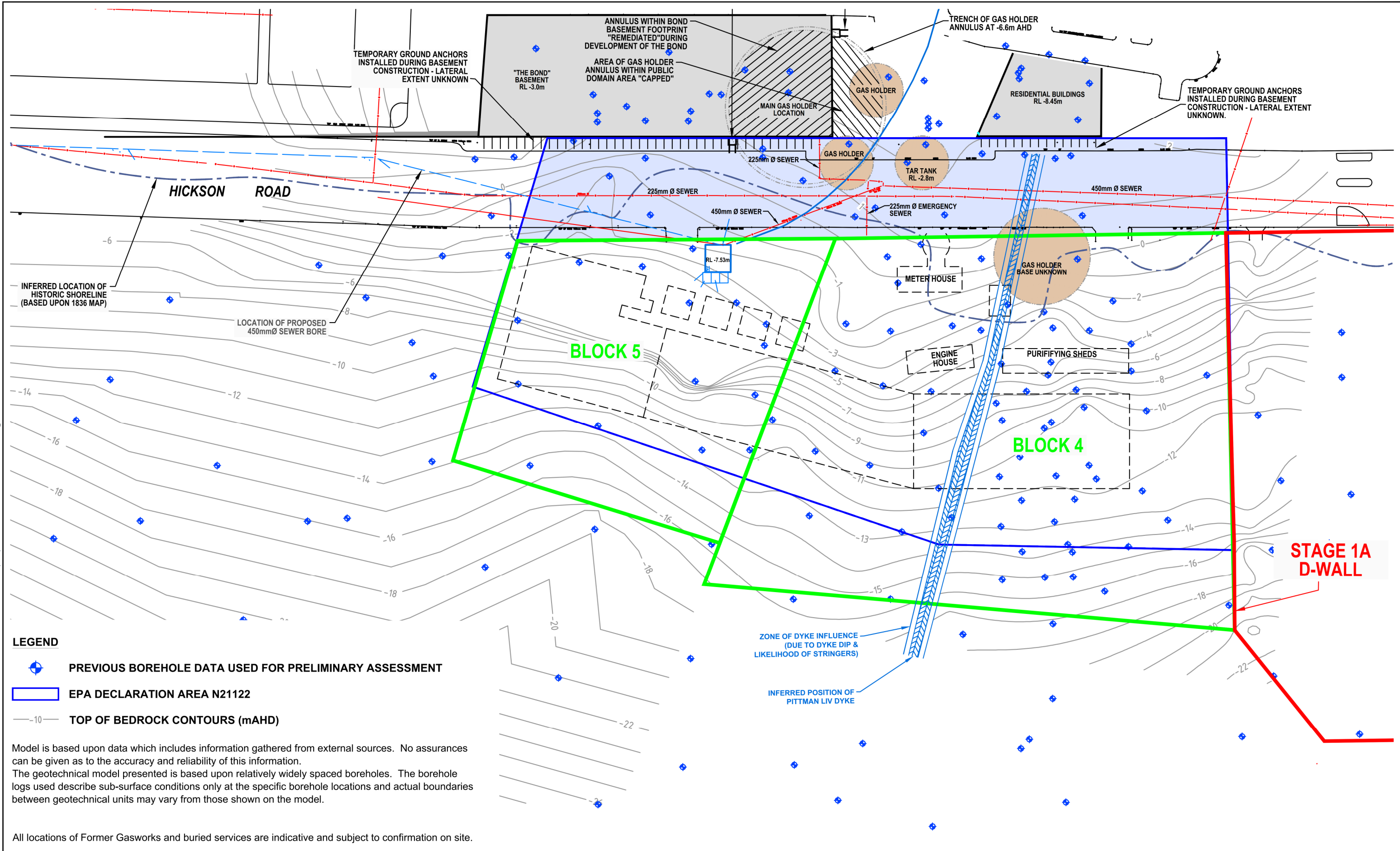
Figures

This page has been left intentionally blank

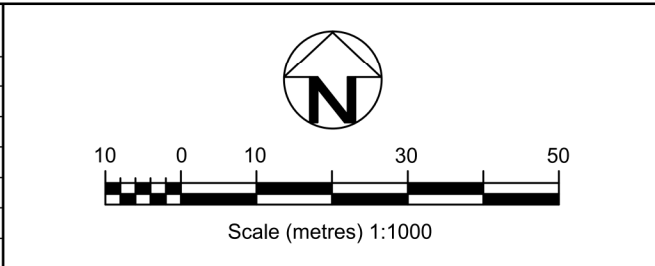


revision	no.	description	drawn	approved	date		drawn	MG / AW		client: LEND LEASE (MILLERS POINT) PTY LTD		
							approved	PS		project: BARANGAROO HICKSON ROAD		
							date	11 / 09 / 14		title: LOCATION OF EPA DECLARATION SITE SHOWING GEOTECHNICAL SECTION LOCATION		
							scale	AS SHOWN		project no: GEOTLCOV24015AL-AE	figure no: FIGURE 2	rev: A
							original size	A3				

