Northern Territory Government

Stage 2a, Darwin City Waterfront Development, Clean Up to the Extent Practicable of Groundwater - Report

Anchorage Court, Darwin

August 2014

Executive summary

This submission to the Northern Territory Environmental Protection Agency (NT EPA) is to establish that Clean Up to the Extent Practicable (CUTEP) of groundwater has taken place in the site located at Anchorage Court, Darwin (the Stage 2a development area) located within the Darwin City Waterfront Redevelopment (the site).

The NT EPA has not published guidance specific to the conduct of environmental audits. In the absence of such guidance, it has been assumed that the audit should be carried out generally in accordance with the Victorian environmental audit system, as outlined by Part IXD of the Victorian Environment Protection Act 1970, and the associated policies and guidelines. As confirmed by the NT EHA/NRETA in their correspondence dated 13 December 2006, this CUTEP report has been prepared in accordance with the requirements of Victorian EPA Publication 840.1, The Clean Up and Management of Polluted Groundwater (February 2014).

A review of the available information pertaining to the groundwater contamination status at the site indicates that the concentrations of TPH, iron and ammonia have potential to adversely affect beneficial uses of the groundwater, particularly *maintenance of ecosystems* and *primary contact recreation and aesthetics*, and the concentrations of TPH have potential to adversely affect *human consumers of food*. The assessment has shown that the TPH does not pose an unacceptable risk to human health.

The remediation program has involved considerable work to identify sources of contamination and to remove free NAPL that has been identified. Where hydrocarbon impacted material was noted within the area of the basement excavation, it was removed. The assessment, remediation and validation work has provided reasonable certainty that:

- NAPL is not present in areas where buildings are present in amounts that would affect the use of the site;
- Residual hydrocarbon contamination is contained on the site and is limited to small pockets of contamination that is most likely to be present in the northern section of the site;
- Hydrocarbon are being degraded and concentrations are reducing over time; and
- The remediation and management strategy involving control through a sub-surface drain (if required) can be expected to provide an effective method of ensuring that any residual contamination will not adversely affect the receiving waters (in particular the lagoon).

The drain has a 50 year design life and it is proposed to be maintained until monitoring shows that contamination at the site will not adversely affect the waters of the lagoon if the drainage system is no longer maintained. In this respect, it is noted that a trial closure of the drain is currently underway and this may become permanent if it is considered that groundwater will no longer present a risk to beneficial uses.

If an Environmental Auditor determines that contamination risks no longer exist and that the subsoil drain is no longer required, the Northern Territory Government may cease maintaining the drain. It is noted that a closure of the drain is currently being trialled to confirm that the lagoon will not be impacted by discharges of contaminated groundwater. The decision whether the drain can remain closed impacts the wider Waterfront area and will be considered separate to this audit. The Ground Water Management Plan will obtain information that will allow confirmation that the situation is satisfactory with the drain closed.

It is proposed that in addition to the sub-surface drain, other controls will be implemented to avoid adverse effects of contaminated groundwater, including:

- The site shall be managed to prevent oily water entering the basement and other subsurface structures. The requirement for a condition requiring tanking of the basement was considered and it was concluded that the probability of oily water entering the basement is low and tanking is not required to preclude oily water ingress. However, it is noted that (uncontaminated) groundwater could enter basements when the water table is high, and the auditor understands that the basement has been tanked to avoid this.
- The management of groundwater in accordance with a Groundwater Management Plan (GMP). This Plan will include measures to ensure that contaminated groundwater is not impacting on the lagoon, measures to prevent the use of groundwater at the site, and a program of groundwater quality and level monitoring together with trigger levels for further action and contingency plans if trigger levels are exceeded.

With respect to determining if it is practicable to carry out further remediation, it is noted that the benefit of further remediation would be to reduce the time over which the drain can be shut down, or to provide more certainty that the residual groundwater contamination will not adversely affect the lagoon.

Options for such further remediation would be:

- Continued operation of the sub-surface drain until it is certain that the contamination no longer poses a concern to the lagoon beneficial uses;
- Excavation and removal of contaminated soil and materials that might form a source of contamination by hydrocarbons and other contaminants;
- Treatment of contaminated groundwater; and/or
- Installation of a reactive barrier along the shore line to treat contamination that might still migrate to the lagoon.

As it seems likely that the drain may have already satisfied its intended purpose and it is possible that the operation of the drain may cease, the auditor considers that the most practicable approach is the first of these options. It is noted that a trial closure of the drain is currently underway to determine if remediation has been achieved. If this works should show that further remediation is required, then this can be undertaken by returning the drain to operation and waiting some further time for reduction in the concentrations of hydrocarbon to acceptable levels to occur.

With respect to the other options listed above, an analysis concludes that these are unlikely to change the risk profile, are logistically very difficult and are very costly, and may pose a risk in terms of the further works involved and their potential to impact on the aesthetic enjoyment of the site and the beneficial uses of the lagoon.

In view of these considerations, the auditor considers that the current level of clean-up is consistent with Clean Up to the Extent Practicable. The auditor notes that groundwater monitoring will be undertaken to ensure that groundwater pollution does not impact on the site development, and URS has identified a number of contingency options should this not be the case, which are detailed in the Groundwater Management Plan.

This report is subject to, and must be read in conjunction with, the limitations set out in Section 1.4 and the assumptions and qualifications contained throughout the Report.

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Appendices

1. Audit background information

This submission to the Northern Territory Environmental Protection Agency (NT EPA) is to establish that Clean Up to the Extent Practicable (CUTEP) of groundwater has taken place in the Stage 2a development area of the Darwin City Waterfront Redevelopment (the site). The report has been prepared with reference to various reports by URS as referenced in Table 2 of this report (and attached in Appendix B of this report), supplemented by the auditor's own observations.

1.1 Background summary information

Site details and information regarding the auditor's appointment are summarised in Table 1.

Table 1 Details on the appointment of the auditor and site description

Item	Description
Name of Auditor	Peter Nadebaum
Term of appointment of Auditor by Victorian EPA	Initially appointed 16 May 1990 currently appointed until 25 September 2015
Owners of the site	Northern Territory Government under the Administration of Department of Planning and Infrastructure.
Person requesting the audit	Terry O'Neill of the Department of Infrastructure and Planning and Environment.
Title Information	Certificate of Title Lots 9196 and part of 9197, Lot Plans LTO2014/058A, LTO2014/058B and LTO2014/058D.
Municipality	City of Darwin
Planning Authority	Darwin Development Consent Authority
Zoning	Central Business Darwin under the City of Darwin Planning Scheme
Current Occupier	Site is currently undergoing remediation and construction

1.2 Audit legislative requirements

1.2.1 Requirements for an Audit

Section 51 of the NT *Planning Act (2007)* requires the consent authority when considering a development application to take into account, amongst other items:

51(d) *an environment protection objective within the meaning of the Waste Management and Pollution Control Act that is relevant to the land to which the application relates;*

51*(g)* *if a public environmental report, or an environmental impact statement, has been prepared or is required under the Environmental Assessment Act in relation to the proposed development – the report or statement and the results of any assessment of the report or statement under that Act by the Minister administering that Act;*

The requirement for remediation of the site was identified in the EIS prepared under the NT *Environmental Assessment Act (1982).*

The Development Permit for the site requires that an independent environmental auditor appointed under the *Environment Protection Act 1970 (Victoria)* provides a Statement of Environmental Audit verifying that “the site has been remediated in such a way that it is suitable for its intended use(s) and any conditions on the Statement are to be complied with in full.”

Prior to use, the developer must obtain a “Certificate of Occupancy” from an independent approved Building Certifier. A Certificate of Occupancy will not be provided unless a “Certificate of Compliance” has been provided by the Development Consent Authority (DCA) confirming all permit conditions have been met (Under Clause s65 of the *Planning Act* NT 1999).

The Northern Territory *Waste Management and Pollution Control Act* 1998, Section 68 specifies that:

“(*1) The Chief Executive Officer must cause to be established and maintained a register of -*

(a) persons qualified to perform environmental audits for the purposes of an environmental audit program;”

Currently persons listed on this register include:

- ‘persons appointed to be environmental auditors (Contaminated Land) for the purposes of section 53S of the Victorian *Environmental Protection Act 1970’;* and
- Site auditors accredited under the NSW *Contaminated Land Management Act 1997*.

Dr Peter Nadebaum of GHD is appointed as an auditor under the Victorian Environment Protection Act, and was appointed through GHD to conduct an environmental audit of the Darwin Waterfront area / development.

The audit was undertaken in accordance with Section 47d of the WMPC Act which states that:

An environmental audit is an evaluation of any of the following:

(d) the likelihood of waste management problems or pollution resulting in environmental harm occurring and the adequacy of safeguards in place to prevent their occurrence or limit their impact on the environment.

1.2.2 Audit methodology

The NT EPA has not published guidance specific to the conduct of environmental audits. In the absence of such guidance, it has been assumed that the audit should be carried out generally in accordance with the Victorian environmental audit system consisting of Part IXD of the Victorian Environment Protection Act, 1970, and the associated policies and guidelines. The site assessment approach is in accordance with that specified in the National Environmental Protection Measure for Assessment of Site Contamination 1999 (as amended 2013), consistent with the requirements of the *National Environment Protection Council (Northern Territory) Act 1994*.

This approach is consistent with the Northern Territory Government Department of Planning and Infrastructure (DPI) request for tender for the audit that specified a work requirement that the environmental audit be undertaken to ‘confirm the condition of the site and whether it is suitable for the proposed use in general conformance with the “Guidelines for Issue of Certificates and Statements of Environmental Audit” Victorian EPA publication 759b Version 1.2 June 2002’. (It is noted that this has been superseded by 759.2 released in February 2014.)

Where it is considered that Victorian guidance may be inappropriate, guidance has been requested by the auditor from the NT EHA/DNRETA (the authority previously responsible for environmental management in the Northern Territory prior to the establishment of the EPA), such as for the purpose of defining Beneficial Uses at the site, and it has been assumed that such advice overrides requirements within the Victorian legislation. In respect to this audit, the auditor (Dr Peter Nadebaum) wrote to the NT EHA/DNRETA on the 28 November 2006 outlining the proposed approach to the audit. The reply from NT EHA/DNRETA dated 13 December 2006, accepted the approach proposed by GHD. These letters are attached as Appendix A to this report.

As specified by the NT EHA/NRETA in this correspondence, this CUTEP report has been prepared in accordance with the requirements of Victorian EPA Publication 840.1, The Clean Up and Management of Polluted Groundwater (February 2014).

A CUTEP report for Stage 1 of the waterfront area was previously prepared by the Auditor, *Northern Territory Government, Department of Planning and Infrastructure, Environmental Audit, Stage 1, Darwin City Waterfront Development, Clean Up to the Extent Practicable of Groundwater – Report* dated 26 March 2008, and submitted to NT EPA. This CUTEP report for Stage 2a follows a similar approach.

1.3 References

The auditor has referred to the documents presented in Table 2 in making his assessment of whether groundwater has been cleaned up to the extent practicable.

Table 2 Documents and other information reviewed for determination of CUTEP

Author	Date	Document Title
URS Pty Ltd	November 2003	Phase I Site Contamination and Geotechnical Preliminary Report and Sampling and Analysis Plan – Darwin Waterfront Project
URS Pty Ltd	December 2003	Phase 2 - Detailed Site Contamination Investigation and Field Geotechnical Investigation Report – Darwin Waterfront Project. Volume 1 to 6
URS Pty Ltd	28 September 2004	Darwin City Waterfront Development Project, Pre-Remediation Site Works Soil Sampling Report. Summary Report.
URS Pty Ltd	October 2004	Phase 3/4 Detailed Site Contamination Investigation Report – Darwin Waterfront Project. Final Report.
URS Pty Ltd	9 August 2005	Remedial Action Plan – Version 6 Final, Darwin City Waterfront Redevelopment
URS Pty Ltd	24 August 2005	Darwin City Waterfront – Annual Report for Quarterly Groundwater Monitoring 2004-2005. Draft
URS Pty Ltd	31 January 2007	Darwin City Waterfront: Quarterly Groundwater Monitoring 2005-2006. Draft Report
URS Pty Ltd	7 February 2007	Letter – Fuel Line Validation Requirements
URS Pty Ltd	24 April 2009	Letter – Groundwater Monitoring Event February 2009 – Darwin Waterfront Redevelopment
URS Pty Ltd	29 April 2009	Groundwater Monitoring Report 2007 – 2008 – Darwin Waterfront Redevelopment. Draft Report
URS Pty Ltd	30 April 2009	Groundwater Management Plan, Darwin City Waterfront Redevelopment, including latest scope revision dated 20 June 2014.
URS Pty Ltd	4 August 2009	Letter – Soil and Surface Water Assessment of the PDI Beach Area

Author	Date	Document Title
URS Pty Ltd	27 September 2010	Final Report, Darwin City Waterfront, Stage 2a Remediation Work Plan.
URS Pty Ltd	9 November 2010	Letter Report – Stage 2a Future Management of Asbestos.
URS Pty Ltd	13 May 2011	Darwin City Waterfront Redevelopment, Groundwater Monitoring Report 2009 – 2010. Draft Report
URS Pty Ltd	5 December 2012	Letter – Subsoil Drain Annual Monitoring Report – December 2011 to October 2012
URS Pty Ltd	19 April 2013	Darwin City Water Waterfront Redevelopment – Groundwater Monitoring Report, December 2010 to March 2012.
URS Pty Ltd	16 July 2013	Darwin City Water Waterfront Redevelopment – Annual Groundwater Monitoring Summary, March 2012 to December 2012.
URS Pty Ltd	21 January 2014	Letter – Darwin Waterfront Precinct – Scope Revision of April 2009 Groundwater Management Plan.
URS Pty Ltd	24 January 2014	Darwin City Water Waterfront Redevelopment – Annual Groundwater Monitoring Summary, March 2013 to June 2013.
URS Pty Ltd	3 February 2014	FINAL REPORT, Validation Report – Stage 2a Residential Validation Report
URS Pty Ltd	20 February 2014	Email –"Waterfront Stage 2a CUTEP – document follow up" from Tim Smith of URS
URS Pty Ltd	6 March 2014	Stage 2A Qualitative Risk Assessment, Darwin City Waterfront, Darwin, Northern Territory.
URS Pty Ltd	March 2014	Darwin Waterfront Lagoon Monitoring – Trace Metal Analysis in Shellfish (Cockles)

1.4 Disclaimer

This report titled *Northern Territory Government, Environmental Audit, Stage 2a, Darwin City Waterfront Development, Clean Up to the Extent Practicable of Groundwater - Report* ("Report") has considered the requirements of The Waste Management and Pollution Control Act NT 1998 and has been prepared in accordance with the general principles for undertaking audits, as outlined by Part IXD of the Victorian Environment Protection Act 1970, and the associated policies and guidelines.

The Report represents the Auditor's opinion of the condition of the site in relation to the presence and impact of contamination of groundwater at the site and its suitability for beneficial uses and whether groundwater has been cleaned up to the extent practicable. This Report:

1. has been prepared by Peter Nadebaum of GHD Pty Ltd ("GHD") and his team as indicated in the appropriate sections of this Report for Northern Territory Government;
2. may be used and relied on by Northern Territory Government;
3. may be used by and provided to EPA;
4. may be provided to other third parties but such third parties' use of or reliance on the Report is at their sole risk; and
5. may only be used for the purpose as stated in Section 1 of the Report (and must not be used for any other purpose).

To the maximum extent permitted by law, all implied warranties and conditions in relation to the services provided by GHD and the Report are excluded unless they are expressly stated to apply in this Report.

The services undertaken by the Auditor and his team in connection with preparing this Report were undertaken in accordance with current profession practice and by reference to relevant environmental regulatory authority and industry standards in accordance with Part IXD of the Environment Protection Act 1970.

The opinions, conclusions and any recommendations in this Report are based on assumptions made by the Auditor when undertaking the audit and preparing the Report. The assumptions are specified throughout this Report.

In undertaking the audit and preparing this Report, the Auditor is required to make judgments regarding the completeness, reliability and accuracy of the information, and the potential for contamination to impact human health and the environment. The Auditor makes these judgments based on the information available, the potential impact of contaminants based on the current scientific understanding of the significance and behavior of contaminants, the specific characteristics of the contaminants matrices and current regulatory policy and legislation. The nature of contaminated site investigations is such that there is always some uncertainty in these matters; as new information can arise, the science underlying these matters can change, and regulatory policy and legislation can change. The Auditor and his team have formed their opinion on the basis of the information available and their understanding of the current science and regulatory policy and legislation, applying processes and considerations in accordance with professional practice. It is possible that new information, a changed scientific understanding or changed regulatory policy and requirements will become available in the future that may lead to a different interpretation. The Auditor and GHD expressly disclaim responsibility for changes that arise because of any such new information, changed science or changed regulatory policy or legislation.

The Auditor and GHD have prepared this Report on the basis of information provided by the Northern Territory Government, the assessment consultant and others who provided information to GHD (including Government authorities). The Auditor and GHD have verified the information received to the extent practicable and within the scope specified in the Guidelines for Issue of Certificates and Statements of Environmental Audit (Publication 759.2, EPA Victoria, 2014). However, there may be some information which the Auditor and GHD cannot independently verify or check (“Unverified Information”).

The Auditor and GHD are not responsible for the Unverified Information, including (but not limited to) errors in, or omissions from, the Report, which were caused or contributed to by errors in, or omissions from, the Unverified Information.

This Report should be read in full and no excerpts are taken to be representative of the findings of this Report.

2. Site background information

2.1 Site description

The location of the Darwin Waterfront Redevelopment is shown in Figure 1 of this report. This CUTEP submission applies only to the Stage 2a area (the site) of this redevelopment, and is shown in Figure 2. The site is located at Anchorage Court, Darwin and encompasses the whole of building 5, building 6 and open space areas, but only the part of building 4 where earthworks will be carried out during this stage of construction (refer to section 2.2.1 for further details). Construction works are currently in progress within the Stage 2a area.

Table 3 Summary site information

Site Locality	Figure 1 shows the location of the Waterfront Redevelopment Project and Figure 2 defines the site boundary.
Site Area	Approximately 1.41 hectares
Surrounding Land Use	North: Kitchener Drive and the escarpment leading to Darwin City. North-west: An active fuel supply pipeline is located adjacent to Kitchener Drive along the northern boundary of the site. The fuel line runs from the Naval fuel supply facility situated to the northeast of the site to the naval docking area located to the south-west of the site. North-east: The completed construction of the Stage 1 Waterfront re-development and the escarpment leading to the central Darwin city. Beyond that is the Naval fuel depot including large fuel storage tanks. East: Stage 1 Waterfront Re-development: Residential Mixed Use Complex, Hospitality building with inset multi-storey carpark with open space parkland, wave pool/lagoon and the Darwin Entertainment and Convention Centre. South: The boating lagoon, Kitchener Bay and the wider Darwin Harbour. West: Stage 2 development site and the wider Darwin Harbour. Activities formerly located in this area include the Shell bitumen plant, Northern Cement Plant, ore handling area, workshops, sulphuric acid storage tank, and incinerator. Currently these areas are being used to stockpile soil and as an unsealed car parking area. The Naval wharf and docking facilities remain to the south-west of the site.
Topography of Audit Area	The topography of the local area slopes very gently towards Darwin Harbour to the south. To the north-north- west is a steep escarpment. Stokes Hill and the escarpment are the closest major topographical features of the site.
Structures remaining on Audit Area	None of the original structures remain on the Audit Area. Site development works have already commenced on the site.
Vegetation within Audit Area	At commencement of development the site was covered in a combination of asphalt, soil and fill with some grass and vegetation which appeared to be healthy. Development is now close to completion and there is no longer any vegetation present at the site (with the exception of a few minor weeds).

2.2 Proposed development

The proposed development at the site comprises the following:

- Three residential, university and/or commercial apartment towers with ground level consisting of mixed residential and commercial space, referred to as buildings 4, 5 and 6;
- Ground level terrace style apartments as part of building 4 but separate to the residential/commercial tower;
- Contiguous basement car park (beneath buildings 5 and 6);
- Loading/docking bays; and
- Landscaped areas including boardwalks, a swimming pool, footpaths and open grassed areas.

A detailed plan of the proposed site development can be found in the Figures B-11 and B-12 of the URS Stage 2a Remediation Work Plan in Appendix B.1 of this report as well as elevation plans for the three buildings in Appendix C.

2.2.1 Stage 2a – Building 4

Building 4 is located near the northern Stage 2a boundary along Kitchener Drive. The building will include a residential dwelling on the ground floor (townhouses), with an adjacent commercial/university/residential tower, above ground car parking and a swimming pool in the open space area. The north-eastern portion of the building (including part of the tower) will overlie the basement car park from the Stage 1 area and is therefore not part of the current audit area. The remainder of the building will have a ground level slab (no basement) placed at approximately 6.5 mAHD. The concrete floor slab of the Stage 1 basement car park rests at 3.0 mAHD.

It is understood that the swimming pool will be located to the south of the townhouses in the open space area. The border of the pool will sit at a RL of 6.45 mAHD and it will have a maximum depth of 2.4 m, making the base of the pool sit at approximately 4.0 mAHD. Since there will be no foundation piles to overcome inherent buoyancy caused by groundwater (making it a “floating” structure), a pressure relief valve has been incorporated into the design to allow groundwater to enter the pool if it were to rise to a level to cause the pool to become buoyant.

Earthworks for building 4 did not include excavations other than to construct the foundation piles.

Aspects of the building construction relevant to contamination management include:

- The ground floor slab (the non-basement portion) will be suspended on piles so the structure is entirely self-supporting and not reliant on the uncontrolled fill that underlies the Stage 2a area;
- The ground floor slab will comprise 40 MPa concrete with a minimum thickness of 220 mm and will include a 50 mm and 20 mm cover of the steel reinforcement at the bottom and top respectively;
- Service conduits will be encased in concrete and attached to the underside of the slab. A pipe jointing system will be incorporated for services at the edges of the building to accommodate any possible vertical and/or horizontal differential movement;
- The floor structure will have a damp proof membrane (plastic layer with a bentonite impregnated geotextile layer fused to one side) and the construction joints will have a “hydrotite” strip as a waterproofing system in order to prevent the ingress of groundwater and soil vapours;

- The Waterfront area currently has a subsoil drain system that prevents the discharge of water into the lagoon. The groundwater level is not expected to exceed 2.0 to 4.0 mAHD with the subsoil drain in operation. However, with no subsoil drain (the drain will no longer be maintained or will be blocked once groundwater contamination no longer poses a risk to the lagoon), the groundwater level is expected to vary from 3.0 mAHD at the lagoon to 5.5 – 6.0 mAHD along Kitchener Drive. The location of the subsoil drain is shown in Figure 3 of this report and the most recent delineation of groundwater contours is shown in Figure 6. It is noted that at the time of writing this report a trial blockage of the drain was in place to allow monitoring of the residual contamination impacts.

2.2.2 Stage 2a – Buildings 5 and 6

Buildings 5 and 6 will be located towards the artificial lagoon along the south-western boundary of the site. Building 5 will be constructed on existing land, whereas building 6 will be partly constructed on recently reclaimed land consisting of imported fill. These buildings will consist of residential towers connected by a contiguous basement, with the top of basement slab being placed at 3.95 mAHD (according to updated construction plans provided to the auditor[1]). Lift overruns stand at approximately 1 m below slab level.

Buildings 5 and 6 construction details are similar to building 4, which include:

- The buildings consist of reinforced basement slabs suspended on piles so that they are not reliant on the uncontrolled fill that underlies the Stage 2a area;
- A hydrostatic relief drain surrounds the basement car park and discharges into a sump located beneath the building 6 basement. This relief drain runs parallel and adjacent to the subsoil drain on the western side of building 5. If the subsoil drain is not blocked, water from the hydrostatic relief drain will discharge into the subsoil drain via the aggregate backfill that separates the drains. The purpose of the subsoil drain is to prevent hydrocarbon contaminated water discharging to the lagoon. This drain will no longer be maintained if hydrocarbon concentrations no longer present a significant risk if the groundwater should discharge to the lagoon. The drain is currently closed on a trial basis, and this closure may become permanent if the monitoring results during the trial period show that this does not give rise to unacceptable effects. In this case the building perimeter drains will discharge solely to the sump beneath the carpark which will be periodically pumped out as may be required;
- The basement floor structure and outside of basement walls will have a damp proof membrane (plastic layer with a bentonite impregnated geotextile layer fused to one side) and the construction joints will have a hydrotite strip as a waterproofing system in order to prevent the ingress of groundwater and soil vapours;
- No service penetrations will be present in the basement slab and limited penetrations will be included in the walls. The wall penetrations will encompass a waterproofing and pipe jointing system to accommodate any shifting; and
- The wall of the Building 6 basement that faces the lagoon will not be enclosed by a concrete wall but will be open and covered only with a grill, allowing significant passive ventilation. A basement ventilation system will provide additional active ventilation providing in total an air exchange rate of 1.5 air exchanges per hour.

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[1] The Health Risk Assessment referred to later in this report assumed that the basement floor slab was lower, at 3.25 mAHD

2.3 Site history

The Stage 2a area covers a portion of three different assessment areas based on historical filling and use: Recently Reclaimed Land, Warehouse and the Old Northern Cement Plant. These areas and other off-site areas of concern are discussed in Section 2.3.1 and 2.3.2 as per the site history review carried out by the assessor. Figure 4 illustrates the historical site use boundaries.

2.3.1 On-site historical areas

The historical use of each area, including the entire area rather than just the Stage 2a segment, is detailed below.

Warehouse Area

- Between 1941 and 1969 the larger Warehouse Area was reclaimed and levelled to varying extents. The western side had been reclaimed but was yet to be levelled and was believed to have been likely still operating as a land filling area. Fill is believed to have included old aeroplane engines and ex-army vehicles, natural material sourced from the excavation of Stokes Hill and other fill material understood to have been sourced from Cyclone Tracy debris;
- Anecdotal information suggested that the south western end of the Warehouse Area was used for sandblasting operations, possibly for structures such as buoys, boats and metal objects. Some of the objects sandblasted may have comprised of lead paint;
- Ore handling activities reportedly occurred in the western part of the Warehouse Area;
- Anecdotal information indicated that the Warehouse Area was used for methylbromide fumigation of quarantine cargo (period unknown); and
- Subsidence of the ground surface occurred in the car park to the east, which was excavated and backfilled after empty drums were discovered.

Recently Reclaimed Land

- Reclamation of the Recent Reclaimed area began in 1975, with the western side being reclaimed by the late 1970s. Uncontrolled filling included general waste, construction material, waste oil drums, and machine parts continuing until the 1990s;
- In 1990, a channel located approximately 50 m inland from the southern boundary of the Recent Reclaimed area and to the south of Warehouse 2 was constructed to drain stormwater;
- The western portion of the Recent Reclaimed area had been used to stockpile excavated soil from the Mitchell Centre underground car park construction, which was positioned from the eastern side of Warehouse 1 to the western side of Warehouse 2. There was no known environmental sampling of this material;
- Bombing raids impacted the area during World War II. Therefore, the potential for unexploded ordnance to be present is possible as the raids occurred prior to the land being reclaimed;
- The area just north of the cement plant was used as a landfill for construction waste, including materials containing asbestos; and
- Anecdotal evidence suggested that boats were dumped, doused in fuel and burned in the western section of the Recent Reclaimed area. There was also information suggesting that the armed forces used the boats for target practice.

Old Northern Cement Plant

- The land that formerly contained the northern cement plant operations was reclaimed in 1965 specifically for the construction of the plant. The fill material was consistent with the rest of the waterfront site, consisting of some non-putrescible building and demolition waste;
- The historical information suggests that the site was used for the storage of bulk dry materials, with no raw materials being mixed onsite. Drilling mud, primarily consisting of barite and bentonite, was debagged into 600 tonne silos. Quicklime was also stored in a 3000 tonne silo. A breakage in the elbow of the silo caused a quicklime spill to occur, resulting in quicklime being spread over a wide area;
- Anecdotal information suggests that the facility was in operation until approximately 1999, with the onsite infrastructure being demolished soon after closure. A former office building was believed to have contain asbestos cement sheeting;
- An unbunded diesel above ground storage tank (AST) was believed to have been used for refuelling an onsite mobile compressor and forklift. The diesel was also understood to have been used to burn off local vegetation to discourage the homeless from trespassing onto the site boundaries; and
- Anecdotal information suggests that quarantine waste was burned onsite (or directly adjacent to the site). The quarantine waste was believed to contain waste from shipping operations (rubbish, food scraps, etc.) but the full range of waste and its composition is not known.

2.3.2 Off-site historical areas

Kitchener Drive

- The northern perimeter of the Darwin Waterfront project area was identified as a key potential source of contamination due to fuel pipelines and WWII storage tunnels;
- The original fuel line was built in the current location (running along the northern boundary of Kitchener Drive) in 1944 and ran overland from the entry of the access road from the esplanade to the entry of McMinn Street. Further lines were added in the early 1960s and a valve pit area was also installed;
- There were reports of minor leaks occurring whilst pumping from Iron Ore Wharf to the Oil storage tanks, but no major spills were known to have occurred along the above ground length of pipe;
- A spill of fuel was reported to have occurred due to a ruptured fuel line adjacent to the Boral gas site, which was located approximately 250 m off site, north of Fort Hill. (Details not known);
- The storage tunnel system was constructed in 1943 for storing fuel but was never used during wartime. However, tunnels 5 and 6 were used from 1955 for three years to store jet fuel; and
- It was believed kerosene was spilt during a recent military exercise in one of the tunnels, as a result of a pipe breaking. It was reported that visitors detected petroleum odours and sheens after rain.

Shell Bitumen Plant

- The area was reported to be underlain by fill material comprising discarded material from boom sheds located to the west and general landfilled materials (armour plated steel, old pipes and cables). The former coastline is understood to have been located along the southern side of Kitchener Drive (northern boundary of the Bitumen Plant and the Stage 2a area) with the site reportedly being filled in the late 1950s.
- Discussions indicated that the Shell Bitumen Plant was constructed on the reclaimed land in 1963, with the feed line and first bitumen shipment occurring in 1966. The site was believed to be a vacant lot prior to the construction of the Bitumen Plant. Over the duration of its operation, several spills were known to occur. Spills occurred as a result of overfilling of the bitumen feed stock and holding tanks, cracks in the site triple interceptor trap (TIT) and various spills from pipes and small tanks.
- The Port of Darwin plan of 1940-1950 indicates a series of railway lines running in a northeast to south westerly direction across the site.
- A workshop was located in the northern area of the site. This former workshop was reported to be part of a coal mill that used to produce diesel.
- An electrical substation was located in the northern corner of the bitumen plant.

2.4 Potential sources of contamination

2.4.1 Potential on-site sources

The former uses of the site indicate that there was potential for contamination of land and groundwater, and an investigation of the site was undertaken to consider this. Table 4 details the historical use and the particular potential contaminants of concern as identified by URS.

Table 4 Potential on-site sources of contamination

Site activity / Source	Potential Contaminants of Concern
WAREHOUSE AREA	
Land Reclamation (Fill)	Asbestos, TPH, BTEX, Metals, PAHs, OCs, OPs and UXO
Bulk Storage	Metals
Sandblasting	OPs, Metals
Fumigation for Quarantine (methylbromide)	Metals
Transformer	PCBs, TPH, BTEX, PAHs
RECENTLY RECLAIMED LAND	
Land reclamation (Fill)	Asbestos, TPH, BTEX, Metals, PAHs, OCs, OPs and UXO
Dumping of boats (burning and target practice)	UXOs, PAHs, TPH, BTEX, Metals, tributyl tin
Stockpiles	PAHs, TPH, BTEX, Metals
OLD NORTHERN CEMENT PLANT	
Land reclamation (Fill)	Asbestos, TPH, BTEX, Metals, PAHs, OCs, OPs and UXO
Bulk Storage (Quicklime)	pH
Dumping of boats (burning and target practice)	UXOs, PAHs, TPH, Metals, tributyl tin
Bitumen Feedstock spills from Shell Bitumen Plant site.	TPH, PAH

Site activity / Source	Potential Contaminants of Concern
Diesel Storage (also used for clearing boundaries)	TPH, PAH
ACROSS ALL AREAS	
Pipelines (fuel, oil etc)	TPH, BTEX, PAHs
Drains (possible preferential pathway for contamination)	TPH, BTEX, PAHs, Metals
Quicklime spill.	Metals
WW 2 Attacks	UXOs

2.4.2 Potential off-site sources

Potential off-site sources of contamination to land and/or groundwater that may have impacted the environmental quality of the audit site are detailed in Table 5.

