Hazardous Ground Gas Assessment and Management Plan

Site 9

ECOVE

DL_S005964

December 2016

PROJECT NAME	Site 9 - Hazardous Ground Gas Assessment and Management Plan
PROJECT ID	DL3620
DOCUMENT CONTROL NUMBER	S005964
PREPARED FOR	ECOVE
APPROVED FOR RELEASE BY	Aidan Marsh
DISCLAIMER AND COPYRIGHT	This report is subject to the copyright statement located at www.pacific-environment.com © Pacific Environment Operations Pty Ltd ABN 86 127 101 642

DOCUMENT CONTROL

VERSION	DATE	COMMENT	PREPARED BY	REVIEWED BY
Version A	11.10.16	Draft for Auditor comments	Aidan Marsh, Sam Butler, Human Health Risk Assessment – Dr. Lyn Denison	Aidan Marsh
Version B	25.11.16	Auditor comments addressed	Aidan Marsh, Sam Butler, Human Health Risk Assessment – Dr. Lyn Denison	Aidan Marsh
Version C	1.12.16	Final	Aidan Marsh, Sam Butler, Human Health Risk Assessment – Dr. Lyn Denison	Aidan Marsh
Version D	19.12.16	Final with additional Auditor comments addressed	Sam Butler	Aidan Marsh

DLA Environmental Services Pty Ltd: ABN 80 601 661 634

BRISBANE
Level 19, 240 Queen Street
Brisbane, Qld 4000
Ph: +61 7 3004 6400
Ph: +61 7 3004 6400

ADELAIDE
35 Edward Street, Norwood, SA 5067
PO Box 3187, Norwood, SA 5067
Ph: +61 8 8332 0960
Fax: +61 7 3844 5858

PERTH
Level 1, Suite 3
34 Queen Street, Perth, WA 6000
Ph: +61 8 9481 4961
Fax: +61 2 9870 0999

SYDNEY
Suite 1, Level 1, 146 Arthur Street

North Sydney, NSW 2060
Ph: +61 2 9870 0900
Fax: +61 2 9870 0999

DLA ENVIRONMENTAL SERVICES
Unit 3, 38 Leighton Place
Hornsby, NSW 2077
Ph: +61 2 9476 1765
Fax: +61 2 9476 1557

42B Church St
Maitland NSW 2320
Ph: +61 2 4933 0001

MELBOURNE
Level 17, 31 Queen Street
Melbourne, Vic 3000
Ph: +61 3 9036 2637
Fax: +61 2 9870 0999

DISCLAIMER

DLA Environmental Services (DLA) acts in all professional matters as a faithful advisor to the Client and exercises all reasonable skill and care in the provision of its professional services. Reports are commissioned by and prepared for the exclusive use of the Client. They are subject to and issued in accordance with the agreement between the Client and DLA. DLA is not responsible for any liability and accepts no responsibility whatsoever arising from the misapplication or misinterpretation by third parties of the contents of its reports. Reports cannot be copied or reproduced in whole or part for any purpose without the prior written agreement of DLA.

The conclusions presented in this report are relevant to the present condition of the Site and the state of legislation currently enacted as at the date of this report. DLA do not make any representation or warranty that the conclusions in this report will be applicable in the future as there may be changes in the condition of the Site, applicable legislation or other factors that would affect the conclusions contained in this report.

List of Acronyms/Abbreviations

AHD	Australian Height Datum
bgl	below ground level
BH	Borehole
BPEM	Best Practice Environmental Management
BS	British Standard
BTEX	Benzene, Toluene, Ethylbenzene, Xylene
CIRIA	Construction Industry Research and Information Association
CH_4	Methane
CO_2	Carbon Dioxide
CO	Carbon Monoxide
CQA	Construction Quality Assurance
CS	Characteristic Gas Situation
CSM	Conceptual Site Model
CFD	Computational Fluid Dynamics
DEC	Department of Environment and Conservation
DLA	David Lane and Associates
DP	Deposited Plan
DPE	Department of Planning and Environment
EMP	Environmental Management Plan
EPA	Environmental Protection Authority
FOD	First Order Decay
GSV	Gas Screening Value
HSE	Health & Safety Executive (UK)
H_2S	Hydrogen Sulphide
LandGEM	US EPA Landfill Gas Emissions Model
LB	Liquid Boot
LEL	Lower Explosive Limit
LFG	Landfill Gas
LFGMP	Landfill Gas Management Plan
LOR	Limit of Reporting
LTEL	Long Term Exposure Limit
mb	Millibar
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NIOHS	National Institute for Occupational Health and Safety
NMOC	Non-methane Organic Compounds
NSW	New South Wales
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyls
PID	Photoionisation Detector
QA/QC	Quality Assurance / Quality Control
SEPP	State Environment Protection Policy
STEL	Short Term Exposure Limit
SWL	Standing Water Level
TOC	Total Organic Compounds
TPH	Total Petroleum Hydrocarbons
TRH	Total Recoverable Hydrocarbons
TSS	Total Suspended Solids
UEL	Upper Explosive Limit
USEPA	United States Environment Protection Agency
VOC	Volatile Organic Compound
v/v	Volume/Volume (in atmospheric air)

EXECUTIVE SUMMARY

DLA Environmental Services (DLA) was engaged by ECOVE to develop a Hazardous Ground Gas Management Plan (HGGMP) for Site 9, Sydney Olympic Development (the Site) based upon a meeting held on 24 August 2016 and the correspondence with NSW EPA, stating:

'The EPA further recommends that the Department of Planning and Environment (DPE) requires a separate risk analysis and assessment that considers the details of the gas and leachate management systems and evaluates both probabilities for the systems to fail and consequences if the systems were to fail (in that context, DPE may consider the applicability of State Environmental Planning Policy 33 (SEPP 33) and relevant documents listed In Appendix 1 of this SEPP; we also refer DPE to the document entitled "EPA Guidelines for the Assessment and Management of Sites Impacted by Hazardous Ground Gases 2012" (http://www.epa.nsw.gov.au/resources/clm/120932GroundGas.pdf).

The Site is proposed to undergo redevelopment to recreational use on the ground floor with high density residential and offices on upper levels. This development scenario is consistent with the definition of 'Residential with minimal opportunities for soil access provided in Schedule B7 of the NEPM (NEPC, 2013).

This report presents the design basis to ensure that an appropriate level of protection measures are provisioned during and post construction for the safety of personnel, on and off-Site. The report objectives are as follows:

- Provide background information on health and safety aspects associated with the planned development and how this relates to the design.
- Undertake risk assessments to inform the design basis of the ground gas protection measures and associated calculations that will provide an acceptable level of protection against the hazards associated with ground gas.
- Provide a set of concept design drawings that can be incorporated into the ECOVE overall design package.

Based on the information provided, the area of investigation is known to have received waste and fill material as part of the Golf Driving Range landfill. The Site is located on the boundary of the Golf Driving Range landfill and encompasses both fill material and natural soils, with an existing cap and contain approach for the landfill.

Risk from leachate was discounted as leachate system plans made available did not show any infrastructure installed on Site. In addition, to this Sydney Olympic Park Authority Site management plans describe the leachate pipework as being installed in the base of the cells at least five to eight metres below ground level. The majority of the proposed ground slab will not require excavation below the current ground level. Where excavation for the building slab profile is required, it will extend up to approximately one metre below ground level in places. Services such as the lift shafts are expected to be deeper (~ 3.5 metres below ground level) but not expected to intersect the groundwater at approximately five metres deep.

An initial conceptual site model was developed and considered the primary source of ground gas was landfill gas derived from bacterial decomposition of the buried putrescible (biodegradable) waste in the former landfill site. Methane present in the landfill gas mixture poses an acute risk to humans and this is compounded by the fact it is odourless, colourless and lighter than air which means the concentration of the gas can build up to the explosive limits without any indication of its presence. Other gases are present in the landfill gas mix can be hazardous at lower concentrations.

The pathway for potential gas movement was identified as directly through the soil or via preferential pathways such as structural piles and services. It was considered gas could potentially move via advection or diffusion or a combination of both to human receptors based in proposed building. The landfill waste is separated from the base of the building by over two metres of compacted clay rich soil so attenuation of gases would occur through this layer.

LFG was recorded in boreholes and landfill gas generation modelling reported LFG is in an active stage of generation, albeit in the final stages and would continue for many years. The modelling has estimated, that from the overall waste mass, the generation rate of methane was is than 100 m^3/h. A credible pathway exists from the landfill to base of the building. The fill material on Site and the continuity of the relatively higher permeability lithology could potentially create a situation where LFG could move through soil and/or along preferential pathways into voids and accumulate to unacceptable levels if no mitigation measures are taken.

On-site monitoring from boreholes was undertaken to assess the ground gas status and help select the most appropriate mitigation measures using a NSW EPA approved method. Methane was recorded up to approximately 70 %v/v in the soil which is above NSW trigger levels for further investigation and remedial action for development. A qualitative risk assessment (termed Level 1 in the NSW EPA 2012 Guidelines) undertaken considered '*very high risk*' due to the presence of methane in the ground and the potential ignition sources inside the building. This ranking was due to the identified likelihood and severe consequences of an explosive incident occurring. However, with implementation of the proposed mitigation measures residual risk could be reduced to an acceptable '*low risk*'.

A semi-quantitative Level 2 Risk Analysis was undertaken using borehole monitoring over three occasions, methane ranged from 0.3 %v/v on BH1 (8 February) to 70.8 %v/v on BH4 (5 February).

Methane recorded with the GA5000 on 6 September on BH6 was 48.3 %v/v and methane concentration by chemical analysis and a suma canister submitted to the laboratory was recorded as 63 %v/v.

Gas screening values were calculated for each borehole under consideration due to limited monitoring data, the calculation was carried out conservatively for methane and carbon dioxide with the worst-case monitoring values adopted at each monitoring location. The calculation was performed and a range of 0.0 (very low risk) to 5.17 (Moderate to High Risk) was recorded.

Based upon the findings of the Level 2 Risk Analysis, a Characteristic Gas Situation of 4 (*Moderate to High Risk)* was recorded for the Site. The ground floor level usage of the Site is considered to align with a '*Standard commercial buildings (offices, etc.)*' as described within Table 7 of the NSW EPA Guidelines (2012).

A Level three methane intrusion and fault tree risk analysis was undertaken for the Site. The methodology developed and applied by DLA to the assessment of LFG risks is based on the 'Fault Tree Analysis' described in CIRIA 152.

Based upon Darcy's Law, a flow rate of 1.1 m^3/hr over the Site area was calculated and based upon the Peckson method, a flow rate of 2.5 m^3/hr over the Site area was calculated. Using these outputs two risk scenarios were modelled for the Site considering both methods:

Scenario A – Construction including the installation of a membrane barrier
Scenario B – Construction without the installation of a membrane barrier or failure of the methane barrier.

A 99.4% reduction in potential methane entry through the building slab by the installation of a methane barrier is achieved. This factor is based on the permeability of the proposed Liquid Boot membrane is less than 40 ml/day/m^2. The probability of an explosion due to build-up of methane if the methane barrier is installed was estimated to be between 3.43×10^{-61} and 4.73×10^{-54} by the use of the Darcy and Peckson calculation methodologies. It is therefore considered the probability of explosion due to build-up of methane in Scenario A is within an allowable tolerable risk range.

The probability explosion due to build-up of methane without the installation of a methane barrier is considered to be between 9.37×10^{-14} and 1.29×10^{-6} by the use of the Darcy and Peckson calculation methodologies. Based upon the CIRIA Report 152, a tolerable level of risk is considered to be between 10^{-6} and 10^{-7}. It is therefore considered that the probability explosion due to build-up of methane in Scenario B is on the threshold of a tolerable risk.

The outcome of the Fault Tree analysis is termed quantitative, however DLA considers some of the input steps to ascertain the probability of the event occurring are somewhat subjective. CIRIA 152 also recommend that caution should be given where numerical values are used and that professional judgement is employed in the selection if mitigating engineering measures

A preliminary vapour intrusion screening assessment has been undertaken to provide an indication as to whether the measured soil gas concentrations that exceed the HSLs have the potential to impact on the health of the occupants of the proposed building. The screening assessment has also back-calculated the sub-slab concentrations that would be required to ensure that the intrusion of vapours into the ground floor space would not lead to unacceptable risks to the health of the building occupants. For benzene and vinyl chloride for the liner failure scenario the air quality guidelines are predicted to be exceeded. All other contaminants are well below the screening levels and can be considered, based on limited sampling, unlikely to pose a vapour intrusion risk.

The findings of the preliminary screening vapour intrusion assessment for these gases within the landfill gas indicate that with the liner intact the risk to occupants of the ground floor of the development for the commercial scenario are all within the acceptable risk criteria established by NSW EPA (2012). For the residential scenario, the indicative risk potentially posed by exposure to benzene is at the acceptable risk level for carcinogenic risk. The risk can be brought within acceptable risk levels by increasing the building ventilation rate from 0.5 air changes per hour to 1 air change per hour. The proposed use for the ground floor of the development is commercial use and a fitness centre and the potential risks for these scenarios are within acceptable risk criteria.
In the event of liner failure, the acceptable risk criteria are exceeded. Management actions such as increasing the air change rate within the building or establishing target sub slab contaminant concentrations should be considered to reduce the risk within acceptable levels.

The mitigation system will combine the following measures to exceed the gas protection score of five:

- Implementation of a sub-slab active abstraction system – extraction from a true air filled void 50 mm thick (2.5)
- Reinforced concrete cast in situ-slab with minimal service penetrations and water bars around all penetrations and at joints (1.5)
- Proprietary gas-resistant membrane to reasonable levels of workmanship under independent construction quality assurance with integrity testing and independent validation (2)
- Intermittent Hand held monitoring (0.5)

In addition to these measures and to act as redundancy the following was described:

- A sub-slab pressure relief system.
- Implementation of indoor air screening and monitoring.
- Implementation of post construction monitoring program (Landfill Gas Management Plan (LFGMP)).

A monitoring program has been developed to ensure that potential build-up of methane and other gases in the sub-slab void are identified. The target concentration of methane of 2.5 %v/v of methane and 100 parts per million of volatile organic compounds in the void was selected to ensure a margin of safety i.e. the optimum sub-slab concentration required to ensure that even with liner failure that the indoor risk levels were maintained within acceptable levels. The active extraction system will be run if methane concentrations exceed 2.5 %v/v.

Validation of the gas vapour barrier installation following QA/QC requirements are required to be implemented as part of the verification process for the LFG mitigation system. Following completion of the construction works the Auditor will review the completed Validation Report that shall comprehensively compile details of the construction works and remedial validation works.

The validation process is completed in four ways:

- Construction quality assurance of gas vapour barrier
- Pre-occupancy checks inside the building
- Indoor air quality monitoring
- Validation reporting

By using these four validation methods the physical installation is ensured as well as by demonstrating vapour is not venting into the building by stringent air quality testing. Measurement of sub-slab concentrations of gases does not form part of the validation process as the successful implementation of the barrier cannot be measured by gas accumulation underneath it.

TABLE OF CONTENTS

List of Figures

List of Tables

APPENDICES

1.0 INTRODUCTION

1.1 General

DLA Environmental Services (DLA) was engaged by ECOVE to develop a Hazardous Ground Gas and Management Plan (HGGMP) for Site 9, Sydney Olympic Development (the Site).

The report has been prepared utilising information obtained as part of the assessment process, from previous assessment reports and from experience, knowledge, and current industry practice in the investigation of similar Sites.

1.2 Objectives

This design basis report comprises part of the project design for the Site 9 development. It presents the design basis to ensure that an appropriate level of protection measures is provisioned during and post construction for the safety of personnel, on and off-Site.

These design parameters relate to risk from landfill gas (LFG) derived from the decomposition of organic wastes deposited at the Site (i.e. predominately the acute risk of explosion from an accumulation of LFG) and compliance with relevant regulatory requirements or industry guidance.

The report objectives are as follows:

- Provide background information on health and safety aspects associated with the planned development and how this relates to the design.
- Undertake risk assessments to inform the design basis of the LFG protection measures and associated calculations that will provide an acceptable level of protection against the hazards associated with LFG.
- Provide a set of concept design drawings that can be incorporated into the ECOVE overall design package.

1.3 Scope of work

To achieve these objectives, DLA carried out the following works:

- Desktop study including a review of the available current and historical information, previous monitoring data and investigations.
- Development and documentation of a Conceptual Site Model (CSM) based on the available information.

- Data assessment and reporting including comparison of LFG concentrations against relevant NSW Environmental Protection Agency (EPA) made or endorsed guideline investigation levels.
- A risk assessment in accordance with NSW EPA 2012 guidelines.
- Development of a summary of LFG risk assessment to assess whether the Site is suitable, from a LFG perspective, for its proposed land use.
- Development of a design of Site gas mitigation measures for ECOVE review and suitable to use for tendering purposes.

1.4 Guidance and information sources

The design is based on First Order Principals and a standard design convention, and has been developed in accordance with:

- British Standard 'Code of Practice for protection of below ground structures against water from the ground', BS: 8102, (2009).
- Construction Industry Research and Information Association (CIRIA), 'Assessing Risk Posed by Hazardous Ground Gases to Buildings', Report No. (C665, 2007) and C735 (2014) '*Good practice on the testing and verification of protection systems for buildings against hazardous ground gases'*.
- Department of the Environment Waste Management Paper 26B: Landfill Design, Construction and Operational Practice (1995).
- DLA Environmental Supplementary Site Assessment, Site 9 - Sydney Olympic Park, corner of Sarah Durack Avenue and Olympic Boulevard, Sydney Olympic Park, NSW 2127 (2016).
- Douglas Partners Pty Ltd Report on Waste Classification Assessment, Site 9, cnr Sarah Durack & Olympic Boulevard Sydney Olympic Park, NSW (2003).
- NEPC National Environment Protection (Assessment of Site Contamination) Measure (No.1) (2013).
- NIOSH Documentation for Immediately Dangerous to Life or Health Concentrations (1994).
- NSW DEC Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales (2007).
- NSW EPA Environmental Guidelines: Assessment, Management and Classification of Waste and Liquid Waste (1999).
- NSW EPA Guidelines for the Assessment and Management of Sites Impacted Hazardous Ground Gases (2012).
- NSW EPA Environmental Guidelines, Solid waste landfills, second edition (2016).
- Safe Work Australia, Workplace Exposure Standards for Airborne Contaminants (December, 2011).
- Sydney Olympic Park Authority DRG No. 052-G-G-0001 REV. E
- Sydney Olympic Park Authority *Remediated Lands Management Plan* (January, 2009)
- UK EA Guidance on the management of landfill gas (2004).
- URS Environmental and Geotechnical Investigation – Site 9, Sydney Olympic Park (2002).
- URS Indicative Remediation Action Plan, Site 9, Sydney Olympic Park (2002).

- VIC EPA Siting, design, operation and rehabilitation of landfills, Best Practice Environmental Management (2015).
- Wilson, S. Card, G & Haines, S. *Ground Gas Handbook*. Whittles Publishing, (2009).

A full set of references is presented in Section 15 of this Report.

2.0 SITE DESCRIPTION

2.1 Site identification

The Site identification details are summarised in Table 1:

Table 1 - Site identification summary

ITEMS	DETAILS
Site Name	Site 9 – Sydney Olympic Park
Address	Corner Sarah Durack Ave and Olympic Boulevard
Local Government Authority	Auburn City Council
Lot and Deposited Plan (DP)	Part Lot 2004 DP 1192085 - Refer to **Appendix A – Figure 2**
Development Controls	Auburn Local Environmental Plan 2010
Site Zoning	Major Development – State Environmental Planning Policy (SEPP) 2005
Current Use (NEPM 2013 Table 1A(1)	Carpark
Proposed Use (NEPM 2013 Table 1A(1)	Commercial / Industrial & Residential B
Site Area (approx.)	3,186 m^2 (0.31 ha) - Refer to **Appendix D – Figure 7**
Locality Map	Refer to **Appendix A, Figure 1** – Site Location

NEPM: *National Environment Protection (Assessment of Site Contamination) Measure 1999* as amended published by National Environment Protection Council (NEPC).

2.2 Proposed development

The design approach for the building comprises of four principal parts including the ground level interface, parking podium, SOPA's office space and the residential tower. The ground floor level steps down the Site over three levels to relate to the existing street interface. The ground floor comprises of a North and South Wing which is split by a 'Through Site Link' between the two Wings. Floor levels proposed will generally comprise of the following main usage elements and users:

Table 2 – Main usage and expected users

Element	Area	Expected Users of Area
Ground Floor – Northern Wing		
Retail	North Wing	Residents, general members of the public, retail employees and maintenance workers
Retail / Club	North Wing	Residents, general members of the public, retail employees and maintenance workers
Retail Grease Arrestor	North Wing	Retail workers and maintenance workers

Element	Area	Expected Users of Area
Retail Waste Room	North Wing	Retail workers and maintenance workers
Commercial Waste Room	North Wing	Commercial workers and maintenance workers
Carpark Entrance	North Wing	All Site users
Substation / Plant Room	North Wing	Maintenance workers
Gas Site Regulator	North Wing	Maintenance workers
Booster Valve	North Wing	Maintenance workers
Ground Floor – Southern Wing		
Residential Lobby Entrance	South Wing	Residents and maintenance workers
Fire Control Room	South Wing	Maintenance workers
Mail Room	South Wing	Residents and maintenance workers
Residential Bike Storage	South Wing	Residents, maintenance workers
Fan Room	South Wing	Maintenance workers
Residential Loading	South Wing	Residents and maintenance workers
Cold Water Meter Room	South Wing	Maintenance workers
General Waste Room	South Wing	Maintenance workers
Risers	South Wing	Maintenance workers
Pump Room	South Wing	Maintenance workers
Water Storage Tank	South Wing	Maintenance workers
Retail / Club South Wing	South Wing	Residents, retail/club workers and maintenance workers
Retail / Club Carpark Stair	South Wing	Residents, retail/club workers and maintenance workers
Lift Shafts	South Wing	Residents, workers and maintenance workers
Level 1 – Level 4		
Residential Parking	North and South Wing	Residents and maintenance workers
Bike Storage		Residents and maintenance workers
Level 5 – Level 7		
Commercial	North Wing	Commercial workers and maintenance workers
Roof landscaping	South Wing	Residents and maintenance workers
Residential Units	South Wing	Residents and maintenance workers
Level 7 – Level 36		
Residential Units	South Wing	Residents and maintenance workers

This development scenario is consistent with the definition of 'Residential with minimal opportunities for soil access' provided in Schedule B7 of the NEPM (NEPC, 2013).

2.3 Boundaries and surrounding land use

The boundary and surrounding landscape features of the Site are summarised in Table 3:

Table 3 - Boundaries and Surrounding Land Use

DIRECTION	DETAILS
North	Sarah Durack Avenue
East	P3 Carpark
South	Tom Wills Oval and Learning Life Centre
West	Olympic Boulevard

2.4 Site geology and soils

Review of the Geological Survey map of NSW Sydney 1:100,000 Geological Series Sheet 9130 (Edition 1) indicates that the Site is underlain by Quaternary sands, silty clays and man-made filling.

Review of the Sydney 1:1 000 000 Soil Map (Sheet 9130) indicates that the Site is underlain by the Blacktown Landscape Group. This is characterised by gently undulating rises with local relief to 30m and slopes usually <5%. Broad rounded crests and ridges with gently inclined slopes. Soils comprise shallow to moderately deep red and brown podzolic soils on crests, upper slopes and well drained areas, and deep yellow podzolic soils and soloths on lower slopes and in areas of poor drainage. Limitations of the soils of the Blacktown landscape group include moderately reactive highly plastic subsoil, low soil fertility and poor soil drainage.

The majority of the Site (with the exception of the north-western corner) comprises of landfill with existing cap and contain measures. Based on Site observations, the containment measures consist of clay capping at the surface.

Previous investigations (DP, 2003) indicate that landfilled material comprises decomposing putrescible waste including organic fibres, wood, metals, plastic and soils. This material was typically overlain by fill material consisting of clay and gravel to depths between 2m and 3m below ground level (bgl).

2.5 Site topography

The Site is relatively flat with a gentle slope down towards the south east. The elevation of the Site ranges from 17 m Australian Height Datum (AHD) in the north-west corner to 14 m AHD in the south-east corner.

2.6 Hydrology and hydrogeology

The Site surface area is covered with bitumen, asphalt concrete over lying compacted clay. Rainfall falling on sealed surfaces is expected to flow into the underground stormwater drainage system. Approximately 25 % of the Site is unsealed and situated on permeable soils. As such, rainfall is expected to infiltrate the unsealed surfaces of the Site, excess rainfall would be expected to flow toward the stormwater drainage system.

A search of the Department of Natural Resources groundwater database was also performed to identify wells in the vicinity of the Site. The search results identified thirteen registered groundwater bores located within 1km radius of the Site, the information of which is presented Table 4:

Table 4 - Regional Groundwater Summary Data

BORE ID	DISTANCE FROM SITE (m)	PURPOSE	DEPTH (m)	STANDING WATER LEVEL (m)	SALINITY (µS/cm)
GW111341	N – 365m	Monitoring	8.00	No Data	No Data
GW111342	N – 370m	Monitoring	8.00	No Data	No Data
GW111343	N – 360m	Monitoring	8.00	No Data	No Data
GW102550	W – 700m	Monitoring	4.00	1.80	No Data
GW102553	W – 935m	Monitoring	4.00	1.83	No Data
GW102555	W – 850m	Monitoring	4.00	1.83	No Data
GW102556	W – 915m	Monitoring	4.00	1.83	No Data
GW102557	W – 910m	Monitoring	4.00	No Data	No Data
GW102558	W – 745m	Monitoring	4.00	1.83	No Data
GW102559	W – 750m	Monitoring	4.00	1.83	No Data
GW102561	W – 600m	Monitoring	4.00	1.83	No Data
GW102562	W – 485m	Monitoring	4.0	1.83	No Data
GW102645	S – 800m	Monitoring	10.00	No Data	No Data

It is expected that the localised hydraulic gradient at the site, in particular with the landfilled section, will be slightly negative with general flow towards the centre of the landfill in order to manage the leachate flow.

Eight boreholes were advanced on Site (BH1 to BH8), refer to **Appendix A – Figure 2**. Groundwater levels on Site are approximately 5 mbgl.

2.7 Site meteorology

The Bureau of Meteorology NSW gives the average annual rainfall for the Sydney Olympic Park area at 884.0mm, with an annual daytime temperature range of 13.9° to 28.4°C, and an annual average temperature of 23.6°C.

2.8 Site history summary

The area of investigation is known to have received waste and fill material as part of the Golf Driving Range landfill. Unauthorised and uncontrolled dumping of over nine million cubic metres of domestic, commercial and industrial wastes around Homebush Bay was commonplace from the 1950s to the 1980s. Remediation of the Homebush Bay Site commenced in 1994, in partial fulfilment of a commitment to a "green" Olympic Games for September, 2000. The landfill remediation strategy focused on the consolidation and isolation of wastes and on the management of surface waters and leachates emanating from them. Waste was relocated to large containment mounds (including the Golf Driving Range landfill), which have since been capped and re-landscaped as shown in **Appendix A - Figure 3**.

The Site is located on the boundary of the Golf Driving Range landfill and encompasses both fill material and natural soils, with an existing cap and contain approach for the landfill. The Site is bound by the 'P3' car park to the North which is known to have significant concentrations of landfill gas. It is understood that the landfill design in Golf range area of the Site includes the excavation of a landfill cell that was subsequently backfilled with unsuitable materials and capped with clay fill materials. It is understood that an inward hydraulic gradient is used to prevent the migration of contaminants off-site. Landfill leachate is collected via a gravity drain which drains into a leachate rising main. Although there is no leachate collection and transfer infrastructure located on the development site, the proposed design for the Site is not expected to compromise the Golf Driving Range leachate management system. The known extent of the Golf Driving Range Landfill was obtained from the Sydney Olympic Park Authority and is presented in **Appendix A - Figure 4 and Figure 5**.

Previous contamination investigations have identified elevated concentrations of Benzene, Toluene, Ethylbenzene and Xylenes (BTEX), naphthalene and Total Petroleum Hydrocarbons (TPH) on the Site (Section 3.0).

The Site was previously redeveloped as part of the wider Sydney Olympic Park area and has been used as an open-air car park since approximately 2000.

3.0 SUMMARY OF PREVIOUS INVESTIGATIONS

3.1 Environmental and geotechnical investigation, site 9 Sydney Olympic Park (URS, November, 2002)

A summary of investigation is provided below:

- Six boreholes (BH111 to BH116) were drilled across the Site with samples collected for contamination and geotechnical purposes. A monitoring well was installed within borehole BH112.
- Landfill odours were noted within all boreholes, predominately in the fill material and slightly extending into the residual clay.
- Depth to bedrock varied between 5.7m (BH115) and 9.3m (BH111) bgl.
- Groundwater was encountered at 5.5m bgl in boreholes BH111 and BH112, and at 6.0m bgl in borehole BH116.
- TPH (C_{10}-C_{36}) was reported at concentrations that exceeded the adopted assessment criteria in soil samples collected from the Site, with a maximum concentration of 15,318mg/kg in borehole BH112 at a depth of 6.0m bgl. Ethylbenzene was reported to exceed the adopted assessment criteria in soil collected from borehole BH111 at a depth of 7.0m bgl with a concentration of 78.8mg/kg. All other samples contained contaminant concentrations below the adopted assessment criteria or the laboratory limit of reporting (LOR).
- Heavy metals (chromium, copper, zinc and mercury) and TPH were reported at concentrations exceeding the adopted trigger values in a groundwater sample collected from BH112. All other contaminants reported concentrations below the laboratory LOR.