PLOT DATE: 11/09/2014 1:39:17 PM DWG FILE: F:\GEO\TECHNICS\11\PROJECTS\GEOTLCOV24015AL BARANGAROO SPECIALIST DESK TOP STUDY - LEND LEASE (BOND)\HICKSON ROAD\FIGURES AE\GEOTLCOV24015AL-AE.FIGURE 2.3.DWG



revision	no.	description		drawn	approved	date

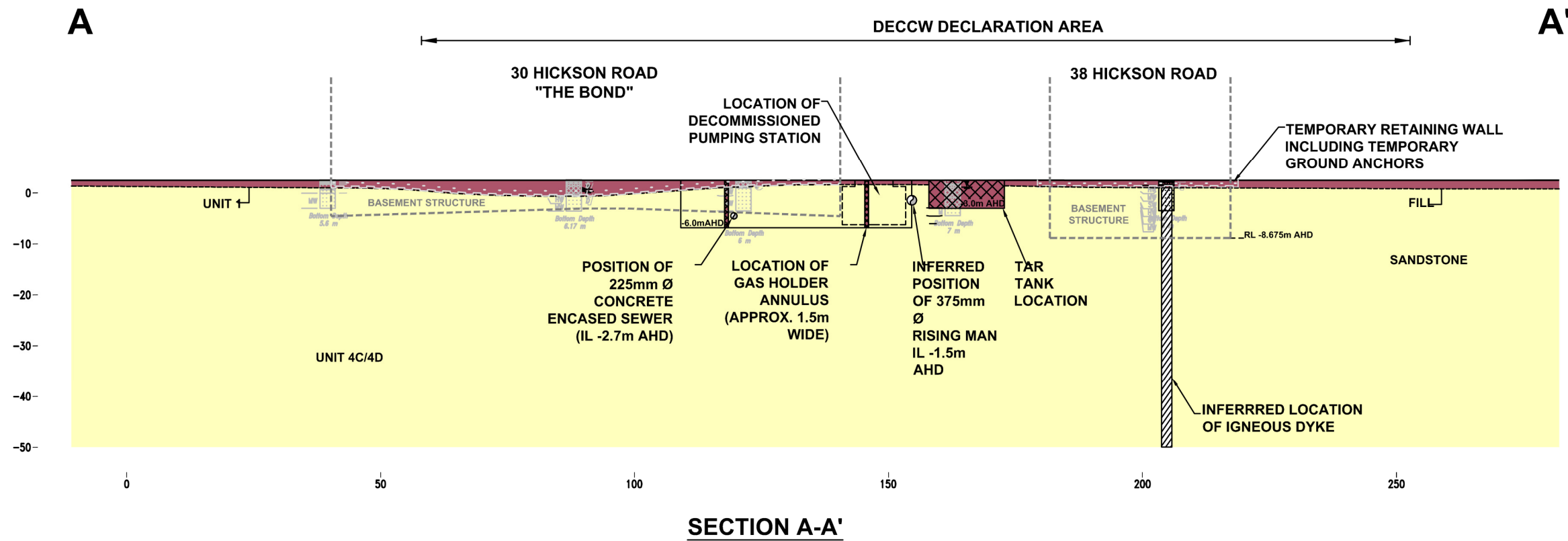


drawn	MG / AW
approved	PS
date	11 / 09 / 14
scale	AS SHOWN
original size	A3



client:	LEND LEASE (MILLERS POINT) PTY LTD		
project:	BARANGAROO HICKSON ROAD		
title:	HISTORICAL BOREHOLE LOCATION PLAN WITH INFERRED BEDROCK CONTOURS		
project no:	GEOTLCOV24015AL-AE	figure no:	FIGURE 3
		rev:	A

PLOT DATE: 11/09/2014 2:07:15 PM DWG FILE: F:\GEO\TECHNICS\1 PROJECTS\GEOTLCOV24015AL BARANGAROO SPECIALIST DESK TOP STUDY - LEND LEASE (BOND)\HICKSON ROAD\FIGURES AE\GEOTLCOV24015AL-AE.FIGURE 2.3.DWG



LEGEND

-  INFILLED BELOW GROUND GASWORKS STRUCTURE
-  UNIT 1 (Fill)
-  UNIT 2A (Holocene Estuarine Sediments)
-  UNIT 2B (Pleistocene Alluvium)
-  UNIT 4A/4B (Class V & Class IV Sandstone)
-  UNIT 4C/4D (Class III or better sandstone)
-  INFERRED POSITION OF GEOTECHNICAL UNITS
-  PREVIOUS INVESTIGATION BOREHOLES

NOTE:
1. ALL LOCATIONS OF BURIED STRUCTURES AND SERVICES ARE INFERRED FROM INFORMATION PROVIDED BY LLMP, ALL POSITIONS ARE INDICATIVE AND ARE TO BE CONFIRMED ON SITE.

revision	no.	description	drawn	approved	date	10 0 10 30 50 Horizontal Scale (metres) 1:1000 10 0 10 30 50 Vertical Scale (metres) 1:1000	drawn	MG / AW		client:	LEND LEASE (MILLERS POINT) PTY LTD		
							approved	PS		project:	BARANGAROO HICKSON ROAD		
							date	11 / 09 / 14		title:	CROSS SECTION A-A'		
							scale	AS SHOWN		project no:	GEOTLCOV24015AL-AE	figure no:	FIGURE 4
							original size	A3				rev:	A