Table 5 Potential off-site contaminants of concern

Site activity / Source	Potential Contaminants of Concern
STOKES HILL – Off site to the East	
Land reclamation (Fill)	Asbestos, TPH, BTEX, Metals, PAHs, and UXOs
Bulk Storage	Metals (U)
Destruction of Tanks (Bombing and fire)	TPH, BTEX, PAHs, Metals, VOCs
Oil Tanks (leaks)	TPH, BTEX, PAHs, ClHC
Water Tank (pump house and diesel tank)	TPH, PAHs, Metals
Transformer leaks	PCBs
Surface staining	TPH, BTEX, PAHs, Metals
Workshop and waste oil store.	TPH, BTEX, VOCs, PAHs Metals
Railway lines	TPH, PAH
Hydrocarbon odours and soil staining.	TPH, BTEX, PAHs, Metals
SHELL BITUMEN PLANT and associated areas – Off site to the West	
Bitumen Plant Area	
Previous Investigation Exceedences	VOCs, TPH (soil and groundwater), As, Cu, Pb
Land Reclamation (Fill)	Asbestos, TPH, BTEX, Metals, PAHs
Storage/Pipe Spills (fuel oil, bitumen, bitumen feedstock, diesel)	TPH, BTEX, PAHs, Metals
Bitumen Tanks	Asbestos
Fire Pump (diesel tank and hydrocarbon staining)	TPH, BTEX, PAHs, Metals
Hydrocarbon surface staining	TPH, BTEX, PAHs, Metals
Drainage (hydrocarbon staining)	TPH, BTEX, PAHs, Metals
Workshop (Includes the bitumen pumps, hydrocarbon staining)	TPH, BTEX, PAHs, Metals
Main interceptor building (hydrocarbon staining)	TPH, BTEX, PAHs, Metals
Process area (hydrocarbon staining)	TPH, BTEX, PAHs, Metals
Loading gantry (hydrocarbon staining)	TPH, BTEX, PAHs, Metals
Pipelines (hydrocarbon staining)	TPH, BTEX, PAHs, Metals
Batch tank (hydrocarbon staining)	TPH, BTEX, PAHs, Metals

Site activity / Source	Potential Contaminants of Concern
Railway Lines	TPH, PAH
Tipping Shed Area	
Land Reclamation (Fill)	Asbestos, TPH, BTEX, Metals, PAHs
Railway Lines	TPH, PAH
Electrical substation	PCBs
Transfer of iron ore and ore concentrate	Metals
Workshop	TPH, BTEX, PAHs, Metals, VOCs
Cockburn Cement Area	
Cockburn Cement Plant	pH, Metals
Railway Lines	TPH, PAH
Pipelines (hydrocarbon staining)	TPH, BTEX, PAHs, Metals
KITCHENER DRIVE (FUEL PIPELINES AND WW2 TUNNELS)	
Fuel Pipelines	TPH, BTEX, PAHs,
Jet Fuel Storage	TPH, BTEX, PAHs, VOC

3. Geology and hydrogeology

The geology and hydrogeology has been described in the URS assessment reports, and can be summarised as follows.

3.1 Regional geology

The 1:100 000 scale 'Darwin' (1983) Geological Survey of Northern Territory, sheet No. 5053, indicates that the underlying geology of the site consists of:

- Coastal sedimentation along the foreshore consisting of mud, clays, silts and intertidal marine alluvium. Quaternary and Recent aged sediments are developed in the intertidal zone as poorly sorted fragments of quartz sand, coral and shell debris. Limonitic and lithic material occurs in the swash zone;
- Bathurst Island Formation sediments of the Lower Cretaceous age, comprising radiolarian claystone, sandy claystone, clayey sandstone, quartz-sandstone, ferruginous sandstone and glauconitic sandstone; and
- Burrell Creek Formation of the Proterozoic age Finniss River Group, comprising siltstone, shale, sandstone (quartz arenite, sublitharenite), quartz pebble and conglomerate. The Burrell Creek Formation is metamorphosed to lower greenschist facies and referred to as phyllite.

The area is also characterised by land reclamation, filling and raising of the coastal embayment between Fort Hill and Stokes Hill and the enlarging of the peninsulas formed by these hills.

3.2 Local geology (site)

The general subsurface soil profile across the development site consists of the soil units summarised below, listed in order of depth from the ground level:

- FILL: Significant land reclamation has occurred on the site area within Kitchener Bay. Fill comprising clay, silt and pieces of weathered siltstone and phyllite was encountered from ground level to depths ranging between 5.0 m and 6.0 m below ground level (mBGL). The fill materials are recognised as being heterogeneous, forming widely variable and anisotropic medium and also containing a range of anthropogenic material and building debris;
- MUDS: typically comprising dark grey to blue-grey sandy silts/muds with mangrove matter and shells; and
- BEDROCK: phyllite bedrock.

Groundwater was encountered at depths of between 0.82 and 5.26 mBGL.

3.3 Local hydrogeology

3.3.1 Local groundwater flow system

The local groundwater flow system is controlled by the adjacent topographic features, the artificial lagoon located south east of the site and a subsoil drain constructed parallel to Kitchener Drive together with collector drains on the waterfront area, with the objective of collecting groundwater and discharging it to the Port of Darwin located to the west of the site, to prevent hydrocarbon contaminated groundwater discharging to the lagoon. The topographic features consist of the escarpment to the north and Stokes Hill to the east, which both rise approximately 20 m above the Site and are located within a distance of 50 and 350 – 400 m of the Site boundary respectively. The artificial lagoon to the south east of the site holds water at a level between 2.5 and 3.0 mAHD. The main subsoil drain runs along Kitchener Drive and discharges to Darwin Harbour at a location to the west of the site, after running through an oil / water separator. It sits at a level of 2.0 m AHD. A number of secondary branches run from within the waterfront area and discharge to the Kitchener Drive drain and these drains sit between 2.5 and 2.0 m AHD (see Figure 3). With the subsoil drain in operation, groundwater on the Stage 1 and 2a areas of the waterfront, generally runs away from the lagoon towards the drains. Groundwater from the area upgradient of the site (the escarpment) also discharges to the drain. At the time of the completion of this report a trial blockage of the drain had been in place for 6 months. This will result in a reversal of groundwater flow towards the lagoon and if there is no visible evidence or significant flux of contamination entering the lagoon, then the drain may not need to continue to operate.

Higher density fill located to the west of the site in the Fort Hill area is also likely to influence groundwater flow, with groundwater flowing radially towards the site from this area. Historical groundwater investigations have identified that a groundwater table depression is present immediately to the west of the Site at the former location of the Shell Bitumen Plant, which may be attributed to lower density fill, or stormwater drains known to be present in this area. Groundwater extends into the fill.

Prior to operation of the drain and the construction of the lagoon, the site experienced significant fluctuations in groundwater depths between the dry and wet seasons (up to 4 m variation) and to a lesser extent, tidal changes. The depth to the water table across the site ranged from ground level (wet season) to 15 m below ground level (dry season), but was generally 3 to 5 m below ground level. The difference in groundwater levels between the wet and dry seasons increased to the north of the site, closer to the adjacent escarpment, which contributes to the groundwater recharge from the site, along with direct rainfall recharge.

Tidal impacts on water levels were identified by URS to approximately 50 m from the shoreline. URS indicated that the harbour experienced tidal variations of up to 8 m, but typically the variations are in the order of 6 m. URS undertook gauging of groundwater bores over a tidal cycle (prior to construction of the lagoon), and the results identified tidal influenced groundwater level fluctuations within 50 m of the shoreline. Lag times up to four hours were noted between tidal level peaks and groundwater peaks, and tidal efficiency (change in groundwater levels divided by change in tidal levels) was up to 70% in bores closer to the shoreline.

URS completed a slug test that gave ranges of interpreted hydraulic conductivity for the materials in the aquifer zone as follows:

- 0.01 to 0.1 m/day for Fill (dense);
- 1.0 to 20.0 m/day for Fill (loose);
- 0.001 m/day for Marine sediment; and
- 0.001 m/day for Burrell Creek Formation.

Prior to the installation of the drain and reversal of groundwater flow after filling of the lagoon, the Site was a preferred groundwater flow zone, with groundwater flowing from the adjacent areas towards the site and eventual discharge to Kitchener Bay.

URS classified the fill as generally dense in the northern area and loose in the southern side of the site. (See Figure 2 of the URS CUTEP report). The fill exhibited higher permeability than the marine sediments and the phyllite bedrock in which groundwater flow was restricted to joints and fissures.

URS advised the auditor during his site visit in January 2008 that it has been observed that the yield of water during dewatering carried out as part of the site development works in the Stage 1 area to the east of the Site, drops off rapidly (within a week or two), and water levels recover only very slowly with pumping requirements remaining low. URS concludes from this that the rate of groundwater flow such as may be collected by sub-surface collection drains may be small. Between December 2011 and October 2012 the flow rates of groundwater collected by the drainage system ranged from being absent to 7.5 L/min, supporting the URS conclusion.

3.3.2 Groundwater TDS

According to the September 2012 groundwater monitoring event, total dissolved solids (TDS) range between approximately 190 mg/L (MW128) and 25,200 mg/L (MW09). Groundwater is generally fresh/brackish (low TDS) in the northern area of the site and rapidly becomes saline towards Kitchener Bay as it is influenced by seawater intrusion and evaporation.

There is significant variation in the salinity between the wet season and the dry season, with much lower TDS values at a given area of the site during the wet season. The lower TDS is a result of the increased fresh water infiltration and flow that occurs during the wet season; during the dry season there is less dilution by fresh water, and in addition the lower water table elevations can allow greater sea water intrusion and increased TDS through evaporative losses.

The underlying bedrock is generally more saline than the overlying fill; this is probably the result of the deeper formations having lain beneath the tidal zone prior to the reclamation works.

3.4 Adequacy of hydrogeological assessment

A total of twenty five (25) groundwater monitoring wells (GMWs) were installed across the Darwin Waterfront area as part of URS Phase 2 stage of works. A further twenty eight (28) were installed during Phase 3 of the site investigation and twenty three (23) again in Phase 4. Eleven (11) pre-existing wells were present around the Shell and Bitumen Plant sites.

Six (6) of the groundwater bores (Phase 2: RR_MW16, NC_MW17; Phase 3: WA_MW33, SMW01, RR_MW16A, NC_MW17A) were located within the Stage 2a site. Twelve (12) off-site groundwater monitoring wells were identified which could be considered indicative of groundwater conditions at or leaving the site. The relevant off-site monitoring wells include: KD_MW04, KD_MW04A, KD_MW03 and KD_MW03A (located upgradient to the site); RR_MW15, and RR_MW15A (located to the east of the site); BP_MW47A, BP_MW47B, BP_MW35, SMW02, SMW03 and SMW04 (located to the west of the site). The location of these monitoring wells is shown in Figure 5 (Figure 2 of the URS Groundwater Monitoring March 2006 report). A groundwater monitoring program has been and continues to be undertaken at approximately quarterly intervals. Complete details of these investigations are included in the Phase 2, Phase 3/4 and annual groundwater monitoring reports produced by URS (refer to Appendix B).

Between September 2007 and June 2008 an additional thirty six (36) wells were installed across the Darwin Waterfront area as a result of the damage or destruction of several wells during the construction phase. Three (3) of these wells (MW106, MW113 & MW114) were installed on the Stage 2a site. Four (4) wells were installed within close proximity to the Stage 2a site (MW111 and MW112 (located to the south of the site in close proximity of the boundary), MW115 (located to the east of the site) and MW125 (located to the north, upgradient to the site)). These additional wells provided information on groundwater conditions on and adjacent to the Stage 2a area. Complete details of the groundwater monitoring carried out at the various investigation locations are included in the Groundwater Monitoring Reports (refer to Appendix B). The locations of the additional wells are shown in Figure 6 (Figure 4b of the URS 2013 Groundwater Monitoring Report).

The groundwater monitoring sampling and analysis program for the wells at the site are summarised in Table 6 and Table 7.

Table 6 Groundwater monitoring undertaken for relevant bores (December 2003 to September 2009)

	Sampling Round																
	Well ID	Dec 2003	Feb 2004	Sep 2004	Dec 2004	Feb 2005	May 2005	Nov 2005	Feb 2006	Jun 2006	Sep 2006	Nov 2007	Jul 2008	Nov 2008	Feb 2009	June 2009	Sept 2009
Off-site wells adjacent to Stage 2a Site																	
Phase 2	KD_MW03	-	26-Feb-04	D	D	D	D	D	D	D	D	D	D	D	D	D	D
	KD_MW04	4-Dec-03	26-Feb-04	D	D	D	D	D	D	D	D	D	D	D	D	D	D
	RR_MW15	4-Dec-03	25-Feb-04	8-Oct-04	D	D	D	D	D	D	D	D	D	D	D	D	D
Phase 3	KD_MW03A	-	30-Mar-04	3-Sep-04	21-Dec-04	15-Feb-05	30-May-05	3-Nov-05	2-Mar-06	6-Jun-06	D	D	D	D	D	D	D
	KD_MW04A	-	30-Mar-04	3-Sep-04	9-Dec-04	17-Feb-05	27-May-05	27-Oct-05	NS	30-May-06	NS	D	D	D	D	D	D
	SMW02	-	31-Mar-04	8-Sep-04	22-Dec-04	20-Feb-05	30-May-05	7-Nov-05	13-Mar-06	8-Jun-06	NS - Well Covered	D	D	D	D	D	D
	SMW03	-	31-Mar-04	8-Sep-04	14-Dec-04	20-Feb-05	27-May-05	7-Nov-05	NS	6-Jun-06	NS - Well Covered	D	D	D	D	D	D
	SMW04	-	31-Mar-04	Not Found	Not Found	20-Feb-05 (HC sheen present but sampled)	27-May-05	1-Nov-05	21-Feb-06 (HC sheen present but sampled)	6-Jun-06 (HC sheen present but sampled)	Covered	D	D	D	D	D	D
Phase 4	BP_MW35	-	31-Mar-04	16-Sep-04	10-Dec-04	20-Feb-05	27-May-05	NS – Well Dry	21-Feb-06	7-Jun-06	NS - Well Covered	D	D	D	D	D	D
	RR_MW15A	-	-	8-Oct-04	8-Dec-04	14-Feb-05	31-May-05	2-Nov-05	D	D	D	D	D	D	D	D	D
	BP_MW47A	-	-	10-Sep-04	NS	24-Feb-05	31-May-05	1-Nov-05	21-Feb-06	7-Jun-06	NS - Well Covered	D	D	D	D	D	D
	BP_MW47B	-	-	10-Sep-04	NS	24-Feb-05	31-May-05	1-Nov-05	21-Feb-06	1-Jun-06	NS - Well Covered	D	D	D	D	D	D
Replacement works (Sept 07 – June 08)	MW111	-	-	-	-	-	-	-	-	-	-	1-Nov-07	NS	28-Oct-08	3-Feb-09	NS	3-Sept-09
	MW112	-	-	-	-	-	-	-	-	-	-	1-Nov-07	NS	28-Oct-08	4-Feb-09	NS	9-Sept-09
	MW115	-	-	-	-	-	-	-	-	-	-	31-Oct-07	7-Jul-08	3-Nov-08	9-Feb-09	17-Jun-09	11-Sept-09
	MW125	-	-	-	-	-	-	-	-	-	-	31-Oct-07	9-Jul-08	4-Nov-08	3-Feb-09	NS – Well Covered	11-Sept-09
Stage 2a Onsite Wells																	
Phase 2	RR_MW16	4-Dec-03	26-Feb-04	D	D	D	D	D	D	D	D	D	D	D	D	D	D
	NC_MW17	4-Dec-03	25-Feb-04	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Phase 3	RR_MW16A	-	-	2-Sep-04	8-Dec-04	14-Feb-05	6-Jun-05	2-Nov-05	D	D	D	D	D	D	D	D	D
	NC_MW17A	-	-	3-Sep-04	21-Dec-04	14-Feb-05	1-Jun-05	7-Nov-05	D	D	D	D	D	D	D	D	D
	WA_MW33	-	31-Mar-04	09-Sep-04	08-Dec-04	14-Feb-05	31-May-05	02-Nov-05	D	D	D	D	D	D	D	D	D
	SMW01	-	31-Mar-04	8-Sep-04	14-Dec-04	20-Feb-05	27-May-05	7-Nov-05	21-Feb-06	8-Jun-06	NS - Well Covered	D	D	D	D	D	D
Replacement works (Sept 07 – June 08)	MW106	-	-	-	-	-	-	-	-	-	-	31-Oct-07	NS	30-Oct-08	4-Feb-09	NS - Well Covered	NS - Well Covered
	MW113	-	-	-	-	-	-	-	-	-	-	1-Nov-07	1-Jul-08	28-Oct-08	4-Feb-09	NS	3-Sept-09
	MW114	-	-	-	-	-	-	-	-	-	-	1-Nov-07	NS	28-Oct-08	4-Feb-09	NS	3-Sept-09

NS – Not Sampled	NS - Well not sampled due to PSH or HC sheen	D – Well Destroyed

Table 7 Groundwater monitoring undertaken for relevant bores (December 2009 to December 2012)

	Sampling Round															
	Well ID	Dec 2009	Feb 2010	June 2010	Sept 2010	Dec 2010	Feb 2011	June 2011	Sept 2011	Dec 2011	March 2012	June 2012	Sept 2012	Dec 2012	March 2013	June 2013
Off-site wells adjacent to Stage 2a Site																
Replacement works (Sept 07 – June 08)	MW111	NS	8-Mar-10	NS	27-Sept-10	NS	D	D	D	D	D	D	D	D	D	D
	MW112	08-Dec-09	24-Feb-10	NS	NS	NS	D	D	D	D	D	D	D	D	D	D
	MW115	9-Dec-09	23-Feb-10	16-Jun-10	24-Sep-10	17-Dec-10	9-Feb-11	23-Jun-11	29-Sep-11	13-Dec-11	8-Mar-12	13-Jun-12	4-Sep-12	11-Dec-12	5-Mar-13	27-Jun-13
	MW125	8-Dec-09	24-Feb-10	15-Jun-10	29-Sep-10	20-Dec-10	10-Feb-11	22-Jun-11	29-Sep-11	13-Dec-11	8-Mar-12	13-Jun-12	4-Sep-12	12-Dec-12	4-Mar-13	26-Jun-13
Stage 2a Onsite Wells																
Replacement works (Sept 07 – June 08)	MW106	8-Dec-09	17-Feb-10	15-Jun-10	27-Sep-10	NS	NS	NS	NS	NS	NS	NS	NS	12-Dec-12	D	D
	MW113	08-Dec-09	18-Feb-10	NS	27-Sep-10	NS	14-Feb-11	NS	28-Sept-11	NS	12-Mar-12	12-Jun-12	5-Sep-12	NS	D	D
	MW114	08-Dec-09	17-Feb-10	NS	27-Sep-10	NS	14-Feb-11	NS	28-Sept-11	NS	8-Mar-12	12-Jun-12	5-Sep-12	NS	D	D
NS – Not Sampled (well damaged, not found, covered or not accessible)																
NS – Not Sampled but gauging data collected																
NS – Well not sampled																
D – Well Destroyed																

The wells drilled in the Phase 2, Phase 3/4 works, were installed by J&S Drilling using a hollow stem auger technique constructed with 50 mm diameter Class 18 PVC casing. Each bore was constructed with a basal slotted section of 5 to 8 m length at a depth of 6 to 10 m to accommodate the seasonal fluctuations, and a PVC cap at the base.

As shown in Table 6, five of the monitoring wells have an associated ‘’A’’ well (KD_MW04, KD_MW03, RR_MW15, RR_MW16 and NC_MW17). These additional “A” wells (KD_MW04A, KD_MW03A, RR_MW15A, RR_MW16A and NC_MW17A) were installed in March 2004 and were drilled adjacent to their original number, but at different depths to capture the fluctuations in groundwater depths with the season. The original wells installed in the Phase 2, 3 and 4 stage of works were destroyed in the process of the Stage 1 construction works.

The auditor considers that the investigations have been appropriate for characterising groundwater conditions at the site. In this, the auditor has considered:

- The number of wells formerly surrounding the site characterising the aquifer(s),
- The number of wells currently present at the site,
- The number of sampling rounds undertaken within the bores,
- The consistency of the data collected across the site with the site history information, the site layout and known infrastructure,
- The veracity of the data as evidenced by quality control checks, and
- The experience of the assessor in undertaking this type of work.

4. Assessment guidelines

4.1 Beneficial uses/environmental values of groundwater to be protected

The Northern Territory Environmental Protection Agency (Program)[2] of the Department of Natural Resources, Environment and the Arts specified in their correspondence of the 13 December 2006 that the Beneficial Uses of the Groundwater should be determined in accordance with the National Environment Protection Measure (*Assessment of Site Contamination)* 1999 herein referred to as the NEPM). Under the NEPM Schedule B (6) '*Groundwater is assessed on the basis of its suitability for current or realistic future use'.*

Schedule B (6) of the NEPM (*Assessment of Site Contamination)* specifies six environmental values. They are:

- Aquatic ecosystems;
- Aquaculture and human consumers of food;
- Agricultural water (irrigation and stock watering);
- Recreation and aesthetics;
- Drinking water; and
- Industrial water.

Given that the groundwater at the site will sit within the zone where the foundations of buildings and structures will be present, the impact of groundwater contamination on the foundations has also been considered.

The Environmental Values that apply to the site based on the suitability of water for current or future use are listed in Table 8. The subsoil drain alters the groundwater flow regime to avoid discharge of groundwater to the lagoon, and while this occurs it may be considered that protection of aquatic ecosystems is not a relevant beneficial use. However, the subsoil drain is part a remediation system for the site and, when the groundwater contamination has reduced and stabilised to the point where it no longer poses a risk to the environmental values (particularly aquatic ecosystems), the operation of the drain will no longer be required and it may no longer be maintained. Stopping operation and maintenance of the drain will only occur with the approval of an Environmental Auditor and only on the basis that contamination risks no longer exist. As a result, the audit has assessed the relevance of environmental values in Table 8 assuming that the subsoil drain is not operating and groundwater will discharge to the marine environment. It is noted that a trial shutdown of the drain is occurring at the time of writing this report.

[2] Note that the Environment Protection Agency Program is shortly to become the Environment Protection Agency under the Environment Protection Agency Bill NT 2007.

Table 8 Protected environmental values (beneficial uses) of groundwater for the Stage 2a area

Environmental Value	Current Use?	Realistic Future Use?
Aquatic Ecosystems	**On-site – No** There are no onsite aquatic water bodies. **Off-site – Yes** The lagoon is immediately down gradient of the site and the drain is currently (deliberately) closed. Groundwater from the site is likely to discharge to the lagoon and the lagoon water will be circulated to the wider Darwin Harbour.	**On-site – No** There are no onsite aquatic water bodies. **Off-site – Yes** Groundwater will discharge to the lagoon and the lagoon water will be circulated to the wider Darwin Harbour.
Aquaculture and Human Consumers of food	**On-site – No** There are no onsite aquatic water bodies. **Off-site – Yes** No fishing' signs are present next to the lagoon and the pool lifeguards are required to prevent people fishing. URS advised that their staff regularly visiting the site have not observed anyone fishing. The lagoon water is circulated to the wider Darwin Harbour. Some fishing and collection of molluscs occurs in the wider Darwin harbour area, which has unrestricted access areas.	**On-site – No** There are no onsite aquatic water bodies. **Off-site – Yes** As per the current use.
Agricultural water (irrigation (garden watering) and stock watering)	**On-site – No** The site is currently under development and water is being supplied as required from the potable water system. **Off-site – No** Garden watering and stock watering are not protected uses within the central Darwin area. Garden areas are present off site. The limited extent of the water (near the escarpment) of a suitable salinity and the low yield of the formation make this use unlikely and reticulated towns water is used for this purpose if required.	**On-site – No** Garden watering and stock watering are not protected uses within the central Darwin area. Garden areas will be present within the development area. However the limited extent of the water (near the escarpment) of a suitable salinity and the low yield of the formation make this use unlikely and reticulated towns water will be used for this purpose if required. **Off-site – No** The surrounding land use is consistent with the onsite use, and the discussion for onsite use applies.
Recreation and Aesthetics	**On-site – No** There are no onsite aquatic water bodies. **Off-site – Yes**, Swimming and recreational activities occur in the down gradient lagoon.	**On-site – No** Groundwater could enter the pool via a pressure release valve if groundwater levels are higher than the pool levels. **Off-site – Yes** Swimming and recreational activities occur in the down gradient lagoon.

Environmental Value	Current Use?	Realistic Future Use?
Drinking Water	**On-site – No** The background water quality does not support such a use. The low yield of groundwater and availability of reticulated towns water also make it unlikely that groundwater would be extracted for such use. **Off-site – No** The on-site situation applies off site.	**On-site – No** The water quality of the groundwater would generally preclude such a use. **Off-site – No** The water quality of the groundwater would generally preclude such a use.
Industrial	**On-site – No** The site is currently under development and water is being supplied from the potable water system. **Off-site – No** There is no industrial use in the surrounding areas.	**On-site – No** Background water quality indicators (including salinity) and low yields make this use unlikely. Industrial use is not proposed for the site. **Off-site – No** Background water quality indicators (including salinity) and low yields make this use unlikely.
Buildings and Structures	**On-site – Yes** The foundations of some structures within the site sit below the water table. **Off-site – Yes** Adjacent structures have foundations that sit below the water table level.	**On-site – Yes** Piles and basements will sit below the groundwater level. **Off-site – Yes** Future construction stages adjacent to Stage 2a may have foundations that will sit below the water table level in addition to the buildings that have already been constructed.

The assessment of groundwater with respect to the applicable beneficial uses and quality criteria is provided in Chapter 8 of this report.

4.2 Groundwater quality criteria

The water quality criteria for the relevant environmental values are specified in Table 9 below. The water quality criteria listed in these various guidelines have been adopted for initial screening purposes. Some of the published guideline values have limited relevance to the site situation, and this is taken into account in the following sections of this report when evaluating exceedences of the guideline values.

Table 9 Groundwater quality indicators of relevant environmental values

Beneficial Use Category	Water Quality Indicators
Maintenance of Ecosystems	ANZECC/ARMCANZ 2000, *Australian and New Zealand Guidelines for Fresh and Marine Water Quality,* National Water Quality Management Strategy, Australian and New Zealand Environment and Conservation Council / Agriculture and Resource Management Council of Australia and New Zealand (Chapter 3, table 3.4.1). For Stage 2a the relevant guideline corresponds to the trigger values for marine water with a level of protection for 95% of the species.
Aquaculture and Human Consumers of food	ANZECC/ARMCANZ 2000, *Australian and New Zealand Guidelines for Fresh and Marine Water Quality,* National Water Quality Management Strategy, Australian and New Zealand Environment and Conservation Council / Agriculture and Resource Management Council of Australia and New Zealand (Chapter 4, table 4.4.3). For Stage 2a the relevant guideline corresponds to the toxicant guidelines for the protection of aquaculture species for saltwater production.
Recreation and Aesthetics	NHMRC (2008) Guidelines for Managing Risks in Recreational Water. These guidelines refer to the NRHMC 2011, *Australian Drinking Water Guidelines 6*, National Water Quality Management Strategy, National Health and Medical Research Council (Chapter 10, table 10.5). For Stage 2a the guideline values correspond to the health criteria, which cover both drinking and recreational uses. In the cases where the aesthetic criterion is lower or a health-based value is not provided, the aesthetic value has been used. Aesthetic water quality considerations include visual impacts, (nuisance organisms such as algae, clarity, colour, debris and odour. Secondary contact recreation water quality characteristics also include microbiological guidelines and toxic chemicals.
Buildings & Structures	Introduced contaminants should not cause groundwater to be corrosive to structures or building materials. The NEPM does not specify particular criteria, and reference has been made to AS2159-2009 Piling – Design and installation for pH, sulphate and chloride. The values shown in the Standard do not constitute guidelines that can be exceeded but define exposure categories (based on pH, sulphate and chloride values for soil and groundwater) and the corresponding design requirements.

4.3 Site-specific groundwater criteria

Site-specific groundwater criteria were not developed for assessing groundwater samples. However, there are several groundwater constituents that have published guideline values that have been used for screening purposes, but have limited relevance at the site. These are:

- Recreation and aesthetics: the NRHMC (2011) guideline lists a value of 600 mg/L for TDS as an aesthetic criterion (no health-based value is provided), and this has been used for initial screening purposes. This value is based on taste considerations for drinking water, where 600 mg/L is considered good quality and 1200 mg/L is considered as unacceptable. In a seawater environment this value is not appropriate and much higher values (e.g. seawater) can be accepted, particularly when these values apply to recreational criteria.

- Recreation and aesthetics: sulphate (250 mg/L), chloride (250 mg/L) and sodium (180 mg/L) are listed in the NRHMC (2011) guidelines as aesthetic criteria and have been used for screening purposes. These values are based on taste and health considerations for drinking water and in a seawater environment these values are not appropriate and much higher values (e.g. seawater) can be accepted, particularly when these values apply to recreational criteria.
- Recreation and aesthetics: an iron value of 0.3 mg/L is listed in the NRHMC (2011) guidelines as aesthetic criteria and has been used for screening purposes. This value is based on taste considerations for drinking water and in a seawater environment this value is not appropriate and much higher values can be accepted.
- Recreation and aesthetics: The ANZECC 2000 guidelines state that "Recreational water should contain no chemicals that can irritate the skin of the human body. To protect swimmers from harmful effects through ingestion, the guidelines from Tables 5.2.3 and 5.2.4 should be applied for other toxicants. Special care must be taken to check for substances that can enter the body by absorption through the skin. Higher concentrations of toxicants may be tolerated occasionally if it is assumed that no person will ingest more than a maximum of 100 mL water during a normal swimming session (NHMRC 1990) compared with 2 L/d for potable water."

  Therefore, primary contact recreation criteria can be taken as up to 20 times the drinking water criteria, where contaminants are not volatile, and therefore do not represent an inhalation risk, and the dermal contact risk is assumed to be minimal.

  Section 9.3.2 of the ANZECC 2008 Guidelines for Managing Risks in Recreational Water specifies that "environmental quality standards for chemicals in recreational waters should be based on the assumption that recreational water makes only a relatively minor contribution to intake. They assumed a contribution for swimming of an equivalent to 10% of drinking water consumption. Since most authorities (including WHO) assume consumption of 2 litres of drinking water per day, this would result in an intake of 200 mL per day from recreational contact with water (WHO 2003). This provides for a simple screening approach in which a substance occurring in recreational water at a concentration of 10 times that stipulated in the drinking water guidelines may merit further consideration." It is noted that this presents slightly varying assumption about the quantity of water that is likely to be consumed as drinking water and that which is imbibed during recreational activities. Given that the recreational guidelines postdate the ANZECC 2000 guidelines and that the Recreational Guidelines are more conservative, a tenfold factor for impacts to recreational uses has been adopted for the appropriate parameters (i.e. for chemicals that do not present a dermal contact or vapour risk).
- Recreation and aesthetics: the NRHMC (2011) drinking water guideline lists a value of 0.5 mg/L for ammonia and this has been used for screening purposes. It can be expected that ammonia will not be limiting for recreation and aesthetics (with the possible exception of algal growth in surface waters) due to the following:
  - The guideline value of 0.5 mg/L has been set for drinking water on an aesthetic basis due to the corrosion of copper pipes and fittings and can support the nuisance growth of bacteria and algae;
  - According to the NRHMC (2011) guideline, the odour threshold for ammonia is 1.5 mg/L; and

  - A health based guideline value for ammonia has not been set because the concentrations at which effects might be observed are very high and generally will not be exceeded, therefore much higher concentrations of ammonia are acceptable in drinking water. In this respect, the guideline notes that, at doses above 32 mg of ammonium per kilogram of body weight per day, ammonium chloride may have adverse health effects. Assuming a 10 kg baby drinking a maximum of 100 mg of water (specified by the NRHMC (2008) *Guidelines for Managing Risks in Recreational Waters* as an amount swallowed during swimming), water concentrations of ammonium would have to be greater than 3200 mg/L to impact on human health, supporting the conclusion that concentrations of ammonium should not be limiting;
  - There is a very high level of dilution of groundwater in the lagoon and groundwater inputs to the lagoon are likely to be very small compared with the design turnover rate of water in the lagoon (23,500 m^3/day).