DLA notes that BH111 and BH112 are outside the current scope of assessment.

3.2 Remediation plan (URS, December 2002)

A summary of the remediation plan is provided below:

- Contaminated soil identified during previous investigations required remediation. The preferred remediation method was excavation and off-site removal to a licensed landfill.
- Following excavation and off-site disposal of the contaminated soils, the RAP suggested that a layer of clean material may be required for any unsealed areas (landscaped) of the Site to mitigate potential exposure of future Site users to the underlying impacted soils.
- The recommended remediation plan was not implemented on the Site as the proposed development of the site at the time did not occur.

3.3 Waste classification assessment (Douglas Partners, May 2003)

A summary of the assessment is provided below:

- A waste classification assessment was conducted facilitate off-site disposal of soil excavated from the Site as part of the proposed redevelopment. Twelve boreholes (BH1 to BH12) were drilled to a maximum depth of 6.5m bgl or refusal, whichever was shallower.
- Sample BH7 (5.0m) reported heavy metals and organic contaminants (BTEX, naphthalene and TPH) at concentrations exceeding the adopted assessment criteria. This contamination was attributed to heavy industrial oily liquid waste or similar substances within the landfill.
- Fragments of asbestos cement sheeting were observed in sample BH5 (2.9-4.0m), however the extent of asbestos impacted soil was not assessed.
- The material to be excavated from the Site was classified as solid waste and hazardous waste in accordance with NSW EPA (1999) *Assessment, Classification and Management of Liquid and Non-Liquid Wastes*. The solid waste classification applied to all material greater than 0.5m bgl, with the exception of material from borehole BH7 at depths between 4.5m and 6m bgl, which was classified as hazardous waste. The asphalt, topsoil and road base (present across the Site to depths of 0.5m bgl) were classified as inert waste.

Borehole locations are presented in **Appendix A – Figure 2**.

3.4 Supplementary site investigation (DLA Environmental, February 2016)

A summary of the investigation is provided below:

- Eight boreholes (BH1 to BH8) were drilled in targeted locations to provide coverage of the Site area.
- Total Polycyclic Aromatic Hydrocarbons (PAH), benzo(a)pyrene and naphthalene were detected in soil samples collected from the landfill material, however concentrations were reported to be below the adopted assessment criteria.
- Total Recoverable Hydrocarbons (TRH) F2 and F3 were detected in soil samples collected from the landfill and fill materials located on-site, however concentrations were reported to be below the adopted assessment criteria.
- Asbestos fibres were identified in borehole BH7 at a depth of approximately 4.0m bgl. The asbestos fibres were expected to be contained at depth and therefore not considered to be a risk to human health.

- Groundwater monitoring wells were installed within boreholes BH1, BH4 and BH8. Methane, phenols, ammonia, total suspended solids (TSS), total organic compounds (TOC) and nitrogen in groundwater were reported at concentrations above the laboratory LOR.
- Heavy metals in groundwater were reported to exceed the adopted assessment criteria in all three monitoring wells. The reported concentrations were not considered a risk to human or ecological health risk within the urbanised area of the Site.
- A Gas Screening Values assessment undertaken concluded that the site exhibited a 'High Risk' due to the identified likelihood and severe consequences of an explosive incident occurring.
- A Characteristic Gas Situation (CS) of four (4) (Moderate to High Risk) was applied to the Site. In accordance with guideline requirements, gas protection measures for the Site are therefore required.

Site layout and bore locations are included in **Appendix A - Figure 2**.

3.5 Sydney Olympic Park Authority – remediated lands management plan (2009)

Section 3.5 Golf Driving Range (landfills) extract from Sydney Olympic Park Authority's (SOPA) – *Remediated Lands Management Plan* (2009) was made available for DLA's review in September 2016.

The report extract describes the Site history and management of LFG and leachate in the Golf Driving Range (GDR) area (see **Appendix B**). The relevant findings of this report are summarised below:

- The GDR landfill was formed by consolidation of three separate former landfills (western, northern and southern landfills).
- Final remediation was completed in 1999 and a Site Audit Statement issued on 14 December ref. WRR85.
- The landfilling 'precinct' covers approximately 42 ha and was used for uncontrolled deposition of municipal waste from 1965 to 1982.
- The total volume of waste is not known as no records were presented in the report.
- Between 1991 and 1993, approximately 130,000 cubic metres of waste was relocated from the western (Site 9 area) and southern landfills to the northern landfill. A mound was made approximately 15 m that formed the new GDR landfill. The extents of the GDR landfill can be seen in **Appendix A, Figure 5**.
- The former western and southern landfill pits were validated and tested to ensure residual contamination was removed, prior to backfilling with 'clean imported fill'.
- The 'waste containment system' comprised:
    - 650 mm low permeability clay laid over the waste with a 300 mm layer of sand then 100 mm of topsoil.

    - A vertical cut-off barrier made from clay and bentonite constructed along the northern edge of Boundary Creek
    - Low permeability clay placed on top of the residual clays underlying the waste.
- A gas management system was installed in 2000 when the area was recontoured for use as a park and sports pitch. The gas management system was comprised of two components:
    - A gas drainage layer installed under the turf consisting of a matrix of perforated pipes terminated in vents located on the GDR building (see **Appendix A Figure 5**).
    - A gas extraction system located below the P3 car park. The system was described as being *'continuously operated with fans and vent stacks which extend 5 m above the upper level of the car park'*.
- A leachate management system is installed at the GDR site. The system comprises of a series gravity fed and pumped sumps that reticulate leachate to a lagoon located to the south of the site (seen on **Appendix A Figure 5**).
- A gravity fed trench has been installed into the residual clays at the base of the site. Inside the trench is a polyethylene drainage cell overtopped by 1500 mm of drainage sand.
- One trench extends to within 100 m of the southern end of Site 9 (seen on **Appendix A Figure 5**). Gas monitoring at the GDR was discontinued following recommendations made by Environmental Earth Sciences in October 2007.

3.6 Contamination status

3.6.1 Soils

Fill material consisting of sandy clay, clayey sand and general refuse (including plastic, rubber, timber and unidentifiable black mass) was identified on-site to a depth of 7.9m bgl. Natural soils consist of red, white and yellow silty clay and sandy clay overlying extremely weathered shale.

Soil samples collected during the Supplementary Site Investigation (DLA, 2016) reported heavy metals, BTEX, TRH, Naphthalene, benzo(a)pyrene, Total PAH, polychlorinated biphenyls (PCB) or pesticides at concentrations below the adopted assessment criteria of *Residential B* (NEPC 2013).

Conversely, previous investigations by URS (2002) and Douglas (2003) reported TRH, BTEX and PCB at concentrations exceeding the adopted assessment criteria.

3.6.2 Groundwater

Methane, phenols, ammonia, TSS, TOC and nitrogen were detected in groundwater collected from monitoring wells installed within the landfill. The concentration of the analytes was noted to be higher within the landfill when compared to concentrations outside of the landfill (BH1). Groundwater within the landfill is considered to be leachate.

BTEX, naphthalene and TRH F1, TRH F2 and TRH F3 were detected in groundwater collected from the monitoring wells, however concentrations remained below the adopted assessment criteria.

Arsenic, cadmium, chromium, copper, nickel and zinc in groundwater collected from the monitoring wells were reported to exceed the adopted assessment criteria. The elevated concentrations are expected to be attributed to the leachate from the landfill material and are not considered significant in the context of a human or ecological health risk within the urbanised area of the Site.

3.6.3 Soil gas and landfill gas

All borehole locations were assessed for major LFG constituents; methane (CH_4), carbon dioxide (CO_2), oxygen (O_2), carbon monoxide (CO) and hydrogen sulphide (H_2S). All sample locations reported concentrations of CH_4, CO_2, CO concentrations above the detection limit of the GFM430.

Details of the results of the monitoring and an assessment of major constituents and trace gases can be found within Section 6.0. The results of the assessment of bulk gases is contained within Table 15.

A LFG risk characterisation and assessment based upon the results of the field investigation can be found in Section 0 and Section 8.0 respectively.

4.0 CONCEPTUAL SITE MODEL

The Conceptual Site Model (CSM) is a simplified representation of a complex relationship between the contaminant **sources, pathways and receptors** (i.e. pollution linkages). In this context, the purpose of the CSM is to establish whether it is possible for a link to exist specifically pertaining to landfill gas. Inherently, the CSM is an iterative tool that will evolve as the assessment, risk characterisation and response actions are developed.

The objective of this CSM was to establish if a credible linkage exists between the source (LFG in the former landfill mass) and the end receptors (construction personnel and future Site users). The reader should refer to the RAP (DLA, May 2016) for a discussion of the CSM relative to other media/pathways.

The degree of hazard associated with LFG and the consequent risk to development will depend on an assessment of the gas regime. The work previously undertaken on-site included the assessment of the composition of the gas and individual concentrations of the component gases (DLA, 2016).

The initial CSM prepared for the Site has been updated to include an estimate of the rate of production of gas at the source and the potential for transmission through the ground.

Using available site information (e.g. borehole logs, contour plans and existing survey data) the CSM was articulated in a cross-section and plan scale drawing, presented in **Appendix A - Figure 6 and Figure 7.**

The scope of the initial CSM addressed the following concepts:

- **Source** of gas including the origin, dimension of plume, composition, rate of generation and properties of gas (e.g. is the gas pressure in the waste mass greater than atmospheric pressure?) The generation and transport of LFG through the subsurface is highly variable and will be affected by atmospheric conditions such as rainfall and barometric pressure fluctuations.
- Potential **pathways** in which ground gas can move are affected by the presence of preferential pathways, geology and hydrogeology. Landfill capping, containment, perched water, layers and types of fill are also significant in affecting gas movement. Natural attenuation mechanisms and chemical reactions likely to occur in the sub-surface, so should be considered.
- Potential **receptors**, where are they, what are they, types of construction of buildings (e.g. is there crawl space or is there a concrete floor directly laid on the ground i.e. a slab on grade construction, is there a presence of basements and confined spaces inside the buildings).

4.1 Source of ground gases

The primary source of ground gas was considered to be derived from bacterial decomposition of the buried putrescible (biodegradable) waste in the former landfill site i.e. LFG. It is also possible that the ground gas present is derived from other sources. Sources of other potential ground gas in the vicinity of the site are:

- Imported fill and man-made ground
- Natural attenuation gas derived from the biodegradation of groundwater impacted by organic carbon compounds such as Volatile Fatty Acids (VFAs) in landfill leachate outside of the site
- Partitioning of LFG dissolved in migrating groundwater
- Mains sewer gas
- Mains reticulated natural gas
- Hydrocarbon contamination in the soil.

Each source of gas will typically contain a range of different compounds in different proportions and is referred to as the 'gas fingerprint'. The differences in compounds present can be used to ascertain the most likely source of the gas.

4.1.1 Landfill gas

LFG is produced by the decomposition of organic matter within landfill waste by bacteria. LFG production typically begins six to 12 months after waste placement and may last for 30 to 50 years (or beyond) following closure of the landfill. The generation of LFG occurs over several phases as the organic fraction of the waste decomposes. This sequence is summarised in Figure 1.

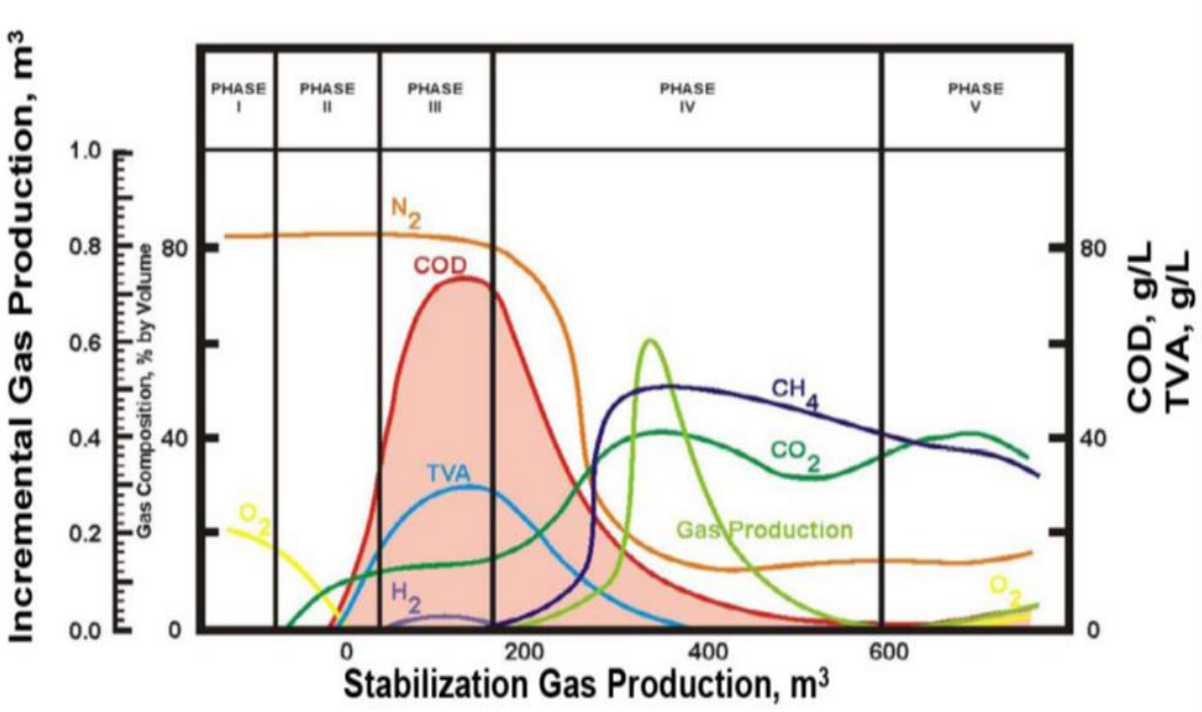


Figure 1 - Stages of landfill gas generation (NHBC 2007)

LFG typically contains approximately 55 % volume/volume (v/v) methane, 45 %v/v carbon dioxide and typically over 100 trace gaseous compounds termed VOCs, a typical LFG composition[1] is presented in Table 5. The properties and hazards relating to the gases are described further in Section 0.

4.1.2 Trace gases

LFG contains numerous non-methane Volatile Organic Compounds (nmVOCs) that can pose a long-term chronic risk.

Ground gases derived from hydrocarbon contamination may also be present in the soil outside the site. During the period the landfill was open, chemicals and petroleum hydrocarbon liquids may have been deposited into the ground. These liquids may have been deposited in a variety of different vessels including oil drums, tanks and cans. When such vessels leak or rupture chemical releases could occur. If the chemicals are volatile or semi-volatile, e.g. petroleum hydrocarbons they may partition from liquid to gas phase and accumulate in the subsurface.

[1] A UK Environment Agency example has been used as regional analysis was not available

The risks to humans are predominantly from exposure to vapour and the magnitude of risk increases with a number of factors including the replenishment of the source and the vertical distance to the source. It is unlikely that there is a large volume of petroleum hydrocarbons or volatile chemicals in the site due to the age and compaction status of the soil, however the risks from vapours has been explored as part of this risk assessment.

Table 5 - Typical composition of landfill gas (UK EA 2004)

Component	% (v/v)	Characteristics	Toxicity
LFG (CH_4)	45–60	LFG is a naturally occurring gas. It is colorless and odorless and highly flammable.	Low toxicity but can cause asphyxiation due to displacing oxygen
Carbon dioxide (CO_2)	40–60	Carbon Dioxide is naturally found at small concentrations in the atmosphere (0.03%). It is colorless, odorless, and slightly acidic.	Low toxicity but can cause asphyxiation due to displacing oxygen
Nitrogen (N)	2–5	Nitrogen comprises approximately 79% of the atmosphere. It is odorless, tasteless, and colorless.	Inert gas
Oxygen (O_2)	0.1–1	Oxygen comprises approximately 21% of the atmosphere. It is odorless, tasteless, and colorless.	Not toxic at atmospheric concentrations
Ammonia	0.1–1	Ammonia is a colorless gas with a pungent odor.	Can be toxic in high concentrations. As it is highly soluble it is dangerous to aquatic ecosystems
NMOCs (non-LFG organic compounds)	0.01–0.6	NMOCs are organic compounds (i.e., compounds that contain carbon). (LFG is an organic compound but is not considered an NMOC.) NMOCs may occur naturally or be formed by synthetic chemical processes. NMOCs most commonly found in landfills include acrylonitrile, benzene, 1,1-dichloroethane, 1,2-cis dichloroethylene, carbonyl sulfide, ethyl-benzene, hexane, methyl ethyl ketone, tetrachloroethylene, toluene, trichloroethylene, vinyl chloride, and xylenes.	Can be highly toxic and linked to cancer at low concentrations
Sulphides (H_2S)	0–1	i.e. Chemicals that contain sulphur. Sulphides (e.g., Hydrogen Sulphide, dimethyl sulfide, mercaptans) are naturally occurring gases that give the landfill gas mixture its rotten-egg smell. Sulfides can cause unpleasant odors even at very low concentrations.	Highly toxic at low concentrations
Hydrogen (H)	0–0.2	Hydrogen is an odorless, colorless gas. Highly flammable.	Non-toxic
Carbon Monoxide (CO)	0–0.2	Carbon Monoxide is an odorless, colorless gas.	Highly toxic at low concentrations

The volume of gas involved influences the potential acute risk to humans from LFG; this is a function of the rate of gas generation and the volume of the gas source. The larger the gas producing body, the greater the volumes, and thus the greater potential sphere of influence of the gas body. Of particular importance is the depth of the gas source, as the greater the depth, the greater the potential for lateral subsurface migration.

LFG is generated by microbial activity on carbonaceous matter, and so the total gas quantity depends on the size of the carbon reservoir (potential or actual). The total carbon reservoir in a landfill will influence the potential lifetime of gas generation, and may indicate that the potential exists for gas generation even if it is not occurring at present. To assess the potential for LFG to migrate into spaces and voids in the subsurface of the Site and within Site buildings, LFG generation modelling was undertaken.

4.2 LFG generation modelling

LFG generation modelling was undertaken using the US EPA Landfill Gas Emissions Model (LandGEM) which is able to provide potential gross estimates of LFG generation rates for total LFG, carbon Dioxide, nmVOCs and individual air pollutants from solid waste landfills. Waste input records were not available therefore the model outputs were intended to be for comparative purposes only. The model estimates should be viewed in the context of this assessment as an indicator of the range of possible LFG emission rates.

The LandGEM Technical Guidelines include an outline of calculation methods and criteria for determining greenhouse gas emissions from landfill facilities and were used to estimate landfill emissions. The LandGEM Method is based on a First Order Decay (FOD) model to estimate emissions over a set time period. This model estimates gas emissions generated by the decay of the carbon stock in a landfill Site, which reflects waste disposal activity over many decades.

4.3.1 Input parameters

An estimate of the volume of waste that may have been deposited, historical information and a review of historical borelogs from the Site was undertaken. To estimate the volume, the parameters described in Table 6 were used.

Table 6 - Landfill information

Parameter	Input
Estimated Landfill operating period	1950 - 1980
Estimated Landfill Area (m^2)	130,500
Estimated Landfill Depth (m)	8.0
Total Waste (m^3)	1,050,000

The model uses estimates of likely LFG emissions considering estimated type, tonnage and age of waste disposed at the Site. Assumptions for the LandGEM model are summarised in Table 7.

Table 7 - LandGEM Parameters

Parameter	Input
LFG Generation Rate, k (year $^{-1}$)	0.05
LFG Generation Capacity, L_o	170 m^3/t
CH_4 content (% by volume)	50%

The LFG generation constant 'k' value describes the rate at which waste placed in a landfill decays and produces LFG. The k value is expressed in units of yr-1. The value of k is a function of waste moisture content, availability of nutrients for LFG-generating bacteria, pH and temperature. The k value for this assessment was set at the LandGEM default value of 0.05.

The potential LFG generation capacity, or L_o, describes the total amount of LFG gas potentially produced by a metric ton of waste as it decays. The US EPA have determined that the appropriate values for L_o range from 56.6 to 198.2 m^3 per metric ton of waste. The LFG generation capacity for this assessment was set at the LandGEM default value of 170 m^3/t.

Based upon recent DLA (2016) assessment of LFG flow at the Site, the main LFG components comprise of 50% CH_4 and 50% CO_2. The predicted flow of methane and total LFG are presented Table 8.

Table 8 - Predicted historical landfill gas flow

Year	Expected LFG flow (m^3/h)	
	Total LFG (m^3/hr)	*methane (m^3/hr)*
1950	0.00	0.00
1951	66.04	33.02
1952	128.86	64.43
1953	188.61	94.31
1954	245.45	122.73
1955	299.52	149.76
1956	350.95	175.47
1957	399.87	199.94
1958	446.41	223.20
1959	490.67	245.34
1960	532.78	266.39
1961	572.84	286.42
1962	610.94	305.47
1963	647.18	323.59
1964	681.66	340.83
1965	714.45	357.22
1966	745.64	372.82
1967	775.32	387.66
1968	803.54	401.77
1969	830.39	415.20
1970	855.93	427.97
1971	880.23	440.11
1972	903.34	451.67
1973	925.32	462.66
1974	946.23	473.11
1975	966.12	483.06
1976	985.04	492.52
1977	1003.04	501.52
1978	1020.16	510.08
1979	1036.44	518.22
1980	1051.93	525.97

Predicted current landfill gas flow is shown in Table 9.

Table 9 - Predicted current landfill gas flow

Year	Expected LFG flow (m^3/h)	
	Total LFG (m^3/hr)	*methane (m^3/hr)*
2016	*185.36*	*92.68*
2017	176.32	88.16

Year	Expected LFG flow (m^3/h)	
	Total LFG (m^3/hr)	*methane (m^3/hr)*
2018	167.72	83.86
2019	159.54	79.77
2020	151.76	75.88
2021	144.36	72.18
2022	137.32	68.66
2023	130.62	65.31
2024	124.25	62.12
2025	118.19	59.10
2026	112.43	56.21
2027	106.94	53.47
2028	101.73	50.86
2029	96.77	48.38
2030	92.05	46.02
2031	87.56	43.78
2032	83.29	41.64
2033	79.23	39.61
2034	75.36	37.68
2035	71.69	35.84
2036	68.19	34.09
2037	64.86	32.43
2038	61.70	30.85
2039	58.69	29.35
2040	55.83	27.91

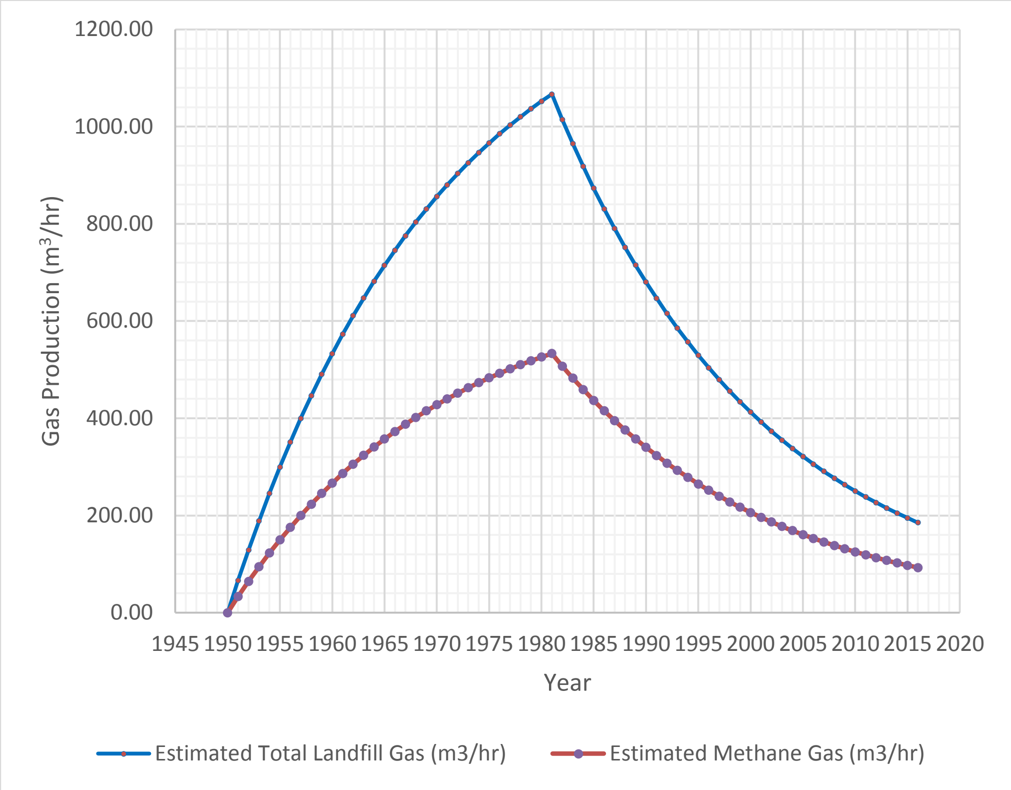


Figure 2 - Estimated landfill gas production rates

Total landfill gas and LFG gas generation rate is depicted in Figure 2. The LandGEM model estimates that 185 m^3/hr of total LFG and 93 m^3/hr of methane is currently produced (in 2016) from the landfilled material.

4.3 Release and transport mechanisms

The driving force of LFG is affected by a number of variables. For LFG to migrate away from the waste mass a pathway must be available, and for migration to be sustained the source of gas must be replenished. NSW EPA (2012) describe three main factors that influence LFG migration:

- Pressure differential
- Diffusion
- Gas in dissolved form in liquids.

The three factors and the relevance to this Site are described in more detail in the following sections.

4.3.2 Pressure differential and diffusion

Movement of ground gases occur either as a result of a variation in concentration (diffusion) or due to a pressure differential (advection). If a pressure differential exists (e.g. due to influx of gas or temperature effects), the high-pressure gas will move to an area of lower pressure to reduce the pressure gradient.

Acute problems with LFG accumulation such as explosion or flammability are usually associated with LFG movement because of pressure driven flow into, for example, a confined space. Pressure driven flow due to changes in barometric pressure is usually the dominant driving force.

Movement and accumulation of LFG via diffusion typically occurs over a much longer period and is usually associated with long-term problems chronic issues such as exposure to VOCs present as trace gas in the LFG mixture. Although, given the right circumstances accumulation via diffusion could still result in sufficient volumes of LFG to be hazardous.

During thee monitoring events on Site (1, 5 and 8 February) pressure differential was recorded inside the monitoring boreholes BH2, BH4, BH5, BH7 and BH8. The pressure recorded indicates the waste mass is still producing LFG and the accumulation in the boreholes is resulting in a higher pressure that outside the waste mass. The positive pressure ranged from 0.03 Millibar (mbar), (BH7 on 1 February) to 0.47 mbar (BH2 same date). The results are discussed further in Section 6.0 and estimations of likely pressure driven flows described in Section 8.0.

The movement of gas through the soil and fill layers has been estimated in the Section 8.7.2 using Darcy's law for pressure driven flow and the Pecksen method as described in Haines, Card and Wilson (2009).

4.3.3 Barometric pressure

The rate of fall of atmospheric pressure is more significant than the actual pressure level in influencing LFG movement in the subsurface. Rapidly falling pressure can lead to a pressure differential between the waste mass and the external atmosphere in general, thus providing a motive force for LFG migration. Once equilibrium of pressure has been reached, even at low barometric pressure, the motive force is removed and the influence of barometric pressure on potential LFG migration is greatly reduced.

Review of BOM data from February 2016 (presented in **Appendix E**) found falling barometric pressure on 1 February (1004.2 mb at 09.00 to 1001.1 mb at 15.00) and on 8 February 1019.1 mb to 1017.6 mb recorded at the same times). Pressure on 5 February was relatively stable.

4.3.4 Rainfall

Precipitation can lead to a reduction in the permeability of the ground surface by sealing migration routes, again leading to a build-up of pressure within a gas body, and the potential for an increase in subsurface migration.

The Site surface is covered in asphalt concrete so direct effects on the top of the landfill are not relevant. However, the remaining landfill in the former golf driving range area is covered in grass so heavy rainfall could provide a more effective seal and therefore gas that was vented may migrate via a sub-surface pathway.

4.3.5 Anthropogenic influences

The potential also exists for LFG to preferentially migrate through subsurface structures such as buried utility lines, where more permeable sands and gravels may have been used during the construction of these services. Potential exposure pathways are discussed further in Section 4.7.

4.4 Potential modes of gas migration at the site

Based on the data available and an assessment of the initial CSM, there are several possible modes of LFG occurrence and movement including:

- Current migration of LFG (both shallow and deep)
- Historic deep migration LFG
- Residual LFG
- Dissolved shallow methane derived from methane partitioned from groundwater.

4.4.1 Current shallow migration

Current shallow migration is considered to be migration of LFG, due to advective migration or pressure from the waste mass into the natural ground outside the landfill site, into the shallow soil zone. Low permeability landfill capping and an absence of active extraction can promote this mode of migration.

Methane that migrates into the shallow soil may be oxidised to carbon dioxide and water by aerobic methanotrophic bacteria present in the soil. Therefore, this mode is potentially not as hazardous as deep LFG migration that could migrate through the permeable soils/geology and up directly under the development, fissure or preferential pathway.

Diffusive flow depends on a concentration gradient being present i.e. LFG moves from an area of high concentration to a low concentration. LFG will travel greater distances under pressure than due to diffusion alone (CIRIA C665, 2007). The dominant pathway for LFG migration on-site is not considered to be diffusion alone but LFG recorded may be present as a result of advective and diffusive flow.