- Maintenance of Ecosystems: Section 8.3.7.2 of the ANZECC 2000 guideline specifies that the toxicity of ammonia varies with the balance between the ionised (NH_4^+) and un-ionised (NH_3) fractions and this is highly dependent on pH and temperature. The general guideline value listed for 95% protection of marine ecosystems is 0.91 mg/kg and this assumes a pH of 8 which is similar to the pH of seawater. Ecosystems may also be present in the sediment interface between the lagoon and the groundwater aquifer. In this zone the pore water pH may be lower and therefore a higher criterion may be applicable.
- Recreation and aesthetics: the NRHMC (2011) lists a health-based value of 500 mg/L for sulphate in consideration to possible purgative effects. It can be expected that sulphate will not be limiting for recreation and aesthetics since health-based values for drinking water consider an intake of 2 L per day, whereas recreation use considers an intake of 200 ml (10% of the drinking intake). Accordingly, a recreation and aesthetic value 10 times higher than the health-based value (5000 mg/L) could be accepted.
- Recreation and aesthetics: the NRHMC 2011 guideline stipulates a criterion for chromium VIII and not for chromium III. Chromium VI was not considered during this assessment as the presence of this chemical was not expected based on the history of the site. Therefore no guideline value for chromium was considered.
- Maintenance of Ecosystems: the ANZECC 2000 guideline value for chromium VI was not considered during this assessment as the presence of this chemical was not expected (due to lack of sources). Therefore, only the chromium III guideline value of 0.0274 mg/L was taken into consideration.
- Maintenance of ecosystems and protection of aquaculture species: the ANZECC 2000 lists toxicity guideline values for ammonia of 0.91 mg/L for the maintenance of marine ecosystems and of 0.1 mg/L for the protection of aquaculture species, both of which have been used for screening purposes. As detailed in section 8.3.7.2 of the guidelines, ammonia concentrations are highly dependent on pH and temperature, and therefore much higher values can be accepted.

- Recreation and aesthetics: nutrients causing algal problems – Nutrients present in groundwater may act as a direct or indirect stressor on ecosystems. A direct stressor is directly toxic to organisms and indirect stressors may impact ecosystems by causing adverse changes to the ecosystem. An example of an indirect stressor is where the presence of nutrients can result in excessive algal growth and cyanobacterial blooms, which may in turn reduce light, produce their own toxins, obstruct waterways, reduce the oxygen content in water etc. Table 3.4.1 of the ANZECC guidelines specify toxicity criteria of 900 ug/L and 700 ug/L for ammonia and nitrate respectively (as N) for moderately disturbed ecosystems, but notes that the ammonia criteria may not protect key species. Table 3.3.4 in this document specifies the criteria for tropical Australia at which nutrients may give rise to adverse effects in estuarine systems of 15 ug/L and 30 ug/L for ammonia and nitrate respectively (as N). Given the generally elevated values across the site the former values have been adopted as initial screening criteria for the purpose of understanding the significance of the values, but it is noted that lower concentrations may give rise to nutrient effects that need to be considered.

Further discussion on the relevance of the groundwater criteria is provided in Section 8.2 of this report.

4.4 Soil quality criteria

According to the proposed development of the site, residential (with limited access to soil), parks, open space recreational areas and commercial land uses have been identified as relevant for the Stage 2a soil assessment. Table 10 details the soil contaminant acceptance criteria used for the Waterfront Development; these have been based on the NEPM 1999 Ecological Investigation Levels (EILs) and Health Investigation Levels (HILs), and the NSW EPA Service Station Guidelines. The application of these guidelines is detailed in the following section (site-specific criteria).

Table 10 Soil acceptance criteria

Analyte	Class 1 (mg/kg) (NEPM EIL)	Class 2A (mg/kg) (NEPM HIL E)	Class 2B (mg/kg) (NEPM HIL F)
Inorganics			
Arsenic	20	200	500
Barium	300	-	-
Cadmium	3	40	100
Cobalt	100[2]	200	500
Chromium[1]	400	240000	60%
Chromium VI	1	500	500
Copper	100	2000	5000
Cyanide (free)	20	500	2500
Lead	600	600	1500
Manganese	500	3000	7500
Mercury	1	30	75
Molybdenum	40	40	40
Nickel	60	600	3000
Selenium	3	10	10

Analyte	Class 1 (mg/kg) (NEPM EIL)	Class 2A (mg/kg) (NEPM HIL E)	Class 2B (mg/kg) (NEPM HIL F)
Tin	50	50	50
Vanadium	50	-	-
Zinc	200	14000	35000
Organics			
Benzene	1	1	1
Ethyl benzene	3.1	3.1	3.1
Toluene	1.4	1.4	1.4
Xylene	14	14	14
TPH C_6-C_9[5]	65	530[6]	No free hydrocarbons[3]
TPH C_{10}-C_{36}	1000	1000	-
TPH C_{10}-C_{15}	-	855[6]	-
TPH C_{15}-C_{36}	-	-	-
Total PAHs	20[2]	40	100
Benzo(a)pyrene	1[2]	2	5
Phenol (total)	10[4]	17000	42500
PCB	10[2]	20	50
Aldrin + Dieldrin	2[4]	20	50
Chlordane	2[4]	100	250
DDT+DDD+DDE	2[4]	-	1000
Heptachlor	2[4]	20	50
Sulphate	2000	2000	2000
pH	6-8	5-10	5-10
Aesthetics/volatiles	No odour or staining	No odour or staining	

Notes:

[1] Assumes all chromium present as trivalent chromium.

[2] NEPM HIL A used for public open space in the absence of NEPM EIL guidelines.

[3] Field procedures to be established to determine acceptable level.

[4] Based on Dutch Intervention Criteria.

[5] Health-based guideline.

[6] Based on findings of Quantitative Risk Assessment for buildings with basements for car parking and no habitable areas.

4.5 Site-specific soil criteria

Site-specific soil contamination acceptance criteria were developed to classify soil samples. The classifications were based on investigation data, contaminant criteria and proposed land uses for their application. The classifications are:

- Class 1 – Material must contain no hydrocarbon odour or staining, Phase Separated Hydrocarbons (PSH), or mixed or iron ore material. Materials are to comply with the NEPM EIL guidelines with the NSW EPA service station guidelines applied for TPH. A sample that exceeds the specified criteria can remain only if the average of the four adjacent grid based samples or the four bracketed samples within one metre, is less than the Class 1 criteria and no individual sample exceeds criteria by more than 2.5 times. This material is suitable for use in the top 1.0 m of public open space, residential areas and areas of landscaping around buildings;
- Class 2A – Material exhibits hydrocarbon staining or detectable odour. Materials are to comply with the NEPM HIL E guidelines with hydrocarbon guidelines as developed in previous quantitative risk assessment reports. A sample that exceeds the specified criteria can remain only if the average of the four adjacent grid based samples or the four bracketed samples within one metre, is less than the Class 2A criteria and no individual sample exceeds criteria by more than 2.5 times. The material is suitable for use within 1.0 m depth of finished surface level for permanently paved areas;
- Class 2B – Materials are to comply with the NEPM HIL F guidelines with no free hydrocarbons. A sample that exceeds the specified criteria it can remain only if the average of the four adjacent grid based samples or the four bracketed samples within one metre, is less than the Class 2B criteria and no individual sample exceeds criteria by more than 2.5 times. The material is suitable for use below buildings, although to avoid possible occupational health and safety concerns for workers during construction, URS proposed that this material should be covered in at least 0.3 m of suitable fill. The material may also remain at least 1.0 m below finished surface level for garden areas, recreational space, grassed playing fields, parks, and paved areas. The results of a risk assessment are included in the next section;
- Class 3 – Material is observed in the vicinity of PSH by smearing on soils or an oil layer greater than 2 mm on groundwater. Hydrocarbon impacted materials that exceed the NEPM HIL F guidelines. This material is not suitable to remain on site without treatment, validation and re-classification. For hydrocarbon impacted soils, validation sampling must include analysis of TPH fractions and select sample analysis for speciated TPH; and
- Class 4 – Non-treatable Class 3 contaminated soil, slurries, soil containing non-aqueous phase liquids and soils containing more than 10% solid inert waste. This material is to be disposed off-site.

4.6 Revised NEPM 2013 criteria

The NEPM was originally issued in 1999, but has since been revised, with the updated version issued in May 2013. Both versions refer to the following water quality guidelines:

- Australian Water Quality Guidelines (AWQG)
- Australian Drinking Water Guidelines (ADWG)

The AWQG were reissued in 2000 and the ADWG were reissued in 2004 and again in 2011. As revised version of these documents have been issued, they have been referred to in the environmental assessment and auditing process as a representation of the latest science. In this respect the water quality guidelines referred to in this report have not altered as a result of the update of the NEPM, although it is noted that the updated versions are now specifically referred to in the most recent update.

5. Condition of site prior to remediation

5.1 Initial assessment of soil contamination (whole of the Darwin Waterfront site)

Field investigations were carried out across the various areas that make up the whole of the Darwin Waterfront development in numerous phases/stages of work. The detailed site history of the Phase 1 investigations provided information on the activities historically undertaken at the site and the surrounding areas and the associated likely contaminants of concern. The primary field works at the site were the Phase 2, 3 and 4 investigations. Sampling was initially conducted on a 30 m grid, followed by targeted sampling of specific locations. Referring to the Australian Standard (AS 4482.1, Table E1) the sampling plan and density were deemed adequate to characterise the material across the entire site and, in particular, to identify the range of composition of fill and contamination likely to be present.

Although the sampling plan was considered to be sufficient to successfully identify broad areas of contamination across the site, it was recognised that it would not necessarily provide for identification and delineation of localised areas of fill and contamination. Where exceedences of the site-specific criteria were observed and it was considered that the contamination could pose a risk to human health, further sampling was undertaken in the vicinity. Sampling points including test pits and boreholes were logged in detail; this included recording information about the extent and depth of the smear zone, and the presence of odours.

The auditor concludes that the body of information assembled was sufficient for purposes of characterising the range of composition of fill and contamination present across the various areas that make up the whole of the Waterfront Development, and identifying broad areas of contamination.

5.2 Stage 2a initial soil and groundwater investigation

5.2.1 Phase 2 and 3 soil investigation

The initial soil investigation locations analysed within the Stage 2a boundary are shown in Figures 7, 8 and 9 of the Stage 2a Remediation Work Plan in Appendix B.1 of this report. These investigations were carried out during phase 2 and phase 3 site works. No sample locations were analysed within the Stage 2a area during the Phase 4 investigation. Locations are shown in Figure 7 and Figure 8 (Figures 5 and 6 of the URS validation report).

The results of the initial testing indicated that there were slightly elevated metal concentrations mainly present within the northern half of the site (the former Warehouse and Recently Reclaimed areas). Exceedences of the Class 1 criteria were noted for arsenic, barium, cadmium, copper, manganese and zinc, while only one exceedence for Class 2A was noted for arsenic. All of these were identified from a depth of 0.0 mbgl to 2.0 mbgl, with the exception of one manganese result at 4.0 mbgl for WA_SB03. Refer to Table 11 for further details of the metal exceedences noted for the Stage 2a area.

Table 11 Phase 2 and 3 on-site soil metal exceedences

Sample ID	Sample Depth (mbgl)	Result (mg/kg)	Criteria Exceeded
Phase 2 metal exceedences			
WA_TP02	0.1	Arsenic – 129 mg/kg, copper – 389 mg/kg, zinc – 655 mg/kg	Class 1 (NEPM EIL)
WA_TP06	0.1	Copper – 580 mg/kg, zinc – 1470 mg/kg	Class 1 (NEPM EIL)
	0.1	Arsenic – 233 mg/kg	Class 2A (NEPM HIL(E))
WA_TP07	0.1	Arsenic – 143 mg/kg, copper – 467 mg/kg, zinc – 749 mg/kg	Class 1 (NEPM EIL)
WA_TP10	0.1	Arsenic – 51 mg/kg, copper – 162 mg/kg, zinc – 712 mg/kg, manganese – 614 mg/kg	Class 1 (NEPM EIL)
WA_SB02	0.1	Arsenic – 50 mg/kg, copper – 254 mg/kg, zinc – 1810 mg/kg, barium – 451mg/kg	Class 1 (NEPM EIL)
	2.0	Arsenic – 31 mg/kg	Class 1 (NEPM EIL)
WA_SB03	2.0	Copper – 138 mg/kg	Class 1 (NEPM EIL)
	4.0	Manganese – 916 mg/kg	Class 1 (NEPM EIL)
NC_TP01	0.1	Zinc – 212 mg/kg, barium – 1670 mg/kg	Class 1 (NEPM EIL)
RR_TP23	0.5	Cadmium – 28 mg/kg, zinc – 3630 mg/kg	Class 1 (NEPM EIL)
RR_MW16	0.0	Zinc – 429 mg/kg	Class 1 (NEPM EIL)
	1.0	Zinc – 430 mg/kg	Class 1 (NEPM EIL)
	2.0	Cadmium – 18 mg/kg	Class 1 (NEPM EIL)
Phase 3 metal exceedences			
WA_TP06N	0.0	Manganese – 2350 mg/kg	Class 1 (NEPM EIL)
WA_TP06S	0.1	Arsenic – 33 mg/kg, Barium – 323 mg/kg, Zinc – 427 mg/kg	Class 1 (NEPM EIL)
WA_TP06E	0.0	Arsenic – 181 mg/kg, Copper – 533 mg/kg, Zinc – 1150 mg/kg	Class 1 (NEPM EIL)
WA_TP06W	0.1	Arsenic – 31 mg/kg, Barium – 393 mg/kg, Zinc – 225 mg/kg, Manganese – 1700 mg/kg	Class 1 (NEPM EIL)
WA_SS07	0.1	Arsenic – 20 /kg	Class 1 (NEPM EIL)
WA_SS08	0.1	Cadmium – 3 mg/kg, Zinc – 433 mg/kg	Class 1 (NEPM EIL)

Visual evidence observed in several testpit logs indicated the presence of hydrocarbon-impacted soils at various locations on the site. Although the hydrocarbon contamination was noted in the logs and detected at some locations, the laboratory analytical results obtained during the sampling program indicated TPH exceedences at only two depths in NC_TP16, during Phase 3 sampling (see Table 12). Results at this location exceeded the Class 2A criteria but in accordance with the site-specific criteria this material (classified as Class 2B) was suitable to remain in situ. No exceedences were recorded during Phase 2 sampling.

Table 12 Phase 2 & 3 on-site soil TPH detects and exceedences

Sample ID	Sample Depth (mbgl)	Result (mg/kg)	Criteria Exceeded
Phase 2			
WA_TP07	0.1	C_{10} - C_{36} – 144 mg/kg	No
NC_TP10	0.1	C_{10} - C_{36} – 158 mg/kg	No
Phase 3			
WA_TP42	6.5	C_{10} - C_{36} – 651 mg/kg	No
NC_TP14	4.0	C_6 – C_9 – 17 mg/kg	No
		C_{10} - C_{36} – 674 mg/kg	
	6.5	C_{10} - C_{36} – 192 mg/kg	
NC_TP15	3.0	C_{10} - C_{36} – 482 mg/kg	No
	5.0	C_{10} - C_{36} – 110 mg/kg	
NC_TP16	5.0	C_6 – C_9 – 20 mg/kg	No
		C_{10} - C_{36} – 6780 mg/kg	Class 2A (NSW EPA Service Station Guidelines)
	5.0	C_{10} - C_{14} – 1350 mg/kg	Class 2A (QRA based criteria)

Although TPH results were found at only a few locations within the Stage 2a area, the auditor notes that the presence of hydrocarbon contamination was observed in the logs at a number of other locations, and these samples were not analysed. These observations were consistent with hydrocarbon contamination being present in the groundwater smear zone at depth between the seasonal groundwater high and low levels, as observed elsewhere across the wider Darwin waterfront area (Refer to Table 13).

Table 13 Initial investigation locations for visually identified hydrocarbon contamination

Location ID	Sample & observation depth (mbgl)	Logged Observations	TPH (C_{10}-C_{36}) Concentration*
PHASE 2			
RR_TP23	2.0	Slight black staining, slight hydrocarbon odour	Not analysed
RR_TP24	3.0	Slight black staining	Not analysed
RR_MW16	2.4	Hydrocarbon odour	Not analysed
WA_TP02	5.2	Water entry at 5.2 m, sheen on surface	Not analysed (Note: Sample analysed at 5.0 m; TPH C_{10}-C_{36} result: non-detect)
	6.0	Dark grey staining, hydrocarbon odour	Not analysed
WA_TP06	3.0	Water entry at 3.0 m, slight sheen	Non-detect
WA_TP07	3.0	Water entry at 3.0 m, sheen on surface	Non-detect
	3.1	Slight hydrocarbon odour from pit	Not analysed
WA_TP10	2.0	Diesel odour	Not analysed
	3.0	Strong diesel odour	Not analysed
	5.0	Slight diesel odour	Not analysed

Location ID	Sample & observation depth (mbgl)	Logged Observations	TPH (C_{10}-C_{36}) Concentration*
	5.1	Water entry at 5.1 m, oil film on water surface	Not analysed
WA_TP11	2.0	Slight hydrocarbon odour	Not analysed
	3.0	Strong hydrocarbon odour	Not analysed
	6.0	Slight hydrocarbon odour	Not analysed
WA_TP12	1.8	Strong hydrocarbon odour from pit	Not analysed
	2.0	Slight staining, strong hydrocarbon odour	Not analysed
	4.0	Slight odour	Not analysed
	4.5	Water entry at 4.5, slight odour	Not analysed
NC_TP13	4.0	Strong hydrocarbon odour, black staining	Not analysed
PHASE 3			
RR_MW16A	3.2	Hydrocarbon odour	Not analysed
	4.7	Hydrocarbon odour	Not analysed
NC_TP14	4.0	Hydrocarbon odour	674 mg/kg
	6.6	At contact of phyllite fill and marine sediments - shells and black oil	Not analysed (Note: Sample analysed at 6.50 m; TPH C_{10}-C_{36} result: 192 mg/kg)
NC_TP16	0.0	Some hard black materials	Not analysed
	2.0	Some black staining	Not analysed
	2.5	Some black materials	Not analysed
	3.0	Some black materials	Non-detect
	5.0	At contact of fill and marine sediments, black oil, hydrocarbon odour and sheen on the water.	6780 mg/kg

Benzo(a)pyrene and Total PAH results were found to exceed the Class 2A criteria at a depth of 3.0 mbgl at NC_TP15 with values of 3.6 mg/kg and 44.7 mg/kg respectively. These exceedences were noted during Phase 3 investigations.

pH results varied across the site between 4.6 and 10.5, with most of the exceedences being pH values that were above the Class 1 criteria of pH 6 to pH 8 (i.e. were more alkaline). In Phase 2, a total of 35 samples were analysed for pH, with 22 of the 35 samples exceeding the specified pH range. In Phase 3, nine samples were analysed for pH, with seven of them falling outside of the Class 1 criteria. During Phase 2, four results were found to exceed the Class 2A criteria (pH 5 to pH 10). Refer to Table 14 for pH analytical results falling below six or above eight within the Stage 2a area.

Table 14 Phase 2 and 3 soil pH exceedences

Sample ID	Depth (mbgl)	pH value	Sample ID	Depth (mbgl)	pH value
Phase 2 pH exceedences					
WA_SB02	2.0	8.3	WA_TP10	0.1	8.5
	5.0	8.6		1.0	8.9
WA_SB03	1.0	8.3		2.0	8.7
WA_TP02	0.1	8.7		5.0	8.3
	1.0	5.3	WA_TP12	0.5	8.9
	2.0	4.7		1.0	8.6
WA_TP04	0.1	8.2	NC_MW17	0.0	9.0
WA_TP05	0.1	8.3		2.0	4.9
	1.0	5.3		6.0	4.6
WA_TP06	0.1	8.9	NC_TP09	1.0	9.9
	1.0	8.2		5.0	9.8
	2.0	8.3	RR_MW16	1.0	8.1
WA_TP07	2.0	8.8		2.0	10.5
	5.0	8.2		6.0	8.5
Phase 3 pH exceedences					
WA_TP06W	0.1	9.2	WA_TP06S	0.1	8.8
WA_TP06E	0.0	9.4		1.0	8.4
WA_TP06N	0.0	8.2			

Regarding PASS, these were identified at WA_SB03 (between 7.6 and 10 m depth), WA_TP02, WA_TP05 (at 5.7 m depth), WA_TP07 (at 5 m depth), NC_MW17 (at 13.5 and 14 m depth), RR_MW15 (between 6.2 and 10.5 m depth), RR_MW16 (between 3 and 11 m depth). WA_TP05 was also classified as AASS due to its low pH_{KCl} value. PASS materials were identified within clay rich marine sediments and underlying fill materials (in the case of NC_MW17) and AASS is locally present at the interface of fill materials and underlying marine sediments. Lab testing also suggests that minor acid neutralizing capacity is present at some locations but generally insufficient to neutralize the acidity generated.

5.2.2 Pre-remediation soil investigation

Soil sampling was carried out during demolition and excavations activities undertaken in 2004 for the removal of old subsurface infrastructure, pavements and building slabs and foundations that remained within the former warehouse, tipping shed, Cockburn cement and northern cement areas. Out of the 33 locations sampled six were located within the current Stage 2a area (EST02, EST04, EST05, EST29, EST65, EST71 and EST77), which are shown in Figure 9 (Figure 2 of the Pre-Remediation Soil Sampling Report).

Metal exceedences of the Class 1 and 2A criteria for arsenic, copper and zinc were found at two locations while a lead exceedence of the Class 2A criteria was recorded at one location. Refer to Table 15 for details on the location and depth of the metal exceedences found within the Stage 2a area. The results from the TCLP test performed on EST29 for arsenic, copper and zinc suggested that these metals will have low mobility.

Table 15 Pre-remediation works soil metal exceedences

Sample ID	Sample Depth (mbgl)	Result (mg/kg)	Criteria Exceeded
Pre-remediation works metal exceedences			
EST29	0.4 – 0.5	Arsenic – 382 mg/kg	Class 2A (NEPM HIL(E))
		Copper – 1160 mg/kg, Zinc – 829 mg/kg	Class 1 (NEPM EIL)
EST65	0.6	Lead – 1210 mg/kg	Class 2A (NEPM HIL(E))
EST71	0.1 – 0.15	Arsenic – 136 mg/kg , Copper – 416 mg/kg, Zinc – 983 mg/kg	Class 1 (NEPM EIL)

Free sulphur was also noted in the form of yellow staining and pieces at one location, EST65, at a depth of 0.6 m. Laboratory results indicated elevated concentrations of 39.6% by mass of sulphur.

Of the six locations, five were analysed for pH with three of them being outside the Class 1 criteria range (pH between 6 and 8): EST29 (pH 8.7), EST71 (pH 8.7) and EST77 (pH 8.5). Additionally, one sample, EST65 showed a pH value of 2.4, falling outside the Class 2A and 2B criteria (pH between 5 and 10).

No exceedences were registered for TPH, BTEX, PAHs and PCBs at any of the locations within the Stage 2a area.

5.2.3 Initial groundwater sampling (Phase 2, Phase 3/4 and annual groundwater monitoring events from 2004 to 2006)

Six groundwater monitoring wells were installed within the Stage 2a site during Phase 2 (RR_MW16, NC_MW17) and Phase 3 (RR_MW16A, NC_MW17A, WA_MW33, SMW01) investigations. WA_MW33 was located along the northern boundary of the site; RR_MW16 and RR_MW16A were located within the central region of the site close to the eastern boundary; SMW01 was located centrally within close proximity to the western boundary; NC_MW17 and NC_MW17A were located within close proximity to the south eastern boundary, near the edge of the lagoon. Twelve additional groundwater monitoring wells were identified off-site in areas representative of the site, which could be considered indicative of groundwater conditions at or leaving the site (refer to Figure 5 for the location of these wells). Groundwater sampling was undertaken at these locations at regular intervals between December 2003 and September 2006. Refer to Table 6 for the list of on-site and off-site wells and their sampling dates (due to well destruction and installation of replacement wells, not every well was sampled in each sampling round).

Across all sampling rounds these well locations were below detection limits for BTEX, except for the February 2005 sampling round, where toluene was detected in MW47A (114 µg/L) and in MW47B (32 µg/L), both values being above the recreation and aesthetics and protection of aquaculture species criteria.

Hydrocarbon detected concentrations TPH C_{10}-C_{36} were in the range between 81 µg/L to 1943 µg/L for the Stage 2a on-site wells, whereas TPH C_{10}-C_{36} detected concentrations for off-site wells ranged from 60 µg/L to 7600 µg/L. Refer to Table 16 for the TPH values in each sampling round. This table does not include sampling rounds in which wells were not monitored or TPH was not detected (TPH was not detected at KD_MW03 and KD_MW04A in any of their sampling rounds).

Table 16 TPH (C_{10}-C_{36}) detected at monitoring wells during the initial groundwater sampling

Monitoring Well ID	Sampling round	TPH (C_{10}-C_{36}) µg/L	Monitoring Well ID	Sampling round	TPH (C_{10}-C_{36}) µg/L
Stage 2a On-site Monitoring Wells					
WA_MW33	Feb 2004	970	NC_MW17A	Feb 2004	740
	Sep 2004	240		Sept 2004	172
	Dec 2004	572		Dec 2004	855
	May 2005	100		May 2005	200
	Nov 2005	260		Nov 2005	390
WA_MW33 (Duplicate)	Sep 2004	189	SMW01	Feb 2004	123
				Sep 2004	234
RR_MW16A	Feb 2004	1943		Dec 2004	81
	Dec 2004	284		Nov 2005	110
	Feb 2005	820		Feb 2006	270
	May 2005	360		June 2006	190
	Nov 2005	540			
Stage 2a Off-site Monitoring Wells					
KD_MW03A	Dec 2004	789	SMW02	Feb 2004	722
	June 2006	100		Sep 2004	711
KD_MW04	Dec 2003	924		Dec 2004	1473
RR_MW15	Sep 2004	207		Feb 2005	2550
RR_MW15A	Sep 2004	134		May 2005	1240
	Dec 2004	183		Nov 2005	480
	Nov 2005	190		Feb 2006	2010
BP_MW35	Feb 2004	233		June 2006	990
	Dec 2004	835	SMW03	Feb 2004	712
	May 2005	250		Nov 2005	60
	Feb 2006	520		June 2006	200
	June 2006	410	SMW04	Feb 2004	4973
BP_MW47A	Sep 2004	1185		Feb 2005	5700
	Feb 2006	340		May 2005	5330
BP_MW47B	Feb 2005	450		Nov 2005	4590
	Nov 2005	1000		Feb 2006	7600
	Feb 2006	180		June 2006	2770
	June 2006	180			

Metal impacts found to exceed the ANZECC 2000 for Aquatic Ecosystems, the ANZECC 2000 for the Protection of Aquaculture Species and/or the NRHMC 2011 for Recreation and Aesthetics guidelines were identified at all the onsite monitoring wells and all the offsite wells relevant to the Stage 2a site. The exceedences identified between the December 2003 and September 2006 groundwater sampling rounds are summarised in Table 17, in which different colours have been used to identify the different criteria considered and the highest guideline value has been highlighted in red.

The main impacts are for manganese, with results exceeding the recreation and aesthetics criterion (1 mg/L; the higher value) at nine of the 18 wells. The magnitudes of the manganese exceedences were typically in the same order of magnitude except for two wells, MW47A and MW47B, which consistently presented results around one order of magnitude greater than the criterion. The nine remaining wells exceeded only the protection of aquaculture species criterion (0.01 mg/L), in almost all sampling rounds. Generally the manganese results were consistent with those observed across the Darwin Waterfront, and are typical of those expected to occur where reducing conditions occur (such as can occur naturally, and where hydrocarbons and other biodegradable organic constituents are present).

Copper impacts in excess of the Aquatic Ecosystem criterion were identified at nine of the 18 wells. Exceedences were in the same order of magnitude than the criterion, except for MW03A in November 2005, where the concentration was also in excess of the protection of aquaculture species criterion. These results were consistent with the concentrations of copper detected across the wider area suggesting that the levels observed at these wells are likely to represent background water quality conditions.

Zinc concentrations were found to slightly exceed the Aquatic Ecosystem criterion at 13 of the 18 monitoring wells and the protection of aquaculture species criterion at one additional well, during at least one or more sampling rounds. Generally the magnitude of the exceedences was not significant (within the order of magnitude of the criteria), with the exception of SMW03, for which the results were found to be approximately one order of magnitude larger than the criteria for six of its seven sampling rounds. In general, the results were consistent with other results observed across the Darwin Waterfront, suggesting that these were background concentrations.

Lead was found to exceed the protection of aquaculture species criterion at seven of the 18 wells with one well (MW17A in February 2005) also exceeding the aquatic ecosystems criterion. Exceedences were in the same order of magnitude as the criteria and are consistent with other results observed across the Darwin Waterfront.

Nickel exceedences were found at one well, RR_MW16 in December 2003, above the aquatic ecosystems and protection of aquaculture species criteria. However, this was an isolated event and none of the following rounds of sampling at that well showed exceedences and subsequent sampling at the adjacent “A” well (RR_MW16A) did not report nickel results in exceedence of the guidelines. The result is also consistent with other results observed across the Darwin Waterfront suggesting that it is representative of background levels.

Cadmium exceedences of the protection of aquaculture species criterion were found at five of the 18 wells. In one of them (SMW03), two sampling rounds were found to exceed the aquatic ecosystems criterion, which is one order or magnitude higher than the protection of aquaculture species one. The magnitude of these exceedences was only marginal (within the order of magnitude of the corresponding criteria), and they were consistent with other results observed across the Darwin Waterfront suggesting that they are representative of background levels.

Two silver exceedences, one of the Aquatic Ecosystem criterion and one of the protection of aquaculture species criterion were found in MW35 (December 2004) and SMW02 (February 2005), respectively. Both concentrations were within one order of magnitude of the corresponding criterion.

In the case of iron (total, ferrous and ferric), the measured concentrations showed exceedences at six wells over the guideline value of 3 mg/L for recreation and aesthetics (guidelines do not provide separate criteria for ferric and ferrous iron, so the value for total iron was used for screening purposes), with three of these locations (MW17A, MW03A and SMW02) presenting significantly elevated concentrations (reaching two orders of magnitude or more greater than the guideline value). The specified guideline value of 3 mg/L is based on taste considerations and higher values can be accepted in marine water systems.

Table 17 Metal exceedences reported at monitoring wells during the initial groundwater sampling (December 2003 to September 2007)

	Cadmium (mg/L)	Copper (mg/L)	Zinc (mg/L)	Iron (mg/L)[3]	Manganese (mg/L)	Nickel (mg/L)	Lead (mg/L)	Silver (mg/L)
Aquatic Ecosystem criteria	0.0055	0.0013	0.015	No value	No value	0.070	0.0044	0.0014
Recreation and aesthetics criteria	**0.02**	**10**	**30**	**3**	**1**	**0.2**	**0.1**	**1**
Aquaculture species criteria	0.0005	0.005	0.005	0.01	0.01	0.1	0.001	0.003
Stage 2a On-site Groundwater Monitoring Wells								
RR_MW16 (2 sampling rounds)					0.567 (Dec 03) 0.432 (Feb 04)	0.158 (Dec 03)		
RR_MW16A (5 sampling rounds)					1.52 (Dec 04) 1.13 (Feb 05) 1.2 (Jun 05) 1.78 (Nov 05)		0.002 (Feb 05)	
NC_MW17 (2 sampling rounds)			0.028 (Dec 03) 0.019 (Feb 04)		5.22 (Dec 03) 1.84 (Feb 04)			
NC_MW17A (5 sampling rounds)	0.0005 (Sept 04)	0.002 (Dec 04) 0.003 (Feb 05)	0.046 (Sep 04) 0.079 (Dec 04) 0.043 (Feb 05) 0.026 (Jun 05) 0.037 (Nov 05)	Total iron: 18.4 (Feb 05) 51.4 (Nov 05) 21.5 (Jun 05) Ferrous Iron: 84.4 (Dec 04) 16.5 (Jun 05) 2.28 (Feb 05) 55.5 (Nov 05) Ferric iron: 16.1 (Feb 05) 4.94 (Jun 05)	4.66 (Sep 04) 7.7 (Dec 04) 5.79 (Feb 05) 4.77 (Jun 05) 7.8 (Nov 05)		0.005 (Feb 05) 0.001 (May 05)	
WA_MW33 (6 sampling rounds)		0.003 (Feb 05)	0.023 (Sept 04) 0.016 (Duplicate Sep 04) 0.024 (Triplicate Sep 04) 0.019 (Dec 04) 0.06 (Feb 05) 0.006 (May 05) 0.012 (Nov 05)	Total iron: 6.56 (Nov 05) Ferrous iron: 5.76 (Nov 05) Ferrous Iron: 1.3 (Sep 04) Ferric iron: 0.8 (Nov 05)	0.396 (Sep 04) 0.425 (Duplicate Sep 04) 0.4 (Triplicate Sep 04) 0.268 (Dec 04) 0.622 (Feb 05) 0.305 (May 05) 0.231 (Nov 05)		0.003 (Feb 05) 0.001 (May 05)	
SMW01 (8 sampling rounds)			0.024 (Mar 04) 0.015 (Sep 04) 0.008 (Dec 04) 0.006 (Feb 05) 0.007 (May 05) 0.009 (Nov 05) 0.007 (Feb 06) 0.006 (Jun 06)		1.48 (Jun 06) 0.242 (Mar 04) 0.638 (Sep 04) 0.244 (Dec 04) 0.139 (Feb 05) 0.671 (Nov 05)		0.003 (Feb 05)	
Stage 2a Off-site Groundwater Monitoring Wells								
KD_MW03 (1 sampling round)		0.002 (Feb 04)	0.013 (Feb 04)		0.042 (Feb 04)			
KD_MW04 (2 sampling rounds)		0.003 (Dec 03) 0.002 (Duplicate, Dec 03) 0.002 (Split, Dec 03)	0.021 (Dec 03) 0.088 (Duplicate, Feb 04) 0.011 (Duplicate, Dec 03) 0.014 (Feb 04)		0.052 (Dec 03) 0.086 (Duplicate, Dec 03) 0.054 (Triplicate, Dec 03) 0.124 (Feb 04) 0.12 (Duplicate, Feb 04)			

[3] Guidelines do not provide separate criteria for ferric and ferrous iron, so the value for total iron was used for screening purposes.