4.4.2 Current deep migration

It is possible LFG may move through the geology as a result of migration of LFG derived from biodegradation from the deeper waste layers and migrating under buoyant rise mechanisms through preferential pathways such as fault and fissures in the basement geology. Lateral migration is determined by the presence of overlying low permeability soil zones. The drilling logs available show that the underlying rock is very firm without any sand lenses. However, the drilling may have missed faults or lenses in the geology, meaning that potential occurrence of migration via this pathway are still unknown.

4.4.3 Historic deep migration

LFG may be present in the subsurface due to migration off-site under previous conditions e.g. when the landfill was operational and being filled as the 'western landfill'. Migration of LFG into a deeper unsaturated zone created around the site during the operational life of the landfill and prior to landfill closure acts as a reservoir of gas to migrate out under diffusion gradients at a later time. This mode of migration may lead to the presence of residual LFG in the underlying geology, although the relative impermeable nature of the rock will mean that, it unlikely to act as significant reservoir of LFG.

4.4.4 Residual landfill gas

LFG may be present as a mostly residual subsurface reservoir of LFG, without advective flow. Hence, migration appears to occur primarily by diffusion and as such LFG slowly migrates along available pathways and dissipates into ambient air. This is a slow process, which would mean that elevated LFG levels could be measured in the subsurface through some parts of the site for a prolonged period, unless removed. The sand overlying the relatively firm geology will reduce the gas holding potential of the soil when compared to a deep clay rich soil.

The lack of significant levels of positive pressure recorded in the boreholes supports this assertion as this mode is source limited and the long-term risks are reduced. In fact, the positive pressure recorded on Site was below the lower limit of the analysers accuracy of 0.5 mb.

4.4.5 Dissolved shallow methane

Methane can be transported as a dissolved product in groundwater (although solubility is very low around 25 to 35 mg/L) and when the pressure is reduced the methane will volatise out of solution. Groundwater will carry a LFG contamination plume from the site down gradient. Estimates of dissolved methane equate to 25 mg/L or 3 to 6 %v/v in a monitoring bore (Card and Haines, 1995).

It is unlikely that a significant risk is posed from LFG dissolved in groundwater due to:

- Methane gas will not easily dissolve into groundwater or leachate at, or close to, atmospheric pressures. Carbon dioxide is more likely to dissolve into ground water than methane.
- It is unlikely that there would be a sufficient volume of LFG dissolved to present a hazard, although this cannot be discounted.
- The groundwater level is a minimum of 4 m below the base of the proposed slab. Where the structures are closer to groundwater e.g. the lift shafts will come within approximately 1.0 m of the ground water. These structures will be tanked with water-proof membrane as well as the gas mitigation measures.

4.5 Delineation of gas migration

The extent of migration off-site is unknown due to a lack of installed monitoring infrastructure in the industrial estates that surround the site. Little is also understood about the dimension, if at all present, of any subsurface LFG plume potentially migrating off-site.

It is envisaged that the proposed remediation measures installed on the Site is unlikely to change the sub-surface gas regime significantly. If anything the installation of void layer under the building and open to atmosphere is likely to increase the likelihood of preferential flow from the soil to atmosphere rather than laterally sub-surface.

4.6 Groundwater levels

Ground water or perched leachate levels as they rise and fall inside a waste mass or soil can reduce or increase the amount of available LFG respectively. The concentration of LFG can also increase in an area that has been reduced by rising water levels. The ground water parameters were recorded by DLA and summarised in Table 10.

Table 10 - Ground water parameters from DLA 2016

PARAMETER	BH1	BH4	BH8
Date	1/2/2015	1/2/2015	1/2/2015
SWL (metres below top of casing)	4.115	4.191	5.285
Temp (°C)	21.5	23.7	23.0
DO (ppm)	4.41	0.72	0.55
Conductivity (µs/cm)	2410	5110	2690
pH	5.25	6.67	6.27
Redox (mV)	137.3	-220.0	-128.5

4.7 Exposure pathways

LFG can enter buildings via fractures in subsurface walls and wall cavities. A potential exists for cracks to occur at any location across the slabs, generally as a result of induced stresses during or soon after construction, or from differential settlement or damage during use. Cracks can also occur at the floor/wall perimeter from settlement.

LFG could potentially enter the building at the ground floor club level and accumulate via the following routes listed below:

- Service penetrations and cable conduits such as the incoming high voltage conduits routed into base of the transformer room.
- Vertical structures such as foundation piles. The building will be supported on a number of grout-filled piles.
- Cracks or gaps in walls and floors. The proposed slab is 300 mm thick and poured therefore unlikely that cracks would form.
- Settlement voids and joints formed during the construction process.
- Around service pipes, ducts and drains.

Man-made pathways can also increase permeability and create preferential pathways. This can be done by a variety of ways: air blast rotary drilling, installation of bores and wells, piling, cable ducts and services, pavement substructures, granular backfill, drains, ducts, trenching excavations and pits under floor spaces and basements. All of these structures may provide preferential LFG migration pathways.

Where interstitial water is present in rocks and/or sediments, the greater the amount of water present, the less permeable the unit is with respect to ground gases, as there is less volume of space available for movement of gas. The soil underlying the Site was recorded as dry during installation of boreholes (see **Appendix F** for borehole logs).

The building will be supported on a number of structural piles that DLA understands will be drilled into the underlying rock between 10 and 12 mbgl. The piles will be formed using a grout filling method. The process of drilling is likely to increase vertical preferential pathways from the waste up to the base of building, however the grout filling technique is thought to reduce pockets and voids created during drilling as the grout will move into voids and expand under pressure.

5.0 FIELD INVESTIGATION AND MONITORING

5.1 Objectives

The CSM was refined by the findings of the LFG investigation and monitoring. The objectives for the Site investigation are described in *NSW EPA Guidelines for the assessment and management of sites affected by hazardous ground gases 2012*, summarised as follows:

- Establishment of the lateral and vertical extent of the ground gas source, if present, and the current extent of ground gas migration.
- Measurement of gas composition and concentration under the slab area of the proposed Site development.
- Construction of an adequate number of gas monitoring points to provide coverage of the Site and potential pathways.
- Provision of the gas concentration and gas flow data required to calculate a gas screening value.
- Assessment of the influence of a full range of weather conditions on gas concentrations and flow rate.

5.2 Monitoring borehole installation

Monitoring borehole locations for ground gas investigations drilled across the Site and located considering the following:

- Boreholes were drilled in locations appropriate to assess worst-case conditions, and peripheral locations to confirm the extent of the source.
- Boreholes were designed to be able to assess potential migration pathways, and at least some of these should extend to the full known depth of the source.
- The depth of investigation will take into account the actual or proposed construction methods, such as piling.
- The sensitivity of the planned site use, the nature of the gas source and the heterogeneity of ground conditions, as well as the assessed robustness of the conceptual site model.

The following specification was considered appropriate for installation of the construction of ground gas monitoring boreholes:

- Monitoring borehole casings were constructed from 50 mm diameter Class 50 screw-jointed uPVC.
- Screen sections had a 0.4 mm factory-cut slots as standard giving approximately 10 to 20 % open area.
- Screen depth was from between 1 and 1.5 mbgl to base (5.0 to 7.9 mblg).
- A washed sand annulus was placed from the bottom of screen to 0.5 m above the top of the screen.
- At least an 0.8 m thick fully hydrated bentonite-pellet seal was placed ontop of the sand annulus to seal the well installation.
- Monitoring boreholes were fitted with a gas- tight cap and sample point.

Six ground gas monitoring boreholes were installed across the Site (BH1, BH2, BH4, BH5, BH7 and BH8) refer to **Appendix A, Figure 2** for locations.

Monitoring borehole screen placements were installed to allow the dual-purpose measurement of both LFG and groundwater. Screens were designed to intercept potential movement of ground gas and placed across the permeable horizons of interest.

Gas monitoring wells were fitted with a cap tapped to take a quick-connect fitting that seals the monitoring point and allows for connection to a measurement instrument. A handheld landfill gas measurement device GFM430 (Calibration details within **Appendix G**) was utilised to assess gas concentrations, pressures and flow rates at each monitoring bore.

The boreholes were drilled and installed on 25 February 2016. Borehole logs were prepared in accordance with the United Soil Classification System and presented in **Appendix F**.

5.3 Sub-surface gas monitoring

The purpose of subsurface gas monitoring was to measure concentrations of LFG in the unsaturated zone in and around the monitoring boreholes. The results of the monitoring data were used to assess the potential for vertical movement of LFG.

5.3.1 Monitoring procedure

The following procedure was used:

- Open bore cover to expose gas tight fitting
- Zero flow reading on analyser
- Connect LFG flow inlet tube to borehole, wait 60 seconds for flow to stabilise and record flow

- Zero differential pressure reading
- Connect LFG analyser to bore and record differential pressure
- Sample (minimum 2-minute period) until stabilised or 10 minutes (whichever comes first)
- Record available gas readings. If stabilisation is not achieved, then record peak and final gas concentrations with a note that stabilisation has not occurred. Data to be reviewed as per data validation procedure.
- Disconnect analyser, secure probe and perform fresh air purge before commencing monitoring at next gas bore.

The parameters described in Table 11 were recorded; the results are presented in Section 6.0.

5.3.2 Monitoring devices

A zeroed and calibrated GFM430 and GA5000 landfill gas analyser was used to conduct sub-surface gas monitoring (refer to ***Appendix G*** for the calibration certificates). The GFM430 range of Gas Analysers has capability that includes measurement of the following:

- Gases including methane (%v/v), carbon dioxide (%v/v), oxygen (%v/v), carbon monoxide (parts per million (ppm)) and hydrogen sulphide (ppm).
- Borehole pressure and barometric pressure (millibar).
- LFG flow (l/hr) from borehole.

The monitoring parameters undertaken on perimeter LFG monitoring boreholes are detailed in Table 11.

Table 11 - Monitoring parameters

Parameter	Unit of Measurement	Accuracy GA5000	Accuracy GFM430	Threshold
Methane (CH_4)	%v/v	+/- 0.5 %v/v		1.25
Carbon dioxide (CO_2)	%v/v	+/- 0.5 %v/v		Information only. Increases above background should be observed
Carbon monoxide (CO)	ppm	+/- 2 % over full scale		>0 ppm
Hydrogen sulphide (H_2S)	ppm	+/- 2 % over full scale		>0 ppm
Oxygen (O_2)	%v/v	+/- 0.5 %v/v		n/a
Flow rate	Litres/hour	+/- 0.3 L/hr	+/- 0.1 L/hr	Information only
Pressure	mb (equivalent to Hpa)	+/- 0.5 mbar to 15 mbar max	+/- 1 mb	Information only
Water level	mbgl	N/A		Information only

While carbon dioxide monitoring is very useful in terms of understanding the sub-surface conceptual model, landfill emissions based on carbon dioxide regulation is difficult to administer and empirically justify because there are many other natural sources of carbon dioxide that can cause interference. If there are confined spaces or basements next to the landfill, then carbon dioxide is a reasonable parameter to regulate because there is a high-risk receptor in close proximity. However, in all other circumstances, sound regulation can be achieved by enforcement of a site-specific gas management and understanding that methane is the principle risk driver.

5.3.3 Monitoring duration

Monitoring was undertaken on three occasions over eight days e.g. 1, 5 and 8 February 2016.

For bulk ground gases and moderate-sensitivity development (equivalent to the residential use with minimal access to soil exposure setting), UK CIRIA C665 recommends "*6–12 monitoring events extending over 3–12 months (CIRIA 2007)*". However, the key requirement in regards to Australian guidance is to capture the worst-case meteorological scenario which is considered to be a 5th percentile three-hour pressure decrease rate for the Site, based on a two-year data set.

Based upon the last two years of with continuous barometric data obtained from the Bureau of Meteorology (BOM), a 5th percentile three-hour pressure decrease rate for the Site, based on a two-year data set, was calculated to be 1.232 mb. Three-hour pressure decrease rate data was assessed to determine if during the monitoring event, a decrease rate of greater than 1.3 mb (thereby meeting worst case conditions) was recorded on 1 and 8 February monitoring visits. A summary of the relevant weather conditions during each monitoring visit is provided in Table 12 below. Weather data for the month of February 2016 is included in ***Appendix E***.

Table 12 – Summary of weather data during monitoring

Date	Rain	Evap	9:00 AM					3:00 PM				
			Temp	RH	Dir	Spd	MSLP	Temp	RH	Dir	Spd	MSLP
	mm	mm	°C	%		km/h	hPa	°C	%		km/h	hPa
01-2-16	0.2	8.0	26	42	NNW	2	1004.2	25.5	52	SE	15	1001.1
05-2-16	3.6	9.6	22	59	S	31	1017.4	23.9	56	SSE	39	1017.6
08-2-16	0	4.6	22.8	68	WNW	11	1019.1	27	54	ESE	17	1017.9

We therefore consider that although the monitoring period was relatively short, one set of readings were taken during a falling barometric pressure event that characterised worst case in accordance with NSW 2012 guidelines.

5.4 Trace gas sampling and analysis

The objectives of trace gas analysis were to:

- Establish the source of the gas or identify any compounds that indicate other sources in addition to LFG.
- Confirm the bulk gas compositions measured using the hand held GA5000.
- Establish the concentration of compounds that are significant in human health impact and provide an indication of trace gas concentrations for a screening Human Health Risk Assessment (HHRA).
- An assessment of whether the gas mixture would be odorous if left to vent to the atmosphere.

The presence of trace gas compounds is important to characterise, as many of the compounds are toxic at low concentrations and therefore potentially present a longer term (chronic) risk. The UK EA (UK EA, 2004) has compiled a list of priority trace gases that are routinely tested for on UK landfill sites[2] and is presented in Table 17.

5.4.1 Sampling methodology

On the day of sampling only one borehole (BH7) was accessible for sampling due to construction and excavation works. BH7 was considered representative of the waste mass and appropriate as relatively high HGGs concentrations had been previously recorded from this location and was in close proximity to the sub-surface areas with the highest concentrations of HGG.

Prior to sampling the integrity of the sample train and borehole seal were assessed. To test the integrity of the sample train the valve on the end of the train was closed and the main canister valve was opened fully. The pre-loaded vacuum was recorded – 25 Hg" and following 3 minutes not difference in pressure was noted on the gauge.

To assess the integrity of the well seal a visual inspection of the inside of the gatic cover was undertaken and the cement bentonite seal was found to be in good condition with no cracks or desiccation evident. The gatic was mounted inside a concrete collar in the car park surface with no gaps evident.

[2] An Australian equivalent was not available, hence the UK data presented here

A GA5000 gas analyser was first attached to the well sample port and the pump turned on and left pumping for 120 seconds until parameters stabilised. No oxygen was recorded indicating no atmospheric air ingress was occurring and that the sample location integrity was satisfactory. Purging the borehole was not considered necessary as the gas parameter concentrations were stable at the time of monitoring and peak readings were the same as stable readings (see reading sheet in ***Appendix H***).

One trace gas sample was taken from BH6, representing gas from inside the waste mass between 1 and 5 mgbl. The sample was taken by a DLA Scientist using a canister with a pre-determined vacuum supplied by Envirolabs in Sydney (a NATA accredited laboratory). The vacu-canister was attached via a disposable Teflon sample train to the sample point and the valve opened until the bottle was filled with a gas sample. The main valve was closed when the gauge indicated -5 Hg", leaving a slight vacuum in the bottle. The bottle was packaged and delivered to Envirolabs the following day. The laboratory QA sheet recorded -5 Hg" i.e. indicating no sample loss or ingress of atmospheric air (refer to laboratory COC sheet presented in ***Appendix H***).

A summary of the results is presented in Section 6.2. The full laboratory documentation is presented in ***Appendix H***. Weather conditions for the day of trace gas sampling is included in Table **13**.

Table 13 – Summary of weather data during trace gas sampling

Date	Rain	Evap	9:00 AM					3:00 PM				
			Temp	RH	Dir	Spd	MSLP	Temp	RH	Dir	Spd	MSLP
	mm	mm	°C	%		km/h	hPa	°C	%		km/h	hPa
06/09/2016	0.2	0.6	17.4	62	W	9	1018.3	22.7	32	W	15	1013.3

5.5 Data quality objectives

The NEPM (NEPC, 2013) and Australian Standard (AS) 4482.1-2005 recommend that data quality objectives (DQOs) be implemented during the investigation of potentially contaminated sites. The DQO process described in AS 4482.1-2005 *Guide to the Investigation and Sampling of Sites with Potentially Contaminated Soil Part 1: Non-Volatile and Semi-Volatile Compounds* has been adapted for the ground gas assessment in accordance with Section 3.4 of NSW 2012.

The DQOs have been summarised in Table 14:

Table 14 - Summary of DQOs for ground gas assessment

1	State the Problem	The Site has historically been used as a landfill. Previous environmental investigations documented elevated concentrations of LFG in boreholes.
2	Identify the Decisions	The decisions to be made on the data required includes considering relevant Site contamination criteria for gaseous phase accumulated in the monitoring boreholes. Decisions include: – Do contaminant concentrations in gas comply with the adopted Assessment Criteria? – Have the previous land uses affected the environmental quality of the land? – Do residual gas pose an unacceptable risk to human health or the environment?
3	Identify Inputs to Decisions	– Previous environmental data. – Assessment objectives. – Relevant NSW EPA produced or endorsed criteria. – The proposed land use. – Systematic sub-surface gas monitoring, sampling and analysis across the Site. – Determination of potential gas exposure levels and potential risk to current and future site owners/residents/land users/workers. – Identifying current and future potential receptors and the likelihood of exposure to unacceptable levels of contamination both on and off the Site.
4	Define Study Boundaries	– The study will focus gas within the Site's boundary.

5	Develop Decision Rule	The Site will be considered suitable for its intended land use if concentrations gas comply with the screening levels of the Assessment Criteria, as determined by the following decision rules being applied to the data: – The individual contaminant concentration should not exceed the screening level by more than 0.1 %v/v i.e. the sensitivity of the hand-held analyser – The analyser has been calibrated by the supplier If methane is recorded, is it above the threshold concentration of 1.25 %v/v? if yes, continue monitoring and assess requirement for further investigation and risk assessment. Is methane concentration below the level of detection for 4 events? If yes and barometric pressure is falling by at least 1.5 mb over three hours, and the laboratory analysis confirms the accuracy of the GA5000 then further investigation and risk assessment unlikely to be required.
6	Specify Limits on Decision Errors	Within the specification of the equipment and laboratory QA/QC. The trace gas sample will be subject to in-house laboratory QA/QC but will not require a duplicate sample as is it for screening purposes only. Data Quality Indicator (DQIs) are only appropriate for laboratory QA/QC[3].
7	Optimise Design for Obtaining Data	– Ensure access to all relevant and previous environmental data. – Identify the most resource-effective sampling and analysis design for general data that are expected to satisfy the DQOs. The LFG specialist will use an infrared LFG analyser designed specifically for LFG. The preferred LFG analyser is the GA5000 (or equivalent) due to its ability to monitor LFG, hydrogen compensation to enable more accurate carbon monoxide readings and flow rate measuring capability.

5.6 Assessment criteria

The assessment criteria have been chosen in accordance with current Australian and NSW EPA guidelines. Australian Guidelines have been used in preference to international guidelines where

[3] In the event that a DQI is not met by laboratory analyses, the field observations relating to the nature of the samples will be reviewed. If there is no obvious source for the non-conformance is identified, such as an error in sampling, preservation of sample/s or heterogeneity of sample/s, liaison with the laboratories will be undertaken in an effort to identify the issue that has given rise to the non-conformance.

available. The criteria provided are the most current and widely accepted for Tier 1 assessment of land use suitability at present in Australia, and have generally been developed using a risk-based approach. The risk assessment approach is introduced in more detail in Section 8.2. Indoor air quality criteria is addressed in Section 8.8 utilising the NSW DECCW 2010 Practice Note on Vapour Intrusion. Validation Criteria is addressed in Section 14.

6.0 RESULTS

The results of the site monitoring and trace gas analysis are described in the following sections.

6.1 Bulk gases

Bulk gases in particular methane and carbon dioxide have been recorded along with other parameters as described in Table 11. The results were taken on three occasions 1, 5 and 8 February 2016 have been summarised in Table 15 and

Table 16. One reading was taken with a GA5000 analyser on 6 September 2016 immediately prior to and following collecting the trace gas sample for laboratory analysis (refer to ***Appendix H*** for field reading sheet).

6.1.1 Methane

Methane ranged from 0.3 %v/v on BH1 (8 February) to 70.8 %v/v on BH4 (5 February). Methane recorded with the GA5000 on 6 September on BH6 was 48.3 %v/v and methane concentration by chemical analysis in the laboratory was 63 %v/v. The higher concentration result has been taken forward for the risk assessment. The methane concentration is typical of landfills in active stages of LFG generation. BH1 was the only borehole with relatively low concentrations of methane. However, methane measured on 1 February was 1.4 %v/v.

6.1.2 Carbon dioxide

The methane to carbon dioxide ratio was slightly less than the typical 60:40 ratio of (3:2) that is usually seen in LFG. However, the concentration of carbon dioxide is typical of LFG and increases resulting in more carbon dioxide can be a direct result of oxidation of methane to carbon dioxide in the upper soil layers.

6.1.3 Oxygen

Oxygen was recorded at 0 %v/v all boreholes apart from BH1 and BH8 on 8 February (0.2 %v/v). This indicates that LFG is being generated at a rate sufficiently high enough to excludes atmospheric oxygen from the borehole.

The oxygen concentration reported by laboratory at 0.58 %v/v indicates that very little oxygen was introduced into the canister during sampling.

6.1.4 Nitrogen

Nitrogen is an inert gas and as such has not been considered further as part of the risk assessment.

6.1.5 Hydrogen sulphide

Hydrogen sulphide was reported by the laboratory at 50 µg/m^3 (refer to Table 16). This concentration is within the odorous range. The concentration recorded by the GA5000 at the same time was 10 ppm (equivalent to 0.035 µg/m^3). This was supported by a pungent odour noted during the time of sampling. Hydrogen sulphide was recorded by the GFM430 at a highest concentration of 86 ppm in BH1 on 1 February. This is equivalent to approximately 0.06 µg/m^3).

6.1.6 Carbon monoxide

Carbon monoxide was reported by the laboratory below the instruments limit of detection at <0.01 %v/v. It should be noted that the lower level of detection is equivalent to 100 ppm. The GFM is accurate to low ppm ranges. However, it is common for CO cells to record a false positive that is typically attributed to other trace gases in the LFG mixture. We consider the monitoring results showing high CO at BH1 and BH5 as a cross reaction with other gases (see Table 17 summarising other gases present) or an erroneous reading as subsequent monitoring results show a reduction to close to background concentrations.

6.1.7 Borehole differential pressure

Borehole differential pressure was not recorded above 0.5mb i.e. the accuracy of the GFM400 on any occasion.

6.1.8 Flow rates

LFG flow was measured in all boreholes (BH2, BH4, BH5, BH7 and BH8) that were within the Golf Driving Range landfill footprint. BH2 recorded the highest flow rate of 8.1 L/hr on the 1/2/16. BH1 which was installed outside the landfill boundary, did not record any flow rate during all monitoring visits.

Table 15 - Gas monitoring results 1 to 8 February 2016

ID	DATE	CH_4 (%v/v)	CO_2 (%v/v)	O_2 (%v/v)	Pressure[4] (mbar)	FLOW (L/hr)	CO (ppm)	H_2S (ppm)	Balance (%)	Barometric Pressure
BH1	1/02/16	1.4	13.8	12.5	0.0	0	1029	86	72.3	998
	5/02/16	0.4	12.1	14.5	0.0	0	247	23	12.0	1013
	8/02/16	0.3	17.7	9.4	0.0	0	8	1	10.2	1013
BH2	1/02/16	63.8	17.7	0.0	0.47	8.1	13	1	18.5	996
	5/02/16	70.7	17.3	0.0	0.35	6.4	6	1	73.0	1014
	8/02/16	71.1	18.7	0.0	0.33	6.3	2	5	72.6	1014
BH4	1/02/16	63.5	18.0	0.0	0.29	5.5	8	0	18.5	996
	5/02/16	70.8	16.8	0.0	0.31	6	5	3	12.4	1013
	8/02/16	70.3	16.4	0.0	0.30	5.8	5	3	42.1	1013
BH5	1/02/16	45.6	26.0	0.0	0.04	1.5	221	11	28.4	997
	5/02/16	55.1	26.9	0.0	0.15	2.8	24	2	18.0	1013
	8/02/16	58.5	26.9	0.0	0.20	3.9	19	2	13.3	1011
BH7	1/02/16	60.6	25.8	0.0	0.03	0.6	8	0	13.6	997
	5/02/16	61.7	25.3	0.0	0.16	3.1	13	2	13.0	1013
	8/02/16	64	27.6	0.0	0.18	3.4	6	2	14.6	1011
BH8	1/02/16	39.5	18.4	0.0	0.09	1.6	13	0	42.1	996
	5/02/16	33.8	15.8	0.0	0.17	3.2	8	2	50.4	1012
	8/02/16	33.8	15.8	0.0	0.17	3.2	8	2	8.4	1012

Table 16 – Selected analysis (Bulk gas results) from laboratory compared with GA5000 readings taken at same time on 6 September 2016

Name	Analysed concentration Site 9 – BH7	Gas readings by GA5000 taken at the same time Site 9 – BH7
Helium	NA	NA
Hydrogen	<0.01 %v/v	NA
Oxygen	0.58 %v/v	0.0%
Nitrogen	NA	13.1 %v/v
Methane	63.0 %v/v	48.3 %v/v
Carbon dioxide	21.0 %v/v	38.6 %v/v
Carbon monoxide	<100 ppm	6 ppm

[4] Note; all pressure readings are below the lower detection level of the gas analyser pressure transducer.

Name	Analysed concentration Site 9 – BH7	Gas readings by GA5000 taken at the same time Site 9 – BH7
Hydrogen sulphide	0.035ppm	10 ppm

NA – not analysed

Field monitoring records for landfill gas monitoring is included in **Appendix H**.

6.2 Trace gases

Trace gases or VOC results from the vacuum canister gas sample are summarised in Table 17.

6.3.1 Presence of chlorinated hydrocarbons

Chlorinated hydrocarbons are man-made chemicals found in general waste that are not often found naturally. Because of their volatility, these compounds are not usually found in the atmosphere. If they are found in the boreholes in the landfill it is likely they have migrated from the landfill waste below.

The top six (accounting for approximately 90% of the chlorinated hydrocarbons content of LFG) are:

- Freon
- Cis 1,2-Dichloroethene
- Chloroethene
- Trichloroethene
- Dichloromethane
- Tetrachloroethene.

As the waste has been in-situ for over 30 years' many compounds may have already degraded. Freon 11 is present in the sample from BH6, the source of these compounds are typically from refrigerants or the chemical manufacturing processes. This confirms the source of LFG from previous waste disposal at the Site.

6.3.2 Mercaptans and other compounds

Natural (mains reticulated) gas is spiked with odorous compounds such as mercaptans or diethyl sulphide. Mercaptans gas were measured below the Practical Quantitation Limit. If the source of gas were from mains gas, it would be expected to find these compounds in the gas mixture. These compounds would only be present if they had not volatised before the bulk gases. The gas sample had relatively high concentration of ethane and propane, which is usually found in high concentration in mains gas and could be a result of leakage from discarded gas bottles.

6.3.3 Other hydrocarbons

BTEX, TPH and pentane species are at elevated concentrations that are not typically recorded in landfill sites (EA 2004). This indicates that the source of these gases is likely to be derived from former fuel tanks or contaminated soil.

Table 17 - Trace gas results from BH6

Name	Analysed conc. (μg/m^3) Site 9 – BH6	Potential health effect	Chemical type
1,1-Dichloroethane	<17	Health	Halogenated organics
1,1-Dichloroethene	<17	Health	Halocarbon
Benzene	6200	Health	Aromatic hydrocarbon
1,3-Butadiene	<9	Health	Aliphatic hydrocarbon
Chlorobenzene	7800	Health	Halogenated organics
1,1,1-Trichloroethane	<23	Health	Halogenated organics
Tetrachloroethene	56	Health	Halogenated organics
Toluene	880	Health	Aromatic hydrocarbons
Chloroethane	570	Health	Halogenated organics
Chloroethene	NA	Health	Halogenated organics
Ethylbenzene	1500	Health	Aromatic hydrocarbons
cis-1,2-Dichloroethene	210	Health	Halogenated organics
Xylene	6910	Health	Aromatic hydrocarbons
n-hexane	39000	Health	Alkanes
1,2-Dichloroethane	<17	Health	Halogenated organics
Trichloroethene	63	Health	Halocarbon
Dimethyl sulphide	60	Odour	Organosulphur
Hydrogen sulphide	50	Health and odour	Sulphured compounds
Methyl Mercaptan	<9.8	Odour	Sulphured compounds
Ethyl Mercaptan	<13	Odour	Sulphured compounds
Dimethyl Sulfide	20	Odour	Sulphured compounds
n-Propyl Mercaptan	NA	Odour	Sulphured compounds
Thiophene	NA	Odour	Sulphured compounds
n-Butyl Mercaptan	NA	Odour	Sulphured compounds

Name	Analysed conc. ($\mu g/m^3$) Site 9 – BH6	Potential health effect	Chemical type
Tetrahydrothiophene	NA	Odour	Sulphured compounds
Freon	230	Health	Halocarbon compound
Vinyl Chloride	650	Health	Organochloride compound
Dichloromethane	<143	Health	Organic compound

NA – not analysed

7.0 LANDFILL GAS RISK CHARACTERISATION

Aspects of LFG characterisation is presented in the following section in the context of the CSM.