	Cadmium (mg/L)	Copper (mg/L)	Zinc (mg/L)	Iron (mg/L)[3]	Manganese (mg/L)	Nickel (mg/L)	Lead (mg/L)	Silver (mg/L)
Aquatic Ecosystem criteria	0.0055	0.0013	0.015	No value	No value	0.070	0.0044	0.0014
Recreation and aesthetics criteria	**0.02**	**10**	**30**	**3**	**1**	**0.2**	**0.1**	**1**
Aquaculture species criteria	0.0005	0.005	0.005	0.01	0.01	0.1	0.001	0.003
KD_MW03A (7 sampling rounds)		0.003 (Dec 04) 0.002 (May 05) 0.013 (Nov 05)	0.029 (Sep 04) 0.026 (Feb 05) 0.035 (May 05) 0.086 (Nov 05) 0.044 (Mar 06) 0.013 (Dec 04) 0.011 (Jun 06)	Ferrous Iron 48.5 (Sep 04) Total iron: 0.1 (May 05) 0.07 (Jun 06) 0.19 (Mar 06) Ferrous iron: 0.08 (Mar 06) Ferric iron: 0.1 (May 05) 0.07 (Jun 06) 0.1 (Mar 06)	0.061 (Sep 04) 0.055 (Dec 04) 0.099 (Feb 05) 0.016 (May 05) 0.014 (Nov 05 0.074 (Feb 06) 0.034 (Jun 06)		0.002 (Feb 05)	
KD_MW04A (6 sampling rounds)		0.002 (Dec 04)	0.015 (Sep 04) 0.022 (Dec 04) 0.044 (May 05) 0.019 (Oct 05) 0.014 (Feb 05) 0.012 (Jun 06)		0.068 (Sep 04) 0.089 (Dec 04) 0.059 (Feb 05) 0.047 (May 05) 0.046 (Oct 05) 0.032 (May 06)			
RR_MW15 (3 sampling rounds)			0.092 (Dec 03)		1.72 (Dec 03) 2.32 (Feb 04) 2.94 (Oct 04)			
RR_MW15A (5 sampling rounds)					2.13 (Oct 04) 1.11 (Feb 05) 0.672 (Dec 04) 0.646 (May 05) 0.333 (Nov 05)		0.001 (Feb 05)	
BP_MW35 (7 sampling rounds)		0.002 (Feb 05) 0.002 (Feb 06) 0.002 (Jun 06)	0.022 (Sep 04) 0.026 (Dec 04) 0.025 (Feb 05) 0.021 (May 05) 0.021 (Feb 06) 0.025 (Jun 06)	Total iron: 0.11 (Feb 06) 0.94 (Jun 06) Ferrous iron: 0.64 (Jun 04) 0.2 (Sep 04) Ferric iron: 0.11 (Feb 06) 0.29 (Jun 06)	2.09 (Sep 04) 3.61 (Dec 04) 3.65 (Feb 05) 1.86 (Feb 06) 1.22 (Jun 06) 0.862 (May 05)			0.002 (Dec 04)
BP_MW47B (6 sampling rounds)	0.0006 (Sept 04) 0.0011 (May 05) 0.0011 (Nov 05)		0.091 (Nov 05)	Total iron: 1.75 (Feb 06) 0.73 (Jun 06) Ferrous Iron: 1.42 (Feb 06) 0.53 (Jun 06) Ferric iron: 0.33 (Feb 06) 0.2 (Jun 06)	7.62 (Sep 04) 10.3 (Feb 05) 8.49 (May 05) 10.5 (Nov 05) 9.91 (Feb 06) 10.9 (Jun 06)		0.002 (Feb 05)	
BP_MW47A (6 sampling rounds)				Total iron: 16.4 (Nov 05) 20.9 (Jun 06) 19.2 (Feb 06) Ferrous Iron: 16.4 (Nov 05) 22.1 (Jun 06) 23.7 (Feb 06)	14.8 (Sep 04) 15.2 (Feb 05) 10.4 (May 05) 13.1 (Nov 05) 12.7 (Feb 06) 13.5 (Jun 06)			

	Cadmium (mg/L)	Copper (mg/L)	Zinc (mg/L)	Iron (mg/L)[3]	Manganese (mg/L)	Nickel (mg/L)	Lead (mg/L)	Silver (mg/L)
Aquatic Ecosystem criteria	0.0055	0.0013	0.015	No value	No value	0.070	0.0044	0.0014
Recreation and aesthetics criteria	**0.02**	**10**	**30**	**3**	**1**	**0.2**	**0.1**	**1**
Aquaculture species criteria	0.0005	0.005	0.005	0.01	0.01	0.1	0.001	0.003
SMW02 (8 sampling rounds)	0.0007 (Sept 04) 0.0014 (Dec 04) 0.0006 (May 05) 0.0032 (Nov 05)	0.002 (May 05)	0.020 (Mar 04) 0.075 (Dec 04) 0.020 (Feb 05) 0.022 (May 05) 0.064 (Nov 05) 0.008 (Jun 06)	Total iron: 40.7 (Feb 05) Ferrous Iron: 4.9 (Dec 04) Ferric Iron: 39.3 (Feb 05) Total iron: 2.52 (May 05) 1.03 (Nov 05) 1.89 (Mar 06) 1.27 (Jun 06) Ferrous iron: 1.43 (Feb 05) 2.63 (May 05) 0.85 (Nov 05) 1.67 (Mar 06) 1.31 (Jun 06) Ferric iron: 0.18 (Nov 05) 0.22 (Mar 06)	0.374 (Mar 04) 0.542 (Sep 04) 0.673 (Dec 04) 0.546 (Feb 05) 0.515 (May 05) 0.408 (Nov 05) 0.484 (Mar 06) 0.246 (Jun 06)			0.007 (Feb 05)
SMW03 (7 sampling rounds)	0.0013 (Feb 04) 0.0007 (Dec 04) 0.0017 (Feb 05) 0.0054 (May 05) 0.002 (June 06) 0.0055 (Sept 04) 0.0081 (Nov 05)	0.002 (Mar 04) 0.003 (Jun 06)	0.097 (Mar 04) 0.099 (Sep 04) 0.110 (Dec 04) 0.097 (Feb 05) 0.118 (May 05) 0.143 (Nov 05) 0.083 (Jun 06)		0.557 (Mar 04) 0.389 (Sep 04) 0.016 (Dec 04) 0.666 (Feb 05) 0.647 (Jun 06)			
SMW04 (6 sampling rounds)	0.0008 (Mar 04)		0.042 (Mar 04) 0.006 (Feb 05) 0.007 (May 05) 0.01 (Nov 05) 0.008 (Feb 06)	Total iron: 10.1 (Nov 05) Ferrous Iron: 10.1 (Nov 05) Total iron: 3.04 (Feb 06) 2.54 (Jun 06) Ferrous iron: 2.4 (Feb 06) 2.46 (Jun 06) Ferric iron: 0.63 (Feb 06) 0.07 (Jun 06)	0.328 (Mar 04) 0.564 (Feb 05) 0.61 (May 05) 0.655 (Nov 05) 0.405 (Feb 06) 0.287 (Jun 06)			

Ammonia concentrations in excess of one of the guideline criteria were identified at most well locations (with the exception of SMW03 which was never analysed for ammonia) almost every time when it was analysed, with the majority of the exceedences being greater than the protection of aquaculture species criterion (the lowest value). The maximum ammonia concentration, 48.8 mg/L, was identified at NC_MW17A, an on-site well located within close proximity to the south eastern boundary of the site. This exceedence was identified in February 2004, whereas subsequent analysis carried out in February 2005, June 2005 and November 2005, reported concentrations of 2.92 mg/L, 3.67 mg/L and 4.54 mg/L respectively. Concentrations in this well are also the highest compared to the other relevant wells.

TDS, sodium, sulphate and chloride were observed in excess of the recreation and aesthetics criteria (ADWG 6, NRHMC 2011) in the majority of the wells, however these results are considered typical of saline conditions associated with seawater effects, as noted previously in Section 4.3.

The groundwater pH results were within the criteria for recreation and aesthetics (pH 6.5 to pH 8.5) with the exception of the results taken from six locations (MW03A, MW04, MW04A, MW17A, SMW01 and MW47B). Only one of these wells, MW04A exhibited three results also outside the criteria for the protection of aquaculture species (pH 6.0 to pH 9.0). Table 18 shows the laboratory results for the aforementioned locations below the acceptable criteria range, with the exceedences ranging from 5.73 to 6.49.

Table 18 Groundwater pH exceedences from initial groundwater sampling

Groundwater Monitoring Well ID	Sampling round	pH value	Criteria exceeded
KD_MW03A	Feb 2006	6.19	Recreation and aesthetics (ADWG 2011)
KD_MW04	Feb 2004	6.06	Recreation and aesthetics (ADWG 2011)
KD_MW04 (Duplicate)	Feb 2004	6.00	
KD_MW04A	Sep 2004	6.12	Recreation and aesthetics (ADWG 2011)
	Dec 2004	6.49	
	Feb 2005	5.73	Protection of aquaculture species (ANZECC 2000)
	Oct 2005	5.80	
	Jun 2006	5.61	
NC_MW17A	Sep 2004	6.19	Recreation and aesthetics (ADWG 2011)
	Dec 2004	6.31	
	Feb 2005	6.14	
	Jun 2005	6.22	
	Nov 2005	6.30	
SMW01	Feb 2005	6.46	Recreation and aesthetics (ADWG 2011)
BP_MW47B	Feb 2005	6.47	Recreation and aesthetics (ADWG 2011)

After 2006, several groundwater wells were lost across the Waterfront site. Details of the replacement and new wells relevant for the Stage 2a area and the subsequent groundwater monitoring events results are provided in Section 6.1.3.

6. Clean up and validation of the site

The clean-up and validation requirements were originally specified by the Remediation Action Plan issued by URS on 9 August 2005 and the Validation and Monitoring Brief issued by GHD on the 21 October 2005. After that time URS undertook a more detailed risk assessment of the site (Quantitative Risk Assessment, Stage 2a Darwin City Waterfront, 2 February 2010), which more closely considered the contaminants present on site (i.e. the Stage 2a area rather than the broader waterfront site) and this resulted in less stringent clean-up / contamination management requirements. URS compiled a remediation work plan (Stage 2a Remediation Work Plan, 27 September 2010), which outlined the strategy for managing soil and groundwater issues within the Stage 2a area and the remedial works that needed to be undertaken as part of the site development works. The strategy is based on the RAP developed in 2005, but includes amendments that were accepted by the auditor. Clean up of the site was generally based on the principles that:

- Any sources of hydrocarbon contamination, including historic pipelines, must be removed as far as practicable;
- Where non-aqueous phase liquid (NAPL) is encountered / or known to be present, it should be removed;
- An investigation strategy should be adopted to provide confidence that NAPL is not present under building footprints;
- NAPL that may be present outside of building footprints and remains undetected in the investigation and site works programs can be expected to be of sufficiently limited extent that it does not pose a risk to the use of the site and may remain in place;
- Soil that is visually contaminated will be removed when identified within the top meter of soil in open space areas. In other areas or where contaminated soil has been removed and validated, an assessment will be made on a case by case basis. Visually contaminated material is defined as that which has been proved to be chemically uncontaminated but contains foreign material (metal, rubble, concrete blocks, ore material, etc.) or other components that result in unacceptable discolouration, texture or odour; and
- Other contaminants or potentially hazardous material such as asbestos, ASS or UXO have a low probability of being present and it can be expected that any such material that may be present at the site will be contained and will not pose a risk to the future use of the site after development, and that any such material that may be identified and exposed during site works should be managed in accordance with a Construction Environmental Management Plan (CEMP) and removed as necessary.

To provide confidence that NAPL is not present under building footprints, validation of the material beneath building footprints involved a 10 m grid of either test pits that were excavated to the water table (if possible), or groundwater bores drilled and installed with temporary standpipes. It was required that test pits and/or bores must remain open for sufficient time to allow hydrocarbons if present to equilibrate (preferably overnight where occupational health and safety requirements allow) and remediation must occur where the thickness of hydrocarbons is greater than 2 mm.

Information on the management measures undertaken to ensure that residual contamination does not present a risk to the current and future use of the site (i.e. relevant beneficial uses or environmental values) is provided in Section 9.

6.1 Remediation and validation

Following the demolition and removal of above and underground infrastructure and excavation of the basement, validation works were undertaken to delineate the contamination that may be encountered beneath the building and construction footprints within the Stage 2a area and ensure that contamination that was unsuitable to remain onsite was removed. The investigation was carried out between August 2009 and December 2013 and consisted in four different stages:

- August 2009: drilling of 88 soil bores (TB01 – TB88) to a depth of 6 m bgl on a 10 m grid across the site, with the majority of the bores located within the buildings footprints. Temporary groundwater piezometers were installed into the drilled soil bores to assess the presence (or absence) of phase separated hydrocarbons (PSH) and to gauge the groundwater levels;
- November 2009: seven test pits (TP89 – TP95) were excavated to an approximate depth of 6 m bgl in areas not accessible during the August drilling works and at hot spot locations identified during the August drilling works. All drilling and excavations works were carried out prior to the trimming works for Building 4 and basement excavation of buildings 5 and 6; and
- December 2012 – March 2013: excavations for the basement of Building 5, Building 6, car park areas, service trenches and piling works were observed for indications of soil contamination. Building footprints were excavated up to a depth of 3.5 to 4 m bgl (approximately 3 m AHD). A total of 159 samples of the stockpiled spoil from different excavations were analysed and 11 additional samples were collected from the walls and base of a hydrocarbon impacted area at the northeast corner of the Building 5 footprint.

6.1.1 Soil validation works (August and November 2009)

Borehole and test pit soil assessment

A total of 149 soil samples from 88 soil bores and seven test pits were analysed. The location of the soil bores is shown in Figure 10 (Figure 2 of the URS Validation Report). All samples were analysed for TPH, BTEX, PAH and metals and, additionally, ten soil bore samples and all test pit samples were analysed for phenols.

TPH were detected at 21 of the 88 locations (in 29 primary samples), but staining and / or hydrocarbon odour was identified in only two of them, specifically in TB78 and TB80. However, the TPH C_{10}-C_{36} results exceeded the Class 1 and Class 2A criteria of 1000 mg/kg at three other soil bores as listed in Table 19, despite no odour and/or staining was reported at these locations.

Table 19 TPH exceedences reported during the soil bore validation investigation

Sample ID	Sample Depth (mbgl)	C_{10} – C_{36} result (mg/kg)	Criteria Exceeded
TB01	3.0	6600 mg/kg	Class 2A (NEPM HIL E)
TB43 (triplicate sample)	3.0	1280 mg/kg	Class 2A (NEPM HIL E)
TB78	4.0	1155 mg/kg	Class 2A (NEPM HIL E)

Subsequent test pitting conducted at targeted locations (including TP95 at TB01, TP92 at TB78 and TP93 at TB43) to further analyse the extent of hydrocarbon impacted soil reported laboratory results for TPH C_{10}-C_{36} below the Class 1 criteria for all samples, with TPH detections only at TP90 (1.5 m bgl), TP91 (5 m bgl) and TP94 (1 m bgl). Hydrocarbon odour was reported only at TP90, TP91 and TP95. Results tables for the soil bore and test pit samples can be found in Table 1 of the URS Validation Report (Appendix B.2).

In regard to metals, the results of the validation analytical testing indicated that there were slightly elevated concentrations present across the Stage 2a area. Exceedences of the Class 1 criteria were noted for arsenic, cadmium, copper, lead, nickel, manganese and zinc at the locations and depths specified in Table 20.

Table 20 Metal exceedences reported during the 2009 soil validation investigation

Sample ID	Sample Depth (mbgl)	Result (mg/kg)	Criteria Exceeded
TB02	3.4	Mn – 600 ; Zn – 2400	Class 1 (NEPM EIL)
	5.5	Cu – 180; Zn – 500	Class 1 (NEPM EIL)
TB03	3.0	Zn – 520	Class 1 (NEPM EIL)
TB05	6.0	Zn – 230	Class 1 (NEPM EIL)
TB07	4.0	Mn – 660	Class 1 (NEPM EIL)
TB08	5.0	Zn – 370	Class 1 (NEPM EIL)
TB17	5.0	As – 55; Cd – 5.4; Cu – 240; Mn – 2000; Ni – 190; Zn – 3700	Class 1 (NEPM EIL)
TB23	2.0	As – 49; Cd – 16; Pb – 1200; Zn – 1600	Class 1 (NEPM EIL)
TB41	2.0	Cu – 110	Class 1 (NEPM EIL)
TB56	3.0	Mn – 820	Class 1 (NEPM EIL)
TB68	1.0	As – 28	Class 1 (NEPM EIL)
TB70	2.0	Zn – 430	Class 1 (NEPM EIL)
TB71	2.0	Cd – 8.7; Zn – 940	Class 1 (NEPM EIL)
	4.0	Cd – 9.3; Zn – 1500	Class 1 (NEPM EIL)
TB72	5.0	As – 98; Cu – 1500	Class 1 (NEPM EIL)
TB78	3.0	As – 23	Class 1 (NEPM EIL)
TB82	5.0	As – 21; Mn – 860; Zn – 2200	Class 1 (NEPM EIL)
TB86	2.0	Zn – 220	Class 1 (NEPM EIL)
TB87	4.0	Zn – 300	Class 1 (NEPM EIL)
TP95	3.5	Mn - 2440	Class 2A (NEPM HIL E)

The metal concentrations during the soil bore investigation were similar to the concentrations encountered during the pre-validation investigation works (Phase 2 and 3). Within test pit samples, the only reported exceedence corresponds to TP95_3.5 with a manganese concentration of 2440 mg/kg, which exceeds the Class 2A site specific criteria of 500 mg/kg.

No other exceedences of the site specific criteria were noted. pH was not analysed for in the bores or test pits during this validation works.

Groundwater observations

Groundwater was inspected for the presence of phase separated hydrocarbons (PSH) during test pitting and via the temporary 88 piezometers. PSH or sheens were not observed in the test pits or piezometers, except for a slight hydrocarbon odour and sheen (highly degraded globules) encountered in the groundwater at TP91. In accordance with the site remediation principles this did not require further remedial work.

Subsoil and spur drain excavations

During 2006 and 2007 excavations were undertaken for the installation of the subsoil drain along Kitchener Drive and the alignment of the spur drains that run parallel to the western boundary of the stage 2a area (refer to Figure 3 for the location of these drains). Hydrocarbon odours and staining were noted at a depth of 4 m bgl to 6 m bgl (approximately 2.5 to 0.5 m AHD) within the excavations, however no PSH was observed. This material was removed from and stockpiled for its management and future reuse.

6.1.2 Excavation validation works (December 2012 to March 2013)

This stage of the validation works were undertaken during Building 5 and 6 basement excavation works between December 2012 and March 2013. The assessment included the observation of earthworks and spoil to indicate contamination and the removed material was stockpiled on site for assessment and sampling and consequent on-site reuse or off-site disposal. Samples were collected from stockpiles coming from different excavations and depths and analysed for metals, TPH and TRH, with some samples also analysed for BTEX, PAH, MAH, phenols, VOCs and pesticides.

A total of 159 primary, nine duplicate and five triplicate samples from the excavated soil were analysed (apart from a hydrocarbon impacted area which was sampled separately) with no detects for BTEX and detects for TPH/TRH in three samples (SP02_58 on 7 January 2013 and SP02A_56; SP02A_57 on 15 January 2013), but these were below Class 1 soil acceptance criteria. On the contrary, several metal exceedences were found in all sampling events and especially for vanadium for which Class 1 concentrations were exceeded in 112 out of the 159 samples. Especially high concentrations were found for barium in two samples (1750 mg/kg and 2560 mg/kg on 15 January 2013; Class 1 criterion: 300 mg/kg) and for zinc in three samples (1410 mg/kg, 3170 mg/kg and 3380 mg/kg on 29 January 2013; Class 1 criterion: 200 mg/kg). Class 2A criterion was exceeded on two occasions for lead (a primary and its duplicate; 1550 mg/kg and 1520 mg/kg on 29 January 2013 and 671 mg/kg on 16 April 2013). Out of the 159 samples, only 65 were analysed for pH and 45 exceedences of the Class 1 criteria were registered.

Hydrocarbon impacts were encountered at one location in the northeast corner of Building 5 (Figure 5 of the URS Validation Report) during basement excavations works on 11 January 2013 (the basement was excavated to a depth of approximately 3.5 – 4 m bgl). This location (refer to Figure 11 (Figure 3 of the URS Validation Report) for the location of the impacted area) is close to the location of test pit TP91 where a minor hydrocarbon odour and sheen had been detected in the groundwater (refer to Section 6.1.1 – Groundwater observations). The impacted location was excavated further to an extent where no odour or staining was observed in the walls and at least 1 m below the basement slab level. The excavation was then backfilled with Class 1 site material. A total of eight primary samples and one duplicate were taken from the wall of the excavation (samples EXED01 to EXED08) and three samples were collected from the base (samples EXBOT01 to EXBOT03) before backfilling. TPH, TRH and PCBs detections (Table 5 of the URS Validation Report in Appendix B.2) were only found at two of the base samples (EXBOT01 and EXBOT02) but all below Class 1 soil criteria. PCBs were detected up to 1.2 mg/kg. BTEX results were all non-detects and only minor vanadium exceedences were found in seven samples (with a maximum concentration of 80 mg/kg). These exceedences were consistent with vanadium results for the rest of the validation samples. pH was not tested for the samples from this excavation .

Spoil from the hydrocarbon impacted area was stockpiled separately in the stockpile management area for landfarming. Three soil samples were collected from the stockpile on 11 January 2013, with TPH and TRH being detected in two of them but below Class 1 criteria. BTEX was detected in one sample which exceeded the total xylenes criterion and two vanadium, one copper and one arsenic exceedences were also noted, with all of the exceedences being slightly above their corresponding criterion. Additional samples were collected on 4 June (three primary, one duplicate and one triplicate) and 22 August 2013 (three primary) to verify the remaining concentrations after the landfarming process. TPH, TRH and BTEX were non-detects in all samples and only vanadium exceedences slightly above the criterion were found in seven out of the eight samples.

The foundation piles for Stage 2a used the Franki piling system (driven piling system); therefore no material was removed from location during their installation. No material impacted by hydrocarbon odour and staining was noted during piling works. No acid sulphate soils (ASS/PASS) were detected during excavation works for the Stage 2a.

Further details on soil movements and sampling undertaken can be found in the Classification of Stockpiled Excavated Material – Stage 2a letters attached in Appendix D of this report.

Groundwater observations

No PSH was noted in the groundwater during December 2012 to March 2013 excavation works.

6.1.3 Ongoing groundwater monitoring (new wells installed between November 2007 and June 2008)

As a result of the damage or destruction of several wells during the construction phase (including the Stage 2a relevant wells mentioned in Section 5.2.3), 36 new wells were installed across the Darwin Waterfront Area between September 2007 and June 2008. Three of these wells (MW106, MW113 & MW114) were installed within the Stage 2a boundary and four wells were installed within close proximity to the Stage 2a site: MW111 and MW112 (located to the south of the site in close proximity of the boundary), MW115 (located to the east of the site) and MW125 (located to the north, upgradient to the site) (refer to Figure 6 for the location of these wells). Groundwater sampling was undertaken at these locations during the following sampling events: November 2007, July and November 2008, February, July, September and December 2009, February, June, September and December 2010, February, June, September and December 2011, March, June, September and December 2012, and March and June 2013. As noted in Table 7, only MW115 and MW125 remain operational.

Across all sampling rounds these well locations were below detection limits for BTEX except for MW113 on the September 2011 round where xylene was detected (2 µg/L). Hydrocarbon detected concentrations (TPH $C_{10} – C_{36}$) were between 70 µg/L and 24,750 µg/L for the Stage 2a on-site wells and between 140 µg/L and 142,300 µg/L for off-site wells. The exceptionally high upper range values were isolated events and detections were much lower for most sampling rounds. Presence of a sheen was reported for MW111, MW112 and MW113 during the November 2007 and July 2008 sampling rounds and no PSH were detected at any time.

Detections of the lighter TPH fraction (TPH $C_6 – C_9$) only occurred in July 2008 for MW106, March 2010 for MW111, November 2007 for MW112, and November 2007, July 2008, October 2008 and December 2009 for well MW113 (on-site well). Additionally, since June 2011 TRH fractions have also been analysed, with detected concentrations (TPH $C_{10} – C_{40}$) of 3,550 µg/L for one on-site well (MW113), and between 120 µg/L and 470 µg/L for the off-site wells. Refer to Table 21 for a complete list of the hydrocarbon detections.

Table 21 TPH and TRH detections (November 2007 to June 2013)

Monitoring Well ID	Date Sampled	TPH (C_{10}-C_{36}) or TRH (C_{10}-C_{40}) in µg/L (unless otherwise specified)
Stage 2a On-site Monitoring Wells		
MW106	Nov 2007	520
	Feb 2009	260
MW113	Nov 2007	24,750
	Nov 2007 (TPH $C_6 – C_9$)	420
	July 2008 (TPH $C_6 – C_9$)	205
	Oct 2008 (TPH $C_6 – C_9$)	110
	Feb 2009	70
	Dec 2009 (TPH $C_6 – C_9$)	20
	Feb 2010	130
	Sept 2011	3,670
	Sept 2011 (TPH $C_{10} – C_{40}$)	3,550
MW113 triplicate	July 2008	270
	July 2008 (TPH $C_6 – C_9$)	120
MW113 duplicate	Feb 2010	130
MW114	Nov 2007	150
MW114 duplicate	Nov 2007	200
Stage 2a Off-site Monitoring Wells		
MW111	Nov 2007	142,300
	Feb 2009	600
	Sept 2009	500
	Mar 2010	2,900
	Mar 2010 (TPH $C_6 – C_9$)	20
	Sept 2010	1,040
MW112	Nov 2007	15,220
	Nov 2007 (TPH $C_6 – C_9$)	240
MW115	Nov 2007	2,580
	Sept 2009	200
	Sept 2011	140
	Sept 2011 (TPH $C_{10} – C_{40}$)	150
	Dec 2011	300
	Dec 2011 (TPH $C_{10} – C_{40}$)	470
	Mar 2012	200
	Mar 2012 (TPH $C_{10} – C_{40}$)	240

Monitoring Well ID	Date Sampled	TPH (C_{10}-C_{36}) or TRH (C_{10}-C_{40}) in µg/L (unless otherwise specified)
MW115 triplicate	July 2008	200
MW115 duplicate	Dec 2009	770
MW125	July 2007	560
	Sept 2011 (TPH C_{10} – C_{40})	120

Metal impacts found to exceed the guideline values listed in ANZECC 2000 for Aquatic Ecosystems, ANZECC 2000 for the Protection of Aquaculture Species, and/or NRHMC 2011 for Recreation and Aesthetics at all the on-site and off-site wells relevant to the Stage 2a site. The exceedences identified during the groundwater sampling rounds (between November 2007 and June 2013) are summarised in Table 22; different colours have been used to identify the different criteria considered and the highest guideline value has been highlighted in red.

Manganese exceedences were found in all wells in every sampling round with several of the results higher than the recreation and aesthetics criteria of 1 mg/L (highest guideline value). Most of the exceedences within the off-site wells were the same range or up to one order of magnitude higher than the criterion, but they were higher in the on-site wells, with several results more than one order of magnitude greater than the criterion with MW114 particularly elevated. Values that exceeded only the protection of aquaculture species criterion were usually one order of magnitude or more above the guideline value. Generally the manganese results were consistent with those observed across the Darwin Waterfront, and are typical of those expected to occur where reducing conditions occur (such as can occur naturally, and where hydrocarbons and other biodegradable organic constituents are present).

Zinc exceedences were also found at every well in most of the sampling rounds, with concentrations higher than the ANZECC 2000 Aquatic Ecosystem criterion and the protection of aquaculture species criterion. Generally the magnitude of the exceedences was not significant (within the order of magnitude of the criteria), with the exception of the June 2009 result for MW115 where the concentration was two orders of magnitude higher than the criterion. The concentrations show a decreasing tendency for some wells. The results were consistent with other results observed across the Darwin Waterfront, suggesting that these were background concentrations.

Copper exceedences were found at six of the seven relevant wells, with three of them above the aquatic ecosystems criteria (lowest one) and the other four above the protection of aquaculture species criterion. All of these results were within one order of magnitude of the criteria and were consistent with the copper detected across the wider Waterfront area, suggesting that the levels observed at these wells are likely to represent background water quality conditions.

Cadmium exceedences were found at three wells: MW113 with one sampling round above the protection of aquaculture species criterion, MW112 with four sampling rounds above the aquatic ecosystems criteria and MW115 with one sampling round above the recreation and aesthetics criterion. The exceedences were within the order of magnitude of the criteria and were not consistently observed within these wells. Given the minor isolated exceedences and the dilution that would occur in the receiving water, these exceedences are considered to pose a low risk.

Lead exceedences were found at two wells: MW113 with one sampling round above the aquatic ecosystems criterion and one sampling round above the protection of aquaculture species criterion, and MW112 with one sampling round above the protection of aquaculture species criterion. Concentrations were slightly above the criteria and were not consistently observed within these wells. Given the minor isolated exceedences and the dilution that would occur in the receiving water, these exceedences are considered to be a low risk.

In the case of iron (total, ferrous and ferric), all wells except for MW112 showed exceedences of the guideline value of 3 mg/L for recreation and aesthetics (guidelines do not provide separate criteria for ferric and ferrous iron, so the value for total iron was used for screening purposes), with only one location (MW114) consistently presenting elevated concentrations. Exceedences were usually in the order of magnitude of the criterion and only MW113 and MW111 presented values around or above one order of magnitude higher than the criterion during one sampling round, but subsequent ones resulted in much lower concentrations and they are considered as an isolated event. The specified guideline value of 3 mg/L is based on taste considerations and a value based on health considerations has not been set. Values that exceeded only the protection of aquaculture species criterion were consistently one order of magnitude or more above the guideline value.