7.1 Hazards associated with landfill gas

Methane can be highly hazardous to humans and the risk is compounded by the fact it is odourless, colourless and lighter than air which means the concentration of the gas can build up to the explosive limits without any indication of its presence.

Carbon dioxide is also odourless and colourless and although it is not flammable or explosive and can collect and in low points as it is denser than air.

7.1.1 Flammability and explosion

Methane is a flammable and potentially explosive gas. When the concentration of methane in air (oxygen 20.9% by volume (%v/v)) is between the limits of 5 and 15 %v/v, an explosive mixture is formed. The Lower Explosive Limit (LEL) of methane is 5 %v/v, which is equivalent to 100 % LEL. The 15 %v/v limit is known as the Upper Explosive Limit (UEL), but concentrations above this level cannot be assumed to represent safe concentrations.

The flammability of gas mixtures is affected by their composition, presence of an ignition source, temperature, pressure and nature of the surroundings. The explosive hazard of a flammable mixture arises from the speed of propagation of the flame in a confined space and the ability of the container to absorb the associated shock wave.

The flammability range can vary depending upon different circumstances. For an explosion to occur, a source of flammable gas or vapour (mixed with air) is required, together with an ignition source and an enclosed space to allow accumulation of the gas.

On its own, carbon dioxide is not flammable and does not support combustion.

7.1.2 Toxicity

Methane is considered a low toxicity gas, but can result in asphyxiation due to its ability to exclude oxygen whereas carbon dioxide is classed as a highly toxic gas. A 3 %v/v carbon dioxide concentration can result in headaches and shortness of breath, with increasing severity up to 5 or 6 %v/v. The next symptoms to develop are visual distortion, headaches, tremors and rapid loss of consciousness at 10 to 11 %v/v with death at concentrations above this.

Safe Work Australia has published information (SWA, 2011) relating to concentrations of carbon dioxide that humans may be exposed to, which uses concentrations contained in the *Workplace Exposure Standards for Airborne Contaminants 2011*.

These are the 8-hour Time-weighted average (TWA) (TWA, 8-hour period) and the Short-term Exposure Limit (STEL, 15-minute period), which are 0.5 %v/v and 3.0 %v/v carbon dioxide, respectively.

7.1.3 Asphyxiant

Although LFG is considered to be of low toxicity, its capability to displace oxygen means that at high enough concentrations it becomes an asphyxiant. Oxygen starvation occurs at 33%v/v LFG, whilst at 75%v/v LFG death results after 10 minutes

7.1.4 Other hazards

Whilst methane and carbon dioxide are odourless, there are trace gases that exist in the LFG mixture. These compounds can be highly odorous. Hydrogen sulphide is commonly found in LFG and can be detected by humans in the parts per million concentrations. LFG can also cause environmental problems associated with vegetation die-back. LFG also contains a complex mixture of VOCs that can also present chronic health effects if un-protected receptors are continually exposed to the compounds.

VOC as a result of filling activities may also be present in the soil outside the site. During the period the landfill was open, chemicals and petroleum hydrocarbon liquids may have been deposited into the ground. These liquids may have been deposited in a variety of different vessels including oil drums, tanks and cans. When such vessels leak or rupture chemical releases could occur. If the chemicals are volatile or semi-volatile, e.g. petroleum hydrocarbons they may partition from liquid to gas phase and accumulate in the subsurface. If buildings are near and a soil vapour pathway is complete, there may be a potential for unacceptable health risks to building occupants as a result of inhalation of vapours. One such pathway would be via groundwater, through services or cracks in the building foundation slabs and into indoor air.

The risks to humans are predominantly from exposure to vapour and the magnitude of risk increases with a number a factors including the replenishment of the source and the vertical distance to the source.

7.2 Potential impacts of landfill gas

A summary of potential hazards and risks associated with LFG is provided in Table 18 (this considers human and environmental aspects):

Table 18 - Summary of potential hazards

Aspects	Potential LFG Hazard	Potential risk associated with hazard	Potential type of risk
Human Health	LFG and Air	Explosion and fire	Acute
	Lack of oxygen	Asphyxiation	Acute
	LFG trace toxics	Inhalation	Acute / Chronic
Buildings and Structures	LFG and Air	Explosion and fire	Acute
	Waste degradation associated with LFG	Subsidence	Acute / Chronic
Aesthetics	LFG	Odour	Acute / Chronic

7.3 Summary of LFG hazards and identification

A summary of LFG hazards and occurrences is presented in Table 19.

Table 19 - Summary of possible events related to risk from LFG migration

Possible event	How could event occur?
Death or serious injury to persons at, or near the landfill due to explosion	Explosion in poorly ventilated building spaces with an ignition source, where methane levels exceed the LEL in the presence of oxygen.
Death by asphyxiation of workers or persons on or off the site	Occurrence of an oxygen deficient space such as a trench or excavation and carbon dioxide present.
Death or serious injury to workers in underground service pits/trenches on and near the site due to explosion	Explosion in a service pit, trench, drilling bore or excavation due to methane levels exceeding the LEL in the presence of oxygen and an ignition source.
Death by asphyxiation of workers in underground service pits/trenches on and near the site	Occurrence of an oxygen deficient space such as a trench or excavation and carbon dioxide present.
Chronic health effects to landfill visitors, workers & neighbours	Inhalation of indoor or outdoor air contaminated by LFG containing volatile compounds, in sufficient doses to be significant
Aesthetic impact on site users and nearby neighbours	Inhalation of LFG containing odorous compounds at sufficient concentration to be offensive

Possible event	How could event occur?
Destruction of infrastructure on and near the landfill site	Explosive demolition or damage to infrastructure above or below ground resulting from explosion of LFG
Damage to infrastructure on and near the landfill site due to corrosion	Corrosion due to contact with acidic LFG or condensates
Greenhouse gas emissions	Uncontrolled release of LFG to atmosphere contributing to global warming

7.4 Risk criteria

A number of Australian and international criteria for LFG have been documented, presented in Table 20 and are pertinent for this assessment.

Table 20 - Landfill risk criteria

Aspect	CH_4			CO_2	O_2	Comment /
	(%v/v)	(%LEL)	Unit (ppm or mg/m2/s)	(%v/v)	(%v/v)	Reference
Methane Upper Explosive limit (UEL)	15	>100				Safework Australia
Methane Lower Explosive Limit (LEL)	5	100				Safework Australia
Methane concentration in soil at a landfill boundary	1	20		1.5		Above background; NSW EPA 2016
Methane concentration in underground services on and off site	1	20		1.5		Above background; NSW EPA 2016
Methane in building/structures on an off-site	1	20		1.5		NSW EPA 2016
Methane concentration through the landfill surface final cover areas and penetrations through it			500 ppm			NSW EPA 2016
Methane concentration within immediate vicinity of penetrations through final cover			1000 ppm			VIC EPA BPEM (2015)
Methane concentration of landfill surface intermediate cover areas not within immediate area of any surface penetrations			0.1 $mg/m^2/s$			VIC EPA BPEM (2015)
Buildings/structures on and adjacent to the site	1	20		1.5		VIC EPA BPEM (2015)

Aspect	CH_4 (%v/v)	(%LEL)	Unit (ppm or mg/m2/s)	CO_2 (%v/v)	O_2 (%v/v)	Comment / Reference
Subsurface services on and adjacent to the site	1	20		1.5		VIC EPA BPEM (2015)
Carbon Dioxide – potentially dangerous to Life or Health				4-25		NIOSH NTIS Pub PB-94-195047
Oxygen concentration needed to sustain breathing					18	Safework Australia

UK EA (2004). *Guidance on the management of landfill gas*. Environment Agency for England and Wales.
Safework Australia, *Guidance on the Interpretation of Workplace Exposure Standards for Airborne Contaminants*.
NSW EPA (2016). *Environmental Guidelines, Solid Waste Landfills*. New South Wales Environment Protection Authority.
VIC EPA (2015). *Siting, design, operation and rehabilitation of landfills, Best Practice Environmental Management* (BPEM). Environment Protection Authority Victoria.
NIOSH (1994). *Documentation for Immediately Dangerous to Life or Health Concentrations*. National Institute for Occupational Safety and Health.

8.0 LANDFILL GAS RISK ASSESSMENT

8.1 Methodology

Four sources of guidance were used to develop the risk assessment:

- NSW Department of Planning and Infrastructure (DOP 2011):
  - Assessment Guideline – Multi-level Risk Assessment.
  - Hazardous Industry Planning Advisory Paper No. 3 – Risk Assessment (HIPAP 3).
  - Hazardous Industry Planning Advisory Paper No 6 – Hazard Analysis (HIPAP 6).
- NSW EPA Guidelines for the Assessment and Management of Sites Impacted Hazardous Ground Gases (2012).
- Construction Industry Research and Information Association (CIRIA), 'Assessing Risk Posed by Hazardous Ground Gases to Buildings', Report No. (C665, 2007) and C152 (1995) 'Risk assessment for methane and other gases from the ground'.

NSW (2012) has been developed from CIRIA C665 and recognizes this document as the most comprehensive and relevant guidance for risk assessment in the specific context of ground. This document sets out detailed, practical procedures for the assessment of risk due to bulk ground gases, and has been used in the preparation of this risk assessment.

The *Assessment Guideline – Multi-Level Risk Assessment* (DOP 2011) recommends a three-stage risk assessment approach involving:

- Preliminary screening
- Risk classification and prioritisation
- Risk analysis and assessment

The guideline states that this approach should be built around a consequence-based screening method and a rapid risk classification technique. The level of risk assessment undertaken should be limited to that necessary to support an appropriate remedial solution or to justify a decision that no action is required.

The methodology steps adopted for this risk assessment is summarized as follows:

- Preliminary screening
- Level 1 Risk analysis and assessment (qualitative)
- Level 2 Risk analysis and assessment (semi-quantitative based on borehole flow rates)
- Level 3 Risk analysis and assessment (simple quantitative based on fault tree arithmetic method).

- Level 1 of a multi-level risk assessment – trace ground gases (NSW 2012)

8.2 Preliminary screening

The methodology described in NSW 2012 was use to undertake a preliminary screening and a simple risk model developed from the initial conceptual site model compiled as described in Section 3 of the NSW 2012 guidelines.

A screening-level risk model identifies:

- potential sources of ground gas
- receptors that could be affected
- possible pathways (linkages) by which gas could reach receptors.

The screening process should provide answers to three questions:

1. Is the CSM based on sufficient, reliable site information to allow its use for screening purposes?
2. Is there a potential source of bulk ground gas?
3. Is there a credible pathway between the source and the receptors?

If the answer to Question 1 is no, then additional information must be obtained before screening can proceed. If the answer to Question 1 is yes, and the answer to either Question 2 or Question 3 is no, then there should be no risk, so that further risk assessment will be unnecessary, and no action to manage bulk ground gas risk will be required. In these circumstances, it is only necessary to document the findings of the preliminary screening assessment; no further data collection or assessment is required.

We consider the answer to all three questions is yes, so the risk assessment has proceeded to Level 1 type assessment as described in NSW 2012.

8.3 Level 1 Risk analysis and assessment

A Level 1 Risk Assessment has been undertaken in accordance with NSW EPA (2012) Guidelines. This guideline presents qualitative measures of impact, likelihood and consequence that are appropriate for the Site.

Consequences and likelihood classifications use for this assessment are presented in Table 21 to Table 24. *Source: NSW EPA (NSW EPA, Nov 2012) and CIRIA C665 (CIRIA, 2007)*

Table 21 - Classification of Consequence

Classification	Definition	Examples
Severe	Fatalities, including multiple fatalities Very serious injuries Catastrophic damage to buildings	Explosion causing building collapse
Medium	Long-term damage to human health Serious injuries Major damage to structures	Permanent injuries Structural damage requiring major repair or demolition and rebuild
Mild	More significant non-permanent injuries Significant damage to buildings, structures or services	Fractures, burns, gas inhalation or other injuries requiring medical treatment Severe cracking requiring closure of building and urgent repair
Minor	Minor non-permanent health effects. Harm that may result in financial loss, business disruption or reputational damage Minor property damage	Minor cuts, bruises requiring first-aid treatment Cosmetic damage to buildings or pavement Damage to landscaping Minor damage to vehicles

Source: NSW EPA (NSW EPA, Nov 2012)

Table 22 - Classification of likelihood

Classification	Definition
High Likelihood	A credible linkage exists and a trigger hazardous event is very likely to occur in the short term, and almost inevitable over the full timeframe of concern (Typically the effective life of a building or development). The likelihood of the stated consequence is also high.
Likely	A credible linkage exists and all necessary elements required for a trigger hazardous event to occur are present. Occurrence is not inevitable, but it is possible in the short term, and probable over the full timeframe of concern. The stated consequence is likely
Low likelihood	A credible linkage exists and circumstances under which a trigger hazardous event could occur are possible. However, it is by no means certain that the event will occur within the timeframe of concern, and it is less likely in the short term. Thus there is a low likelihood that the stated consequence will occur.
Unlikely	A credible linkage exists but circumstances are such that it is improbable that a trigger hazardous event would occur within the timeframe of concern, and therefore unlikely that the stated consequence will occur.

Source: NSW EPA (NSW EPA, Nov 2012) and CIRIA C665 (CIRIA, 2007)

Table 23 - Qualitative Risk Assessment Matrix

		Consequence			
		Severe	Medium	Mild	Minor
Probability	Highly Likely	Very High Risk	High Risk	Moderate Risk	Moderate/low risk
	Likely	High Risk	Moderate Risk	Moderate/Low Risk	Low Risk
	Low Likelihood	Moderate Risk	Moderate/Low Risk	Low Risk	Very Low Risk
	Unlikely	Moderate/Low Risk	Low Risk	Very Low Risk	Very Low Risk

Source: NSW EPA (NSW EPA, Nov 2012) and CIRIA C665 (CIRIA, 2007)

The data presented in Table 15 is considered to be representative of the Site condition and reliable for use in conducting a risk assessment. Based on a Level 1 Risk Analysis and Assessment the initial category has been determined to be *'Very High Risk'* due to the identified likelihood and severe consequences of an explosive incident occurring. The residual risk status of the development following implementation of appropriate mitigation and management systems is reduced to *'Low risk'*.

The primary hazard has been identified as an explosion or fire occurring due to an accumulation of methane within on-Site buildings. The results presented in Table 24 and Table 25 summarise a qualitative considered opinion and analysis of the risks potentially associated with LFG at the Site. A Level 1 risk assessment is included within **Appendix C**.

We have identified a number of potential options to manage the risks identified due to the presence of LFG, consisting of a number of passive measures. These are discussed in the following sections.

Table 24 - Level 1 risk assessment summary (migration of methane and carbon dioxide through soil and fill material)

Aspects	Hazards	Pathways	Receptors	Potential Impacts	Categories		Ranking (LxC) of risk before control measures	Potential control measures	Categories		Ranking (LxC) of residual risk following implementation of control measures
					Likelihood (L)	Consequence (C)			Likelihood (L)	Consequence (C)	
Land	Entry of LFG into building on site	Gas migration through unsaturated Soil under building	Occupants of the development	Death or serious injury due to explosion	3	4	Very high risk	Natural attenuation and oxidation of methane and LFG in the landfill cap Implementation of LFG monitoring program Hot work permits and restricted areas for hot work/potential ignition sources. Installation of low permeability layer and passive ventilation system under building	1	4	Low risk
				Asphyxiation due to low oxygen and high carbon dioxide	2	4	Moderate risk	Material under depot will have low permeability to LFG Indoor monitoring in the building and passive venitilation system allowing LFG to vent freely to the surface where it will be oxidised	1	4	Low risk
			Residential dwellings off-site	Death or injury due to fire or explosion (presence of methane and ignition sources)	2	4	Moderate risk	LFG monitoring bores and monitoring program. Release of any potential accumulation of LFG and migration by advective pressure as high permeability site surface proposed (gravel and crushed rock)	1	4	Low risk
				Asphyxiation due to low oxygen and high carbon dioxide	1	4	Low risk				

Table 25 - Level 1 risk assessment summary (migration of methane and carbon dioxide through services)

Aspects	Hazards	Pathways	Receptors	Potential Impacts	Categories		Ranking (LxC) of risk before control measures	Potential control measures	Categories		Ranking (LxC) of residual risk following implementation of control measures
					Likelihood (L)	Consequence (C)			Likelihood (L)	Consequence (C)	
	Gas entry to underground services or in the ground.	Gas migration via underground service trenches and incoming feeders through the landfill	Occupants of the development	Death or serious injury due to explosion	4	4	Very high risk	Low permeability seal around pipes and in service ducts/trenches. Periodic and regular monitoring of pits Grates and venting of service pits	1	4	Low risk
			Construction workers excavating trenches	Death of serious injury due to explosion	1	4	Low risk	Accumulation is not likely to occur as trenches are open to atmosphere and LFG will be diluted to acceptable concentrations. Hot work permits and restricted areas for hot work/potential ignition sources. No smoking on-site and LEL monitors used with Construction Environmental Management (CEMP)/Environmental Management Plan (EMP)	1	4	Low risk
				Asphyxiation due to low oxygen and high CO2	1	4	Low risk	Personal LEL monitors and no entry into pits or trenches greater than 1.2m deep Implementation and enforcement of Environmental Management Plan (EMP) and construction plan	1	4	Very low risk
			Support infrastructure	Corrosion of in piers, walls and ground infrastructure due to acidic LFG or condensate	1	2	Low risk	Gas membrane and tanking membrane will prevent exposure to any potential leachate. Concrete resistant to attack from acidic LFG and leachate	1	1	Very low risk

8.4 Risk summary – Level 1

The risk priorities identified as unacceptable red are summarised with recommended control measures in the following sections:

8.4.1 Risks to occupants of the future development

The risks of serious injury as a result of methane accumulation in spaces and voids via transport through the soil and preferential pathways (without the installation of a gas mitigation remedial system) was considered '*very high risk'* without the implementation of control measures.

Potential control measures that reduced the category to low risk were:

- Installation of low permeability layer and pressure relief system under building
- Natural attenuation and oxidation of methane in the landfill cap
- Implementation of LFG monitoring program and Landfill Gas Management Plan (LFGMP)
- Hot work permits and restricted areas for hot work/potential ignition sources

8.4.2 Risks to on-site construction workers

The Level 1 risk assessment identified several potential impacts that still had a severe consequence but low probability therefore, a lower priority to on-site construction workers but required addressing in the construction phase:

- Asphyxiation due to low oxygen and high carbon dioxide.
- Exposure to VOCs whilst trenching or excavation works.

The following control measures, in addition to existing measures, were identified to mitigate the risks identified above:

- Strictly no smoking or naked lights within on site at any time.
- Confined space protocols.
- Hot work permits to be issued and the work to be restricted to areas away from potential sources of LFG.
- Personal LEL monitors to be worn by personnel working in close proximity to exposed waste.

8.5 Risks to off-site receptors during the construction phase

The risks to off-site receptors should not be significantly altered as a result of the construction works.

As previously noted there are no LFG monitoring bores outside the footprint of the waste mass, therefore it is not known if LFG is currently migrating off-site.

Other risks associated with construction are exposed waste and waste excavations that may cause odours. In certain wind and atmospheric conditions there may be off-site migration of odour if not appropriately managed.

The following control measures in addition to existing measures (landfill capping) are recommended to mitigate the risks identified above:

- Ambient monitors should be employed to ensure offensive odours are minimised.
- Waste stockpiles should be removed from site or covered immediately.
- The detailed odour management measures should be part to the Environmental Management Plan (EMP).

8.6 Level 2 risk analysis and assessment

Given that the Level 1 Risk Analysis and Assessment concluded that a potential unacceptable risk level exists, a Level 2 assessment has been undertaken. A maximum Gas Screening Value (GSV) and Characteristic Gas Situation (CS) for the Site has been determined based upon Table 6 of the NSW EPA (2012) Guidelines.

The method considers both gas concentrations and borehole flow rates to define a Characteristic Situation (CS) for a Site using a calculation of the GSV, refer to Table 26. The GSV is a multiple of the maximum gas flow rate (litres/hour) from a borehole and the maximum gas concentration (%v/v).

All gas monitoring locations were assessed for relevant landfill gas constituents, weather conditions, soil moisture, flow rates, differential pressure and barometric pressure were recorded. All sample locations reported concentrations of CH_4, CO_2, CO concentrations above the detection limit of the landfill gas analyser (GFM430) as shown in Table 15.

The monitoring data collected during Site investigation works is considered to be representative of the Site condition and reliable for use in conducting a risk assessment. The primary hazard has been identified as an explosion occurring due to the presence of methane in the explosive range, either by:

- An accumulation of methane concentrations within the explosive range within on-site buildings, resulting in an explosion; or
- The exposure of machinery during the construction phase to in-situ methane concentrations in the explosive range, causing an explosion.

The consequences of an explosion on site are deemed to be severe given that fatalities, very serious injuries and/or catastrophic damage to buildings may occur. The probability of this occurring is considered to be likely given the credible linkage based upon the CSM for all necessary elements required for a hazardous event to occur. Based on a Level 1 Risk Analysis and Assessment the risk has been determined to be '*very high risk'* due to the identified likelihood and severe consequences of an explosive incident occurring.

Table 26 - Modified Wilson and Card Classification (Table 6 NSW EPA 2012)

	Characteristic situation	Risk Classification	Gas Screening Value Threshold (GSV) (CH_4 or CO_2) (l/hr)	Additional Factors	Typical source of generation
	1	Very low risk	<0.07	Typically, Methane 1.0 % v/v and/or Carbon Dioxide 5 % v/v. Otherwise consider increase to Situation 2	Natural soils with low organic content "Typical" fill
	2	Low risk	<0.7	Borehole air flow rate not to exceed 70l/hr. Otherwise consider increase to characteristic Situation 3	Natural soil, high peat/organic content. "Typical" made ground
	3	Moderate risk	<3.5		Old landfill, inert waste, mine-working flooded
	4	Moderate to high risk	<15	Quantitative risk assessment required to evaluate scope of protective measures.	Mine-working – susceptible to flooding, completed landfill (WMP 26B criteria)
	5	High risk	<70		Mine-working Un-flooded inactive with shallow workings near surface

	Characteristic situation	Risk Classification	Gas Screening Value Threshold (GSV) (CH_4 or CO_2) (l/hr)	Additional Factors	Typical source of generation
	6	Very high risk	>70		Recent landfill site

GSVs have been calculated for each borehole under consideration (summarised in Table 27) due to limited monitoring data, the calculation was carried out conservatively for methane and carbon dioxide with the worst-case monitoring values adopted at each monitoring location. The GSV calculation was performed and a range of 0.0 (very low risk) to 5.17 (Moderate to High Risk) was recorded.

Table 27 - Gas Screening and Characteristic Gas Situation Values

ID	Worst Case Values			GSV (l/hr) (CH_4)	GSV (l/hr) (CO_2)[1]	Characteristic Gas Situation	Risk
	CH_4 (%v/v)	CO_2 (%v/v)	Flow (l/hr)				
BH1	1.4	13.8	0.0	0.0	0.0	1	Very Low
BH2	63.8	17.7	8.0	5.17	1.18	4	Moderate to High
BH4	70.8	16.8	6.0	4.25	1.01	4	Moderate to High
BH5	58.5	26.9	3.9	2.28	1.05	3	Moderate
BH7	64.0	27.6	3.4	2.18	0.94	3	Moderate
BH8	39.5	18.4	1.6	0.63	0.29	2	Low

Based upon the findings of Table 27, a corresponding CS4 of *Moderate to High Risk* for the Site is recommended. In accordance with NSW guideline requirements, gas protection measures for the Site are required.

8.7 Level 3 – methane intrusion modelling and fault tree risk analysis

8.7.1 Introduction

The methodology developed and applied by DLA to the assessment of LFG risks is based on the 'Fault Tree Analysis' described in CIRIA 152. In summary, this is quantitative methodology[5] that follows a sequential process of identifying the risks, as well as their likelihood and significance or severity of impact (also called consequences).

- Refinement of CSM of the landfill and its surrounds, including evaluation of potential gas sources, pathways of migration and entry, potentially affected receptors and gas controls.
- Identification of hazards and risk screening.
- Simple Quantitative Risk Assessment.

8.7.2 Methane intrusion modelling

In order to estimate the potential flow of methane through the underlying soil two different techniques were used.

Darcy's method

The Darcy equation is based upon the intrinsic permeability of the soil or rock through which the gas is flowing. The intrinsic permeability (K_i) can be determined by the parameters described within Table 28 (Wilson, 2009).

Table 28: Intrinsic Permeability Inputs

Parameter	Unit	Input
Hydraulic Permeability of soil (K_{darcy})	m/s	3.30×10^{-7}
Dynamic viscosity of water (μ)	Ns/m^2	1.002×10^{-3}
Density of water (*p*)	kg/m^3	1000
Gravitational constant (g)	m/s^2	9.81
Intrinsic permeability of material (K_i)	**m^2**	**3.37×10^{-14}**

Based upon drilling records undertaken during the detailed site investigation (DLA, 2016) and a geotechnical investigation (Douglas Partners, 2016), the capping soil was considered to predominantly consist of a slightly compacted sandy clay with a hydraulic permeability of 3.3×10^{-7} m/s. The dynamic viscosity of water, density of water and gravitational constant is based upon published information

[5] Although CIRIA classify this as a quantitative assessment it is the opinion of DLA that due to the subjective nature of the various steps that the assessment should be used for information only.

(Wilson, 2009). The gas pressure gradient (*i*) along the migration route is determined by the following parameters described in Table 29 (Wilson, 2009).

Table 29: Gas Pressure Gradient Inputs

Parameter	Unit	Input
Gas Pressure (Pa)	Pa	47
Unit weight of gas (y)	N/m^3	7.2
Length (migration distance, m)	m	2
Width of migration (m)	m	100
Pressure gradient along migration route	**Pa**	**3.26**

Gas pressure was determined by the worst recorded borehole gas pressure during monitoring which was 47 pa or 0.47 mb i.e. less than the lower sensitivity if the GFM430. The migration distance was considered to be the average thickness of the landfill capping layer of 2 metres and a width of migration of 100 metres to emulate the Site length. The unit weight of methane gas and viscosity of gas (methane) is based upon published information (Wilson et al, 2009). The area of migration is $4000m^2$ as shown on **Appendix D** - Figure 1. Pressure driven flow can be modelled by Darcy's law of fluid flow through porous media for both horizontal and vertical gas flow by the inputs described within Table 28, Table 29 and Table 30 (Wilson, 2009).

Table 30: Darcy's Law Inputs

Parameter	Unit	Input
Unit weight of Methane gas (y)	N/m^3	7.2
Viscosity of gas (methane) being considered (μ)	Ns/m^2	$1.03x10^{-5}$
Area of migration (A)	m^2	4000
Flow of gas (Q_v)	**m^3/hr**	**1.107**

Peckson Method

This method calculates the emission rates from gas flow and concentration measurements from boreholes. Flux box testing has shown that the Peckson Method is generally conservative by a factor of at least 10 and possibly up to 100 (Wilson, 2009). The rationale is as follows:

The area of which the particular borehole degases is assumed to be $10m^2$. The maximum measured methane concentration during monitoring on the Site was 63%[6] with a maximum measured flow rate of 10 l/hr. The surface emission rate of gas was determined by the following parameter inputs as described within Table 31.

[6] From trace gas analysis results

Table 31: Surface Emission Rate Inputs

Parameter	Unit	Input
Gas concentration as ratio (c)		0.63
Borehole flow rate (Q_{bh})	m^3/hr	0.01
Area for radius of influence (A_r)	m^2	10
Surface emission rate of gas (E_{gas})	**$m^3/hr/m^2$**	**$6.30x10^{-4}$**

The hourly methane flow rate was determined for the building footprint by the following parameter inputs as described within Table 32.

Table 32: Methane Flow Inputs

Parameter	Unit	Input
Surface emission rate of gas (E_{gas})	$m^3/hr/m^2$	$6.30x10^{-4}$
Area intersecting landfill (A)	m^2	4000
Methane flow (q_m)	**m^3/hr**	**2.52**

8.7.3 Fault tree analysis

The 'Fault Tree' method is described in CIRIA 152. In principle, the methods starts with the adverse event or 'Top Event' and works through multiple pathways and steps (events) to identify the multiple possible causes and effects of the event.

Probabilities are assigned to each event or fault and an overall probability of occurrence of the Top Event calculated. The methodology sequence is presented from CIRIA 152 in Figure 3. For the Site development, the following Fault Tree Analysis for the '*Explosion Event'* analysis has been developed.

Top Event: Failure to Prevent a Methane Explosion

The worst conceivable adverse event at the Site is an explosion where an occupant of the building subsequently dies or is seriously injured. The perception may be that this is highly unlikely or a low probability, given the control measures, the lack of significant advective gas flow. However, it remains as a possible, and for many people an unacceptable risk. The following sequence identifies the critical elements and probabilities of the chain of failures[7] that would need to happen for this to event to occur.

[7] The outcome of the Fault Tree analysis is termed quantitative. DLA considers some of the input steps to ascertain the probability of the event occurring are somewhat subjective. CIRIA 152 also recommend that caution should be given where numerical values are used and that professional judgement is employed in the selection if mitigating engineering measures

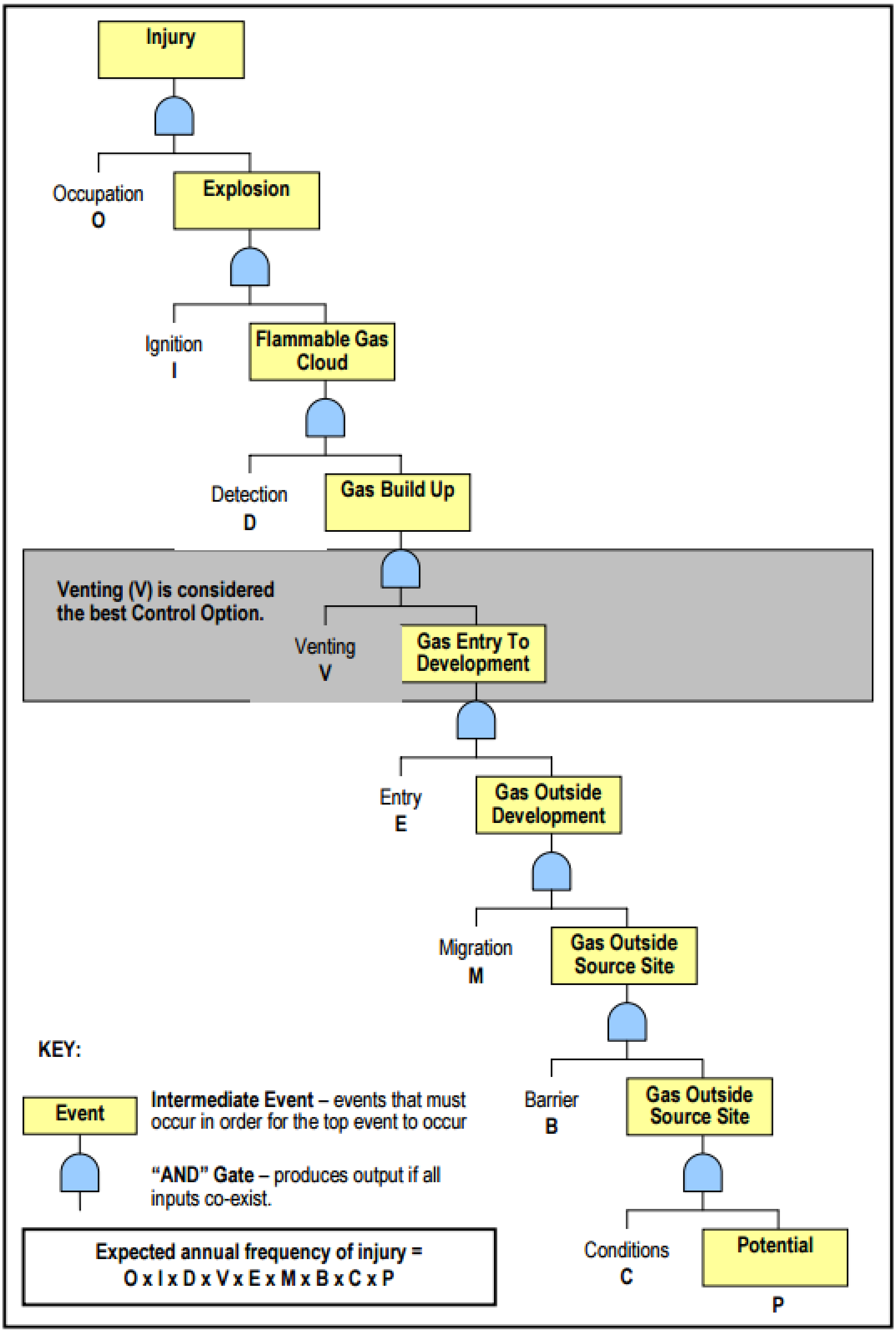


Figure 3 - Fault tree analysis sequence (CIRIA 152)

Failure to prevent OCCUPATION of development (O)

This step requires the probability of that the part of the development susceptible to a methane explosion is occupied. Houses are typically occupied approximately 80 % of the time whereas office blocks are occupied approximately 40 % of the time.

The proposed Site use will be occupied 100 % of the time therefore, makes this failure a near certainty to occur.

Failure to prevent IGNITION of the accumulated gas source (I)

The development will have multiple potential ignition sources in the form of the ground floor transformer room, electrical appliances, light switches and power points and boilers. Avoidance of the electrical ignition sources would require the use of 'intrinsically safe' electrical equipment such as those used in a petroleum industry facility. Such a requirement is unreasonable and not likely to occur. Therefore, the failure to prevent an ignition source would also need to be assumed to be a near certainty to occur.

It is assumed the possible frequency of ignition is 3650 per year. Sparks from switch room and light switches located in confined spaces in the lower ground floor levels (10 times per day for one year)

Failure to DETECT methane in the development (D)

This mode of failure is generally taken to approach certainty as LFG monitors are rarely deployed in residential developments in the general community (CIRIA, 1995) and not planned for this development, therefore:

Failure to VENTILATE adequately (V)

The ventilation status of the building is a critical factor in preventing the accumulation of a potentially explosive methane gas cloud. In principle, the gas cloud cannot accumulate if the rate of gas entry is exceeded by the rate of ventilation. This seems obvious for a case where a high rate of gas ingress (advective flow under pressure) to occur. However, it is also relevant where a very slow rate of gas ingress occurs by diffusive flow. In the latter case, the gas cloud can accumulate if the building is left closed up or is poorly ventilated.

DLA have used a vapour intrusion model to assess methane gas intrusion into the ground floor club room. In addition to this passive ventilation designed into the building, ventilation occurs incidental to entry and exit of persons through the main louvres at each of the club room, doors, opening of windows, use of forced ventilation evaporative coolers. Due to the use of the basement floor for recreational use, it is considered that a value of 1 air change per hour (10 per day) is a realistic figure.

Surface emission rates based upon two scenarios:

- Slab with installed membrane barrier and appropriate quality control
- Slab without membrane barrier
- Surface emissions for both scenarios are included within Table 33.

Table 33: Surface emission rates

Scenario		Millilitre/day/m^2	Cubic Metre/hr/m^2	Cubic Metre/Building area/year
A	With membrane barrier	40	1.67×10^{-6}	58.4
B	Without membrane barrier (Darcy Method)	6,644.4	2.77×10^{-4}	9,700.85
B	Without membrane barrier (Peckson Method)	15,120.0	6.3×10^{-4}	22,075.2

Based upon the surface emission rates contained within Table 33, a 99.4% reduction in potential methane entry through the building slab by the installation of a liquid boot methane barrier is achieved. The hours to fill a 0.8 m^3 cupboard to 5 %v/v methane is reached within the following time periods as described within Table 34.

Table 34: Time periods and risks of occurrence

Scenario		Time to reach 5% methane (vol/vol) (days)	Risk of occurrence
A	With membrane barrier (Darcy Method)	1003	9.68×10^{-31}
A	With membrane barrier (Peckson Method)	440.9	3.6×10^{-27}
B	Without membrane barrier (Darcy Method)	6	1.62×10^{-8}
B	Without membrane barrier (Peckson Method)	2.6	5.9×10^{-5}

5. Failure to prevent methane ENTRY into building (E)

The inclusion of a gas barrier has a significant effect on the entry of gas. With appropriate quality control procedures in place, probability of premature failure is considered to be well below 0.1. For this scenario, the probability of a crack in the concrete slab is nominated at 0.001 for Scenario A and 0.1 for Scenario B.

6. Failure to prevent methane MIGRATION into building (M)

The migration of gas from a source to the development is controlled by three parameters: the pressure gradient, the distance and the soil permeability. The chance of occurrence is considered to be of the same likelihood than the probability of failure described within failure item 4.0.

7. Failure of any confining BARRIERS (B)

The potential for membrane barrier failure is considered to be no greater than 0.1. Therefore, a value of 0.1 is nominated as worst case value for Scenario A and a value of 1.0 for Scenario B is nominated.

8. Failure to prevent methane POTENTIAL (P)

The landfill is known to be gassing and therefore the value nominated for both scenarios is 1.0.

9. Failure to prevent suitable CONDITIONS for methane generation (C)

Atmospheric, temperature and moisture contents all affect the suitable conditions for the generation of methane. As suitable conditions currently exist for methane generation at the Site, both scenarios are given a value of 1.0.

A summary of the likelihood of failure per failure item is described within Table 35.

Table 35: Likelihood of failure per failure item

Failure Item		Scenario A With barrier (Darcy Method)	Scenario A With barrier (Peckson Method)	Scenario B Without barrier (Darcy Method)	Scenario B Without barrier (Peckson Method)
1	Failure to prevent OCCUPATION	1	1	1	1
2	Failure to prevent gas cloud IGNITION	3650	3650	3650	3650
3	Failure to DETECT a gas cloud	1	1	1	1
4	Failure to Ventilate adequately	9.688×10^{-31}	3.601×10^{-27}	1.602×10^{-8}	5.955×10^{-5}
5	Failure to prevent methane ENTRY into building	0.001	0.001	0.1	0.1
6	Failure to prevent methane MIGRATION to the development	9.688×10^{-31}	3.601×10^{-27}	1.602×10^{-8}	5.955×10^{-5}
7	Failure of any confining BARRIERS	0.1	0.1	1	1
8	Failure to prevent methane POTENTIAL	1	1	1	1

Failure Item		Scenario A With barrier (Darcy Method)	Scenario A With barrier (Peckson Method)	Scenario B Without barrier (Darcy Method)	Scenario B Without barrier (Peckson Method)
9	**Failure to prevent suitable CONDITIONS for methane generation**	1	1	1	1
	Probability of Failure	**3.43×10^{-61}**	**4.73×10^{-54}**	**9.37×10^{-14}**	**1.29×10^{-6}**

The probability of failure for Scenario A is considered to be between 3.43×10^{-61} and 4.73×10^{-54} by the use of the Darcy and Peckson calculation methodologies. It is therefore considered that the probability of failure for Scenario A is within an allowable tolerable risk range.

The probability of failure for Scenario B is considered to be between 9.37×10^{-14} and 1.29×10^{-6} by the use of the Darcy and Peckson calculation methodologies. Based upon the CIRIA Report 152, a tolerable level of risk is considered to be between 10^{-6} and 10^{-7}. It is therefore considered that the probability of failure in Scenario B is on the threshold of an allowable tolerable risk.

8.8 Vapour intrusion assessment

The landfill gas sample taken on 6 September 2016 was analysed for trace gases. The analysis showed the presence of a range of VOCs and these have been screened to assess the potential for vapour intrusion and the subsequent risk to human health. As this analysis is based on only one sample the results can only be considered as a preliminary screening analysis and indicative of the potential risk. It has been undertaken to help to inform the landfill gas management options for the site. The number of samples that were available for this assessment cannot be considered as fully characterising the site.

The assessment was undertaken in accordance with the Guidelines for Assessment and Management of Sites Affected by Hazardous Ground Gases (NSW EPA, 2012) and the Technical Practice Note – Vapour Intrusion (NSW EPA, 2010) with the caveat that there was limited sampling available.

8.8.1 Level 1 Screening Assessment

Samples of the soil gas were taken on 6 September 2016 at one bore hole on site. These samples were analysed for the USEPA TO15 suite of VOCs, sulphonated compounds and ozone precursors. The details on the sampling, sampling methods, QA/QC and analysis methods are discussed in Section 5.0 of this report. Given that sampling was only undertaken on one day at one location on the site this vapour intrusion assessment can only be considered as a preliminary assessment to guide the development of the management plan for hazardous gases from the landfill.

The results of the sampling have been screening against the Health Screening Levels (HSLs) for vapour intrusion (soil gas) in the Assessment of Site Contamination NEPM [ASC NEPM] (2013). As only a limited number of HSLs are available in the NEPM, for the other contaminants that were above the level of detection of the analysis method, a Level 1 screen has been undertaken using the Screening Levels from the New Jersey Department of Environmental Protection (2016). The use of international values in the absence of Australian values is consistent with the requirements of the NEPM and the NSW EPA guidance (2010). The New Jersey Screening values are the most recent international values and reflect the current understanding of the health effects associated with exposure to these contaminants. As the proposed use of the ground floor of the building is commercial use, the HSL D for sandy soil has been used.

The results of the screening are shown in Table 36. The values in bold show exceedances of the screening levels.

Table 36: Screening of Soil Gas Concentrations against Soil Gas Screening Levels

Contaminant	Concentration (mg/m^3)	Soil Gas Screening Level (mg/m^3)	Source
Vinyl Chloride	**0.65**	0.1*	ASC NEPM (2013)
Chloroethane	0.57	2200	NJDEP (2016)
Trichlorofluoromethane	0.23	150	NJDEP (2016)
Carbon Disulfide	0.31	150	NJDEP (2016)
Hexane	39	150	NJDEP (2016)
Cis-1,2-dichloroethene	0.2	0.3*	ASC NEPM (2013)
Benzene	6.2	10	ASC NEPM (2013)
Cyclohexane	27	1300	NJDEP (2016)
Toluene	0.88	16000	ASC NEPM (2013)
Tetrachloroethene (PCE)	0.056	8*	ASC NEPM (2013)
Trichloroethylene (TCE)	63	80	ASC NEPM (2013)
Chlorobenzene	7.8	11	NJDEP (2016)
ethylbenzene	1.5	4600	ASC NEPM (2013)
Xylenes	6.6	3200	ASC NEPM (2013)
Styrene	0.22	220	NJDEP (2016)
1,4-dichlorobenzene	**3.3**	0.056	NJDEP (2016)
1,2-dichlorobenzene	0.47	44	NJDEP (2016)
1,2,4-trichlorobenzene	0.045	0.44	NJDEP (2016)
Naphthalene	2.4	15	ASC NEPM (2013)

*Interim soil vapour HIL for volatile organic chlorinated compounds (ASC NEPM, 2013)

As can be seen from Table 36, only vinyl chloride and 1,4-dichlorobenzene exceed the soil gas screening levels. For benzene, chlorobenzene, trichloroethylene and cis-1,2-dichloroethane the contaminant concentration is close to the screening level. It should be noted that the TCE concentration exceeds the residential soil gas screening level in the ASC NEPM (2013). Given the limited amount of data available these contaminants have been taken through for an initial screen of the potential risk to human health for the ground floor of the proposed development.

All other contaminants are well below the screening levels and can be considered, based on limited sampling, unlikely to pose a vapour intrusion risk.

8.8.2 Preliminary Vapour Intrusion Screening Assessment

A preliminary vapour intrusion screening assessment has been undertaken to provide an indication as to whether the measured soil gas concentrations that exceed the HSLs have the potential to impact on the health of the occupants of the proposed building. The screening assessment has also back calculated the sub slab concentrations that would be required to ensure that the intrusion of vapours into the ground floor space would not lead to unacceptable risks to the health of the building occupants. This information will help to inform the management actions that may be required to address trace gases as part of the landfill gas management plan. The assessment has been done based on the proposed building design. The ground floor of the development is proposed for commercial with the inclusion of a fitness centre. These scenarios have been assessed as part of the screening assessment. In addition, the more sensitive residential scenario has been assessed for completeness of the assessment.

The version of the USEPA Vapour Intrusion Screening Model used for the preliminary vapour intrusion risk assessment has been modified by the California EPA Department of Toxic Substances Control (2014). The changes to the model were to update the toxicity reference values used in the risk calculations and to enable modification of some of the input parameters such as building ventilation rates, exposure scenario data, and soil types. The toxicity data used in the model is the most recent data from the Office of Environmental Health Hazard Assessment (OEHHA), the USEPA IRIS Database including the chronic reference concentrations (RfCs) and the Agency for Toxic Substances and Disease Registry (ATSDR). The acceptable risk levels adopted in the assessment are those adopted by NSW EPA (2012) – cancer risk of 1 in 100,000 and hazard quotient of 1. The assessment was conducted for two scenarios: liner intact and liner failure.

8.8.2.1 Exposure pathways

The CSM for the site has identified that the proposed development will be built partially on part of the landfill. The details on the CSM for the site can be found in Section 4.0 of this report. The distance from the slab to the top of the landfill type waste material has been estimated to be approximately 2 m. Diagrams of the services shown in **Appendix D and Appendix I** indicate that the potential vapour intrusion pathways include the conduits for electrical, sewer, hydraulics, communications and gas services as well as four lift cores. The dimensions of these potential gaps were estimated from the diagrams supplied and were found to be a total of 67,550 mm^2.

For the purposes of the assessment the depth of the source below the building was assumed to be 200 cm which is the closest point of the landfill below the proposed development. This distance was used as the distance from the slab to the source in the model. The measured concentrations of the contaminants in soil vapour were used directly as being representative of the concentration entering the building if the liner fails. The air infiltration rate into the building was calculated based on calculations performed in Section 8.7. A reduction of 99.4% was applied to the air infiltration rates to the building to estimate the resultant concentrations indoors with the liner intact and the associated risk to occupants of the building. This factor is based on the permeability of the Liquid Boot which is proposed to be used as the liner. The ventilation rate for the building was assumed to be 0.5 air changes per hour which is typical of a 5-6 Star Energy Efficient building with the windows closed (in reality the ventilation rate is likely to be significantly higher than this due to open louvres on the ground floor). A sensitivity analysis was conducted to investigate the effect of building ventilation rates on indoor pollutant levels and associated health risk.

The soil type for the proposed site was found to be sandy clay. It is proposed that a sandy loam layer be placed prior to construction of the liner. The model was run for both sandy clay and sandy clay loam mix as the soil permeability is dependent on soil type. However, there was no difference in the results as a result of changing the soil type. The results reported are for the sandy clay soil.

8.8.8.2 Exposure Scenarios

The assessment has been conducted for the ground floor of the building as this is likely to be the level that is most affected by the potential vapour intrusion. The plans for the ground floor show a mix of commercial uses as well as a fitness centre. There are no plans for residential use for the ground floor of the proposed development. The scenarios that have been assessed however include a residential scenario as the most conservative as well as commercial use. A sensitivity analysis was conducted to simulate a frequent user of the fitness centre. The assumptions used for each scenario are shown in Table 37.

Table 37: Exposure Assumptions Used in the Vapour Intrusion Modelling

Scenario	Years Exposed	Number of Days per Year	Number of Hours per Day	Number of Days per Week
Commercial	40	240	8	5

Residential	70	350	24	7
Fitness Centre User	10	240	3	5

It should be noted that the scenario for the user of the fitness centre is for the most exposed person and most gym users would attend for lesser periods than this. Staff within the fitness centre are assessed as per the commercial scenario.

8.9 Results

8.9.1 Indoor Air Quality

The results of the soil vapour sampling were run through the Vapour Intrusion model to predict the indoor air concentrations for the contaminants of potential concern. The modelling assumes an air exchange rate of 0.5 air changes per hour which is typical of 5 and 6 star energy efficient buildings. The results of the model were compared to the air quality guidelines contained in Vapour Intrusion: Technical Practice Note (NSW DECCW, 2010). Additional air quality guidelines were sourced from the USEPA Reference Concentrations (RfC) for chronic exposure as recommended in NSW DECCW (2010). The predicted indoor air concentrations are shown in **Table 38**.

The NSW DECCW Technical Practice Note (NSW DECCW, 2010) requires consideration of ambient (outdoor) levels of air toxics that may impact on indoor levels. There is limited data available for NSW on ambient levels of air toxics with the most recent report published in 2004 (NSW EPA, 2004). This report summarises the results of a 5-year study at three sites in the Sydney Greater Metropolitan Region – central CBD, Rozelle and St Mary's. For the purposes of this assessment it was considered that the data from Rozelle would be the most representative for the proposed development at the Olympic Park site.

Ambient air quality data wasn't available for all contaminants of potential concern as is many cases the measured concentrations were below detectable limits. The average concentration for the contaminants for which data was available is shown in Table **38**.

Table 38: Predicted Indoor Air Concentrations for Contaminants of Potential Concern (µg/m^3)

Chemical	Indoor Air Concentration		Air Quality Guideline	Ambient Air Concentrations (NSW EPA, 2004)
	Liner Intact	Liner Failure		
Benzene	1.4	13	1.7	3.6
Vinyl chloride	0.2	1.6	1.1	0.3
Trichloroethylene	0.01	0.1	23	
Chlorobenzene	1.5	14	-	

1,4 - dichlorobenzene	0.5	4.5	800	
1,2,4-trichlorobenzene	0.005	0.044	-	

The results in **Table 38** show that, based on the limited soil gas concentrations measured for the site, for the liner intact scenario the predicted indoor concentrations for the COPCs are below the air quality guidelines (NSW DECCW, 2010), even with the ambient concentrations included. For benzene and vinyl chloride for the liner failure scenario the air quality guidelines are predicted to be exceeded.

As with the previous analysis, given the limited soil gas data, these results can only be considered as indicative as to whether the presence of the trace gases may pose a risk to the indoor air environment for the ground floor of the proposed development.

8.9.2 Preliminary Screening Risk Assessment

The screen of predicted air concentrations described above indicates that with the liner intact and the assumption that the measured soil gas concentrations are typical for the site, the indoor air concentrations are predicted to be within the guidelines set out in the NSW DECCW (2010) Vapour Intrusion Technical Note. For the liner failure scenario exceedances of the air quality guidelines for benzene and vinyl chloride may occur.

To assess the potential impact of the predicted indoor air concentrations on the health of the occupants of the building a preliminary screening risk assessment has been undertaken. This is not to be considered as a full quantitative risk assessment but as a screen to provide guidance as to whether the trace gases may pose a risk to human health. This information is intended to inform the landfill gas management plan.

The screening risk assessment has been conducted for a residential and commercial scenario for benzene, vinyl chloride, TCE, chlorobenzene, 1,4-dichlorobenzene and 1,2,4 - trichlorobenzene. The exposure and potential risk to users of the fitness centre has also been included.

The results of the vapour modelling shows that with the liner intact the risk from all pollutants was within the acceptable risk criteria for the commercial scenario. For the residential scenario, which assumes much longer exposure times, the results for benzene are borderline with meeting the carcinogenic acceptable risk level of 1 in 100,000. Based on the permeability of the Liquid Boot liner and the efficiency in reducing methane concentrations, it was assumed that the presence of the liner would reduce the soil gas concentrations by 99.4%. These results of the preliminary screening risk assessment are shown in Table 39:

Table 39: Results of Vapour Intrusion Risk Assessment with Liner Intact (µg/m³)

Chemical	Residential Scenario		Commercial Scenario		Fitness Centre User		Target Risk Level Carcinogens	Target Hazard Quotient
	Risk Level Carcinogens	Hazard Quotient Non-carcinogens	Risk Level Carcinogens	Hazard Quotient Non-carcinogens	Risk Level Carcinogens	Hazard Quotient Non-carcinogens		
Benzene	1.5×10^{-5}	0.5	6×10^{-6}	0.1	8×10^{-7}	2×10^{-2}	1×10^{-5}	1
Vinyl chloride	4.8×10^{-6}	0.002	2×10^{-6}	4×10^{-4}	3×10^{-7}	6×10^{-5}	1×10^{-5}	1
Trichloroethylene	1.7×10^{-8}	0.006	7×10^{-9}	1.3×10^{-3}	1×10^{-9}	2×10^{-4}	1×10^{-5}	1
Chlorobenzene	-	0.03	-	0.007	-	9×10^{-4}		1
1,4 – dichlorobenzene	2×10^{-6}	6×10^{-4}	8×10^{-7}	1.4×10^{-4}	1×10^{-7}	2×10^{-5}	1×10^{-5}	1
1,2,4-trichlorobenzene	-	3×10^{-4}	-	6×10^{-4}	-	7×10^{-5}		1

Numbers in bold indicate exceedance of acceptable risk criteria

The residential scenario has a range of conservative assumptions built into it including that people are exposed for 24 hours per day/7 days per week/ 350 days per year over a 70-year lifetime. It has also been assumed that the building is sealed with windows closed and a ventilation rate of 0.5 air changes per hour. Increasing the ventilation rate to 1 air change per hour brings the risk down to 7×10^{-6} which is within acceptable risk levels. This could be achieved by increasing mechanical ventilation or the opening of windows.

The proposed use for the ground floor of the development is commercial space and a fitness centre. Although people exercising in the fitness centre will have increased breathing rates, the amount of time that they are exposed will be much lower than that assumed for the residential scenario. This means that the associated risk will also be lower.

To test this assumption a scenario was run to assess the potential exposure of gym users. It was assumed that the most exposed people would attend the gym for a maximum of 3 hours per visit up to 5 times per week over a period of 10 years. All cancer and non-cancer risks are within acceptable risk criteria. The associated cancer risk from exposure to benzene under this scenario, which is the highest predicted risk, is 8×10^{-7}, well below the acceptable risk criteria. It should be noted that most gym users would attend for lesser periods than this and their risk would be reduced even further. The results for the fitness scenario are shown in Table 39.

The same model assumptions were run to gain an indication of the potential risk to building occupants that may arise if the liner were to fail. The soil gas concentrations for all contaminants were used as measured for this scenario – the assumption that there is complete failure of the liner. The results for both the residential and commercial scenarios are shown in Table 40. As can be seen from Table 40 the acceptable risk levels are predicted to be exceeded for benzene, vinyl chloride, and 1,4-dichlorobenzene in the residential scenario and for benzene and vinyl chloride in the commercial scenario. For the fitness scenario all predicted risks were within acceptable risk levels.

A sensitivity analysis was run to investigate the required ventilation rates within the building that would be required to reduce the indoor risk levels below the acceptable risk levels. For the residential scenario, the highest risk contaminant was benzene. Model runs were conducted varying the indoor air change rate between 0.5 and 6 air changes per hour. These results are shown in Table 41. For the liner failure scenario it would take up to 6 air changes per hour to reduce to indoor air concentrations within acceptable risk levels. For the other pollutants potential risk posed to building occupants from indoor air concentrations of the COPCs can be reduced within acceptable levels with 2 air changes per hour.

For the commercial scenario, again benzene was the highest risk contaminant and 5 air changes per hour would be required to bring the potential risk to the building occupants within acceptable risk levels. This would require a significant increase in ventilation rates in the building compared to a typical 5 or 6 star energy efficient building.

Table 40: Predicted Risk Levels for the Residential and Commercial Scenarios with Failure of the Liner (µg/m³).

Chemical	Residential Scenario		Commercial Scenario		Fitness Centre User		Target Risk Level Carcinogens	Target Hazard Quotient
	Risk Level Carcinogens	Hazard Quotient Non-carcinogens	Risk Level Carcinogens	Hazard Quotient Non-carcinogens	Risk Level Carcinogens	Hazard Quotient Non-		
Benzene	1.4×10^{-4}	4.2	5.5×10^{-5}	0.97	8×10^{-6}	0.14	1×10^{-5}	1
Vinyl chloride	4.5×10^{-5}	0.016	1.8×10^{-5}	0.004	2.6×10^{-6}	5×10^{-4}	1×10^{-5}	1
Trichloroethylene	1.5×10^{-7}	0.05	6×10^{-8}	0.01	9×10^{-9}	0.002	1×10^{-5}	1
Chlorobenzene	-	0.26	-	0.06	-	0.009		1
1,4 - dichlorobenzene	1.7×10^{-5}	0.005	7×10^{-6}	0.0012	1×10^{-6}	2×10^{-4}	1×10^{-5}	1
1,2,4-trichlorobenzene	-	0.02	-	0.005	-	7×10^{-4}		1

Numbers in bold indicate exceedance of acceptable risk criteria

Table 41: Impact of Increased Building Ventilation Rates on Predicted Risk Levels for Liner Failure Scenario (µg/m³) .

Chemical	Air Changes per Hour	Resultant Indoor Air Concentration µg/m³	Risk Level Carcinogens	Hazard Quotient Non-carcinogens	Target Risk Level Carcinogens	Target Hazard Quotient
Residential Scenario						
Benzene	0.5	13	1.4×10^{-4}	4.2	1×10^{-5}	1
	1	6.6	**6.8×10^{-5}**	2.1	1×10^{-5}	1
	2	3.3	**3.4×10^{-5}**	1	1×10^{-5}	1
	5	1.3	**1.4×10^{-5}**	0.4	1×10^{-5}	1
	6	1.1	1.1×10^{-5}	0.35	1×10^{-5}	1
Vinyl chloride	0.5	1.6	4.5×10^{-5}	0.02	1×10^{-5}	1
	1	0.8	**2.3×10^{-5}**	0.008	1×10^{-5}	1
	2	0.4	1.1×10^{-5}	0.004	1×10^{-5}	1
	5	0.16	4.5×10^{-6}	0.002	1×10^{-5}	1
	6	0.14	3.8×10^{-6}	0.001	1×10^{-5}	1
1,4 – dichlorobenzene	0.5	4.5	1.7×10^{-5}	0.005	1×10^{-5}	1
	1	2.2	9×10^{-6}	0.003	1×10^{-5}	1
	2	1.1	4.4×10^{-6}	0.001	1×10^{-5}	1
	5	0.5	1.7×10^{-6}	0.0005	1×10^{-5}	1
	6	0.4	1.5×10^{-6}	0.00045	1×10^{-5}	1
			Commercial Scenario			
Benzene	0.5	13	5.5×10^{-5}	0.97	1×10^{-5}	1
	1	6.6	2.7×10^{-5}	0.5	1×10^{-5}	1

	2	3.3	1.4×10^{-5}	0.2	1×10^{-5}	1
	5	1.3	5.5×10^{-6}	0.1	1×10^{-5}	1
	6	1.1	4.6×10^{-6}	0.08	1×10^{-5}	1
Vinyl chloride	0.5	1.6	1.8×10^{-5}	0.004	1×10^{-5}	1
	1	0.8	9×10^{-6}	0.002	1×10^{-5}	1
	2	0.4	4.5×10^{-6}	0.0009	1×10^{-5}	1
	5	0.16	2×10^{-6}	0.0004	1×10^{-5}	1
	6	0.14	1.5×10^{-6}	0.0003	1×10^{-5}	1
1,4 - dichlorobenzene	0.5	4.5	7×10^{-6}	0.0012	1×10^{-5}	1
	1	2.2	3.5×10^{-6}	0.0006	1×10^{-5}	1
	2	1.1	1.7×10^{-6}	0.0003	1×10^{-5}	1
	5	0.5	7×10^{-7}	0.0001	1×10^{-5}	1
	6	0.4	6×10^{-7}	0.0001	1×10^{-5}	1

Numbers in bold indicate exceedance of acceptable risk criteria

To help inform the LFG plan, the vapour intrusion screening model was run to determine the optimum sub-slab concentration required to ensure that even with liner failure that the risk to the health of the building occupants from indoor air concentrations of the COPCs were maintained within acceptable levels. These results are shown in Table 42. These have been calculated for both 0.5 and 1 air change per hour. If sub-slab concentrations measured in the void former (see Section 10.0) are below these target concentrations the risk to the occupants of the building in both the residential and commercial scenarios can be managed to be within acceptable risk levels.