Table 22 Metal exceedences reported at monitoring wells during the additional groundwater sampling (November 2007 to June 2013)

	Copper (mg/L)	Zinc (mg/L)	Iron (mg/L)[4]	Manganese (mg/L)	Cadmium (mg/L)	Lead (mg/L)
Aquatic Ecosystem criteria	0.0013	0.015	No value	No value	0.0055	0.0044
Recreation and aesthetics criteria	10	30	3	1	0.02	0.1
Aquaculture species criteria	0.005	0.005	0.01	0.01	0.0005	0.001
Stage 2a On-site Groundwater Monitoring Wells						
MW106	0.002 (Feb 10) 0.003 (June 10) 0.002 (Sept 10)	0.016 (Oct 08) 0.017 (Dec 09) 0.017 (Sep 10)	Total iron: 8.12 (Dec 09) 4.82 (Feb 10) Ferrous Iron: 3.6 (Nov 08) 4.5 (Feb 10)	15.3 (Nov 07) 17.0 (Nov 08) 2.18 (Feb 09) 19.0 (Dec 09) 6.89 (Feb 10) 17.3 (Dec 12)		
	0.022 (Nov 07)	0.008 (Feb 09) 0.006 (Feb 10) 0.011 (Jun 10)	Ferrous iron: 0.27 (Nov 07) 0.52 (Feb 09) 0.7 (Sep 10) Ferric iron: 0.05 (Nov 08) 0.32 (Feb 10)	0.946 (June 10) 0.934 (Sept 10)		
MW113	0.002 (Feb 09) 0.003 (Dec 09) 0.004 (Sep 10 0.002 (Feb 11) 0.004 (Sep 11) 0.002 (Mar 12)	0.041 (Nov 08) 0.018 (Dec 09) 0.023 (Sep 10) 0.128 (Feb 11) 0.033 (Mar 12)	Total iron: 17.6 (Dec 09) 16.6 (Feb 10) 13.7 (Feb 10, duplicate) Ferrous Iron: 9.92 (Feb 09) 29.0 (Sep 09) 13.9 (Feb 10) 14.0 (Feb 10, duplicate) 3.06 (Sep 10) 9.12 (Feb 11)	1.78 (Nov 07) 2.4 (Jul 08) 2.25 (Jul 08, triplicate) 1.8 (Nov 08) 6.1 (Feb 09) 6.81 (Sep 09) 5.72 (Dec 09) 3.12 (Feb 10) 3.08 (Feb 10, duplicate) 3.62 (Feb 10, triplicate) 2.01 (Sep 10) 3.28 (Feb 11) 3.17 (Sep 11) 2.64 (Jun 12) 3.3 (Sep 12)	0.0034 (Feb 11)	0.008 (Nov 07)
		0.0056 (Jul 08) 0.009 (Jul 08, triplicate) 0.006 (Feb 09) 0.012 (Feb 10, triplicate)	Ferric iron: 7.36 (Sep 11)			0.0012 (Jul 08)
			Total iron: 0.26 (Nov 07) 1.6 (Nov 08) Ferrous iron: 0.24 (Nov 07) 1.7 (Nov 08) 0.05 (Sep 11) Ferric iron: 2.7 (Feb 10) 0.46 (Feb 11)	0.168 (Mar 12)		
MW114	0.002 (Sep 09) 0.002 (Sep 09, duplicate) 0.002 (Dec 09) 0.004 (Feb 10) 0.004 (Feb 10, duplicate) 0.002 (Sep 10) 0.002 (Sep 10, duplicate) 0.002 (Feb 11) 0.002 (Sep 11)	0.02 (Nov 08) 0.026 (Sep 11) 0.017 (Feb 10, triplicate)	Total iron: 5.39 (Nov 07) 5.43 (Nov 07, duplicate) 9.7 (Nov 08) 18.0 (Dec 09) 19.0 (Feb 10) 18.6 (Feb 10, duplicate) Ferrous Iron: 4.33 (Nov 07) 4.36 (Nov 07, duplicate) 10.0 (Nov 08) 17.5 (Feb 09) 16.4 (Sep 09) 17.0 (Sep 09, duplicate) 16.0 (Sep 09, triplicate) 17.1 (Feb 10) 19.1 (Feb 10, duplicate) 5.3 (Feb 10, triplicate) 22.2 (Sep 10) 22.6 Sep 10, duplicate) 19.1 (Sep 10, triplicate) 10.1 (Feb 11) 12.9 (Sep 11) 4.57 (Mar 12) 9.37 (Jun 12) 18.7 (Sep 12) Ferric Iron: 5.5 (Feb 10, triplicate) 6.1 (Sep 10, triplicate)	7.02 (Nov 07) 7.13 (Nov 07, duplicate) 8.8 (Nov 08) 10.1 (Feb 09) 12.9 (Sep 09) 13.0 (Sep 09, duplicate) 16.4 (Sep 09, triplicate) 15.8 (Dec 09) 15.2 (Feb 10) 15.3 (Feb 10, duplicate) 19.8 (Feb 10, triplicate) 10.7 (Sep 10) 10.7 (Sep 10, duplicate) 23.2 (Feb 11) 13.6 (Sep 11) 11.6 (Mar 12) 15.1 (Jun 12) 12.0 (Sep 12)		
		0.01 (Nov 07) 0.009 (Nov 07, duplicate) 0.007 (Feb 09) 0.011 (Sep 09) 0.011 (Sep 09, duplicate) 0.013 (Sep 09, triplicate) 0.014 (Dec 09) 0.009 (Feb 10) 0.01 (Feb 10, duplicate) 0.013 (Sep 10) 0.012 (Sep 10, duplicate) 0.012 (Feb 11) 0.007 (Mar 12) 0.008 (Jun 12) 0.011 (Sep 12)	Ferric iron: 1.06 (Nov 07) 1.06 (Nov 07, duplicate) 1.93 (Feb 10) 0.93 (Jun 12)			

[4] Guidelines do not provide separate criteria for ferric and ferrous iron, so the value for total iron was used for screening purposes.

	Copper (mg/L)	Zinc (mg/L)	Iron (mg/L)[4]	Manganese (mg/L)	Cadmium (mg/L)	Lead (mg/L)
Aquatic Ecosystem criteria	0.0013	0.015	No value	No value	0.0055	0.0044
Recreation and aesthetics criteria	**10**	**30**	**3**	**1**	**0.02**	**0.1**
Aquaculture species criteria	0.005	0.005	0.01	0.01	0.0005	0.001
Stage 2a Off-site Groundwater Monitoring Wells						
MW111	0.004 (Sep 10)	0.01 (Nov 07) 0.011 (Sep 10)	Total iron: 3.92 (Nov 07) 19.0 (Nov 08) 3.75 (Mar 10) Ferrous iron: 4.01 (Nov 07) 17.0 (Nov 08) 39.8 (Feb 09) Ferric iron: 2.34 (Mar 10) 0.72 (Sep 10) Ferrous iron: 1.4 (Mar 10) 0.28 (Sep 10)	1.31 (Nov 07) 1.56 (Feb 09) 1.8 (Sep 09) 0.33 (Nov 08) 0.52 (Mar 10) 0.638 (Sep 10)		
MW112	0.011 (Dec 09)	0.008 (Nov 07) 0.006 (Nov 08) 0.364 (Feb 09) 0.327 (Sep 09) 0.278 (Dec 09) 0.189 (Feb 10)	Total iron: 0.54 (Nov 07) 1.2 (Nov 08) Ferrous iron: 0.5 (Nov 07) 0.97 (Nov 08)	1.1 (Nov 08) 0.638 (Nov 07) 0.212 (Feb 09) 0.026 (Sep 09) 0.029 (Dec 09) 0.086 (Feb 10)	0.0129 (Feb 09) 0.0075 (Sept 09) 0.0064 (Dec 09) 0.0088 (Feb 10)	0.001 (Nov 07)
MW115	0.003 (Jul 08, triplicate) 0.003 (Jun 10) 0.002 (Mar 12) 0.032 (Jun 09) 0.022 (Dec 10) 0.005 (Sep 11) 0.006 (Dec 11)	2.67 (June 09) 0.046 (Sep 10) 0.042 (Sep 10, duplicate) 0.065 (Dec 10) 0.026 (Feb 11) 0.119 (Jun 11) 0.007 (Jul 08, triplicate) 0.009 (Nov 08) 0.007 (Jun 10) 0.009 (Sep 11) 0.01 (Dec 11) 0.006 (Mar 12)	Total iron: 8.5 (Nov 08) Ferrous Iron: 3.8 (Nov 08) 3.63 (Feb 09) 3.63 (Feb 09, duplicate) Ferric Iron: 4.7 (Nov 08) 14.0 (Sep 10, triplicate) Total iron: 1.96 (Sep 09) Ferrous iron: 0.09 (Nov 07) 1.0 (Triplicate, Feb 09) 1.77 (Sep 09) 0.18 (Feb 10) 1.03 (Sep 10) 0.89 (Sep 10, duplicate) 0.5 (Sep 10, triplicate) 0.78 (Feb 11) 2.42 (Mar 12) 2.34 (Jun 12) 1.7 (Sep 12) 1.76 (Mar 13) Ferric iron: 0.19 (Sep 09) 1.78 (Sep 11) 0.15 (Mar 12) 0.25 (Jun 12) 0.13 (Sep 12)	1.82 (Nov 07) 2.2 (Jul 08) 1.3 (Jul 08, duplicate) 1.64 (Jul 08, triplicate) 2.6 (Nov 08) 3.3 (Dec 10) 1.58 (Sep 11) 0.227 (Feb 09) 0.223 (Duplicate, Feb 09) 0.214 (Triplicate, Feb 09) 0.857 (Jun 09) 0.81 (Sep 09) 0.058 (Dec 09) 0.061 (Dec 09, duplicate) 0.309 (Feb 10) 0.304 (June 10) 0.457 (Sep 10) 0.474 (Sep 10, duplicate) 0.413 (Feb 11) 0.941 (Jun 11) 0.557 (Dec 11) 0.327 (Mar 12) 0.795 (Jun 12) 0.072 (Sep 12) 0.164 (Dec 12) 0.04 (Mar 13) 0.409 (Jun 13)	0.0348 (Jun 09)	

	Copper (mg/L)	Zinc (mg/L)	Iron (mg/L)[4]	Manganese (mg/L)	Cadmium (mg/L)	Lead (mg/L)
Aquatic Ecosystem criteria	0.0013	0.015	No value	No value	0.0055	0.0044
Recreation and aesthetics criteria	**10**	**30**	**3**	**1**	**0.02**	**0.1**
Aquaculture species criteria	0.005	0.005	0.01	0.01	0.0005	0.001
MW125		0.019 (Feb 11) 0.007 (Oct 07) 0.007 (Nov 08) 0.005 (Feb 09) 0.012 (Sep 09) 0.009 (Sep 09, duplicate) 0.005 (Sep 09, triplicate) 0.01 (Dec 09) 0.008 (Feb 10) 0.011 (Jun 10) 0.009 (Sep 10) 0.009 (Dec 10) 0.006 (Sep 11) 0.007 (Dec 11) 0.006 (Mar 12) 0.012 (Jun 13)	Total iron: 0.43 (Nov 08) 0.05 (Sep 09) 0.06 (Sep 09, duplicate) 0.08 (Sep 09, triplicate) 0.65 (Dec 09) 0.6 (Feb 10) Ferrous iron: 0.12 (Nov 08) 0.06 (Feb 09) 0.09 (Sep 09) 0.08 (Sep 09, duplicate) 0.44 (Feb 10) 0.61 (Sep 10) 0.16 (Feb 11) 0.56 (Mar 12) 0.19 (Jun 12) 0.14 (Sep 12) 0.15 (Mar 13) Ferric iron: 0.15 (Feb 10) 0.06 (Feb 11) 0.1 (Sep 11) 0.12 (Mar 12)	1.3 (Jul 08) 1.5 (Nov 08) 1.9 (Feb 09) 1.49 (Sep 09) 1.5 (Sep 09, duplicate) 1.35 (Sep 09, triplicate) 2.07 (Dec 09) 1.17 (Feb 10) 1.06 (Sep 10) 1.53 (Dec 11) 1.05 (Mar 12) 0.215 (Nov 07) 0.523 (Jun 10) 0.753 (Dec 10) 0.495 (Feb 11) 0.533 (Jun 11) 0.507 (Sep 11) 0.443 (Jun 12) 0.421 (Sep 12) 0.532 (Dec 12) 0.283 (Mar 13) 0.443 (Jun 13)		

Ammonia concentrations in excess of at least one of the guideline values were identified at all well locations during the November 2007 monitoring round, but ammonia was not analysed during the subsequent sampling rounds. In terms of exceedences, MW106, MW111 and MW115 showed concentrations of 3.01 mg/L, 1.06 mg/L and 11.7 mg/L respectively, all of them above the aquatic ecosystems criterion (0.91 mg/L). MW113 was the only well above the recreation and aesthetics criterion (0.5 mg/L) with 0.54 mg/L and the remaining three wells, MW112, MW114 and MW115, were all above the protection of aquaculture species criterion (0.1 mg/L) with concentrations of 0.21 mg/L, 0.45 mg/L and 0.46 mg/L, respectively. Refer to Appendix B.3 for a complete list of the concentrations encountered at each well location.

Methane detected concentrations were in the range from 11 µg/L to 16,200 µg/L (Bore MW115) for the Stage 2a on-site and off-site groundwater monitoring wells, although samples were not analysed for methane at every monitoring event. Table 23 shows the concentrations and non-detects at each Stage 2a monitoring well. Highest concentrations were detected at MW115, which showed elevated methane levels at almost every sampling round.

It is noted that MW115 is in the Stage 1 area on the other side of the Stage 1 residential area and is considered to be a low risk to the Stage 2a are on the basis that:

- The Stage 2a area of the site contains much less building rubble within the fill material that may be a source of the methane;
- Hydrocarbons may also be a source of methane and the recent basement excavation indicated that hydrocarbons had only a limited presence in the Stage 2a area;
- A methane concentration of around 16 mg/L is less than the solubility of methane in water of around 28 to 30 mg/L where methane will begin to bubble out of the groundwater. (USGS 2006);
- Given that the waste material is at least 25 years old and contains limited putrescible material, that residual hydrocarbon contamination is limited and that significant methane has not been detected at the site during the life of the audit, methane is expected to be limited to isolated pockets. While these pockets may contain high methane concentrations, the limited ongoing sources contributing to the generation of methane means that methane is unlikely to be migrating into building cavities where it will be at risk of causing explosion.

Table 23 Methane detections during additional groundwater sampling

Monitoring well ID	Methane (µg/L)	Sampling round	Monitoring well ID	Methane (µg/L)	Sampling round
Stage 2a On-site Monitoring Wells					
MW106	ND	Nov 2007	MW114	ND	Nov 2007
	11	Nov 2008		11 (duplicate)	Nov 2007
	ND	Feb 2009		17	Nov 2008
	10	Dec 2009		35	Feb 2009
	11	Feb 2010		32	Sep 2009
	ND	Sep 2010		34 (duplicate)	Sep 2009
MW113	197	Nov 2007		21	Dec 2009
	342	Jul 2008		31	Feb 2010
	200	Nov 2008		37 (duplicate)	Feb 2010
	148	Feb 2009		38	Sep 2010
	219	Sep 2009		41 (duplicate)	Sep 2010
	122	Dec 2009		13	Feb 2011
	91	Feb 2010		27	Sep 2011
	95 (duplicate)	Feb 2010		ND	Mar 2012
	154	Sep 2010		40	Jun 2012
	73	Feb 2011		43	Sep 2012
	55	Sep 2011			
	51	Mar 2012			
	95	Jun 2012			
	96	Sep 2012			
Stage 2a Off-site Monitoring Wells					
MW111	135	Nov 2007	MW112	14	Nov 2007
	990	Nov 2008		70	Nov 2008
	33	Feb 2009		ND	Feb 2009
	261	Sep 2009		ND	Sep 2009
	775	Feb 2010		ND	Dec 2009
	1,560	Sep 2010		ND	Feb 2010
MW115	207	Nov 2007	MW125	ND	Nov 2007
	9,770 (triplicate)	Jul 2008		350	Nov 2008
	1,200	Nov 2008		191	Feb 2009
	5,660	Feb 2009		77	Sep 2009
	5,200 (duplicate)	Feb 2009		76 (duplicate)	Sep 2009
	6,640	Sep 2009		250	Dec 2009
	4,440	Dec 2009		210	Feb 2010
	4,680 (duplicate)	Dec 2009		140	Sep 2010
	5,290	Feb 2010		54	Feb 2011
	8,660	Sep 2010		<10	Sep 2011
	8,480 (duplicate)	Sep 2010		131	Mar 2012
	5,040	Feb 2011		101	Jun 2012

Monitoring well ID	Methane (µg/L)	Sampling round	Monitoring well ID	Methane (µg/L)	Sampling round
	7,150	Sep 2011		54	Sep 2012
	5,830	Mar 2012		107	Mar 2013
	631	Jun 2012			
	12,800	Sep 2012			
	16,200	Mar 2013			

TDS, sodium, sulphate and chloride were observed in excess of the recreation and aesthetics criteria in all of the wells in almost all sampling rounds where they were analysed, except for MW125 where chloride and sulphate levels were below criteria and TDS and sodium showed exceedences only from February 2011 onwards. Despite the registered exceedences, the results are considered typical of saline conditions associated with seawater effects. Refer to the groundwater monitoring reports in Appendix B for a complete list of the concentrations encountered at each well location.

The groundwater pH results ranged from 5.80 (at MW115) to 8.60 (at MW114) with all wells having an occasional exceedence, with the exception of MW113, which did not present any exceedences, and MW114 where pH was exceeded in almost every sampling round where pH data was obtained.   As seen in Table 24, most of the exceedences were in respect to the recreation and aesthetics criteria (pH 6.5 to pH 8.5) with three of them also being outside the protection of aquaculture species criteria (pH 6.0 to pH 9.0). Generally the results were only just outside the criteria and mixing with the lagoon water would limit the impact of low pH groundwater.

Table 24 Groundwater pH exceedences from additional groundwater sampling

Groundwater Monitoring Well ID	pH value	Date Sampled	Criteria exceeded
Stage 2a On-site Monitoring Wells			
MW106	6.46	Nov 2007	Recreation and aesthetics (ADWG 2011)
	5.90	Jun 2010	Protection of aquaculture species (ANZECC 2000)
	6.28	Sep 2010	Recreation and aesthetics (ADWG 2011)
	6.10	Dec 2012	
MW114	6.15	Nov 2007	Recreation and aesthetics (ADWG 2011)
	6.34	Nov 2008	
	6.31	Feb 2009	
	6.02	Sep 2009	
	6.25	Feb 2010	
	6.25	Sep 2010	
	5.88	Feb 2001	Protection of aquaculture species (ANZECC 2000)
	6.27	Sep 2011	Recreation and aesthetics (ADWG 2011)
	6.14	Mar 2012	
	5.80	Jun 2012	Protection of aquaculture species (ANZECC 2000)

Groundwater Monitoring Well ID	pH value	Date Sampled	Criteria exceeded
Stage 2a Off-site Monitoring Wells			
MW111	6.27	Feb 2010	Recreation and aesthetics (ADWG 2011)
MW112	6.18	Feb 2010	Recreation and aesthetics (ADWG 2011)
MW115	8.60	Dec 2009	Recreation and aesthetics (ADWG 2011)
MW125	6.14	Jun 2010	Recreation and aesthetics (ADWG 2011)
	6.10	Dec 2011	

Note: pH values shown for the Nov 2007 sampling round correspond to laboratory measured pH. After that date, pH values registered correspond to field pH.

6.2 Conceptual understanding of the contamination of the site

6.2.1 Hydrocarbon contamination

The investigations undertaken by URS and the observations by the Auditor and his support staff during site visits provide an understanding of the presence of hydrocarbon contamination at the Stage 2a site. Although considerable hydrocarbon contamination was identified across the wider Darwin Waterfront area, only minor contamination has been encountered /remains within the Stage 2a site.

The source of groundwater hydrocarbon contamination across the broader Waterfront site appeared to be predominantly from leakage from the pipelines that ran along Kitchener Drive and Stokes Hill Wharf Road, from the Naval fuel facility and Stokes Hill fuel above ground fuel silos to refuel ships at the Stokes Hill and the Fort Hill wharf. Fuel pipelines within the World War 2 tunnels along the escarpment running along the northern boundary of the Stage 1 area and a valve pit may also have contributed to this contamination. In addition, fuel spills that occurred within the former Bitumen Plant area resulted in a small hydrocarbon plume located on its south-eastern border (adjacent to the western boundary of the Stage 2a); this might have also extended into the Stage 2a area. Contamination concentrations were found to be generally greatest along the northern boundary of the Site in the vicinity of the pipelines, and decreased towards the shoreline. The contamination was typically found at depth and generally confined to the soil/groundwater interface or smear zone that is present between the annual high and low water table levels. Hydrocarbon concentrations in the groundwater at a given point, generally increased as the water table level increased, and it would appear that as groundwater levels rose through the smear zone hydrocarbons were de-sorbed from the soils into the groundwater, and groundwater concentrations increased, with the opposite occurring as groundwater levels fall.

During the initial investigation in 2003 and 2004, hydrocarbon impacted soils were encountered at different depths, with the majority being within the groundwater smear zone. Hydrocarbon sheens on groundwater were observed at most test pit locations, particularly at the northern end of the site close to Kitchener Drive.

During the November 2009 validation program where temporary piezometers were installed in 88 bores, sheens were not observed, but during test pitting works that occurred around that time a slight sheen was detected along with some hydrocarbon odour at one location (TP91) and slight odours at another one (TP90). No continuous PSH layer was observed in the testpits. The Building 5 basement excavation works revealed hydrocarbon impacted soils at the location of TP90 and TP91 hydrocarbon impacted soils were present. The impacted soil was removed and the excavation validated. Hydrocarbon impacted soils were not observed in other areas of this basement, although noting that the basement did not extend beneath Building 4 which was identified as one of the most contaminated areas during the initial investigation program. Minor pockets of hydrocarbon contamination may remain in this area.

Groundwater and soil sampling results as well as the visual observations made in the logs from the period between the initial assessment (2003/2004) and the validation investigation (2009 to 2013) for the Stage 2a site, indicate that the presence of hydrocarbon impacted soils have decreased. This observation of decreasing contamination supports the conclusion that biodegradation is likely to be occurring at the site, which could be expected, given that the source has been present for many years allowing the development of a microbial population that is able to break down the hydrocarbons and the warm Darwin conditions that favour natural biodegradation processes. Soils across the wider Waterfront site have also been observed with a green tinge typical of degraded hydrocarbons, and biodegradation has been shown to occur rapidly in biopile treatment of the contaminated soils.

It is concluded that the presence of extensive impacted zones is very unlikely given that a large area was excavated for the basement of buildings 5 and 6 and the validation bore and test pitting investigation locations on a 10 m grid across the Stage 2a site. The potential risk associated with remaining pockets of contaminations is addressed in the URS Qualitative Risk Assessment Report (refer to Section 6.8).

6.2.2 Metal contamination

Several soil metal exceedences for arsenic, barium, cadmium, copper, manganese and zinc were found during phase 2, phase 3 and pre-remediation works with almost all of them being concentrated in the northern half of the site. These only exceeded the Class 1 soil acceptance criteria, except for two samples which also exceeded the Class 2A criteria for arsenic. The only lead exceedence registered was also above the Class 2A criterion (located at a depth of 0.6 m). Validation works showed similar results with a number of exceedences for arsenic, cadmium, copper, manganese and zinc and occasionally also for barium, nickel and lead. Vanadium, which was only tested during the basement excavations in 2012/2013, also exceeded criteria in most samples.

Several groundwater results exceed the ecosystem, recreation and aesthetics and the protection of aquaculture species criteria across the site during several sampling rounds for manganese, copper, zinc and particularly for iron (total, ferric and ferrous). Lead, arsenic, cadmium, silver and nickel exceedences were also reported, but not consistently. The distribution of copper and zinc in the onsite wells indicates that these results are associated with background concentrations. On this basis, and because metal results for soil and groundwater are generally ubiquitous across the site and have been also noted in adjacent areas, the concentrations of metals in groundwater can be considered to be typical of background levels for the area. The exception may be elevated iron and manganese that may be associated with the reducing conditions caused by hydrocarbon degradation. However these concentrations would be expected to decline as the hydrocarbons disappear from the site. Further details are provided in Section 8.2.

6.2.3 Other groundwater and soil contamination

Ammonia concentrations also frequently exceeded guideline values. However, the source of ammonia is not clear. Ammonia can be associated with the natural marine sediments, and it may also arise from degradation of organics present in the fill. The impact of these exceedences is discussed further in Section 8.2.

Methane was also frequently detected in most of the wells and was particularly elevated at MW115 (off site and on the other side of the Stage 1 residential building). The concentrations in groundwater were variable and trends over time were not apparent.

Waste materials were identified at several locations during the soil bore and test pit investigations from a depth of 0.0 mbgl to 5.6 mbgl and visual contamination was identified within 1.0 m of the surface at several onsite locations. These generally consist of bricks, concrete and some minor pieces of metal and wood; putrescible material did not appear to be present. The majority of the waste materials have been removed during the excavations of the basements for Buildings 5 and 6.

6.3 Summary of soil treatment works

Approximately 30 000 m^3 of soils were excavated from the Stage 2a area for development works (basement excavations); of this only 70 m^3 were soils that required to be removed solely for remediation purposes.

6.4 Removal of pipelines

An extensive review of historical plans identified a considerable number of decommissioned and active pipes running along the southern boundary of Stokes Hill Wharf Road (off-site to the northwest of the Site), and along the northern and southern boundaries of Kitchener Drive. As far as possible, any product remaining within the pipes was pumped out and pipelines removed to reduce the potential for ongoing sources of contamination. Active pipelines supplying navy ships at the Fort Hill Wharf remain, but are currently in the process of being removed. It is understood that they have been subject to regular pressure testing and are maintained in good condition. A decommissioned pipeline remains beneath sections of this active pipe (some of these within Stage 2 works area) which could not practicably be removed; this will be removed at the time the active pipe is removed.

All remaining infrastructure and pipelines that were encountered during the excavation works in the Stage 2a area have also been removed.

6.5 Installation of a subsoil groundwater drain

A sub-soil drain has been installed across the Waterfront site to collect groundwater and discharge it after treatment to the sea. Information on the subsoil drain has been provided in various URS reports and plans provided by the Northern Territory Government.

The sub-soil drain system has been designed to manage hydrocarbon impacted groundwater (but also for any other types of contamination) by reversing the direction of groundwater flow at the site away from the lagoon to Kitchener Drive and then to the sea, intercepting groundwater that flows onsite from areas to the north of the Waterfront area, and acting as a remediation system in increasing the removal of hydrocarbon contamination from the site. The drain is designed to operate on a gravity feed basis with any PSH being removed by an oil/water separator prior to discharging to the marine environment.

The sub-soil drainage system comprises a main subsoil drain which runs along the length of Kitchener Drive with several perpendicular spur drains that discharge to the main drain. Within the Stage 2a a spur drains run along the western boundary and central section of the site. The location of this drain network is shown in Figure 3.

The drain has a 50 year design life and consists of 225 mm diameter slotted pipes with an invert level of 2.0 mAHD along Kitchener Drive and 2.5 mAHD to 2.0 mAHD within the spur drains. The pipes sit at the base of a trench and are overlain by 2.0 m of coarse aggregate, and then backfill to surface. The drain extends south-west, past the proposed Stage 2a residential buildings, where it discharges to a grit chamber and an oil water separator, and then to solid pipe that discharges to the sea to the west of the waterfront development area. The outlet drain discharges at 1.0 mAHD and is under water at high tide. A non-return valve prevents seawater flowing back up the drain. URS has advised that the available discharge time (low tide) will be adequate to maintain groundwater levels at around 2.0 mAHD along Kitchener Drive.

In addition to the subsoil and spur drain design, a secondary engineering control has been incorporated in the Stage 2a site by means of a perforated hydrostatic relief drain, installed around the residential basement excavation and along the eastern boundary of the Stage 2a. This drain sits slightly below the top of basement slab level (approximately 3.65 m AHD) and is positioned close to the basement wall but separated from it by a waterproof layer. It consists of a 225 mm perforated pipe surrounded by crushed rock aggregate in a geotextile lined trench that discharges into a sump beneath building 6 car park, which will be pumped out as required. The purpose of this drain is to provide additional drainage and to reduce the possibility that groundwater will rise above the basement floor slab level, and thereby to reduce the possibility of oily groundwater entering the building basement. The relief drain runs parallel and adjacent to the existing subsoil drain (but at higher RL) along the western side of building 5 and water can discharge from hydrostatic relief drain to the subsoil drain via the intervening aggregate backfill. It is intended that, in the longer term after the subsoil drain has ceased operation, this drain will discharge solely to the sump beneath the carpark. The relief drain as built details are provided in Appendix C.

The main subsoil drain system was completed in late 2006/2007. It is understood that only about 20 L of oil had been removed from the oil water separator as of March 2008, with sheens or films of <1 mm since that time and no detections of TPH since November 2009. URS reports that flow in the drain has varied between 0 - 60 L/min, with no flow in the last year. This is consistent with flow rates that have been observed prior to that time. The Auditor inspected the drain at the end of January 2008, August 2008, April 2009 and October 2012 and noted that the discharge at all of these times was free of oil and odour.

It is noted that during 2011 groundwater levels in the waterfront area rose above the level of the lagoon after a high rainfall period, which potentially could have allowed the discharge of oily water to the lagoon. However there was no indication that groundwater contamination affected the lagoon water quality during this period.

The Northern Territory Government advises that, in the future, when it can be shown that the operation of the drain is no longer necessary (i.e. groundwater contamination no longer poses a risk to the environmental values of the site), maintenance and operation of the drain may cease. Groundwater flow would then reverse and discharge to the lagoon and groundwater levels will increase across the site. This would require monitoring to ensure that the lagoon water quality is not affected, and that the increased levels are manageable from a building design perspective (e.g. does not lead to localised flooding and groundwater and stormwater entering the buildings). The auditor understands that the building design has allowed for such effects; however, such hydrologic design considerations are outside the scope of this audit.

Because recent testing has indicated that TPH concentrations in the drain system are now below the level of detection (and have been since November 2009) (refer to the Subsoil Drain Annual Monitoring Report – December 2011 to October 2012 in Appendix B.10 of this report), and because reductions in hydrocarbon concentrations in the groundwater may also result in reduced iron concentrations, a trial closure of the subsoil drain was implemented for the 2013/2014 wet season. This trial is ongoing and is being accompanied by increased monitoring and gauging. The auditor has been consulted with regard to this work and permanent closure of the drain will only occur if the trial indicates that the potential for pollution to impact on the lagoon is low. If it is considered that the drain can remain closed, the option of reinstating the drain still remains should pollution issues arise. The trial will consider the potential aesthetic impacts associated with iron and manganese oxidising bacteria, as well as hydrocarbons. In this respect, it was noted that on 15 July 2009 a discoloured black-grey sandy material was observed in the beach sand of the lagoon. The discoloured beach sand was attributed to “aquic conditions” that are associated with anaerobic microbial conditions in anoxic environments that reduce oxidised forms of iron, manganese and sulphate. This effect can occur naturally, and is not necessarily associated with the presence of contamination. It is understood that this material is still present within the lagoon beach sand.

The auditor has considered whether the increased salinity of the groundwater caused by the reversal of the groundwater flow by the drain could constitute pollution of the site. The overall area that is potentially affected is confined to the northwest by the sub-soil drain and to the east and west by the Stokes Hill and Fort Hill formations respectively. It was concluded that this groundwater control measure is consistent with achieving the desired groundwater clean-up objectives in that:

- The operation of the drain is proposed as a temporary remedial measure while hydrocarbon that may be present degrades, after which the groundwater flow will revert to the lagoon and salinity will reduce.
- The potential increases in salinity pose a low risk to the existing beneficial uses because:
  - Areas of the site close to the original shoreline are already high in salinity, in that the deeper aquifer (in the underlying natural rock) was within the tidal zone prior to land reclamation of the area, and the presence of historical drainage lines have provided preferential pathways for seawater intrusion;
  - URS advises that building foundations such as piles have been designed for saline conditions;
  - URS advises that trees have been selected for suitability for growing on reclaimed land with a saline water table; that trees, lawn areas and garden beds will be irrigated; and these should not be affected by the increased salinity; and
  - Protection of aquaculture species, recreation and aesthetics are related to use of the marine (saline) environment.

6.6 Natural attenuation

In developing a remediation and management strategy, it is helpful to be able to demonstrate that natural attenuation (in particular natural biodegradation) is occurring, as this indicates that residual contamination will degrade naturally and will reduce over time. Although extensive hydrocarbon impacted areas were encountered during the initial investigations, these appear to have reduced significantly since that time. The most recent investigations undertaken by URS identified few locations where odour and/or sheen were detected. Notwithstanding the reduction in hydrocarbons that has taken place, the auditor expects that small pockets of contamination may still remain in the smear zone both at the site and upgradient of the site. Because of this, it is useful to demonstrate that residual petroleum hydrocarbon contamination is naturally degrading at the site.