Table 42: Target Sub Slab Soil Gas Concentrations to meet Acceptable Risk Levels on Ground Floor in the event of Failure of the Liner

Chemical	Air Changes Per Hour	Residential Scenario Target Soil Gas concentration µg/m^3	Residential Scenario Risk Level Carcinogens	Residential Scenario Hazard Quotient Non-carcinogens	Commercial Scenario Target Soil Gas concentration (ppm) (µg/m^3)	Commercial Scenario Risk Level Carcinogens	Commercial Scenario Hazard Quotient Non-carcinogens	Target Risk Level Carcinogens	Target Hazard Quotient
Benzene	0.5	500	1 x 10^{-5}	0.3	1100	1 x 10^{-5}	0.3	1 x 10^{-5}	1
	1	1000			2200				
Vinyl chloride	0.5	140	1 x 10^{-5}	0.003	350	1 x 10^{-5}	0.002	1 x 10^{-5}	1
	1	280			700				
1,4 - dichlorobenzene	0.5	2000	1 x 10^{-5}	0.003	5000	1 x 10^{-5}	0.002	1 x 10^{-5}	1
	1	4000			9500				

8.9.3 Summary of Preliminary Screening Vapour Intrusion Risk Assessment

A preliminary screening vapour intrusion risk assessment has been undertaken to help inform the development of the landfill gas management plan for trace gases. The results are based on very limited data and can only be considered as indicative and not a full quantitative risk assessment. Based on the soil gas sampling undertaken on 6 September 2016, with the exception of vinyl chloride, 1,4-dichlorobenzene benzene, chlorobenzene and cis-1,2-dichloroethane all measured values well below the HSLs in the ASC NEPM (2013) and the NJ DEP soil gas screening levels and are therefore unlikely to pose a vapour intrusion risk. For the contaminants that exceeded the HSLs, the predicted indoor air concentrations for benzene and vinyl chloride, based on limited soil gas monitoring, exceed the air quality guidelines recommended by NSW DECCW (2010).

The findings of the preliminary screening vapour intrusion assessment for these VOCs within the landfill gas indicate that with the liner intact the risk to occupants of the ground floor of the development for the commercial scenario are all within the acceptable risk criteria established by NSW EPA (2012). For the residential scenario the indicative risk potentially posed by exposure to benzene is at the acceptable risk level for carcinogenic risk. The risk can be brought within acceptable risk levels by increasing the building ventilation rate from 0.5 air changes per hour to 1 air change per hour. The proposed use for the ground floor of the development is commercial use and a fitness centre and the potential risks for these scenarios are within acceptable risk criteria.

In the event of liner failure the acceptable risk criteria are exceeded. Management actions such as activation of the sub-slab extraction system and increasing the air change rate within the building or establishing target sub slab contaminant concentrations should be considered to reduce the risk within acceptable levels. These options are discussed in Section 9.0 of this report. In addition, given the limited soil gas sampling available for this assessment and the screening nature of the assessment, consideration should be given to an indoor air monitoring program to ensure that the design of the building and the landfill gas management actions lead to indoor air concentrations of the VOCs that do not pose a risk to the health of the occupants of the building.

9.0 RECOMMENDATIONS

9.1 Ground gas protection basic design concept

Control of LFG migration is usually achieved by breaking the migration pathway between the identified gas source and the sensitive receptor(s). The pathway can be broken either at the source or at the receptor. Control at source typically involves capturing and containing gas emissions within a defined area, and ensuring the gas is safely managed. These techniques are normally applied to management of gas at landfills where, typically, gas extraction bores are installed, and gas is pumped from the wastes and combusted. The source being removed is a rare scenario and consideration can also be given to any potential for the removal of the receptor.

The second option involves protecting receptors (usually buildings) at risk from LFG sources. Buildings are usually at surface level, so the requirement for protection is to control vertical migration of gas from the ground. The concept of the passive dilution barrier is to form a low pressure area relative to the surrounding gassing ground, to encourage LFG to flow towards the barrier. This is achieved by incorporating a sub base void comprising of an efficient geo-composite layer acting as a preferential pathway which is connected to a collection/dilution duct running around the edge of the building.

The duct allows a diffusion of air in and gas, if present out, through it by means of a pressure relief system. Ventilation of the ducts can be achieved using a combination of vent stacks, bollards or ground level boxes. The choice of which depends on the final aesthetics of the building design, gas regime and wind conditions at the Site. The primary method of protection is then the creation of an envelope below the building. Given the inherent difficulties associated with prediction of gas levels within a building it is best practice to endeavour to dilute the LFG before it can enter the building. Concept design drawings are contained within **Appendix D**.

9.1.1 Site specific protection measures

As described within Section 8.0, the NSW EPA risk analysis and assessment methodology for the Site, a Characteristic Gas Situation (CS) of four (4) is deemed suitably representative of the gas situation for the Site. The ground floor level usage of the Site is considered to align with a '*Medium-high density residential (strata title)*' as described within Table 7 of the NSW EPA Guidelines (2012).

The nominated CS and nature of the proposed Site building corresponds to a Gas Protection Guidance Value for the Site of five (5) (Table 7, NSW EPA 2012) which is considered appropriate for Site conditions. It is recommended that the nominated protection measures are equivalent to this guidance value. Scores for each protection level is outlined within Table 43.

Table 43 - Scores for Protection Measures

Measure or system element	Score	Comments
Venting and dilution measures		
Passive sub-floor ventilation with very good performance (steady state concentration of methane over 100% of ventilation layer remains below 1% v/v at a wind speed of 0.3 m/s)	2.5	
Passive sub-floor ventilation with good performance (steady state concentration of methane over 100% of ventilation layer remains below 1% v/v at a wind speed of 1 m/s and below 2.5% v/v at a wind speed of 0.3 m/s)	1	If passive ventilation cannot meet this requirement an active system will be required.
Subfloor ventilation with active abstraction or pressurisation	2.5	Robust management systems must be in place to ensure long-term operation and maintenance.
Ventilated car park (basement or undercroft)	4	Assumes that car park is vented to deal with exhaust fumes in accordance with BCA[a] requirements.
Floor slabs		
Reinforced concrete ground bearing floor slab	0.5	It is good practice to install ventilation in all foundation systems to effect pressure relief as a minimum. Breaches in floor slabs, such as joints, have to be effectively sealed against gas ingress to maintain these performances.
Reinforced concrete ground bearing foundation raft with limited service penetrations cast into slab	1	
Reinforced concrete cast in situ or post- tensioned suspended slab with minimal service penetrations and water bars around all penetrations and at joints	1.5	
Fully tanked basement	2	
Membranes		
Taped and sealed membrane to reasonable levels of workmanship with inspection and validation	0.5	The performance of membranes is dependent upon the design and quality of the installation, protection from and resistance to damage post installation and the integrity of joints in membranes that require joints. Materials that offer some degree of self-sealing and repair are preferred.
Proprietary gas-resistant membrane to reasonable levels of workmanship under independent construction quality assurance (CQA)	1	
Proprietary gas resistant membrane to reasonable levels of workmanship under independent CQA with integrity testing and independent validation	2	
Monitoring and detection (alarms)		
Intermittent monitoring using hand-held equipment	0.5	Monitoring and alarm systems are only valid as part of a combined gas protection system. Where fitted, permanent systems should be installed in the underfloor venting system but can also be provided in the occupied space as a back-up.
Permanent monitoring system installed in the occupied space of the building	1	
Permanent monitoring system installed in the underfloor venting / dilution system	2	
Pathway intervention		

Measure or system element	Score	Comments
Vertical barriers	–	Required for residential and public buildings at CS4 and above.
Vertical venting systems	–	

9.1.2 Venting and dilution measures

A pressure relief system is required for the uninhibited flow of ground gasses from occupied areas and to avoid a build-up of gas beneath the sub-floor. The concept of the pressure relief is to form a low-pressure area relative to the surrounding gassing ground, to encourage gas to flow towards the sub-floor barrier. This is achieved by incorporating an air-filled void and preferential pathway which are connected to collection/dilution ducts. The duct allows a relatively high flow of fresh air through it by means of active extraction to the atmosphere (See **Appendix D** - **Figure 9**).

To assist with pressure relief, the sub-slab active extraction and ventilation system should comprise the following:

- Blower/vaccum pumping system[8]
- Nine (9) x air inlets around the building at at floor seven on the south building (five no.) and floor two on the Boomerang building (four no.). The details of the inlet are shown in ***Appendix D*** - Figure 9 and Figure 2.
- External air brick (or equivalent) to have an open area of 75 mm x 400 mm as detailed within **Appendix D** – Figure 9.
- Each individual inlet will be configured with a flow and gas sampling point. A gate valve for balancing flow will also be installed. By restricting flow from areas near the pump a uniform distribution of vacuum in the void can be ensured.
- Inlet vents connected to sub-slab piping collection and dilution pipework arrangement to 50 mm draincell void former on level 7 north and level 2 south (Boomerang Building). The location of the air inlets are shown within ***Appendix D*** Figure 10, Figure 11 and Figure 12 and the extent of the 50mm drain cell is detailed within **Appendix D** - Figure 2**.**
- The sub-slab piping collection and dilution pipework should be connected to inlets by 50 mm PVC pipe.
- The vacuum blower will be connected to the void in the centre of the building next to the lift shaft. The outlet to the roof will be in 100 mm PVC inside a protective conduit.
- The final outlet and discharge pipe have not yet been confirmed.

[8] Detailed design of the active gas extraction system will be developed at a later stage

Table 44 – Venting and dilution protection score

System Element	Gas Protection Score
Subfloor ventilation with active abstraction	2.5

9.1.3 Floor slab

It is expected that the current design for the building will comprise a 250 mm thick reinforced concrete cast in-situ slab with all services hung or cast in to the slab to compensate for the existing fill material and the expected ground movement / ongoing settlement of the landfill. The 250 mm thick reinforced concrete cast in-situ slab mitigates the potential ground settlement issues which includes stress fractures and cracking of the slab. The 250 mm thick slab will be engineered to receive support from piles anchored into rock and certified by a geotechnical engineer to withstand the development of voids and expected settlement.

A reinforced concrete slab will be constructed to reduce the intrusion of gas from below ground or from potential pathways originating from below ground, including services and relief joints. All joints and penetrations will be sealed with water stops such as epoxy with independent inspection.

The recommended option is to incorporate a reinforced concrete cast in-situ suspended slab with minimal service penetrations and water bars around all penetrations and at joints. The floor slab criteria and corresponding protection scores are described in Table 45. The extent of the floor slab is depicted within **Appendix D** Figure 1.

Table 45 – Floor slab gas protection score

System Element	Gas Protection Score
Reinforced concrete cast in situ slab with minimal service penetrations and water bars around all penetrations and at joints.	1.5

9.1.4 Membranes

A proprietary gas membrane shall be installed underneath the concrete slab. Manufacturers of synthetic membranes will provide instructions on how to lay and install them correctly. The requirements are that the membrane should align with the elements presented in NSW EPA (2012) guidance including:

- Appropriate gas membrane design
- Quality of the installation
- Protection from and resistance to damage post installation
- Integrity of the system including
  - Proposed degree of validation
  - Independent construction quality assurance
  - Integrity testing, and
  - independent validation that will be employed during construction

In addition, it is recommended that the gas membrane:

- Be sufficiently impervious to LFG and VOCs with a transmission rate <40.0 ml/day/m^2/atm (average).
- Be sufficiently durable during the service life of the building with an applicators waranty of at least 20 years from the date of installation.
- Be chemicially resistant to degradation.
- To be able to withstand settlement cracks and stresses.
- Overlain with a protective layer to provide mechanical protection from steel fixers and other workers on top of the membrane.
- Be protected once laid either by the use of temporary boarding or sheeting over the whole area. This is not always practical during construction operations because of the need to make provisions for service connections into the building, and for the construction of internal walls and substructures.

Additional notes on the construction of the membrane:

- All jointing and sealing should be in accordance with manufactures recommendations;
- If chloroprene modified asphaltic emulation and catalyst technique (Liquid Boot™ or Perlastic™ or equivalent) is used, the application must completely encapsulate the foundation, footings, and walls located below grade and be at least 1.5 mm thickness (when cured).
- All sharp protrusions are removed.
- Smoke tested (or equivalent) to demonstrate integrity of membrane.
- Tactile testing should also be undertaken as it is a primary indicator identifying obvious thin spots and can be undertaken on the floor membranes in conjunction with smoke testing.

- Once the gas membrane has been installed a full verification in accordance with CIRIA C735 by a Suitably Qualified Person independent of the installer should be undertaken to ensure adequate protection measures have been implemented. DLA note that a variety of gas membrane products are available and each should be assessed on their own merits.

Service entry points into the building, pose a potentially high risk, to the continuity of the waterproofing and gas membrane therefore appropriate detailing in these areas should be ensured (See ***Appendix D*** - **Figure 4 to 8**).

Areas such as lift shafts which extend deeper into the sub-surface are detailed in **Appendix D – Figure 8**.

All services entering the occupied areas should be constructed in such a manner as to avoid providing a pathway for gas to enter the building. The internal joins shall to the basement walls will be sealed with trowel grade Liquid Boot ™ and smoke tested following installation. The extent of the membrane will cover the entire floor slab which is depicted within **Appendix D, Figure 2**.

The recommended membrane configuration is for the installation and verification by independent construction quality assurance (CQA) with integrity testing and independent validation. The Gas Protection Scores for the installation of a gas-resistant membrane are described in Table 46.

Table 46 – Membrane gas protection score

System Element	Gas Protection Score
Proprietary gas-resistant membrane to reasonable levels of workmanship under independent CQA with integrity testing and independent validation	2

9.1.5 Hand held monitoring

Intermittent hand-held monitoring shall be implemented for nine (9) sub-slab monitoring points for parameters and frequencies as detailed within Table 53. The Gas Protection Score for hand held monitoring is described in Table 47.

Table 47 – Hand-held monitoring protection score

System Element	Gas Protection Score

Intermittent monitoring using hand-held equipment	0.5

9.2 Summary of remediation system approach

DLA recommend that the remediation system approach will comprise of a number of measures in combination including Table 48:

Table 48 – Summary of Remediation System Elements

System Element	Gas Protection Score
Venting and Dilution Measures	
Subfloor ventilation with active extraction	2.5
Floor Slab	
Reinforced concrete cast in situ slab with minimal service penetrations and water bars around all penetrations and at joints.	1.5
Membrane	
Proprietary gas-resistant membrane to reasonable levels of workmanship under independent CQA with integrity testing and independent validation	2
Monitoring and Detection	
Hand held monitoring	0.5
Total Gas Protection Score	**6.5**

With the implementation of the preferred option of each recommended Gas Protection Measure, an overall Gas Protection Score of 6.5 is achieved, meeting the NSW Guidelines for Gas Protection Guidance Score requirement of 5.

Final design, monitoring and CQA measures to ensure the safety of the construction operatives and occupants of future building will be decided following submission of the draft report.

10.0 MITIGATION MEASURES CONSTRUCTION METHODOLOGY AND SPECIFICATIONS

Methane gas concentrations will be required to be below 5% LEL during all construction works. Validation guidelines are included in the following sections of the LFGMP for the Site which will consider the NSW EPA (2012) Guidelines.

The following sequence is proposed for the installation of the LFG mitigation measures[9]:

1. Bulk earthworks completed.
2. Drainage levelling completed.
3. Installation of the base geofabric (T40 or equivalent) over engineering fill layer, including minimum overlaps of 300 mm between geofabric sheets. Where the horizontal slabs are not located on ground, such as where they traverse above the pile caps, beams and batters, installation will likely be required post form-work. Proposed pile cap detail is presented in **Appendix D – Figure 6**.
4. Inspection of the surface and removal of materials which could potentially damage the membrane. Ensure no large protrusions. **(Hold Point 1)**
5. Placement 50 mm drain-cell (specification attached) across the complete building footprint. The specification for the drain cell is included in **Appendix J**.
6. Application of geo fabric (G1000 or equivalent) to top of Drain-cell. The specification for the G1000 layer is included in **Appendix J**.
7. Application of the Liquid Boot (LB) membrane to a minimum thickness of 1.5 mm (measured when cured) including a minimum overlap of 150 mm and 150 mm overlap onto the outside of penetrations (e.g. services, piles). The specification for the LB layer is included in **Appendix J**.Allow curing and prevent foot traffic at this time.
8. Inspection of the membrane by the installer and the CQA consultant post curing. **(Hold Point 2)**
9. A smoke test is to be undertaken on the membrane in 25 m^2 sections to confirm its integrity. Should any areas of the membrane be identified as requiring additional application of LB during the test, then these will be addressed by re-applying LB during the smoke test (or subsequent smoke test) **Trowel grade LB is not be used for sealing imperfections more than 25 mm in diameter.** The smoke test to be certified by the applicator and CQA Consultant. **(Hold Point 3)**
10. Samples to be cut out of the membrane at a minimum rate of 1 per 25 m^2. The LB layer is to be measured on each sample to confirm the required thickness has been met (note: sample

[9] The construction sequence including fan and discharge pipework will be confirmed following engagement of suitably qualified contractors

areas are to be reapplied with spray applied LB). Additional application of LB is required in those areas where LB samples are identified to not meet the required thickness. Subsequent check of the membrane thickness will be conducted following the re-application. The thickness can be confirmed by micrometer slipped in the hole in the LB. Smoke testing holes can be used where appropriate. **(Hold Point 4 – if re-application is required)**

11. Placement of a protection geotextile fabric (G1000 or Polyfabrics TTC1XPP-Black or equivalent) over the LB membrane applied base slab to protect it during works and post installation.
12. 50 mm diameter Solid U-PVC pipes will be connected to the Draincell where it terminates within 500 mm of the exterior wall. The 50 mm pipes will be angled through 90 degrees to daylight at the base of the wall (inside the building). The final layout is TBD, if preferable the pipe can daylight outside the building through a bollard or vent arrangement. Note that a robust grill/mesh will be required on the face of the vent. Minimum size 75 x 400 mm with grilles spacing <3.0 mm.
13. All solid pipes are required to have a minimum 1 % gradient fall towards the Draincell to reduce occurrences of blockages of the solid pipe from a build-up of condensate. Condensate in this instance would flow towards the perforated pipe and into the surrounding gravel blanket.
14. Seal remaining penetrations with trowel grade LB. Wall joins and gaps to be sealed with an elastic and gas tight sealant such as 3M™ Fire Barrier Water Tight Sealants 1000 NS and 1003 SL (or equivalent). **(Hold Point 5)**
15. Following application of the LB membrane, the applicator should supply the CQA Consultant with a record of the quantity of LB applied, certification of the LB supplied and quality assurance/quality control (QA/QC) documentation for each inspection, smoke test and sample thickness check (including a portion of the sample).

Technical data for each remedial component is contained within **Appendix J** which confirms suitability of each layer and its resistance to leachate/groundwater contact.

Specifications are presented in Table 49.

Table 49 - Specifications

Item	Description	Typical Product name (or equivalent)	Supplier
1	Gas collection pipe work	Drain cell	Liquid Boot applicator (included within square meter price for LB)
2	Base geofabric. Non-woven, needle punched, polypropylene staple filament and heat treated. Minimum density of 200 g/m^2 or 20 kN/m. AS3706.2-12	Poyfabrics TT434PP or CETCO G1000 (black) or T40	Polyfabrics Australia, LB applicator CETCO or Geofabrics Australia
3	Cold Spray applied bituminous/polymer membrane. Applied 1.5 mm thick	Liquid Boot or Perlastic	SEQ Civil Linings or CETCO
4	Underside protection geofabric. UV stabilized, needle punched, non-woven, polypropylene staple fibre geotextile minimum 260 g/m^2. AS3760.01	Polyfabrics TTC1XPP-Black or equivalent	Polyfabrics Australia, LB applicator (CETCO) or Geofabrics Australia
5	Hand applied Liquid Boot	Trowel Grade LB	SEQ Civil Linings or CETCO
6	PVC pipe. PVC class 18. 50 mm diameter, glued joint. Conforms to AS/NZS 1477:1999 Series 1	Any that meets specification	
7	Reducers for geovent to 50 mm PVC		Formed on site by plumber or LB applicator
8	Sealants for inside conduits	Sika Flex Tank or 3MFB, Watertight, Sealant. 1000NS1003SL	Hardware suppliers or LB applicators proprietary product
9	Heavy Duty Inlet/outlet grilles. Standard minimum size 75 x 400 mm with grilles spacing <6.0 mm	LBPH Series linear bar grilles	Price Pty or HVAC suppliers

11.0 POST-CONSTRUCTION MONITORING

Post-construction monitoring is required to ensure any accumulation of HGG in the air-filled void under the building is identified early. The results of monitoring will also be used as a trigger to turn on the active extraction system that will be installed in the building.

11.1 Indoor Monitoring

Indoor monitoring will be undertaken during the validation phase and as part of the longer-term post construction monitoring.

11.2 Sub Slab Monitoring

In order to identify accumulations of LFG underneath the membrane, the sub-slab gas concentrations shall be monitored regularly from the nine (9) sub-slab monitoring points located on **Appendix D - Figure 2**. Monitoring will aim to encompass a range of weather/barometric pressure conditions.

The following procedure will be used:

- Open fitting to expose connector next to vent.
- Obtain zero flow reading on analyser.
- Connect LFG flow inlet tube to vent sample point, wait 5 seconds for flow to stabilise (remain at 0.0 L/hr) and record flow.
- Zero differential pressure reading, connect LFG analyser to vent and record differential pressure.
- Sample until stabilised or for 10 minutes (whichever comes first).
- Record available gas readings. If stabilisation is not achieved, then record peak and final gas concentrations with a note that stabilisation has not occurred. Data to be reviewed as per data validation procedure.
- Disconnect analyser, secure probe and perform fresh air purge before commencing monitoring at next location.

An experienced LFG practitioner will use a zeroed and bump tested GA5000 (or equivalent) landfill gas analyser with attached in-line water trap and filter at each sampling location. The device is capable of detecting % v/v concentrations of methane, carbon dioxide, balance gas, hydrogen sulphide and carbon monoxide (ppm) and pressure. VOCs shall be monitored using a ppm range PID.
All sub-slab monitoring will be reported and presented within the Site Validation Report prior to occupancy and the LTEMP post occupancy. Should sub-slab gases exceed the thresholds for actions

specified in Table 50, then the procedures described in the contingency plan must be followed (refer to Section 13.0. A summary of the monitoring parameters and frequencies is presented in Table 50.

Table 50: Monitoring parameters and frequencies

Monitoring Location	Target parameters	Frequency	Threshold for action
Sub-Slab Monitoring Points (no 1 to 9). The opening of the in-situ sample hose will be under the building in the void	Methane, carbon dioxide, oxygen, balance gas, carbon monoxide, Hydrogen sulphide flow and differential pressure VOCs qualitative screen using PID (ppm)	Following remediation and construction works but prior to the occupancy certificate, at least three monitoring events over monthly intervals will be undertaken to encompass a range of weather/ barometric pressure conditions.	If Methane is detected above **2.5 %v/v[10], turn on the active extraction system and monitor gas concentrations.** The Contingency Plan within Section 13.2 must be followed if following active extraction for a period of 72 hours the concentration of methane remain above 2.5 %v/v and/or carbon dioxide at concentrations of 1.5 %v/v within the Sub-slab.
		Following issuance of the occupancy certificate, long- term monitoring is conducted (every three months) for a period of four years with Interim Advices issued after each of the first three years. Monitoring will be undertaken to encompass a range of weather/ barometric pressure conditions	
		After the issuance of the Section A SAS, the monitoring frequency may be able to be adjusted further – this will be detailed in the to-be-developed Long-Term Environmental Management Plan (LTEMP).	

[10] 2.5 %v/v methane has been adopted as a conservative trigger based on Table 8 of NSW EPA 2012 guidelines as equivalent to good performance of passive sub-floor ventilation system i.e. <2.5 %v/v over 100 % of the layer at wind speeds <0.3 m/s)

12.0 VALIDATION OF THE GAS VAPOUR BARRIER INSTALLATION

12.1 Construction Quality Assurance

The following QA/QC requirements are required to be implemented as part of the verification process for the LFG mitigation system. Reference should also be made to the design information outlined throughout this report. Following completion of the construction works the Auditor will review the completed Validation Report that should comprehensively compile details of the construction works and remedial validation works.

The validation process is completed in four ways:

- Construction quality assurance of gas vapour barrier
- Pre-occupancy checks inside the building
- Indoor air quality monitoring
- Validation reporting

By using four methods the physical installation is ensured as well as by demonstrating vapour is not venting into the building by stringent air quality testing. Measurement of sub-slab concentrations of gases does not form part of the validation process as the successful implementation of the barrier cannot be measured by gas accumulation underneath it.

12.1.1 Records

To provide evidence of satisfactory work performance, all stages of the construction works for the works outlined herein shall be documented. The Contractor (and sub-contractors) shall maintain records of all key activities associated with the work. This information is to be provided for inclusion within the Site validation.

12.1.2 Conformance and testing certification

All conformance and testing certification for materials used in construction is to be provided for inclusion within the Site validation. The CQA inspector will collate all conformance and testing certification records for inclusion within the Site Validation Report.

12.1.3 Field testing records

All documentation showing test results from in situ-field testing of materials and the equipment used for construction of the mitigation system is to be provided for inclusion within the Site validation. The CQA inspector will collate all field testing records for inclusion within the Site Validation Report.

12.1.4 Photographs and daily records

The Contractor shall maintain a daily worksheet and photographic record of each phase of works and shall maintain such documentation on site. Daily worksheets are to provide a brief summary of works undertaken with respect to the items outlined within this report and confirm compliance with requirements outlined herein. The CQA inspector will collate all Photographs for inclusion into the final CQA validation plan.

12.1.5 Smoke testing the liquid boot layer

A smoke test is a method of ensuring that the LB membrane is impermeable and free of holes. The smoke test is performed after the LB has been applied but before the protection geotextile is placed over the top of the LB. The test should be undertaken in the following manner:

- A smoke test is to be undertaken on the membrane in 25m^2 sections.
- Following a minimum 24-hour curing period holes should be made in localised areas of the LB. To minimise disturbance and maintain the integrity of the layer, locations should be chosen where there is a planned penetration or overlap e.g. pile caps
- The smoke generator is turned on and the nozzle placed inside the hole. The smoke contains a fogging agent that makes even small amounts of smoke visible
- The pressure of the smoke will make the LB billow and any imperfections will be seen by smoke issuing from the area
- LB shall be reapplied to the area until the smoke is not visible. Should any areas of the membrane be identified as requiring additional application of LB during the test, then these will be addressed by re-applying LB during the smoke test (or subsequent smoke test).
- The injection holes should be patched with spray applied LB.

Trowel grade LB is not to be used for sealing imperfections greater than 25 mm. The smoke test will be undertaken by a certified LB applicator and CQA Consultant/Engineer who will take photographs and a video to document the process.

12.1.6 Thickness testing

The below method is recommended for approximate thickness testing of the LB and are useful in circumstances when the LB is cured to a solid surface i.e. the smoke cannot penetrate the underside of the LB:

- Blunt nose depth gauge: To accommodate compressive ratio, the gauge is calibrated by testing the depth on a destructive sample using a concrete surface. Based on the calculation thickness (on gauge) the units are extrapolated based on the compressed result.
- Tactile testing is a primary indicator identifying obvious thin spots and can be undertaken on the floor membranes in conjunction with smoke testing.

12.1.7 Surveys

The Contractor (and sub-contractors) are required to undertake and provide surveys of the construction works. The surveys are to be provided to is to be provided for inclusion within the Site validation. The following surveys will be required:

- Works as executed drawings.
- Survey of the 50mm drain cell dimensions.
- Survey of the floor slab dimensions.
- Survey of the membrane dimensions.
- Survey of the geotextile panels showing all seams, repairs and the roll numbers used.
- Survey of the vertical vent pipe network showing final locations of all pipes (slotted/perforated and solid).
- Survey of final sub-slab monitoring points.

Along with CQA, monitoring the zone under the membrane, and gases that might potentially vent from under the membrane, is critical in assessing the performance of the LFG mitigation system. The following sections describe the monitoring plan in sufficient detail that it can be used by an experienced LFG Practitioner.