Evidence for natural attenuation is usually circumstantial in nature, and demonstration of multiple lines of evidence is usually required:

- The primary line of evidence involves using historical contamination data to demonstrate that the plume mass and/or concentrations are diminishing over time;
- Secondary lines of evidence involve using chemical and geochemical analytical data to prove a loss of contaminant mass; and
- Tertiary lines of evidence involve the use of laboratory microbiological data to demonstrate that bacteria are present that are capable of degrading the contaminant of concern.

In the case of the Stage 2a site, it is difficult to it is difficult to draw conclusions from such an analysis, because:

- There is a large seasonal variation in the groundwater levels, and a seasonal mixing/dilution of the groundwater with sea water and rain water;
- TPH concentrations vary with groundwater levels;
- Salinity levels vary with location across the site and at a given location on site at different times of year, and with varying salinity the sulphate levels also change. Sulphate acts as an important electron acceptor for hydrocarbon degradation and, because of the variation in concentrations, distinguishing sulphate depletion in areas where TPH is present is difficult; and
- There is a lack of a continuous data set across the site due to the site development works that have resulted in the destruction of bores.

These factors give rise to considerable uncertainty in interpreting the available data, and it is not possible to undertake a quantitative analysis and reach a firm conclusion on each of the various lines of evidence. While a more detailed and complex analysis could be undertaken to account for these factors, the auditor does not consider that this is warranted in this case given the following:

- Alternative remediation and groundwater pollution management measures have been implemented that do not rely on natural attenuation; and
- The body of data and observations give good support to the primary line of evidence that natural attenuation is occurring:
  - Initial soil investigations in 2003/2004 encountered some hydrocarbon impacted soils at different depths (mostly within the smear zone on the water surface), including in some cases black oil and sheens. In August 2009, extensive validation works indicated only minor hydrocarbon impact, with staining and/or hydrocarbon odour noted in only two of 88 drilled soil bores, and concentrations above the screening guideline at three of them, within the smear zone. Further test pitting in November 2009 at the exceedence locations indicated that the extent of the contamination was limited and the results of sample analyses were below the criterion. During basement excavation works (that extend into the smear zone) hydrocarbons were observed in only one area and this corresponded to the bore locations where hydrocarbons were observed during the 2009 work. This contamination was subsequently removed.
  - The initial groundwater investigations indicated TPH C_{10}-C_{36} impacts in almost all on-site and off-site wells in almost all sampling rounds. Highest groundwater concentrations were 24,750 µg/L in one on-site well and 142,300 µg/L in one off-site well in November 2007, but subsequent sampling reported much lower concentrations at these locations and no TRH detections have been detected since March 2012.

- The conditions are conducive to natural attenuation occurring, for example:
  - The warm Darwin temperatures;
  - Dilution of the groundwater with sea water which contains significant sulphate concentrations which also acts as an electron acceptor for hydrocarbon degradation; and
  - Hydrocarbon contamination is present in adsorbed and dissolved form that can be expected to be conducive to biodegradation;
- Stockpiling and monitoring of heavily contaminated soils across the waterfront area (where the type of product and its distribution is very similar to the Site) has shown rapid degradation and substantial reduction of the concentrations of hydrocarbons concentrations over a period of several months, indicating that a hydrocarbon reducing bacteria population is already present in the soil and the rate of degradation is rapid.

6.7 Effectiveness of the remediation

The remediation program across the waterfront area has involved considerable work to identify sources of contamination, and to remove free NAPL that has been identified through this work (where NAPL is encountered). This work has provided reasonable certainty that NAPL is not present in amounts in areas where buildings are present that would affect the use of the site. The remediation and management strategy involving control of contaminated groundwater through the sub-surface drain can be expected to provide an effective method of ensuring that residual contamination will not adversely affect the receiving waters (in particular the lagoon), as well as removing contaminated groundwater from the site. This is discussed in the following sections.

6.8 Acceptability of contamination remaining under buildings

Further assessment of the risk that remaining hydrocarbons may pose to human health and the environment was carried out by URS in the form of a Qualitative Risk Assessment (QRA). The QRA specifically focused on the contamination encountered within the Stage 2a area during validation works and was based on a redevelopment plan with a more sensitive land use including both residential and commercial facilities. Risk characterisation considered the following aspects:

- Review of the current extent, magnitude and type (fractions) of the hydrocarbon contamination remaining beneath the Stage 2a area;
- Identification of the potential human receptors (construction workers, residents, occupational workers in the commercial facilities) and environmental receptors (marine environment); and
- Identification and evaluation (significant or insignificant) of potential exposure pathways.

Analysis results found no unacceptable risks for the Stage 2a arising from the current state of the site, for construction workers, residents and the environment. This conclusion was based on the observations that:

- Limited hydrocarbon contamination was found in the Stage 2a 2009 soil validation works and during basement excavation works in 2013, except for an area in the corner of building 5 (consistent with previous observations). The hydrocarbon impacted soil in the latter area was removed;

- Groundwater TPH concentrations have steadily decreased in Stage 2a on-site wells and relevant off-site wells (and in general for the rest of the broader Waterfront site). TPH has not been detected in wells relevant to the Stage 2a area since March 2012;
- Comparison of the results from 2003/2004 (before commencement of remediation works at the Waterfront site) with the current hydrocarbon levels, it is evident that a reduction in the extent and magnitude of TPH impact has occurred across the Stage 2a and other previously assessed areas, supporting the conclusion that rapid and substantial natural attenuation of hydrocarbons is taking place;
- Hydrocarbons found in groundwater and soil are almost completely within the non-volatile (C_{15} and above) and semi-volatile C_{10} – C_{14}) TPH fractions with the great majority being in the non-volatile fraction;
- The 10 m grid bore validation program of the Stage 2a area during 2009 indicated that significant hot spots are not present beneath the Stage 2a area;
- Structural and engineering control measures such as the existence of subsoil and hydrostatic relief drains, a moisture/vapour barrier installed beneath the basement structures and a forced ventilation system inside the basement are in place to prevent the potential ingress of contaminated groundwater or soil vapour to indoor spaces or the discharge of contaminated groundwater into the lagoon; and
- The southern end of the basement carpark is an open grill allowing significant mixing of ambient air into the basement, particularly the southern end.

Due to lack of potentially significant exposure pathways, modelling was not carried out as part of the risk assessment. Previous modelling undertaken for the Stage 1 and Bitumen Plant areas of the Waterfront using a more conservative approach were included in the report as a second line of evidence to support the conclusion that no unacceptable risks are in place for the Stage 2a. The QRA report is included in Appendix E of this report.

7. Summary of the clean-up works

7.1 Extent and cost of clean-up to date

The remediation program has involved considerable work to identify sources of contamination, and to identify the presence of any free NAPL (and remove, if present). This work has provided reasonable certainty that NAPL is not present in amounts in areas where buildings are present that would affect the use of the site, and the remediation and management strategy involving control through the sub-surface drain can be expected to provide an effective method of ensuring that residual contamination will not adversely affect the receiving waters (in particular the lagoon). This is discussed in the following sections.

The approximate costs to date of assessment, clean up and managing residual contamination at the site, as advised by URS, are in the order of **$700,000 to $800,000** and include the following activities:

- Installation and maintenance of spur drains within the Stage 2a;
- Removal of building and construction waste deposited on site;
- Proportional operating costs of the recreational lagoon;
- Handling and disposal of contaminated wastes and soils;
- Field and desktop environmental investigations between 2003 and 2013; and
- Construction design measures such as basement waterproofing.

It is considered that the remediation activities and costs for the Stage 2a are commensurate with the magnitude and risk posed by the contamination encountered within the site.

7.2 On-going remediation

It is expected that hydrocarbons will continue to decline in concentration as a result of natural degradation processes.

8. Is the groundwater polluted?

8.1 Groundwater pollution assessment

Exceedences of groundwater criteria for the contaminants of concern have been discussed in sections 5.2.3 and 6.1.3 of this report. These exceedences are, in summary:

- Hydrocarbons are present in the groundwater smear zone beneath the site. While this was formerly present over large areas of the site, it is now expected to remain only in isolated pockets of the site and mainly in the northern area away from the lagoon where initial concentrations were highest;
- Metals, particularly manganese, and iron (total, ferric and ferrous), are present at concentrations that exceed the aquatic ecosystem, recreation and aesthetics and/or protection of aquaculture species; and
- Ammonia is present at concentrations that exceed the aquatic ecosystem, recreation and aesthetics and/or protection of aquaculture species criteria at most well locations (ammonia has not been analysed from 2008 onwards).

8.2 Assessment of potential and existing environmental values of groundwater and pollution

For the purpose of assessing whether groundwater is polluted with respect to a particular beneficial use, it was initially assumed that the subsoil drain is not in place. This is because the subsoil drain comprises part of the remedial works to address the pollution and, when monitoring shows that it is no longer necessary, maintenance of the subsoil drain may cease and over time groundwater will again flow towards the lagoon (located immediately downgradient of the site).

8.2.1 Aquatic ecosystems

If the subsoil drain remains closed and groundwater flows towards the lagoon, the potential for the discharges to impact on aquatic ecosystems of the lagoon requires consideration. The auditor notes that the lagoon constitutes an artificial engineered environment and under these circumstances would not constitute an ecosystem that requires protection. Notwithstanding this, it can be assumed that it is necessary to protect the environmental values of the lagoon, of which swimming, recreation and aesthetic enjoyment are the most important. For the purposes of initial assessment, the auditor has assumed that aquatic ecosystems do require protection and that the criteria for protection of aquatic ecosystems are useful initial indicators of effect.

In the case of protection of aquatic ecosystems, “high reliability” ecological investigation levels (EILs) should normally be used for screening purposes where these are available. However, these exist for only a limited number of potential contaminants, and for contaminants without high reliability EILs low reliability EILs have been used for initial screening purposes. The low reliability EILs can be conservative and more detailed consideration may indicate that thresholds of effect occur at considerably higher concentrations. It is important to note that exceedences of low reliability EILs do not necessarily mean that ecosystems have been impacted, but instead that there is a need for further consideration of whether or not impact is likely.

Organics

In the case of petroleum hydrocarbons, Table 3.4.1 of the ANZECC 2000 AWQG does not specify a trigger value for protection of ecosystems, but section 8.3.7.21 of the same document provides a low reliability EIL of 7 µg/L.

Hydrocarbon concentrations in groundwater have been steadily decreasing and have not been detected in on-site or relevant off-site wells since March 2012. Groundwater discharged by the subsoil drain has been recently analysed for TPH, with hydrocarbons not detected. In view of these factors, it is considered that TPH poses a low risk to receiving water ecosystems, although monitoring needs to be carried out once the operation of the subsoil drain ceases, to identify whether TPH may be discharging into the lagoon. While some pockets of hydrocarbons are expected to remain on the site and will give rise to localised hydrocarbon contamination, this is not expected to impact on the ecosystems of the lagoon or other environmental values such as swimming, recreation and aesthetic enjoyment on the basis that:

- These pockets will be isolated and generally immobile and are more likely to be in the north of the site (where initial hydrocarbon concentrations were higher at the commencement of the development);
- The toxicity criterion for TPH is likely to be higher than the low reliability value. It can be noted, by way of example, that the higher reliability toxicity guideline value for benzene is 700 µg/L;
- Biodegradation of the hydrocarbons can be expected to occur as the groundwater flowed towards the lagoon; and
- Groundwater discharges to the lagoon will be highly diluted by the large rate of exchange between the water in the lagoon and seawater from outside the lagoon. The Northern Territory Government advises that the rate of exchange will be in the order of 23,500 m^3/day (the total volume of the lagoon is approximately 200,000 m^3); this is far greater than any groundwater discharge, and will result in a very high level of dilution.

Non-metallic inorganics

Ammonia concentrations exceeding the ecological toxicity guideline value of 0.91 mg/L were reported at several of the Stage 2a on-site and relevant off-site bores up until November 2007, which constitutes the last sampling round where ammonia was analysed. The maximum ammonia concentration detected was 48.8 mg/L in NC_MW17A (part of the initial groundwater investigations and located on-site adjacent to the lagoon), which was well above trigger values, but subsequent sampling at that location measured much lower concentrations, consistent with other wells at or in the vicinity of the site (with the exception of one other result of 11.7 mg/l, all other results were less than 4.6 mg/l). There was no ammonia analysis after November 2007 for the remaining operational wells. The source of the ammonia is likely to be degrading organic matter, of which this might be organics present in the fill, although it could also arise from the decomposition of natural plant material (page 8.3–154, ANZECC 2000).

Ammonia in groundwater has the potential to impact the ecosystems in the sediments as groundwater discharges to the lagoon, and it may also impact on the flora and fauna of the lagoon. As noted in the previous section, given the low discharge rate of groundwater and the high turnover rate of the lagoon, impacts on the ecosystems of the lagoon would be unlikely. It can be concluded that ammonia toxicity to aquatic ecosystems poses a low risk.

Notwithstanding this, it can be assumed that it is necessary to protect the environmental values of the lagoon, of which swimming, recreation and aesthetic enjoyment are the most important.

In addition to the toxicity criterion, ANZECC indicates that more stringent criteria can apply with respect to nutrients containing nitrogen such as ammonia. For example, for estuarine marine systems the criteria for ammonia is 15 ug/L as N for tropical Australia (ANZECC 2000, Table 3.3.4). If these criteria are exceeded, it could give rise to excessive algal growth and algal blooms, which might occur in the lagoon water, or along the shoreline through which groundwater discharges. Such effects on the aquatic ecosystems would have potential to adversely affect the use of the lagoon for swimming and its aesthetic enjoyment. However, the auditor considers that it is unlikely that the lagoon water would be affected, in view of the very high change over rate with seawater from outside of the lagoon. However, this is a potential effect that should be monitored through observation. It is possible that algal growth could occur along the shoreline of the lagoon, before dilution with the lagoon water occurs, and this would be an effect to be monitored through inspection.

In addition to ammonia, nitrate was detected in the groundwater in the vicinity of the site at concentrations up to 7.9 mg/kg. There is no high reliability guideline value for toxicity specified for nitrate in marine environments. ANZECC 2000 specifies that a low reliability value of 13 mg/L was calculated, but specifies that it is preferable that the freshwater value of 0.7 mg/L is adopted. On this basis there is the potential for nitrate to impact the ecosystems in the sediments as groundwater discharges to the lagoon. As discussed above for ammonia, in view of the very high level of dilution that will occur, it can be concluded that nitrate poses a low risk in terms of toxicity. Similarly to ammonia, nitrate is a nutrient and the potential for nutrient effects should be considered, although this would appear to pose a lower risk than for ammonia.

In summary, it is concluded that non-organics such as ammonia and nitrate pose a low risk to the aquatic ecosystems of the lagoon water, but could give rise to impacts on the lagoon shoreline through algal growth.

Metals

A number of results exceeded the maintenance of ecosystems criteria during several sampling rounds for manganese, copper, zinc and particularly for iron (total, ferric and ferrous). Sporadic lead, cadmium, silver and nickel exceedences were also found but these did not show a consistent presence and were detected at concentrations within an order of magnitude of the relevant criteria. Copper and zinc concentrations were detected across the site, including the off-site up-gradient bores and other parts of the Waterfront broader area. . The observations support the conclusion that the concentrations of metals are not associated with a particular source (such as where the spillage of ore has occurred), but are more consistent with being background concentrations and therefore do not constitute pollution.

In assessing the significance of the observed concentrations of metals, it is noted:

- The great majority of the measured concentrations just exceed the criteria for protection of aquatic ecosystems or are within the same order of magnitude, and the distribution and occurrence is consistent with background concentrations;
- The criteria used for assessment of copper and zinc are applicable to slightly-moderately disturbed ecosystems, and can be considered to be conservative as a measure of potential effect for the Waterfront area, where the main concern is to protect recreation and aesthetic enjoyment;

- Iron and manganese exhibited elevated concentrations of up to 84 mg/L for ferrous iron and 23.2 mg/L for manganese. In the case of iron, the ANZECC 2000 guidelines do not provide trigger values and for manganese a low reliability trigger value of 0.08 mg/L exists, but is based on a much reduced number of species toxicological response. Iron and manganese are naturally occurring elements, often observed at elevated concentrations in groundwater. The measured concentrations can be a consequence of the reducing conditions resulting from the presence of organic matter, that gives rise to dissolution of naturally occurring iron and manganese bearing minerals in the fill and the corrosion of iron (such as reinforcing rod) that is likely to be present in the fill. Because the reduced forms of these metals will be rapidly oxidised and removed by precipitation after discharge to the lagoon water, the potential for adverse effects on aquatic ecosystems can be expected to be low. Notwithstanding this, high concentrations of metals such as iron and manganese could result in precipitated suspended material and discoloration of the lagoon water, which could adversely affect values such as swimming and aesthetic enjoyment. In view of the very high level of dilution, such effects are unlikely, but should be monitored.

In view of these considerations, it is concluded that metal concentrations pose a low risk to the waters of the lagoon.

8.2.2 Aquaculture and human consumers of food

The Northern Territory Government has advised that fishing and collection of molluscs from the lagoon will not be allowed, and that signs will be erected banning fishing. For the purposes of this audit, it has been assumed that aquaculture (farming of aquatic species) will not take place in the lagoon, although some incidental fishing might take place, as it has been noted at similar sites in Darwin. URS site observations are that fishing does not generally occur in the lagoon (the pool lifeguards generally move anyone fishing along), but people do collect cockles from the lagoon beach area.

For the purposes of assessing the potential for adverse effect, the protection of aquaculture species criteria listed in the ANZECC 2000 guidelines have been used for initial assessment. These values also cover the ANZECC 2000 criteria for *chemical compounds in water found to cause tainting of fish flesh and other aquatic organisms* (Table 4.4.5 of the guideline) and the G*uidelines for contaminants and natural toxicants* from the Australia and New Zealand Food Standards Code (Standard 1.4.1), thus covering the protection of possible incidental human consumption of aquatic species with respect to the contaminants of concern detected at the site.

It is also noted that the artificial lagoon will be subject to water exchange with the Darwin Harbour making it necessary to take into account a potential impact on aquaculture species within the harbour area.

Organics

In the case of saltwater aquaculture, the guideline for the protection of aquaculture species provides neither a value for maximum TPH concentrations nor a low reliability trigger value but, according to section 9.4.2.3.3 of the guideline, the main concern on the presence of these contaminants lies in taste considerations more than in possible health effects. In regard to animal toxicity, lighter TPH fractions like petrol and BTEX are much more toxic to fish than the heavier ones and these are not generally present at the site. In addition:

- Hydrocarbon concentrations in groundwater have been steadily decreasing and have not been detected in on-site or relevant off-site wells since March 2012. Groundwater discharged by the subsoil drain has been recently analysed for TPH, and concentrations of hydrocarbons have not been detected;

- While small pockets of hydrocarbons are expected to remain on the site, particularly in the northern area, further biodegradation of these hydrocarbons is expected to occur as the groundwater flows towards the lagoon;
- Any groundwater discharge to the lagoon would be highly diluted by the large rate of exchange between the water in the lagoon and seawater from outside the lagoon;
- Concern for TPH is mainly based on taste considerations, and this is of limited relevance to an activity that is not permitted; and
- The Standard 1.4.1 of the Food Standards Code does not specify values for petroleum hydrocarbons.

These considerations support the conclusion that petroleum hydrocarbon contamination poses a low risk with respect to impact on aquatic organisms that may be subject to human consumption.

Non-metallic inorganics

Ammonia concentrations exceeding the protection of aquaculture species guideline value of 0.1 mg/L were reported at all of the Stage 2a on-site and relevant off-site bores up until November 2007, which constitutes the last sampling round where ammonia was analysed.

The discussion in Section 8.2.1 regarding the potential impact of ammonia on ecosystems is relevant. It can also be noted that ammonia is a non-persistent and non-cumulative toxicant to aquatic life (page 8.3–155 ANZECC 2000), and ammonia is of relatively low toxicity to humans (Australian Drinking Water Guidelines p397). These considerations support the conclusion that ammonia poses a low risk with respect to the human consumption of aquatic species.

Metals

A number of results exceeded the protection of aquaculture species criteria across the site and during several sampling rounds for manganese, zinc and particularly for iron (total, ferric and ferrous). Occasional copper, lead, cadmium, silver and nickel exceedences were also observed, but these metals were not consistently present. The metals have been detected at various locations across the site, including the off-site up-gradient bores and other parts of the Waterfront broader area, and the occurrence does not appear to be associated with a particular source (such as where the spillage of ore has occurred), and is more consistent with being indicative of background concentrations.

In assessing the significance of the metal occurrences, it can also be noted:

- The great majority of the measured concentrations just exceed the criteria or are in the same order of magnitude;
- In the case of zinc, the trigger value used by the guideline is conservative, and other publications cited in the guideline have proposed values of up to 0.086 mg/L. Concentrations found in groundwater were much lower and rarely exceeded this value;
- Iron and manganese exhibited some elevated concentrations over their trigger value of 0.01 mg/L with up to 84 mg/L for ferrous iron and 23.2 mg/L for manganese. Iron and manganese are naturally occurring elements, often observed at elevated concentrations in groundwater. The measured concentrations can result from the reducing conditions resulting from the presence of hydrocarbons, dissolution of naturally occurring iron and manganese bearing minerals in the fill, and corrosion of iron (such as reinforcing rod) that is likely to be present in the fill. Because the reduced forms of these metals will be rapidly oxidised and removed by precipitation after discharge, the potential for adverse effects on aquatic ecosystems (and their consumption) is expected to be low;

- Groundwater discharges to the lagoon will be highly diluted by the large exchange rate between the water in the lagoon and seawater from outside the lagoon; and
- Testing of cockles that live in the sediments of the lagoon, through which groundwater discharges to the lagoon, has been carried out to determine their metal content. While there are some metals present in the cockles above the levels that would be expected to be seen in a pristine environment, these do not exceed the levels specified in the Food Standards Code. In addition, the elevated metal levels in cockles are likely to be more the result of metals in the sediments, rather than the discharge of metal contaminated groundwater to the lagoon.

These considerations support the conclusion that metal contamination of groundwater poses a low risk to the human consumption of aquatic organisms in the lagoon.

8.2.3 Recreation and aesthetics

Recreation activities such as swimming will take place at the lagoon, and so the potential for groundwater contamination to adversely affect primary contact recreation needs to be assessed.

The NRHMC ADWG 2011 has been used to assess the potential for adverse effects on human health and aesthetic enjoyment, with the following characteristics being considered:

- Microbiological guidelines
- Nuisance organisms (e.g. algae)

Physical and chemical guidelines:

- Aesthetics
- Clarity
- Colour
- Toxic chemicals
- Oil and debris

As noted in the preceding sections, it is not expected that the discharge of groundwater to the lagoon would give rise to nuisance organisms such as algae, and it is also unlikely that microbiological contamination will be present that would pose a risk with respect to human health. Nutrients (such as ammonia) can be expected to be present however, the high level of exchange of the lagoon water with water from Darwin harbour can be expected to reduce the concentrations of nutrients to below effect levels.

Organics

Regarding hydrocarbons, BTEX and PAHs have not been recently or historically detected on-site, and the main concern regarding the presence of hydrocarbons lies in taste considerations more than in possible health effects. Because hydrocarbon concentrations in groundwater have been steadily decreasing to below detection limits (with biodegradation of hydrocarbons expected to continue over time), and groundwater discharges to the lagoon would be highly diluted by the large water exchange rate with the seawater from Darwin harbour, it is concluded that organic contamination of groundwater poses a low risk to primary contact recreation (swimming) and aesthetic enjoyment.

Monitoring should be carried out when the operation of the subsoil drain ceases, to confirm that hydrocarbons are not discharging into the lagoon at levels of concern.

Non-metallic inorganics

Sulphate, chloride, sodium and TDS exceeded the water quality guidelines for recreational purposes in a number of wells, however these were considered to be associated with normal saline (sea water) background water quality and are not considered to be of concern.

Ammonia exceeded the NHMRC 2008 recreation and aesthetics criterion of 0.5 mg/L at several locations and sampling rounds with a maximum detected concentration of 48.8 mg/L in NC_MW17A (previously located on-site adjacent to the south-eastern boundary, within close proximity to the lagoon), but noting that all but two results were less than 4.6 mg/kg. Ammonia has a low toxicity to human health, and the guideline value has been set on the basis of corrosion of copper pipes and fittings, and concentrations at which effects might be observed are high and generally will not be exceeded.

The odour threshold for ammonia is 1.5 mg/L, but the potential for effects of this type is very unlikely given the very high dilution that will occur in the lagoon.

Ammonia can give rise to nutrient effects, but the high level of dilution that will occur in the lagoon makes it unlikely that such effects will occur, as noted earlier. It is possible that some enhanced algal growth might occur on the shoreline at the point of discharge of groundwater to the lagoon, and the auditor understands that algal or bacterial growth at the shoreline has been observed, and is not uncommon in similar environments elsewhere. URS advises that shoreline impacts are likely to be associated with iron and manganese reduction. This issue remains, and constitutes a minor nuisance. When the operation of the sub-surface drain ceases, then monitoring should be carried out to confirm that the discharge of nutrients does not give rise to objectionable algal growth along the shoreline.

Nitrate contamination of groundwater exists and can give rise to similar nutrient effects as ammonia.

Metals

A number of results exceeded the recreation and aesthetics criteria across the site during several sampling rounds for manganese and iron (total, ferric and ferrous). Occasional arsenic, cadmium and nickel exceedences were detected, but the occurrences were sporadic and are not considered to be significant.

In the case of iron, the value of 0.3 mg/L listed in the ADWG 2011 is an aesthetic criterion based on taste considerations for drinking water and in a seawater environment much higher values can be accepted. No health based trigger value exists for iron and it is not considered to be a concern in this respect. Elevated iron concentrations in groundwater can result in aesthetic impacts associated with iron oxidising bacteria causing oily like sheens or staining at the point of discharge of groundwater to the surface. The very high dilution in the lagoon should limit any such impacts.

In the case of manganese, a trigger value of 0.1 mg/L based on aesthetic considerations (higher concentrations give water an undesirable taste and stains laundry and plumbing fixtures), and a health based criterion of 0.5 mg/L, are specified in the Australian Drinking Water Guidelines (refer to Part V of the ADWG 2011). This value is based on a dose of 1 mg/day of manganese as an amount that can be safely consumed from drinking water and a water consumption of 2 L/day. Assuming that up to 200 mL of water (NRHMC (2008) *Guidelines for Managing Risks in Recreational Waters*) may be swallowed during swimming, the criterion can be increased to 5 mg/L without exceeding maximum allowable daily intake. Manganese concentrations registered in the groundwater were usually lower than this value, except for particular wells where elevated concentrations were consistently recorded. In view of the high level of dilution that will occur in the lagoon, it is concluded that manganese poses a low risk for the recreational use of the lagoon.

Iron and manganese concentrations can be associated with reducing conditions resulting from the presence of hydrocarbons, and are expected to decrease as biodegradation of the remaining hydrocarbons occurs. However, monitoring is recommended to confirm that any discharge of iron and manganese is not of concern with respect to affecting the clarity of the lagoon water or giving rise to other possible effects such as staining the shoreline, or forming an oil-like metallic sheen on the surface.

8.2.4 Buildings and structures

Piles and basements within the Waterfront development are expected to be in contact with the groundwater. Specific criteria are not provided in the NEPM or the Victorian Groundwater SEPP, but the latter states that introduced contaminants should not cause groundwater to become corrosive to structures or building materials and particularly refers to pH, sulphate and redox potential.

AS2159-1995 Piling – Design and Installation standard indicates that additional strengthening and reinforcement of piles is required as measured result of the sulphate, pH and chloride concentrations in groundwater (moderate to severe exposure classification). However, these are associated with natural background concentrations typical of a seawater environment. It is concluded that the composition of the groundwater poses a low risk to buildings and structures beyond that which can be expected in a natural seawater environment.

8.3 Pollution and existing and likely future uses

Table 25 summarises the relevance of protected beneficial uses at the site, without the operation of the subsoil drain. With the drain in operation it is expected that groundwater will not flow to the lagoon, and the beneficial uses should not then be affected.

Table 25 Summary of relevant environmental values, pollution and likelihood of being realised, with the subsoil drain not operating

Current or Realistic Future Use (Environmental Values) of Groundwater	Environmental Value precluded by pollution?	Pollutants	Likelihood of Environmental values being realised		Comment
			On-site	Off-site	
Maintenance of ecosystems	Low risk to the highly modified ecosystems within the sediments of the lagoon.	-	No	Yes	The groundwater will discharge to the lagoon and ultimately to the Darwin Harbour. Groundwater will be highly diluted upon discharge to the lagoon and will present a low risk to the ecosystems within the lagoon. The ecosystems in the shoreline and sediments of the lagoon (at the point of groundwater discharge) may be impacted by ammonia and this could give rise to an aesthetic effect.

Current or Realistic Future Use (Environmental Values) of Groundwater	Environmental Value precluded by pollution?	Pollutants	Likelihood of Environmental values being realised		Comment
			On-site	Off-site	
Protection of aquaculture species and human consumers of food	No	-	No	Yes	While fishing is not permitted in the lagoon, cockles are gathered from the shoreline sediments and incidental ingestion could occur. While the abundance of species normally present in the sediments of such a water body may be reduced, the organisms present are unlikely to contain toxic levels of chemicals. Chemicals present in the groundwater will be highly diluted after discharge, and pose a low risk to fauna within the lagoon.
Recreation and Aesthetics	Monitoring indicates that there may be some localised pollution impacts if the subsoil drain is not in operation.	-	No	Yes	Primary and secondary contact recreation will take place in the lagoon. The levels of chemicals still present at the site do not pose a health risk and they will be highly diluted in the lagoon water. Ammonia, iron and manganese could give rise to some algal growth at the shoreline at the point of discharge. Ingress of water into building basements will be controlled by the hydrostatic relief drain after the subsoil drain ceases its operation. Contaminated groundwater could enter the swimming pool if groundwater sits higher than the pool water levels. The SMP specifies the actions required should this occur.
Buildings and structures	No	-	Yes	Yes	Salinity, sulphate, chloride and pH exceed levels where additional reinforcement of structures is required. However these concentrations are associated with the natural saline (seawater) environment present at the site. It is understood that piles and basements sitting below groundwater level have already been designed and constructed to withstand aggressive saline conditions.

9. Measures to be undertaken to manage groundwater pollution

9.1 Prevention of oily groundwater entering buildings

URS has proposed a number of measures to limit the potential for oily groundwater to enter building basements. These measures are outlined in the following sections, and particularly consider:

- The risk of localised increases in groundwater levels adjacent to buildings due to the intense rainfall events of the wet season; and
- The variable permeability of the fill that may hinder drainage of groundwater.

9.1.1 Removal of hydrocarbon visible beneath basements

At the time of the excavation of the basement for Buildings 5 and 6 at the site, soils identified to be impacted by hydrocarbons in one location were removed from the site.

9.1.2 Subsoil drain

The design and purpose of the sub-soil drain as a remediation system to remove hydrocarbons from the site has been discussed in Section 6.5. The drain will also control contaminated groundwater by lowering the level of the water so that it will generally sit below the level of the basement walls. The subsoil drain will operate until contaminated groundwater no longer poses a risk to the beneficial uses at the site.

9.1.3 Building perimeter drains

The basement for buildings 5 and 6 is bordered by a hydrostatic relief drain consisting on a 225 mm diameter slotted pipe sitting at a level of 3.65 m AHD. The drain is surrounded by crushed rock aggregate in a geotextile lined trench and positioned against the basement wall but separated from it by a waterproof layer. The hydrostatic drain is connected to a sump that sits beneath the basement. This sump can be pumped out as required.

9.1.4 Sealing of basement walls

It is understood that the basement walls have been sealed as a barrier against general groundwater ingress. This provides additional protection against any minor areas of oily groundwater that may remain on site, entering basements.

9.2 Prevention of polluted groundwater entering the lagoon

The sub-soil drain reverses groundwater flow, preventing polluted water from entering the lagoon, if required. This has been discussed in Section 6.5. Closure of the drain is currently being trialled to determine whether contamination is present that still requires its operation. The drain is still in working order and can be returned to operation if required. The requirement for the ongoing operation of the drain across the Stage 1 and 2a areas of the site is being considered separately to this audit.

9.3 Management of polluted groundwater entering the swimming pool

The pool located in the open space area of Stage 2A is constructed as a “floating” structure (i.e. there are no foundation piles to overcome inherent buoyancy). A pressure relief valve has been incorporated into the structure to allow groundwater to enter into the pool, if groundwater were to rise to a level to cause the pool to become buoyant. The pressure relief valve should only operate if the pool is emptied and the water level in the pool falls below the groundwater level (i.e. when the pool is full the internal pressure should overcome any external pressure caused by rising groundwater levels).