12.2 Pre-occupancy and on-going visual checks

Once the system is installed, an inspection should be undertaken to verify that it is functioning consistently with the mandated performance specifications and to establish an operational baseline. Due to sub-surface conditions (e.g. high moisture content), sufficient time will be necessary for the sub-slab area to reach equilibrium after the installation of the LFG mitigation system. Thus, the baseline performance measurements should be collected no sooner than 30 days after the system is activated (Commission Timeframe). This monitoring period is expected to be undertaken before occupancy. The 30-day timeframe also allows the building time to vent prior to collecting verification samples. The system monitoring/inspection should include:

- A visual inspection of the system with the aid of a site-specific LFG mitigation system inspection checklist.
- Establishment of an operational baseline from appropriate parameters identified in post construction inspection.
- Assessment as to whether alterations or augmentation of the system is required;
- Trouble-shoot any problem.
- Assess for any odours being generated.

On-going inspections should be continued on a regular basis (See following sections of this report). Table 51 describes system inspection requirements.

Table 51 – System inspection requirements

<table>
<tr><th>Item</th><th>Works</th><th>Timeframe / Monitoring Frequency</th></tr>
<tr><td>Pre-occupancy and commissioning checks</td><td>Ensure system has been installed in accordance with design</td><td>Once prior to occupancy</td></tr>
<tr><td>Operational Baseline</td><td>Establish operational baseline from initial inspection data.</td><td>10 days after occupation</td></tr>
<tr><td>Visual Inspections</td><td>Inspection of system in accordance with system checklist, to be included within the long term Site management plan.</td><td rowspan="3">Prior to occupation and 10 days after operation, then at monthly intervals during the first year of operation, then every three months thereafter</td></tr>
<tr><td>Assessment of system alteration</td><td>After the completed visual inspection, undertake assessment of any operational deficiencies plan rectification measures (if required).</td></tr>
<tr><td>Odour Assessment</td><td>Assessment for any odours that may be present or generated.</td></tr>
</table>

12.3 Indoor Air Screening

An experienced LFG practitioner will use a zeroed and bump tested GA5000 (or equivalent) landfill gas analyser with attached in-line water trap and filter at each sampling location. Monitoring will be undertaken to encompass a range of weather/ barometric pressure conditions. All indoor air monitoring will be reported and presented within the Site Validation Report.

A monitoring program will be implemented to demonstrate that HGG is not accumulating at dangerous levels in enclosed spaces on the Site. The threshold level for further investigation and corrective action within the Site building is any reading above the detection limit of the instrument for methane as described within Table 52.

Table 52: Methane threshold criteria for further investigation (% v/v)

Parameter	Threshold
Methane	0.1 % v/v

If methane is detected within indoor areas of the Site between >0.1% v/v and <1.0% v/v, the following measures will be taken:

- Delineate the exceedance location;
- Determine an appropriate management strategy; and
- Formulate an action plan.

If methane is detected at concentrations above 1% within indoor areas of the Site, the occupier must notify the EPA within 24 hours. Within 14 days of this notification, the occupier must submit a plan to the EPA for further investigation and/or remediation of the elevated gas levels. A contingency plan is listed within Section 13.0

Indoor air quality testing for toxic organic compounds will also be carried out by a qualified indoor air quality consultant. Indoor air screening criteria for toxic organic compounds will be based upon Site specific uses (such as retail and residential) and will be developed prior to the finalisation of the validation plan for construction.

The following areas will be tested:

- Flooring.
- Stormwater and service pits inside the car park area.

- The transformer room.
- The commercial lift areas.
- Any windows, doors, pipes, air conditioners, gas appliances and drains.

Air pollutants should be sampled and analysed in accordance with the methods specified in the NEPM (NEPC, 2013). An experienced and qualified air monitoring specialist will undertake this work. The parameters to be analysed will include a full suite of laboratory analytes for volatile contaminants including:

- Method TO-15
- Total Petroleum Hydrocarbons
- 5-Sulfides
- Ozone Precursors
- Bulk Gases (methane, oxygen, carbon dioxide, carbon monoxide, hydrogen sulphide and nitrogen)

Methodology for sampling and number of samples collected is to be confirmed by an air quality sampling specialist prior to the finalisation of the validation plan for construction. All equipment used for data collection will be appropriately calibrated and fit for use. Sampling will consider background concentrations introduced to the basement area that are not derived from vapour intrusion, including vehicle emissions, chemical products used during the construction process, and household chemicals stored within the basement area.

12.4 Ambient Air Screening

Criteria for ambient concentrations of toxic organic compounds will be developed prior to the finalisation of the validation plan for construction and will be based upon site specific uses (such as retail and residential). An experienced LFG practitioner (under the NSW EPA's criteria) will test the atmosphere in areas such as:

- The car park
- Outside buildings and
- All structures within the Site boundary.

Methodology for the sampling method and number of samples collected is to be confirmed by an air quality sampling specialist prior to the finalisation of the validation plan for construction. A summary of monitoring and frequency for validation and on-going validation monitoring are presented in Table 53.

Table 53 - Summary of monitoring

Item	Monitoring Location	Target parameters	Frequency	Threshold for action
1	Indoor air screening	TBC	Following remediation and construction works but prior to the occupancy certificate, at least three monitoring events over monthly intervals will be undertaken to encompass a range of weather/ barometric pressure conditions.	Methane thresholds for action are listed within Section 12.3. Indoor air screening criteria for toxic organic compounds will be based upon Site specific uses (such as retail and residential) and will be developed prior to the finalisation of the validation plan for construction.
			Following issuance of the occupancy certificate, long- term monitoring is conducted (every three months) for a period of four years with Interim Advices issued after each of the first three years. Monitoring will be undertaken to encompass a range of weather/ barometric pressure conditions.	
			After the issuance of the Section A SAS, the monitoring frequency may be able to be adjusted further – this will be detailed in the to-be-developed Long-Term Environmental Management Plan (LTEMP).	
2	Ambient air quality (locations TBC by Air Quality Consultant)	TBC	Following remediation and construction works but prior to the occupancy certificate, at least three monitoring events over monthly intervals will be undertaken to encompass a range of weather/ barometric pressure conditions.	TBC prior to the finalisation of the validation plan for construction.
			Following issuance of the occupancy certificate, long- term monitoring is conducted (every three months) for a period of four years with Interim Advices issued after each of the first three years. Monitoring will be undertaken to encompass a range of weather/ barometric pressure conditions.	
			After the issuance of the Section A SAS, the monitoring frequency may be able to be adjusted further – this will be detailed in the to-be-developed Long-Term Environmental Management Plan (LTEMP).	

12.5 Validation report

At the completion of the remediation activities, a Validation Report documenting the works as completed will be prepared. The Validation Report will describe the strategic works undertaken at the Site, assess the result of the validation testing, demonstrate that the objectives of the HGGMP have been achieved and provide justifications for any deviation, statistically confirm that the remediated Site complies with the Validation Criteria and include any other information as deemed appropriate.

The report should contain a description of all testing and/or monitoring undertaken as part of the remedial works including but not limited to validation results, waste classification of material disposed offsite/imported onsite (if any), and an appropriate discussion of field and laboratory work undertaken. It will also include a statement regarding the appropriateness of the remediated site for the proposed land use and any limitations or ongoing monitoring/management required.

Sufficient information must be provided by a person suitably qualified and competent in the implementation of landfill gas protection measures. The person suitably qualified must certify that sufficient information has been provided and he or she is satisfied that the liner design will be effective and fit for purpose. Verification of the LFG mitigation system installation must be undertaken by an appropriately qualified person and in accordance with manufacture's specifications.

If there are events or discoveries made at the Site that would prevent the proposed works complying with the Validation Criteria, or if the selected remediation strategy is not able to proceed, then the following contingency is devised and should be discussed with the Site Auditor prior to occupation.

Should any other viable options be identified during the implementation of the remediation plan these should be reviewed and the validity of the options assessed. Prior to the implementation of the remediation contingency all options should be overseen and approved of by a NSW EPA accredited Site Auditor with specialist knowledge in remediated lands and landfill gas systems to certify that they are fit for purpose.

13.0 CONTINGENCY PLAN

The LFG management plan must be incorporated into building management and fire control plans.

13.1 Indoor Areas

If methane is detected at concentrations above 1.0 % v/v within indoor areas of the Site, the occupier must notify the EPA within 24 hours. Within 14 days of this notification, the occupier must submit a plan to the EPA for further investigation and/or remediation of the elevated gas levels. Depending on the circumstances, this plan may include one or more of the following measures:

- Indoor ventilation;
- Monitoring systems installed in the occupied space of the building;
- Continuous subfloor active extraction;
- Daily testing of the building or enclosed structure until ventilation or other measures have been put in place to eliminate the methane build-up.
- An increase in monitoring frequency and/or the installation of additional monitoring vent points
- Re-assessment of volumetric/gas flow determinations to assess the significance of gas generation rates and the potential scale of off-site gas migration
- Gas accumulation monitoring in enclosed structures located nearby
- A revised landfill gas risk assessment, addressing the source, potential gas migration pathways and potential receptors
- Notifications to potentially affected persons
- Installation of landfill gas controls at the source and/or receptors.

13.2 Sub-slab

The threshold operation of the active sub-slab extraction system is the detection of methane at concentrations above 2.5 % v/v. If following active extraction for a period of 72 hours the concentration of methane remain above 2.5 %v/v and/or carbon dioxide at concentrations of 1.5 %v/v within the Sub-slab the occupier must formulate a plan to reduce sub-slab methane and carbon dioxide concentrations to below 2.5% v/v and 1.5 % v/v respectively which may include one or more of the following measures:

- Indoor ventilation;
- Monitoring systems installed in the occupied space of the building;
- Continuous subfloor active extraction;
- Daily testing of the building or enclosed structure until ventilation or other measures have been put in place to eliminate the methane build-up.
- An increase in monitoring frequency and/or the installation of additional monitoring vent points
- Re-assessment of volumetric/gas flow determinations to assess the significance of gas generation rates and the potential scale of off-site gas migration
- Gas accumulation monitoring in enclosed structures located nearby
- A revised landfill gas risk assessment, addressing the source, potential gas migration pathways and potential receptors
- Notifications to potentially affected persons
- Installation of landfill gas controls at the source and/or receptors.

14.0 LIMITATIONS

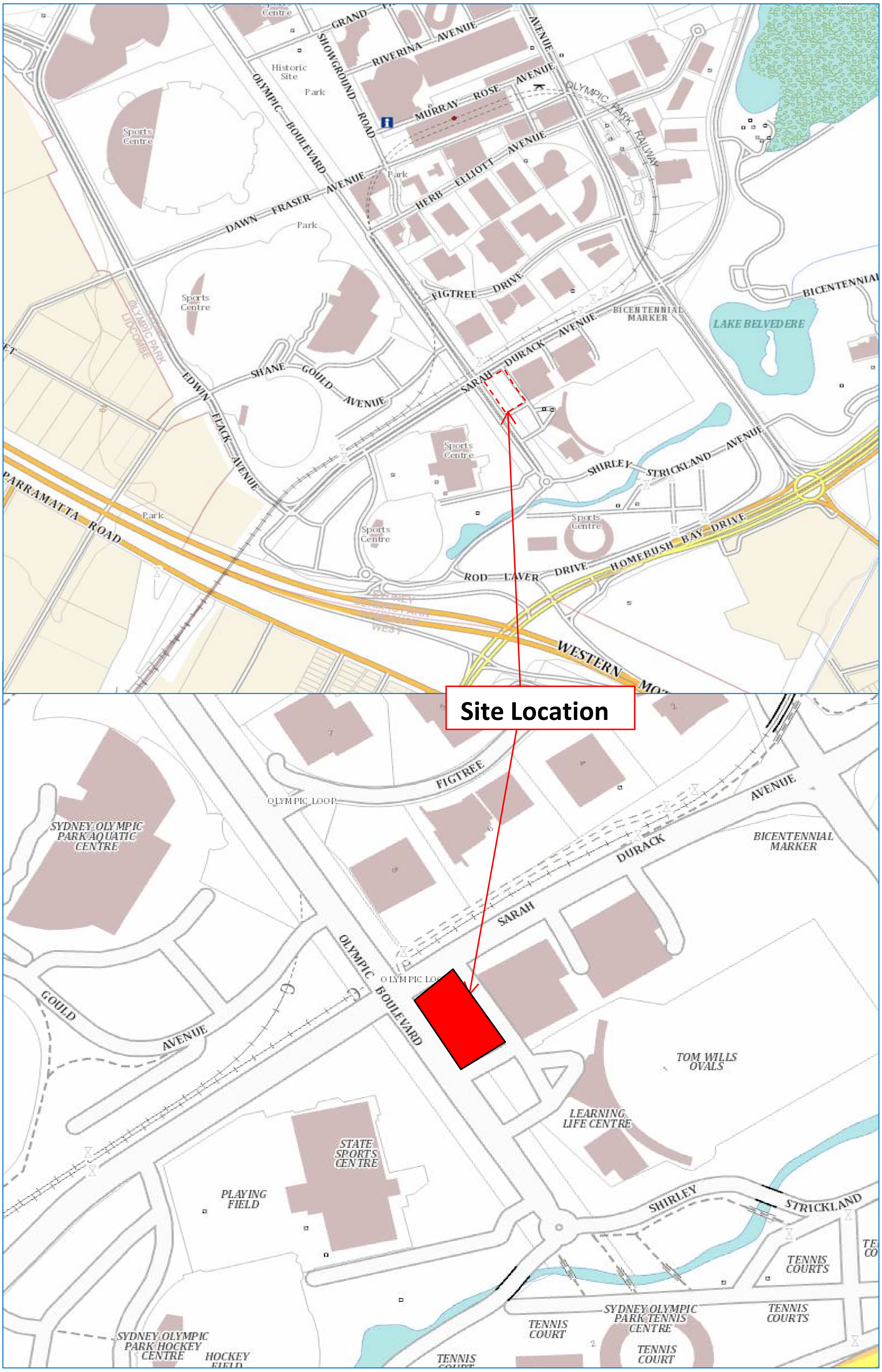
The design has been developed primarily to address to reduce the acute risks associated with the accumulation of LFG inside the building. It is important to note that whilst the indoor air quality will be ensured following the implementation of the appropriate detailed design of measures. There could potentially be residual risk to workers working in close proximity to the vented gases from under the building.

The on-going safety and health of the occupants and users of the Site must be ensured by implementation of a full construction installation and verification package. This will include longer term monitoring plan to observe and record concentrations of LFG when measured from the building vents/inlets. Further actions such as an exposure and human health risk assessment may be required if elevated concentrations of LFG are recorded.

15.0 REFERENCES

- British Standard 'Code of Practice for protection of below ground structures against water from the ground', BS: 8102, (2009).
- Construction Industry Research and Information Association (CIRIA), 'Assessing Risk Posed by Hazardous Ground Gases to Buildings', Report No. (C665, 2007) and C735 (2014) 'Good practice on the testing and verification of protection systems for buildings against hazardous ground gases'.
- Department of the Environment Waste Management Paper 26B: Landfill Design, Construction and Operational Practice (1995).
- DLA Environmental *Supplementary Site Assessment, Site 9 - Sydney Olympic Park*, corner of Sarah Durack Avenue and Olympic Boulevard, Sydney Olympic Park, NSW 2127 (2016).
- Douglas Partners Pty Ltd *Report on Waste Classification Assessment*, Site 9, cnr Sarah Durack & Olympic Boulevard Sydney Olympic Park, NSW (2003).
- NEPC National Environment Protection (Assessment of Site Contamination) Measure (No.1) (2013).
- NIOSH Documentation for Immediately Dangerous to Life or Health Concentrations (1994).
- NSW DEC Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales (2007).
- NSW EPA Environmental Guidelines: Assessment, Management and Classification of Waste and Liquid Waste (1999).
- NSW EPA Guidelines for the Assessment and Management of Sites Impacted Hazardous Ground Gases (2012).
- NSW EPA Environmental Guidelines, Solid waste landfills, second edition (2016).
- Safe Work Australia, Workplace Exposure Standards for Airborne Contaminants (December, 2011).
- Sydney Olympic Park Authority DRG No. 052-G-G-0001 REV. E
- Sydney Olympic Park Authority *Remediated Lands Management Plan* (January, 2009)
- UK EA Guidance on the management of landfill gas (2004).
- URS Environmental and Geotechnical Investigation – Site 9, Sydney Olympic Park (2002).
- URS Indicative Remediation Action Plan, Site 9, Sydney Olympic Park (2002).
- VIC EPA Siting, design, operation and rehabilitation of landfills, Best Practice Environmental Management (2015).
- Wilson, S. Card, G & Haines, S. *Ground Gas Handbook*. Whittles Publishing, (2009).

APPENDIX A FIGURE 1 – SITE LOCATION



DLA Environmental Services
A Pacific Environment company

Unit 3/38 Leighton Place
Hornsby, NSW 2077

DESIGNED:	SITE LOCATION		
DLA			
COMPILED:	CLIENT:	ECOVE	DRAWING:
AP			10.02.16
PROJ. No.	LOCATION:	Cnr Sarah Durack Ave and Olympic Boulevard, Sydney Olympic Park NSW	FIGURE:
DL3620			1

APPENDIX A FIGURE 2 – SITE LAYOUT AND BOREHOLES

Legend

- Groundwater and Gas Well locations
- Gas Well locations
- Borehole locations
- Site Boundary

Approximate Scale
0m 20m 40m

DLA Environmental Services
A Pacific Environment company

Sydney Office
Phone (02) 9476 1765
Fax (02) 9476 1557

Maitland Office
Phone (02) 4933 0001

Title			
Site Layout, lot description and Bore Locations			
Client: ECOVE	Project No.: DL 3620	Figure No: 2	Date: 02/12/2016
	Scale: As Shown	Compiled: AP	Revision: R00

APPENDIX A FIGURE 3 – REMEDIATED LANDFILL AREAS

Legend

Site Boundary

N

DLA Environmental Services
A Pacific Environment company

Sydney Office
Phone (02) 9476 1765
Fax (02) 9476 1557

Maitland Office
Phone (02) 4933 0001

Title	Extent of Golf Driving Range Landfill and Site Location		
Client: ECOVE	Project No.: DL 3620	Figure No: 3	Date: 2/5/2016
	Scale: As Shown	Compiled: SB	Revision: R00

APPENDIX A FIGURE 4 – EXTENT OF LANDFILL CELL

Legend

EXTENTS OF "ADDITIONAL FILL" (AREA 39300 SQ M)

PROPOSED LANDFILL CELL LOCATION

1.00 CONTOUR OF "ADDITIONAL FILL" THICKNESS

Site Boundary

N

Approximate Scale

0m 40m 80m

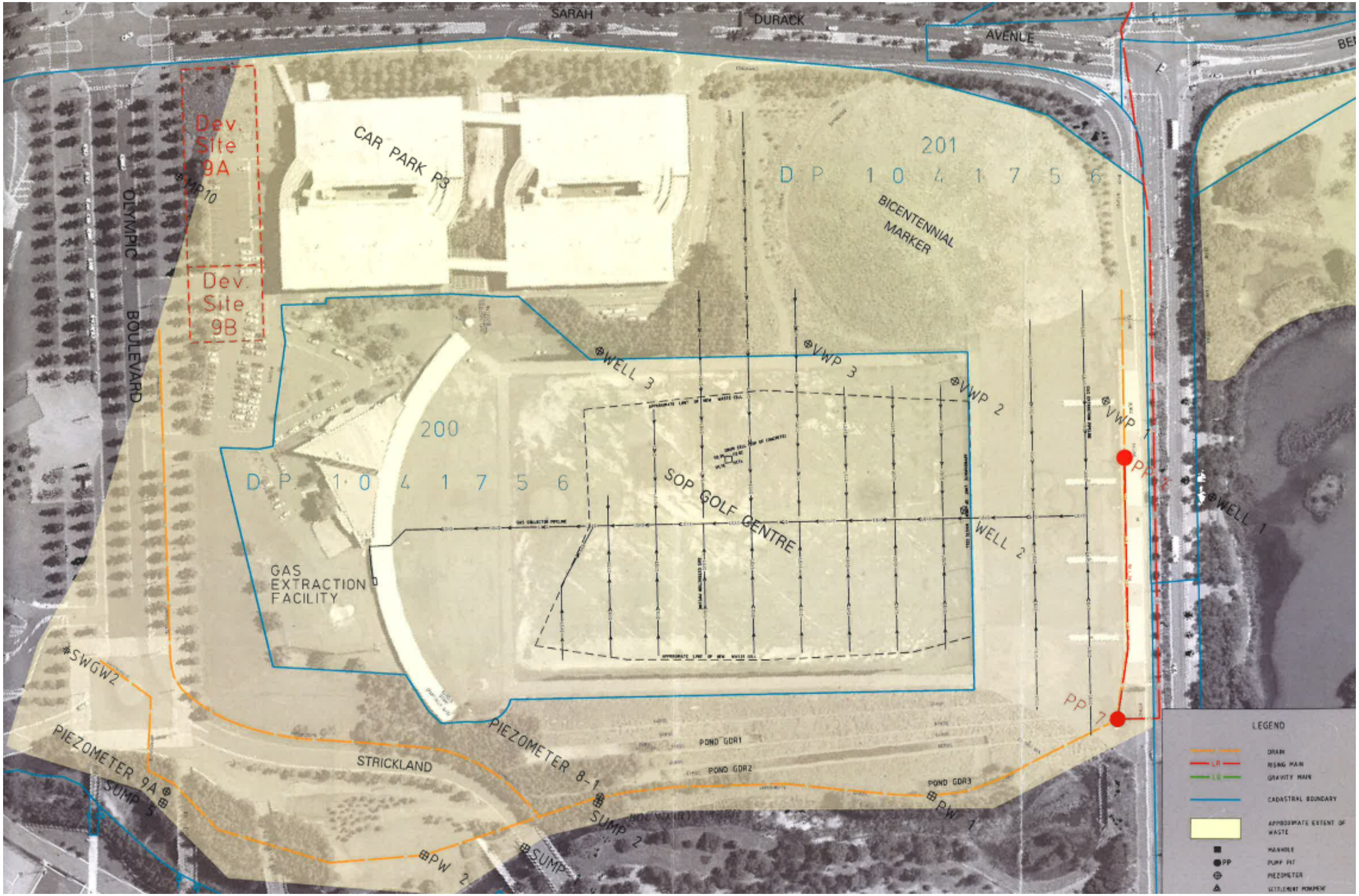
DLA Environmental Services
A Pacific Environment company

Sydney Office
Phone (02) 9476 1765
Fax (02) 9476 1557

Maitland Office
Phone (02) 4933 0001

Title	Golf Centre Landfill System - Extent of Additional Fill and Approximate Landfill Cell Location			
Client: ECOVE	Checked By: AJM	Project No.: DL 3620	Figure No: 4	Date: 4/10/2016
Reference: Consultant: Woodward-Clyde; Drawing Number: A8602318/0001; Drawing Date: 20/08/1999		Scale: As Shown	Compiled: SB	Revision: R00

APPENDIX A FIGURE 5 – GOLF CENTRE LANDFILL SYSTEM



Legend

- Drain
- Site Boundary
- Approximate Extent of Waste

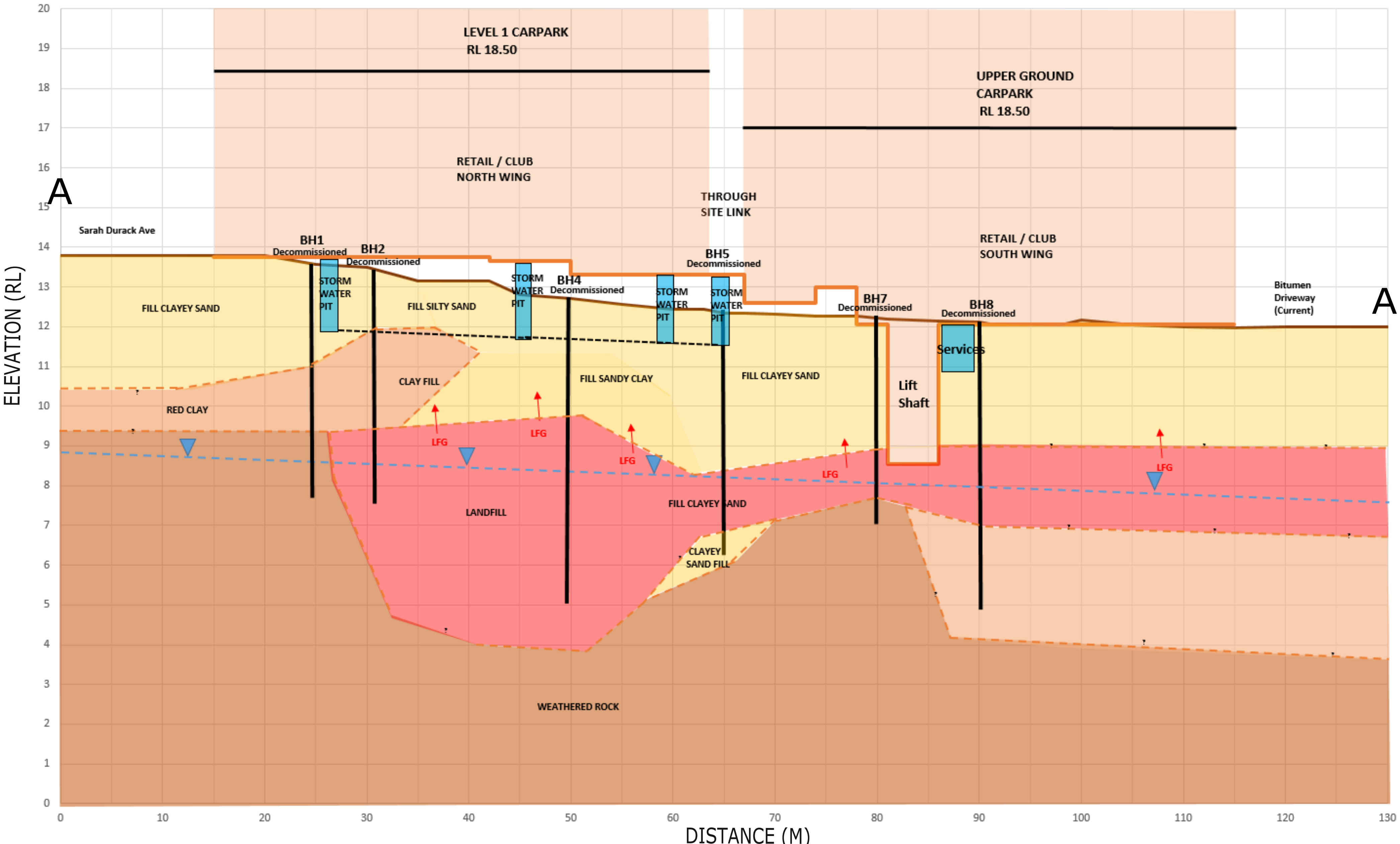
DLA Environmental Services
A Pacific Environment company

Sydney Office
Phone (02) 9476 1765
Fax (02) 9476 1557

Maitland Office
Phone (02) 4933 0001

Title: Golf Centre Landfill System				
Client: ECOVE	Checked By: AJM	Project No.: DL 3620	Figure No: 5	Date: 4/10/2016
Reference: Sydney Olympic Park Authority; Drawing Number: 052-G-G-0001 REV E		Scale: As Shown	Compiled: SB	Revision: R00

APPENDIX A FIGURE 6 – CONCEPTUAL SITE MODEL



Legend	Approximate Extent of Waste	DLA Bore Hole Location	SLAB LEVEL		
	FILL SOILS	CARPARK GROUND LEVEL			
	WEATHERED ROCK				

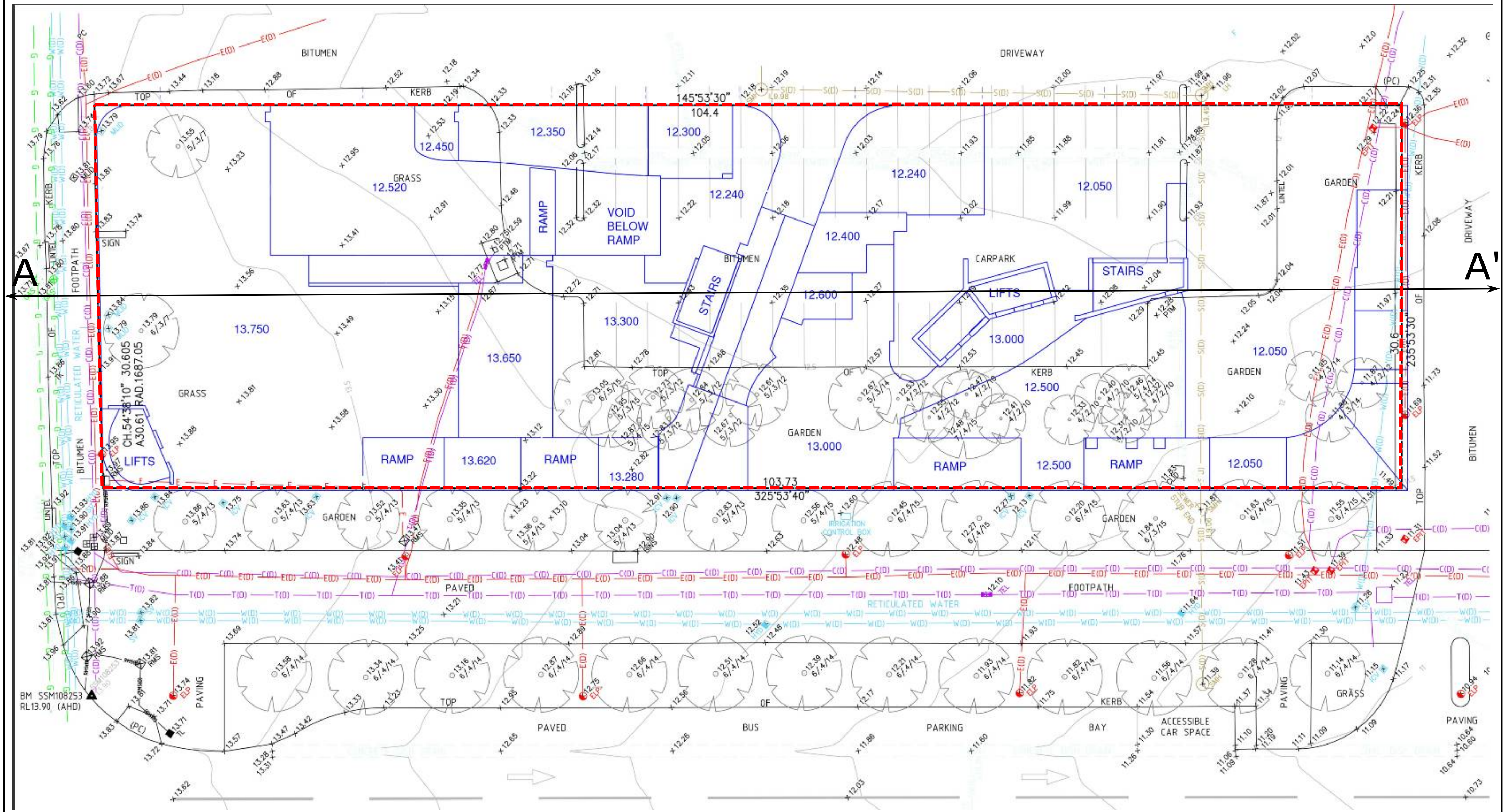
DLA Environmental Services
A Pacific Environment company