If this situation should occur, it would be maintenance workers who are most likely to be exposed to the contaminated groundwater that might enter the pool. In practice, the potential for significant exposure via this possible pathway is considered to be low, for the following reasons:

- Groundwater ingress should only occur when the pool has been emptied to a level lower than the groundwater. The depth to groundwater through the wet season has generally been below the level of the base of the pool structure, and emptying of the pool would not be a regular occurrence. Sufficiently elevated groundwater levels might only be expected to occur during and immediately following unusually extreme rainfall events (such as prolonged active monsoons and tropical lows/cyclones) and the likelihood that this would coincide with the pool being empty is low.
- There is no evidence of hydrocarbon impact in soil or groundwater in this area of the site and no ongoing primary sources of impact. While there is limited recent data, minor groundwater impacts were last identified in this area of the site in February 2009 and concentrations across the site have reduced substantially since this time.
- Workers entering the pool for cleaning or maintenance purposes would be expected to be a relatively infrequent event and in such circumstances, workers might reasonably be expected to wear PPE (Gloves, boots etc.) to reduce exposure to cleaning chemicals and thereby reduce the potential for exposure to site-derived groundwater contamination.

Should groundwater enter the pool it may be a slight orange brown colour (similar to site soils) and/or have an oily sheen and may stain the base of the pool. It is recommended that groundwater that enters the pool be removed, any residual staining cleaned, the pressure relief valve cleaned and checked prior to refilling, and contact with groundwater that has obvious hydrocarbon impact avoided.

9.4 Site management plan (environment)

URS has prepared an annexure to the site management plan (environment) (SMP-E) for the Stage 2a area. The SMP-E will specify the ongoing management requirements necessary to address a range of contamination management issues including:

- Prohibition on the use of groundwater at the site;
- The steps required to manage contamination if development involving sub-surface works is proposed to be undertaken after the completion of the audit;
- Groundwater monitoring to ensure that contaminated groundwater does not impact the beneficial uses at the site (this is further discussed in Section 10);
- The steps required to manage possible groundwater ingress to the swimming pool by means of the pressure relief valve;

- Ensuring that appropriate occupational health and safety standards relating to the contamination present on site are adhered to during inspection, maintenance and site development work; and
- Ensuring that contaminated soil is handled and disposed of in an appropriate manner.

The auditor will include a condition in the statement of environmental audit that the site be managed in accordance with the SMP-E.

10. Control of polluted groundwater

10.1 Controls on beneficial uses precluded by pollution

The Statement of Environmental Audit for the Stage 2a area will make a Statement to the effect that:

- The use of groundwater must be prevented at the site;
- The site shall be managed to prevent oily water entering the basement and other subsurface structures; and
- Groundwater must be managed in accordance with the Groundwater Management Plan (GMP).

It is understood that the Statement of Environmental Audit will be attached to the title. Other management / controls will be administered as follows:

- The Northern Territory Government will retain responsibility for the groundwater monitoring and the updating and implementation of the GMP; and
- The Registered Owner of the site will be made aware of the restrictions on the use of groundwater via the Statement of Environmental Audit (SoEA) and the Site Management Plan.

10.2 The groundwater management plan

10.2.1 Overview

The Groundwater Management Plan (GMP) specifies the activities that must occur at the site to ensure that groundwater pollution is being properly managed, the requirements for assessment and review of the resultant data, and the requirements for actions as may be necessary as a result of that review. When monitoring indicates that it is safe to do so and groundwater pollution no longer poses a concern at the site, the subsoil drain can cease to be maintained and sometime after that monitoring can cease. This will depend on the residual contamination on-site reducing to appropriately low levels and that there is no off-site contamination flowing into the site.

The auditor will include a condition in the Statement of Environmental Audit that groundwater at the Site will be managed in accordance with the GMP.

The GMP will be a living document that will be periodically reviewed, with amendments being included as annexures to the original document. The most recent review was carried out in December 2013/January 2014 in order to include additional options and requirements as a result of the subsoil drain closure trial undertaken during the 2013/2014 wet season. The current version of the GMP and the latest review annexure can be obtained from the Darwin Waterfront Corporation.

In addition to monitoring, the GMP requires regular inspections of:

- Observation piezometers, bore cover/locks and access routes;
- The drains and drainage systems to ensure they are functioning as designed (if the drain is operational);
- The oil/water separator, including the amount of oil in the separator, the maintenance schedule and the product removed (if the drain is operational);
- Basements to ensure that there is no entry of oily water; and
- The lagoon and beach for impact by contamination (particularly hydrocarbons).

10.2.2 Groundwater monitoring

The latest monitoring program is located in the URS Groundwater Management Plan. The program includes the analytical suite and frequency of monitoring of water quality, the sub-soil drain flow, and groundwater levels.

In view of decreasing contamination levels registered at the site, a subsoil closure trial was proposed in order to assess the possible effects that the permanent cease of operation of the drainage system would cause on groundwater levels and quality. For this period a special schedule of monitoring was created:

- Weekly gauging of Stage 1 and Stage 2 wells from immediately before the blockage until four or six weeks after the removal of the plug;
- Weekly inspection of points along the subsoil drain to check for LNAPL presence and gauging with two sampling events during the closure period. After the plug has been removed, daily gauging of the drain discharge will be carried out;
- Water quality in the lagoon will be monitored in specific points across the shoreline, particularly in the case that a rapid response is observed in sentinel wells; and
- The lagoon and beach should also be inspected for contamination impacts (particularly by hydrocarbons).

Further details to the monitoring program during the closure period are provided in the URS Waterfront Monitoring Plan 2013 revision.

In the event that no adverse effects are observed during the closure of the subsoil drain, URS proposes that the monitoring frequency is reduced to once a year during mid/late wet season (nominally February or March), and only for selected wells and lagoon locations across the Waterfront site. Changes to the groundwater monitoring requirements are currently under review and will be subject to the auditor's approval depending on the outcomes of the subsoil drain closure trial period.

10.2.3 Trigger levels

Under the current GMP, the following trigger levels are specified:

- A trend of increasing PSH thickness over three consecutive monitoring rounds in a well that already contains PSH;
- Appearance of a measurable thickness (>2 mm) of PSH in a monitoring well that did not previously contain PSH;
- Greater than one order of magnitude increase in concentration of a potential contaminant in groundwater over the baseline data; and
- Visible sheen or an objectionable effect on the water or beach sand.

10.2.4 Contingency plan

The GMP also specifies possible contingency actions in the case that triggers for groundwater quality are exceeded. Whether contingency actions are carried out would need to be decided at the time of occurrence of an event, and may require approval by EPA.

Possible actions as outlined in the GMP include:

- Re-sampling of existing bores or sampling on a more intense frequency in order to assess trends in more detail;
- Installation and monitoring of additional bores;

- Assessment of the drainage performance including visual inspection and repair if necessary;
- Augmentation of the spur lines for the sub-soil drain;
- Recommissioning of the subsoil drain if it is no longer in use;
- Installation of localised pump and treat systems; and
- Installation of a cut-off wall.

10.3 Periodic review of practicability of clean up

The clean-up of the site has been on-going through natural attenuation and the operation of the subsoil drainage system and has been proven to be successful as evidenced by the monitoring results. As a consequence, a subsoil drain closure trial is currently underway as well as the review of the monitoring requirements detailed in the GMP.

If the results of this trial show that clean-up has progressed to an acceptable level and the operation of the sub-soil drain may be discontinued, a program of decommissioning and the adjustment of the overall GMP will be undertaken.

11. Assessment of whether clean-up has been carried out to the extent practicable

11.1 Basis for determining clean up to the extent practicable

The Victorian EPA Publication 840.1 requires that, in determining if clean-up has been to the extent practicable, consideration should be given to the technical, logistical and financial aspects of carrying out further clean up. In addition, consideration should be given to:

- Whether the clean-up undertaken is commensurate with the significance of pollution including but not limited to the likelihood of beneficial uses being impacted;
- The expected timeframe for restoration; and
- The reasonableness of this timeframe.

11.2 Have the clean-up measures been commensurate with the significance of the pollution?

There has been considerable expense in managing the potential impact of groundwater contamination within the Stage 1 and Stage 2a sites (approximately $14.1 million), of which approximately $0.8 million has been expended for the Stage 2a site. The Stage 2a works have included installation of spur drains, remedial earthworks, basement waterproofing, handling and disposal of contaminated wastes and soils, stockpile management and field and desktop environmental investigations described in previous sections of this report. These are considerable works, and This amount may be considered to be reasonable given that the overall project value is greater than $1 billion and is a high end development aimed at attracting international visitors, and especially when considering that the potential reduction of the amenity for recreation and aesthetics in particular is considered to be high if:

- Oily sheens were to form on the lagoon surface;
- Oily water was to discharge into building basements; or
- Oily water was to seep to the surface of the site.

Because of these considerations, the auditor considers that the clean-up measures that have been adopted are commensurate with the significance of the pollution and its possible interaction with the proposed development.

11.3 Technical, logistical and financial considerations of further clean up

In with respect to carrying out further clean-up of the site, it is noted that the residual soil and groundwater contamination does not pose an unacceptable risk to human health, and while groundwater contamination still exists, it is controlled through the application of a sub-surface drain and does not adversely affect beneficial uses while the drain is in operation. It is intended to rely on natural biodegradation of residual hydrocarbons to reduce the concentrations of hydrocarbons to levels whereby the drain is no longer required to avoid adverse effects on the beneficial uses of the lagoon waters, and the operation of the drain can cease.

In terms of carrying out further remediation, the benefit of this would be to reduce the time over which the drain can be shut down, or to provide more certainty that the residual groundwater contamination will not adversely affect the lagoon.

Options for such further remediation would be:

- Continued operation of the sub-surface drain until it is certain that the contamination no longer poses a concern to the lagoon beneficial uses;
- Excavation and removal of contaminated soil and materials that might form a source of contamination by hydrocarbons and other contaminants;
- Treatment of contaminated groundwater; and/or
- Installation of a reactive barrier along the shore line to treat contamination that might still migrate to the lagoon.

As it seems likely that the drain may have already satisfied its intended purpose and it is possible that the operation of the drain may cease, the auditor considers that the most practicable approach is the first of these options. It is noted that a trial closure of the drain is currently underway to determine if remediation has been achieved. If this works should show that further remediation is required, then this can be undertaken by returning the drain to operation and waiting some further time for reduction in the concentrations of hydrocarbon to acceptable levels to occur.

With respect to the other options listed above, it can be noted:

- Excavation and removal of contaminated soil and materials that might form a source of contamination by hydrocarbons and other contaminants: this is impractical because of the logistics (limitations in access to soil) and cost. With respect to cost, it is noted that URS estimated the cost of excavation and off-site disposal of soil to be many millions of dollars, and could jeopardise the project if this were to be required;
- Treatment of contaminated groundwater: this is considered to be technically infeasible, as it is not possible to identify all sources of contamination and to remediate these, noting the presence of uncontrolled fill with potentially high organic matter inclusions, a heterogeneous sub surface environment, and uncertain and ill-defined location of contaminant sources; and
- Installation of a reactive barrier along the shore line to treat contamination that might still migrate to the lagoon: this would be technically difficult, logistically very difficult in view of the use of the site and the need to maintain the barrier, and costly.

In reaching a conclusion on this matter, it is noted that:

- Clean up may have now been achieved and this is the subject of a trial to determine this;
- If clean-up has not been achieved, then the existing systems can be continued in operation until remediation has been achieved, and the residual contamination does not pose an unacceptable risk to human health or to the environment or to the aesthetic enjoyment of the site; and
- The other options are unlikely to change the risk profile, are logistically very difficult and are very costly, and may pose a risk in terms of the further works and their potential to impact on the aesthetic enjoyment of the site and the beneficial uses of the lagoon.

In view of these considerations, the auditor considers that the current level of clean-up is consistent with Clean Up to the Extent Practicable. The auditor notes that groundwater monitoring will be undertaken to ensure that groundwater pollution does not impact on the site development, and URS has identified a number of contingency options should this not be the case, which are detailed in the Groundwater Management Plan.

11.4 Timeframe for restoration of environmental values and reasonableness of this time frame

The URS assessments undertaken in 2005 (refer to Appendix G of the RAP - Appendix F of this report) indicated that it would take a number of years for TPH to be reduced to concentrations that did not require management through the sub-surface drainage system. Experience since this time supports the conclusion that the timeframe for restoration of beneficial uses is less than had been allowed for, and may have now been achieved. A trial closure of the drain is being undertaken to determine this.

In view of this, it can be assumed that the further time to complete the remediation is likely to only a few years, if it has not been achieved at this time. The auditor considers this to be reasonable time frame, particularly noting that the sub-soil drain prevents the migration of contamination off site and protects relevant beneficial uses until such time as clean-up has been completed.

12. Conclusions and recommendations

A review of the available information pertaining to the groundwater contamination status at the site indicates that the concentrations of TPH, iron and ammonia have potential to adversely affect beneficial uses of the groundwater, particularly *maintenance of ecosystems* and *primary contact recreation and aesthetics*, and the concentrations of TPH have potential to adversely affect *human consumers of food*. The assessment has shown that the TPH does not pose an unacceptable risk to human health.

The remediation program has involved considerable work to identify sources of contamination and to remove free NAPL that has been identified. Where hydrocarbon impacted material was noted within the area of the basement excavation, it was removed. The assessment, remediation and validation work has provided reasonable certainty that:

- NAPL is not present in areas where buildings are present in amounts that would affect the use of the site;
- Residual hydrocarbon contamination is contained on the site and is limited to small pockets of contamination that is most likely to be present in the northern section of the site;
- Hydrocarbon are being degraded and concentrations are reducing over time; and
- The remediation and management strategy involving control through a sub-surface drain (if required) can be expected to provide an effective method of ensuring that any residual contamination will not adversely affect the receiving waters (in particular the lagoon).

The drain has a 50 year design life and it is proposed to be maintained until monitoring shows that contamination at the site will not adversely affect the waters of the lagoon if the drainage system is no longer maintained. In this respect, it is noted that a trial closure of the drain is currently underway and this may become permanent if it is considered that groundwater will no longer present a risk to beneficial uses.

If an Environmental Auditor determines that contamination risks no longer exist and that the subsoil drain is no longer required, the Northern Territory Government may cease maintaining the drain. It is noted that a closure of the drain is currently being trialled to confirm that the lagoon will not be impacted by discharges of contaminated groundwater. The decision whether the drain can remain closed impacts the wider Waterfront area and will be considered separate to this audit. The Ground Water Management Plan will obtain information that will allow confirmation that the situation is satisfactory with the drain closed.

It is proposed that in addition to the sub-surface drain, other controls will be implemented to avoid adverse effects of contaminated groundwater, including:

- The site shall be managed to prevent oily water entering the basement and other subsurface structures. The requirement for a condition requiring tanking of the basement was considered and it was concluded that the probability of oily water entering the basement is low and tanking is not required to preclude oily water ingress. However, it is noted that (uncontaminated) groundwater could enter basements when the water table is high, and the auditor understands that the basement has been tanked to avoid this; and
- The management of groundwater in accordance with a Groundwater Management Plan (GMP). This Plan will include measures to ensure that contaminated groundwater is not impacting on the lagoon, measures to prevent the use of groundwater at the site, and a program of groundwater quality and level monitoring together with trigger levels for further action and contingency plans if trigger levels are exceeded.

With respect to determining if it is practicable to carry out further remediation, it is noted that the benefit of further remediation would be to reduce the time over which the drain can be shut down, or to provide more certainty that the residual groundwater contamination will not adversely affect the lagoon.

Options for such further remediation would be:

- Continued operation of the sub-surface drain until it is certain that the contamination no longer poses a concern to the lagoon beneficial uses;
- Excavation and removal of contaminated soil and materials that might form a source of contamination by hydrocarbons and other contaminants;
- Treatment of contaminated groundwater; and/or
- Installation of a reactive barrier along the shore line to treat contamination that might still migrate to the lagoon.

As it seems likely that the drain may have already satisfied its intended purpose and it is possible that the operation of the drain may cease, the auditor considers that the most practicable approach is the first of these options. It is noted that a trial closure of the drain is currently underway to determine if remediation has been achieved. If this works should show that further remediation is required, then this can be undertaken by returning the drain to operation and waiting some further time for reduction in the concentrations of hydrocarbon to acceptable levels to occur.

With respect to the other options listed above, an analysis concludes that these are unlikely to change the risk profile, are logistically very difficult and are very costly, and may pose a risk in terms of the further works involved and their potential to impact on the aesthetic enjoyment of the site and the beneficial uses of the lagoon.

In view of these considerations, the auditor considers that the current level of clean-up is consistent with Clean Up to the Extent Practicable. The auditor notes that groundwater monitoring will be undertaken to ensure that groundwater pollution does not impact on the site development, and URS has identified a number of contingency options should this not be the case, which are detailed in the Groundwater Management Plan.

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Figures

Figure 1 Darwin Waterfront development site

Source: Figure 1 of URS Phase 3-4 Detailed Site Contamination Investigation Report

Job No.	36909-007-562		Department of Infrastructure, Planning and Environment DARWIN WATERFRONT PROJECT PHASE 3/4	Figure 2
Prep. By	RSM	22 Oct 04		
Chk'd By	BJA	22 Oct 04	**SITE LAYOUT (AIR PHOTO)**	URS
Revision No.		0		

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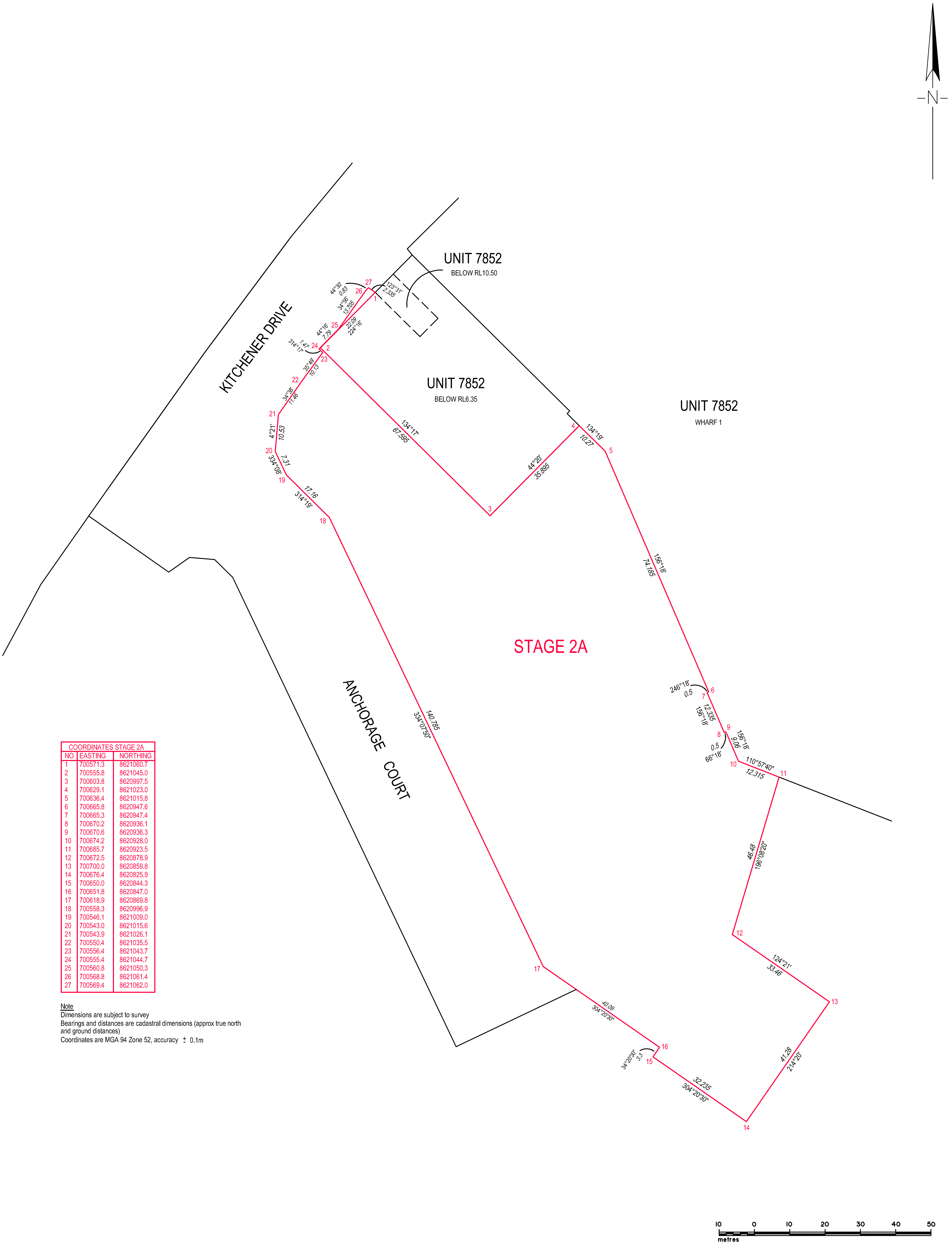
Figure 2 Stage 2a area survey plan

Source: site survey plan provided by the NT Government on 9 July 2014



COORDINATES STAGE 2A		
NO	EASTING	NORTHING
1	700571.3	8621060.7
2	700555.8	8621045.0
3	700603.8	8620997.5
4	700629.1	8621023.0
5	700636.4	8621015.8
6	700665.8	8620947.6
7	700665.3	8620947.4
8	700670.2	8620936.1
9	700670.6	8620936.3
10	700674.2	8620928.0
11	700685.7	8620923.5
12	700672.5	8620878.9
13	700700.0	8620859.8
14	700676.4	8620825.9
15	700650.0	8620844.3
16	700651.8	8620847.0
17	700618.9	8620869.8
18	700558.3	8620996.9
19	700546.1	8621009.0
20	700543.0	8621015.6
21	700543.9	8621026.1
22	700550.4	8621035.5
23	700556.4	8621043.7
24	700555.4	8621044.7
25	700560.8	8621050.3
26	700568.8	8621061.4
27	700569.4	8621062.0

Note
Dimensions are subject to survey
Bearings and distances are cadastral dimensions (approx true north and ground distances)
Coordinates are MGA 94 Zone 52, accuracy ± 0.1m

eja
earl james & associates
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10 HARVEY STREET
DARWIN NT 0801
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darwin@eja.com.au

DARWIN WATERFRONT

STAGE 2A

EXTENT OF WORKS

Client **TOGA CONSTRUCTIONS NT**

Licensed Surveyor:
Date:

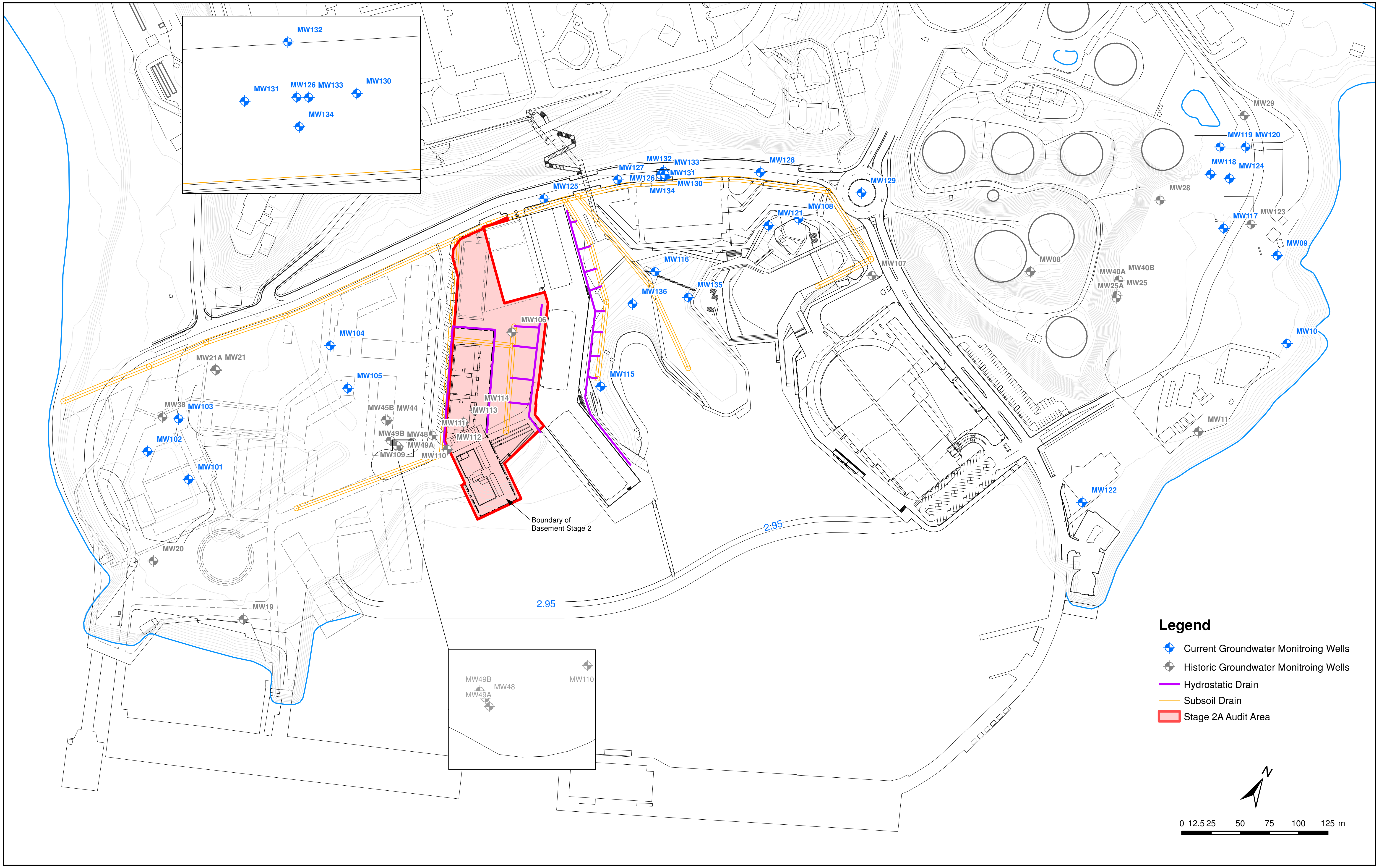
Drawn by: RM
Date: 8.07.14
Cad File: 7324-106B.DWG

Scale: 1:500 (A1)
Datum: MGA 94 ZONE 52

Drawing No: 14/7324/106B

Figure 3 Subsoil drain as constructed

Source: Figure 7 of URS Stage 2a Residential Validation Report



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DARWIN WATERFRONT PROJECT -
STAGE 2A

STAGE 2A DEVELOPMENT
SUBSOIL DRAIN LOCATION PLAN

URS

42213719

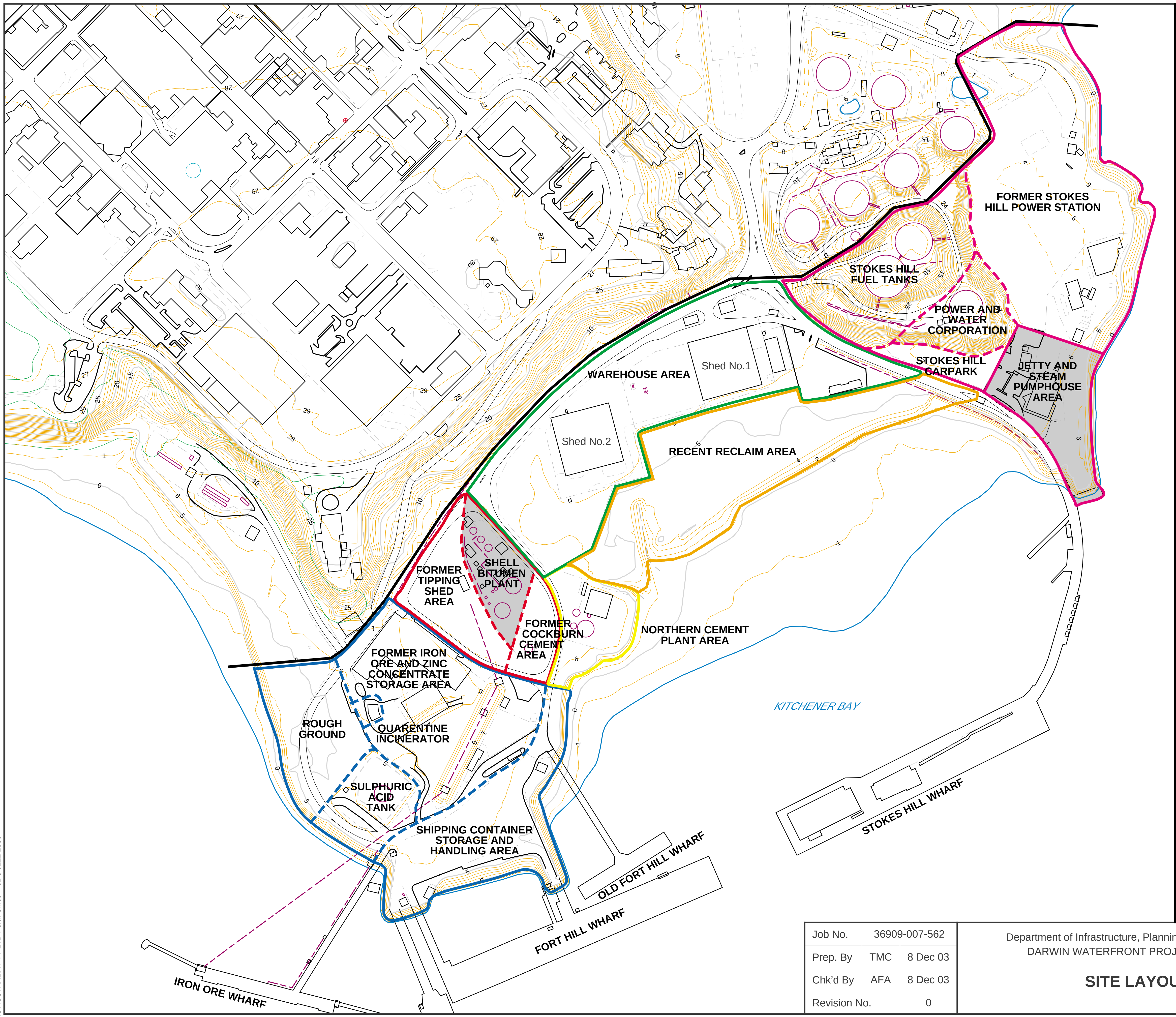
File No: File: 42213719-2A-Dev-007.mxd Drawn: JD Approved: PS Date: 07-04-2012

Figure: 7

Rev. A A3

Figure 4 Waterfront areas defined by historical use

Source: Figure 2 of URS Phase 2 Detailed Site Contamination Investigation Report



LEGEND

- Stokes Hill Area
- Bitumen Plant Area
- Fort Hill Area
- Northern Cement Plant Area
- Recent Reclaimed Area
- Warehouse Area
- Not Included in Phase 2 Assessment

PRELIMINARY DRAFT FOR REVIEW

N

0 40 80 120 160 200

METRES

Job No.	36909-007-562		
Prep. By	TMC	8 Dec 03	
Chk'd By	AFA	8 Dec 03	
Revision No.		0	

Department of Infrastructure, Planning and Environment
DARWIN WATERFRONT PROJECT PHASE 2

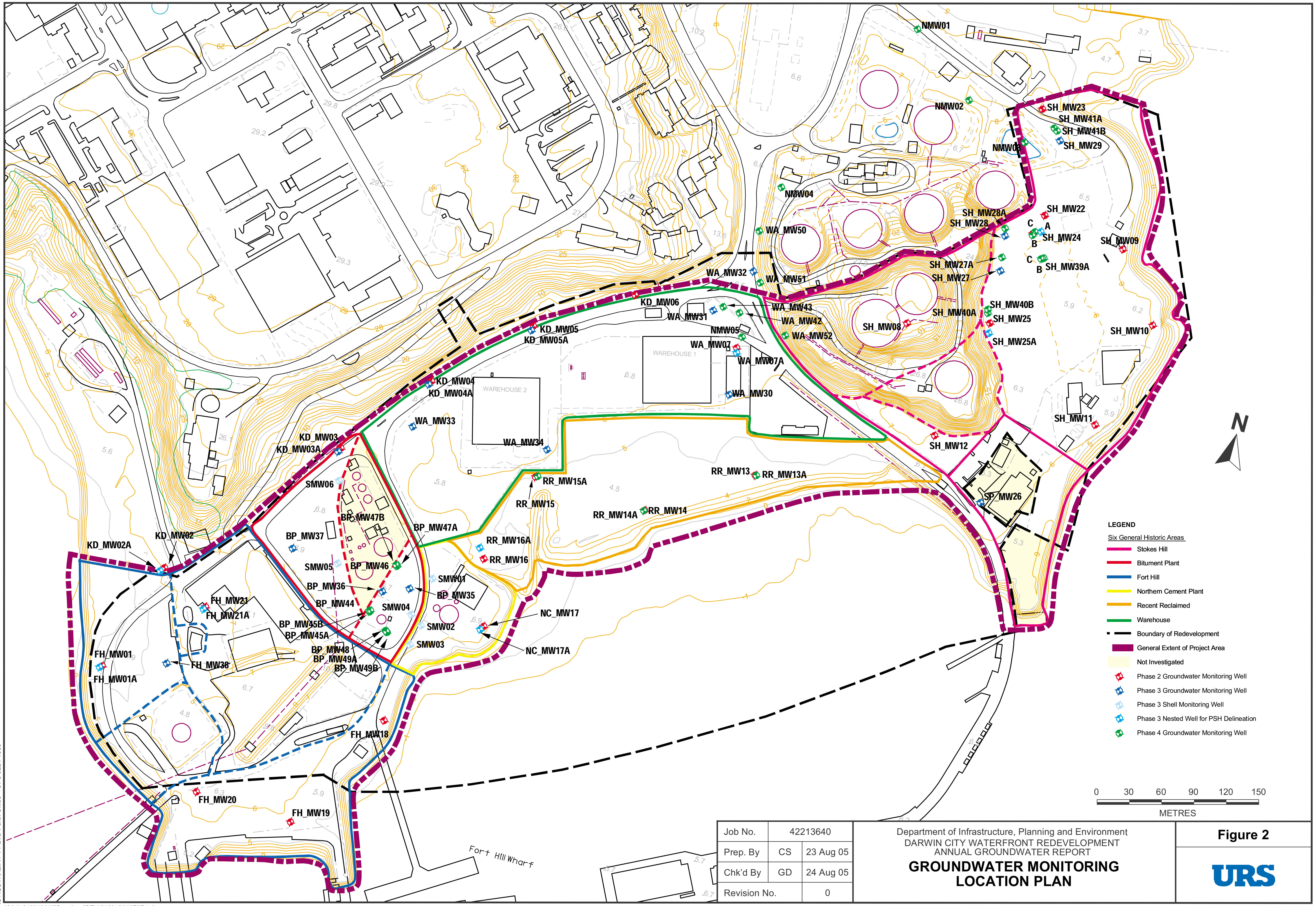
SITE LAYOUT

Figure 2a

URS

Figure 5 Initial monitoring well locations

Source: Figure 2 of URS Groundwater Monitoring Report March 06



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Chk'd By	GD	24 Aug 05
Revision No.	0	

Department of Infrastructure, Planning and Environment
DARWIN CITY WATERFRONT REDEVELOPMENT
ANNUAL GROUNDWATER REPORT

GROUNDWATER MONITORING LOCATION PLAN

Figure 2

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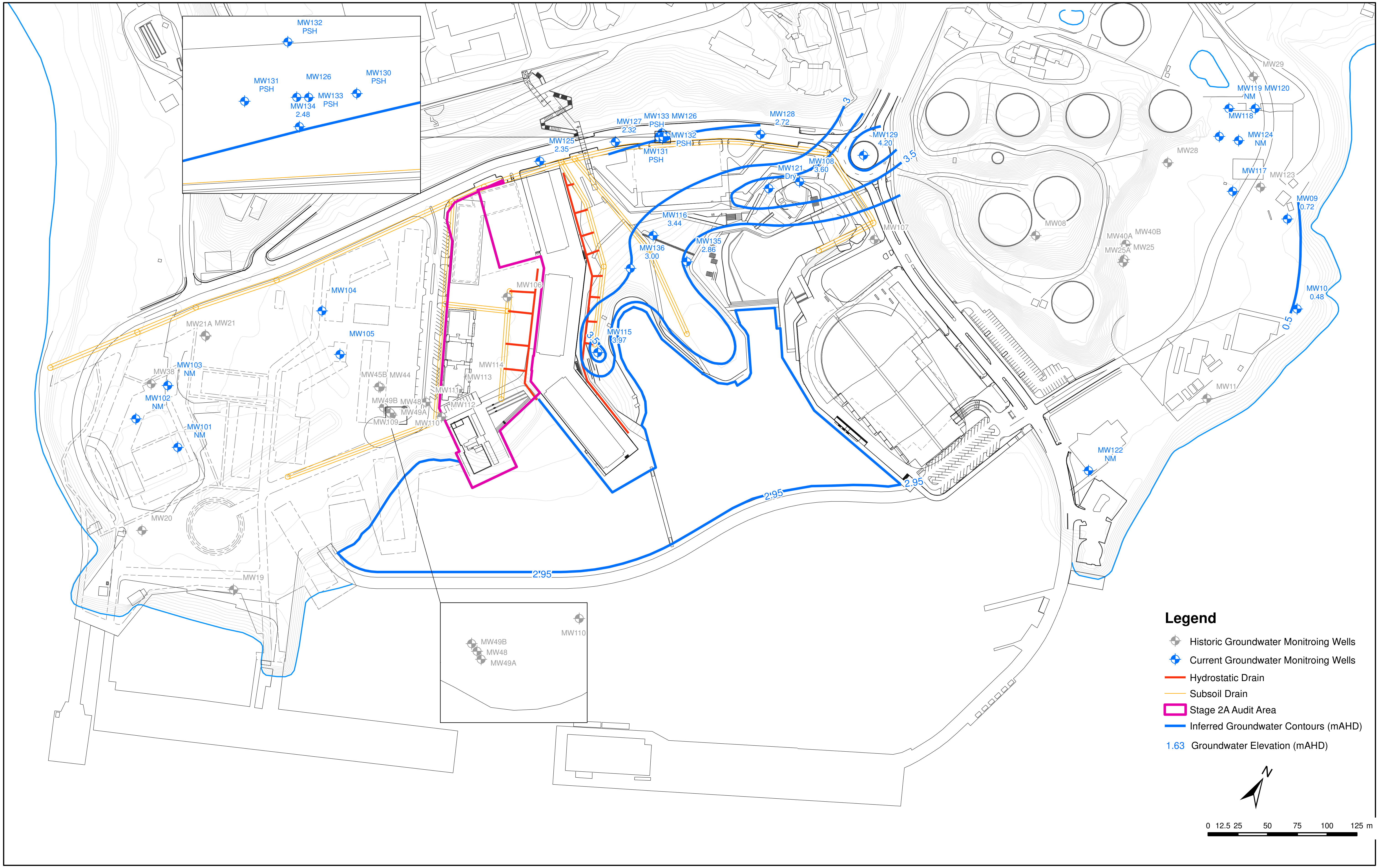
Figure 6 Current monitoring well locations and recent groundwater contours (June 2013)

Source: Figure 4b of URS Groundwater Monitoring Report 2013



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DARWIN WATERFRONT REDEVELOPMENT 2013 ANNUAL GROUNDWATER REPORT

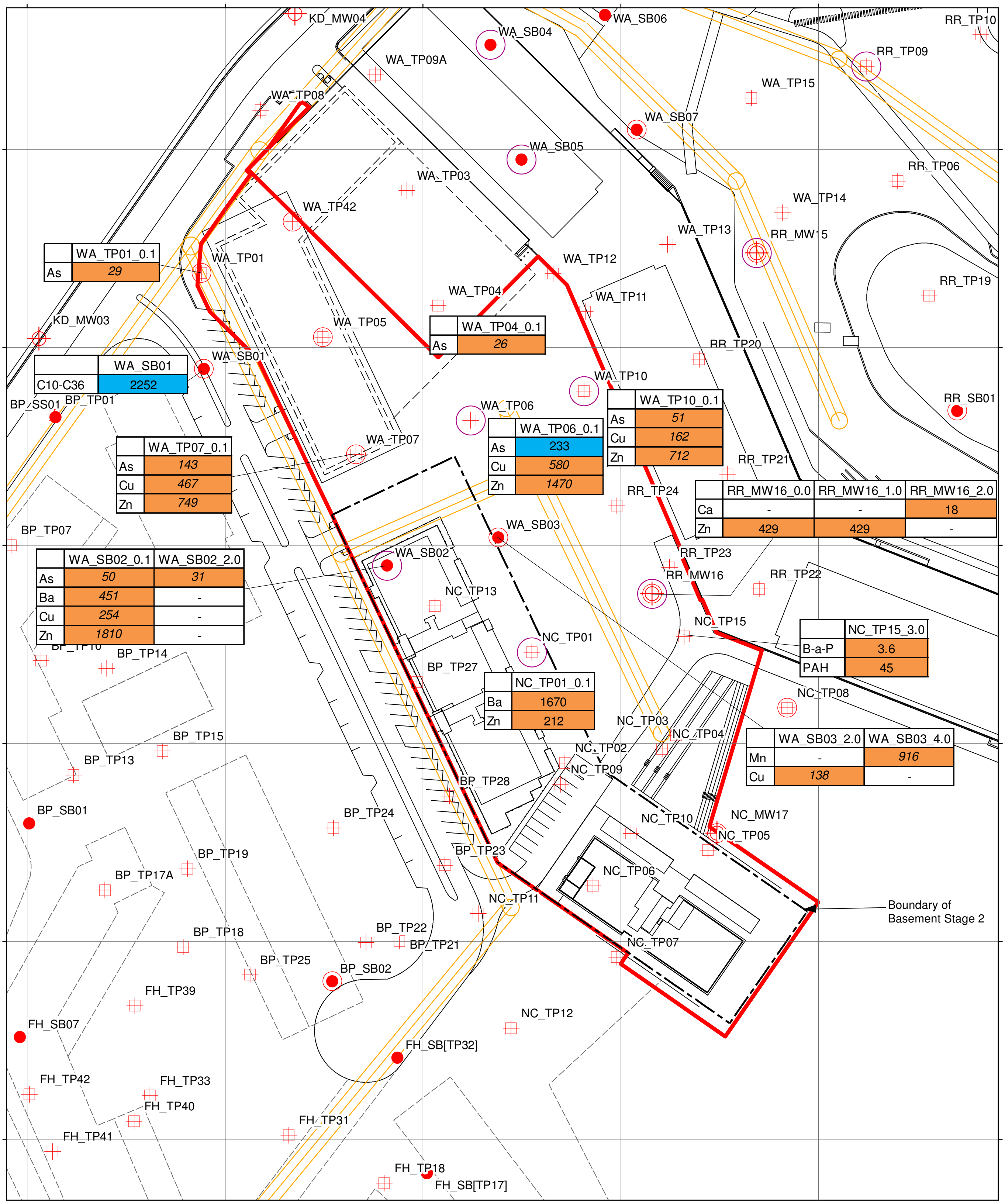
INTERPRETED GROUNDWATER CONTOURS JUNE 2013

URS | 42213719 | Figure: 4b

File: 42213719-AN13-004b.mxd Drawn: JD Approved: BA Date: 10/07/2014 Rev. A A3

Figure 7 Phase 2 soil sampling locations

Source: Figure 5 of URS Stage 2a Residential Validation Report



Legend

- Groundwater Monitoring Wells
- Soil Bore
- Surface and Shallow Samples
- Test Pit
- Acid Sulphate Soil Locations
- Potential asbestos containing fragments collected and analysed
- Soil Samples analysed for asbestos fibres
- Stage 2A Audit Area
- Subsoil Drain

AS= Arsenic (mg/kg)
Ba= Barium (mg/kg)
Ca= Cadmium (mg/kg)
Cu= Copper (mg/kg)
Mn= Manganese (mg/kg)
Zn= Zinc (mg/kg)
C10-C36= Total C10-C36 (mg/kg)
B-a-P= Benzo(a)pyrene (mg/kg)
PAH= Total PAHs (mg/kg)

Greater than Class 1 (NEPM 1999 EIL)
Greater than Class 2A (NEPM 1999 HIL E)

N

0 5 10 20 30 40 m

Datum: GDA 94 Zone 52

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DARWIN WATERFRONT PROJECT - STAGE 2A

STAGE 2A DEVELOPMENT PHASE 2 SAMPLING LOCATIONS (OCTOBER 2003)

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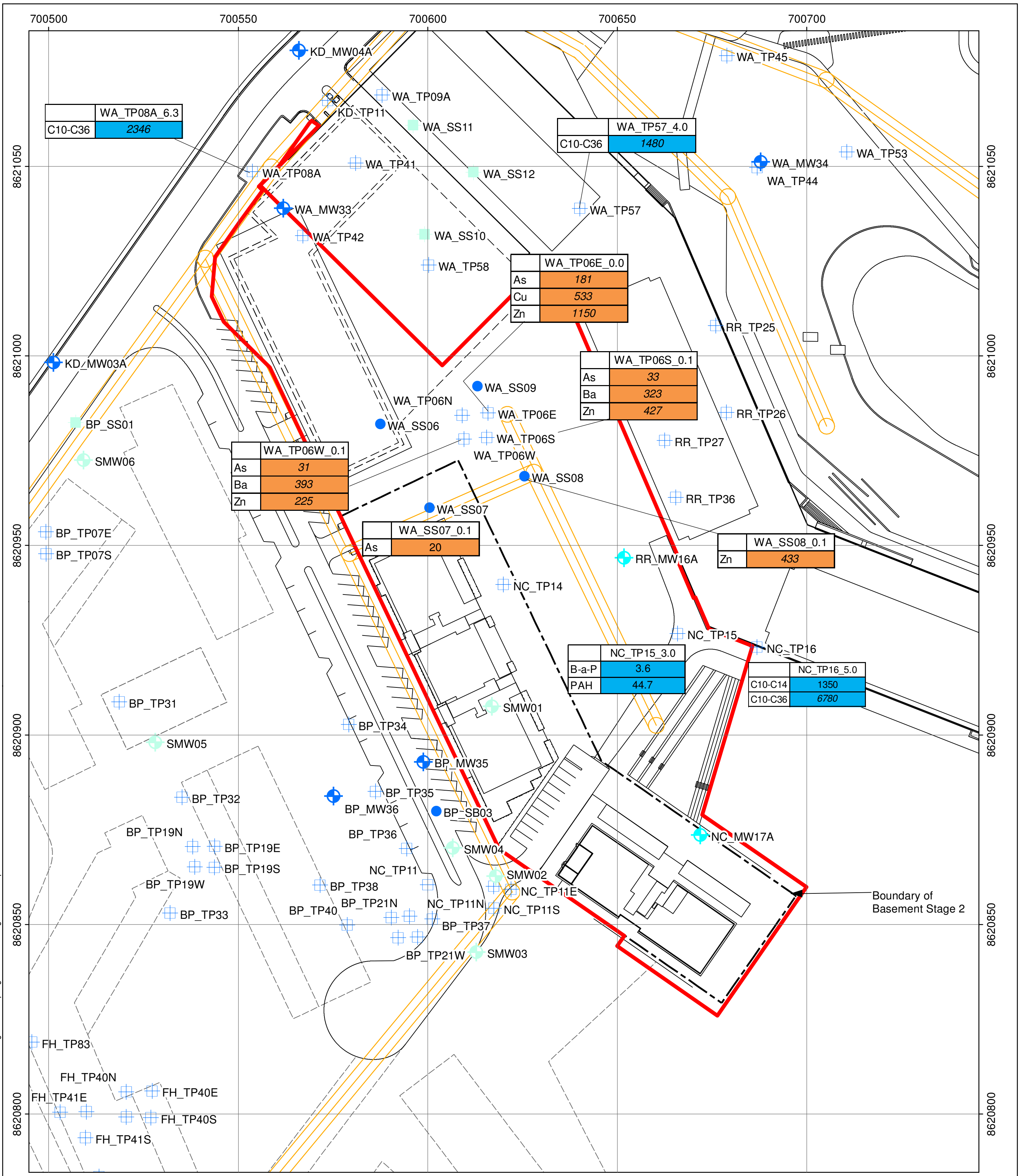
Figure: 5

File: **42213719-2A-Dev-002.mxd** Drawn: **JD** Approved: **BA** Date: **10/07/2014** Rev. **A** A4

Figure 8 Phase 3 soil sampling locations

Source: Figure 6 of URS Stage 2a Residential Validation Report



Legend

- Stage 2A Audit Area
- Subsoil Drain
- Groundwater Monitoring Well
- Shell Monitoring Well
- Nested Well for PSH Delineation
- Phase 2 Groundwater Monitoring Well
- Soil Bore
- Test Pit
- Surface and Shallow Samples

AS= Arsenic (mg/kg)
Ba= Barium (mg/kg)
Ca= Cadmium (mg/kg)
Zn= Zinc (mg/kg)
B-a-P= Benzo(a)pyrene
PAH= Total PAH
C10-C14= C10-C14 (mg/kg)
C10-C36= Total C10-C36 (mg/kg)

- Greater than Class 1 (NEPM 1999 EIL)
- Greater than Class 2A (NEPM 1999 HIL E)

N

0 5 10 20 30 40 m

Datum: GDA 94 Zone 52

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DARWIN WATERFRONT PROJECT - STAGE 2A

STAGE 2A DEVELOPMENT PHASE 3 SAMPLING LOCATIONS (MARCH 2004)

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42213719

Figure: 6

File: 42213719-2A-Dev-003.mxd | Drawn: JD | Approved: BA | Date: 10/07/2014 | Rev. A | A4

Figure 9 Pre-remediation works soil sampling locations

Source: Figure 2 of URS Pre-remediation Site Works, Soil Sampling Report

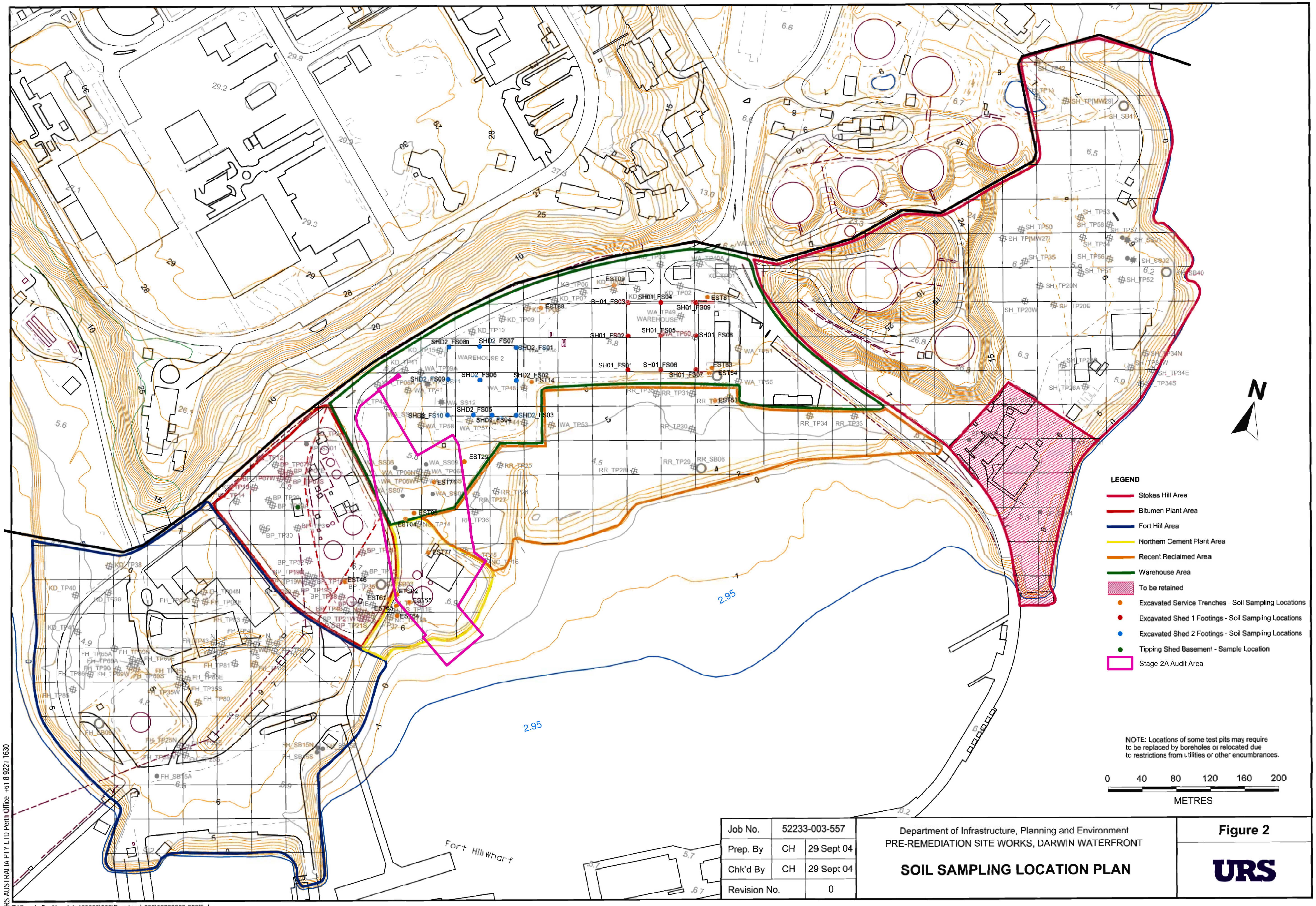

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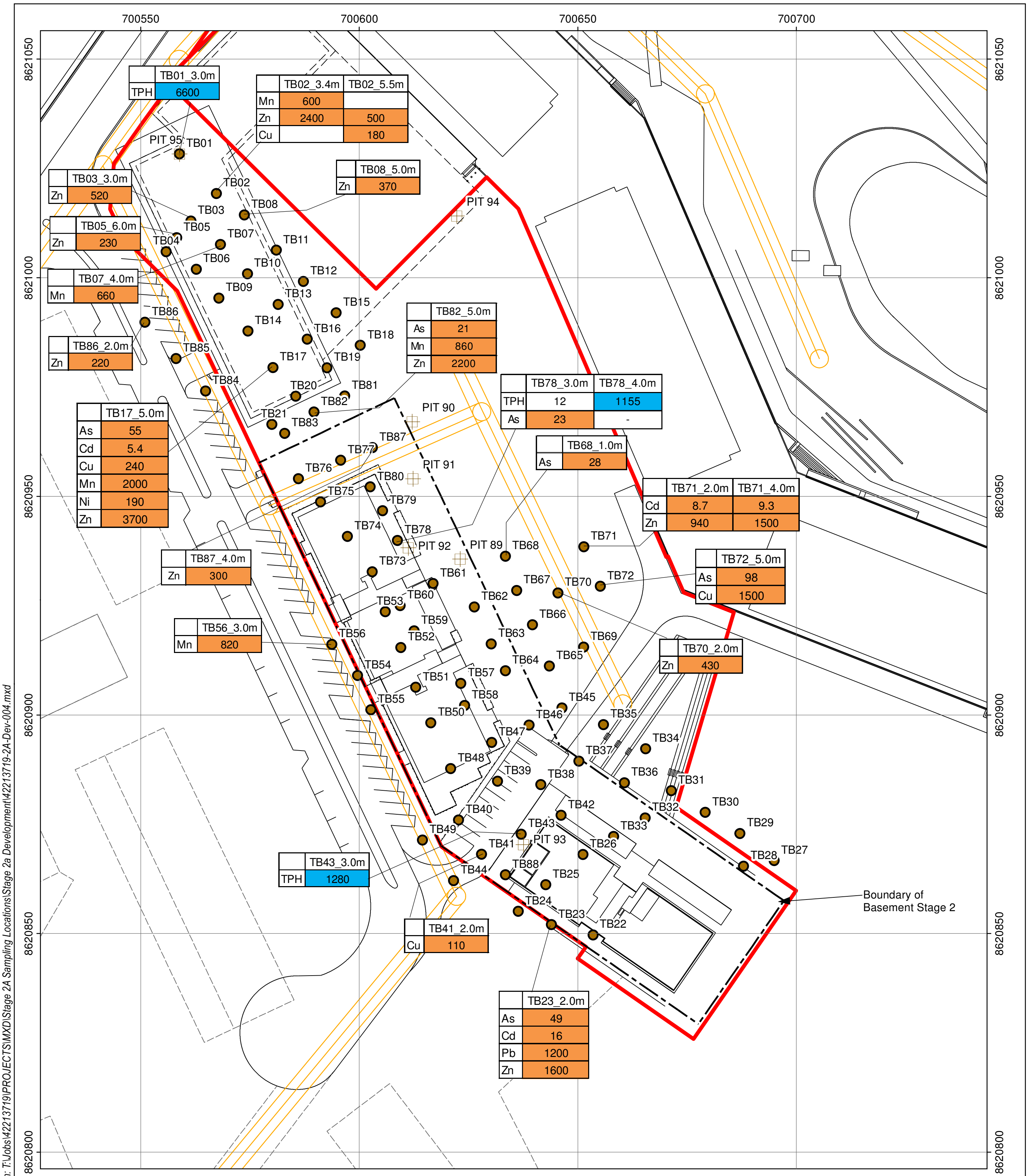
Figure 10 Soil boring and test pitting validation sampling locations – August and November 2009

Source: Figure 2 of URS Stage 2a Residential Validation Report



Legend

- Stage 2A Audit Area
- Subsoil Drain
- EJA_Boundary_Stage2A_Basement_JD_20090826
- Bore Hole (August 2009)
- Test Pit (August 2009)

As= Arsenic (mg/kg)
Ba= Barium (mg/kg)
Cd= Cadmium (mg/kg)
Cu= Copper (mg/kg)
Ni= Nickel (mg/kg)
Mn= Manganese (mg/kg)
Zn= Zinc (mg/kg)
TPH= Total TPH C10 - C36 (mg/kg)

Greater than Class 1 (NEPM 1999 EIL)
Greater than Class 2A (NEPM 1999 HIL E)

N

0 5 10 20 30 40 m

Datum: GDA 94 Zone 52

DARWIN WATERFRONT CORPORATION

DARWIN WATERFRONT PROJECT - STAGE 2A

STAGE 2A DEVELOPMENT AUGUST AND NOVEMBER 2009 SAMPLING LOCATIONS

URS | 42213719 | Figure: **2**

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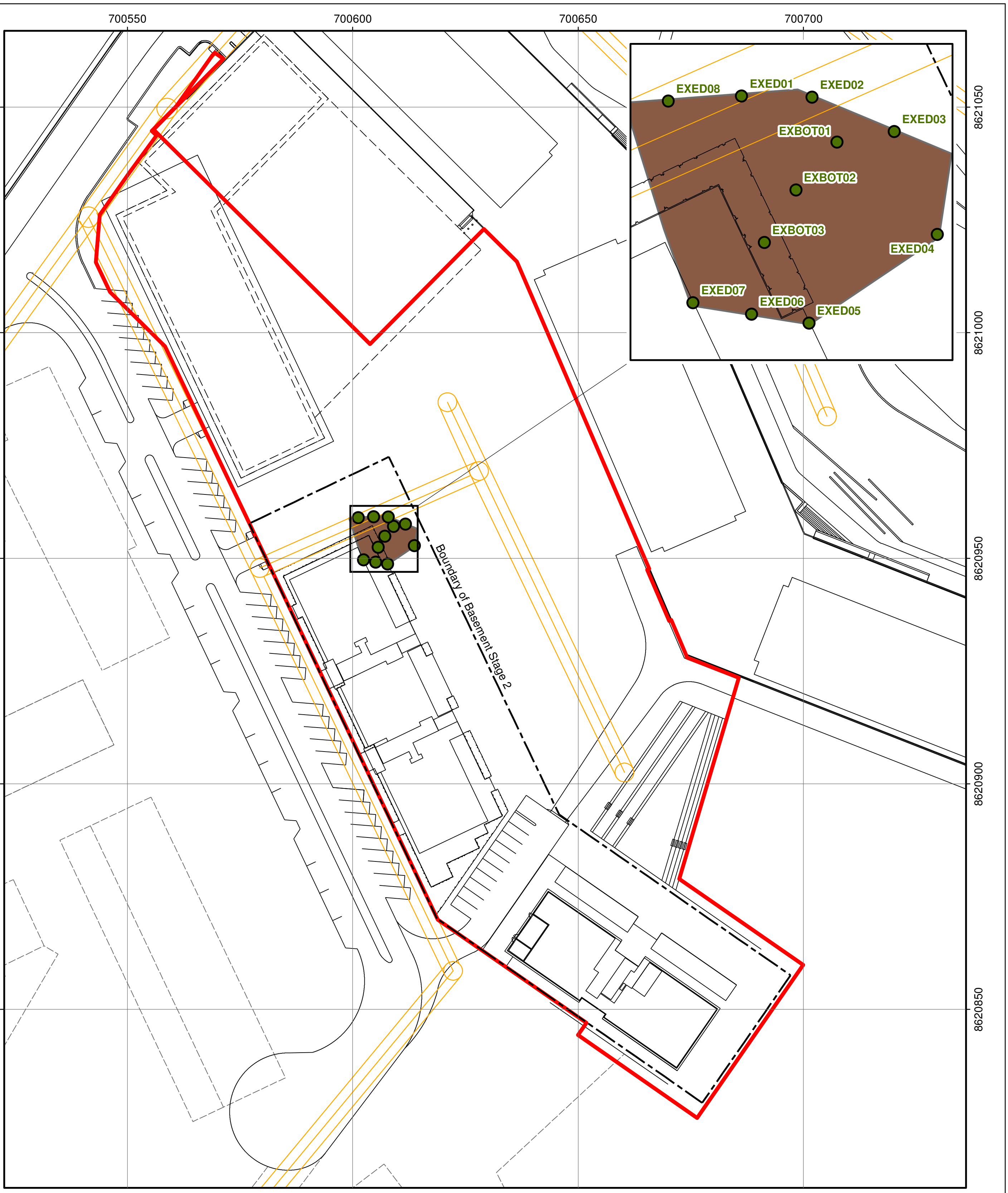
Figure 11 Hydrocarbon impacted excavation validation sampling locations – January 2013

Source: Figure 3 of URS Stage 2a Residential Validation Report



Legend

- Stage 2A Excavation Sample Locations
- Stage 2A Audit Area
- Subsoil Drain
- Hydrocarbon Impacted Soil

N

0 5 10 20 30 40 Meters

Datum: GDA 94 Zone 52

DARWIN WATERFRONT CORPORATION

DARWIN WATERFRONT PROJECT - STAGE 2A

STAGE 2A DEVELOPMENT HYDROCARBON IMPACTED EXCAVATION AND EXCEEDANCES, JANUARY 2013

URS | 42213719 | Figure: **3**

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Appendices

Appendix A – EHA/DNRETA correspondence

Appendix A.1 – Auditor's letter EHA/DNRETA'

Appendix A.2 – EHA/DNRETA's response to the Auditor's letter

Provided on CD

Appendix B – URS reports

Appendix B.1 – Stage 2a Remediation Work Plan

Appendix B.2 – Stage 2a Validation Report

Appendix B.3 – Annual Groundwater Monitoring Summary – March 2013 to June 2013

Appendix B.4 – Annual Groundwater Monitoring Summary – March 2012 to December 2012

Appendix B.5 – Groundwater Monitoring Report – December 2010 to March 2012

Appendix B.6 – Groundwater Monitoring Report 2009 - 2010

Appendix B.7 – Groundwater Monitoring Report February 2009

Appendix B.8 – Groundwater Monitoring Report 2007 – 2008

Appendix B.9 – Annual Groundwater Monitoring Report 2005 – 2006

Appendix B.10 – Annual Groundwater Monitoring Report 2004 - 2005

Appendix B.11 – Subsoil Drain Annual Monitoring Report – December 2011 to October 2012

Appendix B.12 – Stage 2a CUTEP Report

Provided on CD

Appendix C – Construction plans

Provided on CD

Appendix D – Letters for classification of stockpiled excavation material

Provided on CD

Appendix E – Qualitative Risk Assessment (QRA) of TPH

Provided on CD

Appendix F – Appendices D, E and G of the RAP

Appendix F.1 – Appendix D of RAP, Soil Remediation Options Assessment

Appendix F.2 – Appendix E of RAP, Groundwater Remediation Options Assessment

Appendix F.3 – Appendix G1 of RAP, Groundwater Flow and Solute Transport Model

Appendix F.4 – Appendix G2 of RAP, Remediation Drain Design Option

Provided on CD

Appendix G – URS practicability of smear zone removal report

Provided on CD

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