Sydney Office
Phone (02) 9476 1765
Fax (02) 9476 1557

Maitland Office
Phone (02) 4933 0001

Title			
CONCEPTUAL SITE MODEL			
Client: ECOVE	Project No.: DL 3620	Figure No: 6	Date: 21/11/2016
	Scale: As Shown	Compiled: SB	Revision: R00

APPENDIX A FIGURE 7 – SLAB DETAIL AND SURVEY OVERLAY



Legend

CSM CROSS - SECTION

Site Boundary

× Survey Point

DLA Environmental Services
A Pacific Environment company

Sydney Office
Phone (02) 9476 1765
Fax (02) 9476 1557

Maitland Office
Phone (02) 4933 0001

Title			
Current Ground Level and Slab RL			
Client: ECOVE	Project No.: DL 3620	Figure No: 7	Date: 21/11/2016
	Scale: As Shown	Compiled: SB	Revision: R00

LEGEND

BENCH MARK	▲	KERB INLET PIT	KIP	GAS (DBYD)	G
TELSTRA PIT	TEL	SEWER INSPECTION POINT	SIP	TELSTRA (DETECTED)	T(D)
ELECTRIC LIGHT POLE	ELP	LAMP HOLE	LH	OPTICAL FIBRE (DETECTED)	OF(D)
ELECTRICITY PIT	EPIT	SEWER MANHOLE	SMH	WATER (DETECTED)	W(D)
ELECTRICITY BOX	EL	STOP VALVE	SV	STORMWATER (DETECTED)	SW(D)
PIT WITH CONCRETE LID	CLID	HYDRANT	HYD	SEWER (DETECTED)	S(D)
PIT WITH METAL LID	MLID	FIRE HOSE	FH	ELECTRICITY (DETECTED)	E(D)
TRAFFIC LIGHT	TL	IRRIGATION CONTROL VALVE	ICV	ELECTRICITY (SOPA diagram)	E
BOLLARD	BOL	GAS VALVE	GAS	ROAD AUTHORITY (DETECTED)	RMS(D)
ROAD TRAFFIC AUTHORITY	RTA	VEHICLE CROSSING	(VC)		
GRATED INLET PIT	GIP	PRAM CROSSING	(PC)		

NOTES

1. THE BOUNDARIES HAVE NOT BEEN MARKED
2. ALL AREAS AND DIMENSIONS OF PROPOSED LOT 9 HAVE BEEN COMPILED FROM PLANS MADE AVAILABLE BY SOPA BEING "PLAN OF SUBDIVISION OF LOT 3003 IN DP1182609" BY SURVEYOR ZIEMOWIT WIERZCHOWSKI FROM CARDNO HARD AND FORESTER SURVEYORS
3. ORIGIN OF LEVELS ON A.H.D. IS TAKEN FROM **PM68219** R.L. **7.097** (A.H.D.) IN AUSTRALIA AVENUE
4. CONTOUR INTERVAL **0.5 m**
5. CONTOURS ARE INDICATIVE ONLY. ONLY SPOT LEVELS SHOULD BE USED FOR CALCULATIONS OF QUANTITIES WITH CAUTION
6. KERB LEVELS ARE TO THE TOP OF KERB UNLESS SHOWN OTHERWISE
7. FLOOR LEVELS SHOWN ARE THRESHOLD LEVELS. NO INVESTIGATION OF INTERNAL FLOOR LEVELS HAS BEEN UNDERTAKEN
8. AN INVESTIGATION OF UNDERGROUND SERVICES HAS BEEN MADE. UNDERGROUND SERVICES HAVE BEEN DETECTED BY "DOWN UNDER DETECTION SERVICES" AND ARE APPROXIMATE ONLY. SOME SERVICES SUCH AS FIRE&WATER SUPPLY, GAS, OPTICAL FIBRE CABLING & IRRIGATION PIPEWORK DO NOT HAVE METALLIC TRACING WIRES OR METAL PIPES AND MAY NOT HAVE BEEN DETECTED. GAS SERVICES HAVE ALSO BEEN PLOTTED FROM RELEVANT AUTHORITIES RECORDS AS SUPPLIED BY DIAL BEFORE YOU DIG.
9. IRRIGATION PIPES HAVE NOT BEEN PLOTTED FOR CLARITY. PLEASE REFER TO SOPA SERVIES DIAGRAM 051-P-P0051 REV A
10. 8/.4/7 DENOTES TREE SPREAD OF 8m, TRUNK DIAMETER OF 0.4m & APPROX HEIGHT OF 7m
11. SHOWS APPROXIMATE POSITION OF ROAD LINEMARKING AND IS INDICATIVE ONLY
12. BEARINGS SHOWN ARE MGA (MAP GRID OF AUSTRALIA) ADD APPROX. 1°00' FOR TRUE NORTH

DIAL BEFORE YOU DIG www.1100.com.au

REFER TO NOTES AND LEGEND

0 4 6 8 12 16 20
SCALE 1: 200 @ A1

Revision	Date	Description	Reference
D	00/00/00	-	00
C	00/00/00	-	00
B	00/00/00	-	00
A	00/00/00	-	00

THIS IS THE PLAN REFERRED TO IN MY LETTER DATED:

....
Registered Surveyor NSW

LTS LOCKLEY
Registered Surveyors NSW
www.ltsl.com.au
Suite 1, Level 1
810 Pacific Highway
Gordon NSW 2072
Locked Bag 5
Gordon NSW 2072
P 1300 587 000
F 02 9499 7760

Client ECOVE SITE 9 PTY LIMITED

Drawing title
PLAN OF DETAIL AND LEVELS OVER SITE 9 AT THE CORNER OF SARAH DURACK AVENUE & OLYMPIC BOULEVARDE, SYDNEY OLYMPIC PARK

datum AHD
site Area 3186m²
LGA AUBURN
project number 42570
scale 1:200 @A1
reference number 42707DT
date of survey 18/12/15
SHEET 1 OF 1 SHEETS

APPENDIX B – GOLF DRIVING RANGE LANDFILL

3.5 Golf Driving Range

Former names: Homebush Common, Southern Threshold, State Sports Centre Precinct

3.5.1 Summary

The Golf Driving Range landfill (consolidated landfill from 3 separate landfills operating from the 1960s to 1980s) covers an area of 6.2 hectares adjoining Boundary Creek. The final landform was capped and landscaped, and a combined subsoil landfill gas capture system and extraction leachate system was installed.

Remediation was initially completed in 1994, however additional remediation works were undertaken between 1998 – 1999 with additional fill being added. This additional load increased leachate production so further works were conducted to automate leachate collection and connect it to LLWP. This was completed by 2000. An Independent Site Auditor issued a Site Audit Statement on 14 December 2000 (WRR85) declaring the site suitable for use as "*Park, recreational open space and playing field*"

Subject to:

- preparation and implementation of an auditor approved Environmental Management Plan including but not limited to controls to alteration of landforms and excavations to a depth of 0.5 metres
- Implementation of an auditor approved groundwater monitoring program to assess the impact of residual soil contamination on groundwater quality and potential risk to the environment

The Golf Driving Range landfill and leachate interception and pumping system require ongoing management to ensure system integrity and environmental protection, and to meet legal requirements. Site-specific key management objectives and responses are described in Table 3.5.1

3.5.2 Site history

The Golf Driving Range (GDR) landfill is a consolidation of 3 separate landfills from the State Sports Centre Precinct. The precinct was used for the uncontrolled tipping of municipal waste from 1965 to 1982. Waste was stockpiled in three separate landfills over a 42 hectare site north of the rail line; the Western, Northern (now the Golf Driving Range) and Southern landfills. The waste comprised a heterogeneous mix of a wide variety of constituents including variable quantities of putrescible fill.

A remediation strategy for the State Sports Centre site was developed in 1991. Part of the remediation strategy was to consolidate contamination and implement some forms of environmental protection. This included the placement of a low-permeability clay cap and sub-surface drainage system, the installation of a leachate collection system and clay cut-off wall and the redirection and protection of Boundary Creek.

Works were undertaken to consolidate the three landfills into one. Between 1991 and 1993, 130,000 m^3 of waste was shifted from the Western and Southern landfills to overlay the Northern landfill and create a 15 metre high mound. The Western and Southern landfills were then validated by visual inspection and testing of residual soils to ensure that all traces of contamination were removed prior to backfilling with clean imported fill. Remediation of the GDR was initially complete in March 1994 when the site was landscaped.

The original intent was to discharge collected leachate directly to sewer. Changes in Trade Waste requirements however, resulted in sewer discharge being abandoned in 1995 and the construction of a rising main to discharge the leachate to the Kronos Hill system was implemented. While the design and construction of this pipe was being finalised, leachate was extracted and disposed of to the Waste Service NSW Lidcombe Liquid Waste Plant by licensed liquid waste haulage vehicles. The pipe was commissioned in late 1998. To the north of the GDR landfill is an engineered mound, the Bicentennial Marker, which is a site feature made from construction rubble and road base.

Table 3.5.1 Site-specific management objectives for Golf Driving Range

OBJECTIVE	RESPONSE	MONITORING*	MANAGEMENT TARGETS
Comply with conditions of a Notice issued under *Contaminated Lands Management Act 1997*	Manage Golf Driving Range landfill for use as a parklands/open space / playing fields, in accordance with the Remediated Lands Management Plan and associated procedures.	Regular review of Remediated Lands Management Plan and associated procedures for effectiveness.	1. An auditor-approved Remediated Lands Management Plan is developed and implemented. Requirements of the Remediated Lands Management Strategy are applied to all management, operation and development activities. 2. An auditor-approved site-specific environmental monitoring program is implemented 3. No construction of buildings, alteration of landforms, or excavations below 0.5m, without regulatory authority approval
Maintain integrity of waste containment	Waste exposure and surface water infiltration managed by waste encapsulation, surface capping, and subsurface drainage system	Regular visual inspections	4. System components in good condition 5. Capping has no evident surface cracks, potholes, depressions, fissures, erosion or exposure of waste 6. Good vegetation cover on vegetated areas, with no evident vegetation die-off or bare patches. Soil irrigated as required to maintain cover. 7. No discoloured soil or pools of visually evident leachate at toe and batter (particularly after heavy rain when groundwater tables are elevated). 8. Stormwater detention ponds have no evident scouring and good plant growth 9. Proper reinstatement after excavations so erosion risk is minimised. 10. No offensive odour emanating from site
Prevent leachate migration to groundwater and surface waters	Manage the leachate collection and transfer system to maintain an inward hydraulic gradient between the containment mound and Boundary Creek	SCADA Static water level and chemical monitoring	11. PP6 is maintained below 101.2 (analysis of past monitoring data allows for an additional 1.3m safety factor) 12. Key leachate indicators are not detected in groundwater outside the leachate collection drain 13. Leachate drains are operating freely – as confirmed by pump operational data and water level measurements in pump pits and leachate drains
Manage surface gas emissions	Two gas extraction systems installed – on turfed landfill surface, and at adjacent P3 Carpark	Operational checks of fans	14. Excavations at P3 carpark and at Golf Driving Range avoid damage to subterranean infrastructure 15. Fans at golf amenities block and P3 carpark are operational

* see section 11 for detailed program

As part of Olympic Overlay works, the GDR was recontoured during late 1999 / early 2000. The earthworks incorporated some waste movement and recontouring, restoration of the clay cap, minor modifications to the leachate system, the installation of a gas drainage layer and the restructure of the sub-surface drainage system. The site was approved for use as *"Park, recreational open space, playing field"* by an independent site auditor in 2000.

The site was used as a major public recreation / food concession area during the 2000 Olympic Games.

3.5.3 Operational overview

The strategic location of the leachate collection drain is designed to intercept the contaminated water before it can flow beyond the site boundaries. A typical chemical composition of leachate from the GDR is provided in Table 3.5.2.

The drains are graded, so that the collected leachate flows to one of two pumping pits (PP6 and 7). Leachate is stored in the pumping pits until the pump identifies that the height of leachate begins to rise within the pit. At this point, pumping is automatically activated. Leachate combined from the two pits is discharged via a rising main to PP1 of the Kronos Hill leachate system and eventually to LLWP.

Automation of the system is controlled from the SCADA system. Details of the SCADA system are found in section 6. The system monitors the levels in each pumping pit, which pumps are operating, the volume of leachate discharged from the system and the rate of leachate discharge.

The CADD drawing of the Golf Driving Range landfill in Appendix 4 shows the position of the leachate drain, collection sumps and monitoring piezometers.

3.5.4 System components

3.5.4.1 Waste Containment System

The purpose of the waste containment system is to encapsulate contaminated waste material, preventing the exposure to both people and the environment.

The waste containment system consists of:

Capping – Capping consists of a 650mm thick layer of validated low-permeability clay spread over the waste. Immediately above the clay capping is a 300mm layer of drainage sand. 100mm of topsoil and turf overlies the drainage media. The capping reduces stormwater infiltration thus reducing the generation of leachate. The capping also allows the landfill to be used for recreation by eliminating the risk of human exposure to contaminants.

Vertical cut-off barrier – A compacted clay wall / bentonite liner is constructed along the Northern edge of Boundary Creek (that is, between the leachate drain and the creek). The materials combine to act as an impermeable barrier and prevent leachate from migrating toward the creek. The liner is laid into residual clays and to the height of the gabions which are located along the creek bank (RL102.0). An impermeable liner is also laid along the creek bed to restrict any groundwater inflow.

Residual clay – The waste is placed on low-permeability residual clays to limit the downward migration of waste and leachate.

3.5.4.2 Leachate Collection System

The purpose of the leachate collection system is to intercept leachate, preventing contamination of the natural ground and surface waters. The collection system is also responsible for diverting leachate to the transfer system (pumping pits).

The leachate collection system consists of:

Leachate drain – The leachate drain is a longitudinal trench excavated approximately one metre into residual clays. In the trench, an 'Atlantis' polyethylene drainage cell is encapsulated with filter mesh and overtopped with approximately 1500mm of drainage sand. The drain is located around the down-gradient perimeter of the landfill. Thus, the natural outward flow of leachate is intercepted by the sand and leachate filters into the drain. Gravity allows the leachate to travel through the drain and be directed into the nearest pumping pit.

Pumping pits – Each pumping pit is made of a precast concrete well, installed vertically onto a concrete base slab. The interface is sealed with an epoxy mortar. A concrete lid and ladder rungs provide access for maintenance and cleaning. A small capped hole within the concrete lid provides convenient access for inspection. The pit acts as a reservoir, storing collected leachate until such time that it is pumped to the transfer system. A total of two pumping pits (Pump Pits 6 and 7) are located along the leachate drain.

Piezometers – The piezometers are a length of 50mm poly-pipe installed vertically into the leachate drain or on the outside of the cut of walls. The top of the piezometer is located above the ground in a lockable protective monument. The piezometer enables access for extraction of samples for analysis and measurements of leachate and groundwater levels.

Sumps – A series of three sumps enable additional sampling and leachate level monitoring to be undertaken. The sumps consist of a 200mm diameter plastic pipe installed vertically into the fill, backfilled with blue metal. The sumps are constructed outside the leachate drain, along the bank of Boundary Creek. The sumps were installed following groundwater studies of the GDR landfill in 1998. Leachate seeps were identified along the creek bank during these studies. The sumps were installed to collect the seeps before they could migrate to Boundary Creek. One piezometer (9a) is also located outside the leachate drain to assist with the early identification of seeps.

Pumping wells – A series of two pumping wells enables sampling and leachate level monitoring to be undertaken. The wells consist of a 200mm diameter plastic pipe installed vertically into the leachate drain. The wells were also constructed during 1998 groundwater studies of the GDR landfill. The wells were installed to provide additional, temporary points for leachate extraction. These wells are not required for pumping and are usually dry.

3.5.4.3 Leachate Transfer System

The purpose of the leachate transfer system is to extract leachate from the pumping pits and transfer it to the treatment plant. The leachate transfer system consists of:

Submersible pumps – Both pumping pits are fitted with a submersible pump. The pump is located at the bottom of the pit, connected to the top by a galvanised steel chain (the chain allows the pump to be removed from the pit for maintenance and service). The pumps are programmed to operate automatically. The pumps operate in a by-pass mode, whereby PP6 bypasses PP7. PP 6 and 7 then share the rising main, discharging the combined leachate to the Kronos Hill leachate system and eventually to the LLWP.

Level sensors – To prevent pump pit overflows, each pit contains one analog level transducer. The sensor is activated by the pressure of water in the pit relaying the information in % of leachate in the pit.

Pump control – Control of pumping from PP6 and 7 is coordinated by a Grundfos CU300, located on the gabion wall adjacent to Boundary Creek. The control panel consists of an electrical circuit board and a number of switches and acts as the electrical control for the pumps. The control panel is powered from a light pole on Shirley Strickland Avenue. The control panel also provides 'manual override' switches to allow isolation of equipment for servicing.

System Control - Automation of the system is controlled from the SCADA system maintained at PMC. The system uses miri AD2000 to monitor the levels and volume and rate of leachate discharge.

Hydraulic Valve - Pumping to Kronos Hill system through the rising main is controlled by a valve at PP1. When PP1 is at 'high level' the valve will close, preventing the flow of liquid through the rising main. The valve will also shut when the power to PP1 control panel (and thus the link between the

GDR and Kronos Hill systems) is cut off. This emergency function prevents the GDR system continuing to pump after a power failure.

Discharge pipe / non-return valve – A discharge pipe carries leachate from each pump to the top of the pit where it connects with the main discharge line. A non-return valve is fitted at the junction of these pipes to prevent leachate from draining back down the pipe and into the pit when the pipe is full.

Discharge line – There are two discharge lines for the GDR system. A 50mm pipe links PP6 to the main discharge pipe, in the valve pit adjacent to PP7. A 75mm pipe connects PP7 to PP1 at Kronos Hill. The discharge lines are constructed approximately 600mm below the surface. The pipes are a conduit for the transfer of leachate from the system to PP1 and eventually to the LLWP.

Flow meters – Electromagnetic flow meters are installed on the discharge of each pump pit to monitor individual pit performance. The display for these flow meters is located in the control cabinet. An additional flow meter is located at the discharge line outlet at Pump Pit 1 to monitor performance of the overall system. The flow meters allow both the rate and volume of discharge to be measured.

3.5.4.4 Sub-surface Drainage System

The sub-surface drainage system is designed to intercept stormwater infiltration, preventing it from entering the landfill and producing additional leachate. The sub-surface drainage system consists of an agricultural pipe located within the top of the clay cap. The pipe lies beneath a 300mm thick layer of drainage sand. Sub-surface drains are located in a herringbone pattern beneath the areas of the site which have minimal stormwater run-off (i.e. the flat, turfed section of the site).

Collected sub-surface waters are diverted via gravity, to the stormwater detention ponds located on the South-Eastern perimeter of the site.

3.5.4.5 Gas Extraction Systems

There are two gas extraction systems at the GDR Landfill.

1. A gas drainage layer is installed beneath the turfed section of the site, to intercept methane and other landfill gases before they reach the surface. The gas drainage system consists of a matrix of 160mm diameter MDPE pipes, located beneath the clay cap. A 400mm thick layer of drainage aggregate is located immediately above the pipe. The pipe is perforated on the under side allowing gases to be collected and entrapped. Collected gases are extracted, and vented into the atmosphere, by a fan situated at the rear of the golf amenities building.

2. A gas extraction system is located beneath the P3 Car Park to prevent gas accumulation. The system consists of a gas drainage blanket which collects and directs gases to venting pits. Gases are extracted by continuously operated fans and discharged via stacks, which extend from the pits to a height of 5 metres above the upper floor level of the car park.

3.5.5 System management

The landfill is managed in accordance with the objectives, strategy and specifications of the SOPA Remediated Land Management Plan.

Landfill management is a combination of preventative inspection and maintenance, and where required, supply of materials and corrective works of the hydraulic and electrical infrastructure. Regular reports are supplied to SOPA detailing works carried out and potential issues that require action.

The leachate transfer system is remotely monitored via the SCADA system (Section 6). This provides continuously updated data regarding the performance of the transfer system with comprehensive operational and maintenance data.

3.5.6 Contingency plans

Contingency plans and a series of Standard Operating Procedures (section 7) have been developed to address those situations where a system malfunction may lead to environmental harm.

The pump pits and drains provide a reservoir that can store leachate for several days in event of system failure, allowing time for repairs or alternative disposal to be arranged. The SCADA system remotely monitors leachate levels in the pump pits, and can automatically turn on or shut down pumps where levels exceed trigger points (thus preventing overflows), and log alarms for action by contractors. The SCADA system is monitored daily.

Contingency plans for high-risk events at the Golf Driving Range landfill are:

System component / issue	*Response*
Pump failure	Replace pump within 48 hours. Tanker extraction if required
System control / electrical / power failure	Repair components ASAP. Tanker extraction and treatment of leachate at LLWP if required.
Hydraulic failure (pipe rupture, failure of valve)	Repair components ASAP. Tanker extraction and treatment of leachate at LLWP if required
Liquid waste plant reaches capacity	Dispose of leachate through alternative means eg other treatment plant.

3.5.7 Leachate composition

Typical compositional analysis of leachate collecting in PP6 and PP7 at the Golf Driving Range is detailed in the Table 3.5.2 following.

Table 3.5.2 Typical leachate chemical composition – Golf Driving Range July 2007

Analyte	Unit	PP6	PP7	Analyte	Unit	PP6	PP7
Alkalinity	mg/L	295	690	NO_3	mg/L	0.04	7.6
Al	mg/L	<0.05	<0.05	NO_2	mg/L	0.27	0.52
NH_3	mg/L	6.5	33	N (total)	mg/L	8.2	36
As	mg/L	<0.01	<0.01	K	mg/L	47	66
HCO_3	mg/L	360	840	PAH	ug/L	4.73	0
BOD	mg/L	10	81	P (total)	mg/L		0.02
Ca	mg/L	64	180	Na	mg/L	295	460
CO_3	mg/L	<1	<1	SO_4	mg/L	135	155
Cl	mg/L	420	780	TDS	mg/L	1160	2110
Cu	mg/L	<0.001	0.003	TPH C6-9	ug/L	<25	<25
CN	mg/L	<0.005	0.02	TPH C10-36	ug/L	460	1890
F	mg/L	0.39	0.37	Zn	mg/L	0.014	0.012
Fe	mg/L	0.05	0.01	insitu DO	(ppm)	12.30%	30.91%
Pb	mg/L	<0.001	<0.001	insitu EC	(mS/cm)	2.043	3.78
Mg	mg/L	26	67	insitu temp.	`C	17	13.6
Mn	mg/L	0.28	0.19	insitu redox	(mV)	-59	-71
				insitu pH		6.81	6.65

3.5.8 Environmental monitoring

A comprehensive environmental monitoring program is conducted as detailed in Section 11, with the following objectives:

- Assess the effectiveness of the containment structure.
- Identify off-site or on-site movement of leachate.

- Comply with the environmental monitoring requirements established in a Notice issued under the Contaminated Lands Management Act 1997.
- Enable performance assessment and reporting

The south eastern border of the Golf Driving Range with Boundary Creek has been previously identified as the direction of groundwater flow. This pathway has been isolated by means of leachate drains and impermeable lining. Two pump pits store collected leachate prior to it being transported to LLWP via rising main. There are several monitoring piezometers along the leachate drain length and three sumps located on the outer side of the drain adjacent to Boundary Creek which are used to monitor potential off site migration of contaminants.

Soil Volatile Organic Compound (VOC) emanation from the landfill is controlled by a sub-surface gas collection and extraction system. A site horticultural maintenance plan includes fertilising and mowing with the provision of surface irrigation.

3.5.8.1 Leachate analytes

In 2006, SOPA commissioned a review of leachate chemical quality from all landfills to:

- Define the crucial analytes required to monitor the integrity of the remediated land and determine potential environmental harm;
- Define the analytes regarded as superfluous after 6 years of data collection;
- Determine whether the chemical leachate monitoring data adequately helps identify potential leachate migration from remediated land;
- Identify any areas of remediated lands that may require additional monitoring and/or monitoring protocols initiated;
- Optimise a monitoring program that will be significantly more cost effective to SOPA.

[Hanitro Pty Ltd 2006. Leachate and Groundwater Chemical Monitoring Review at Sydney Olympic Park. Report to Sydney Olympic Park Authority].

Assessment of data from chemical monitoring of PP6 and PP7 identified the chemicals of concern that are derived from the original pollution source. Interestingly, BOD results which usually mimic ammonia levels are regularly <50 mg/L except for two occasions in 2002 and 2003. The chemical of concern regularly detected are:

- Ammonia (500 mg/L maximum)
- BOD (110 mg/L maximum)

Hydrocarbon contaminants that are typical of putrescible tip leachate arising from engine oils and greases, are found in low concentrations except for one occasion in 2001 where 0.10 mg/L PAHs were detected in PP6. Typical maximum concentrations since then are

- Total C6 – C36 Petroleum Hydrocarbons (3.2 mg/L maximum)
- Polycyclic aromatic Hydrocarbons (0.014 mg/L maximum)

Also in low concentration are the following heavy metals/metalloids potentially derived from the original pollution source:

- Zinc (0.014 mg/L maximum)
- Cyanide (0.01 mg/L – detected once since 2001 in PP7)
- Copper (0.005 mg/L maximum)
- Lead (0.003 mg/L)

Four other heavy metal or metalloid ions are also regularly detected in the leachate within the containment structures. It should be noted however that these four elements are natural components of estuarine clays, estuarine sediments and sea water and are unlikely to represent a specific pollution source.

- Iron (0.11 mg/L maximum)
- Manganese (0.97 mg/L maximum)

- Boron (1.6 mg/L maximum)
- Barium (2.4 mg/L maximum)

The groundwater monitoring program has not detected the heavy metals arsenic, cadmium, chromium, lead and mercury in leachate from the Golf Driving Range.

A variety of monovalent and divalent cations and anions are also regularly detected in this leachate source (sodium, potassium, calcium, magnesium, chloride, sulphate, nitrate, bicarbonate and fluoride). These analytes are typically found in natural sources such as clays and sea water and do not represent a specific pollution source.

A group of analytes previously analysed in GDR leachate analyses are regarded as being superfluous. These analytes were either:

- Never detected in leachate, (arsenic, cadmium, lead and mercury).
- Infrequently detected and near PQL (chromium).
- Typical natural mineral components of the local geology, (boron, barium, calcium, magnesium, iron, manganese, sodium and potassium).
- Typical natural anion components of seawater, saline clay soils or town water (chloride, fluoride, sulphate, carbonate, bicarbonate and hydroxide).

The current monitoring program reflects the outcomes of this review; analytes to be tested for at this landfill are identified in Table 11.2.

3.5.8.2 Gas monitoring review

SOPA commissioned a review of remediated lands gas monitoring data in 2007. Quarterly gas monitoring had been conducted since January 2001, and over six years of subsurface accumulated gas monitoring data and surface gas monitoring data for the Golf Driving Range landfill was analysed. Depleted oxygen levels were evident in some system components in some samples, surface gas concentrations of methane, oxygen, hydrogen sulfide and carbon monoxide were recorded at non-detectable or background levels.

The review concluded that the subsurface accumulative gas monitoring and surface gas monitoring program could be discontinued at the Golf Driving Range landfill. [Review of the remediated lands gas monitoring program at Sydney Olympic Park. October 2007. Environmental Earth Sciences report to Sydney Olympic Park Authority].

3.5.8.3 Assessment of containment effectiveness

The SCADA system continuously monitors leachate levels and activates the pumps. Containment effectiveness is assessed by reviewing SCADA operational data regarding leachate level management in the Australia Avenue arm of the leachate drain (below design level of RL 101.2), and assessing concentration of groundwater contaminants downgradient from the leachate drain. Manual static water level monitoring provides a check of operational data.

APPENDIX C – RISK MATRIX TABLE

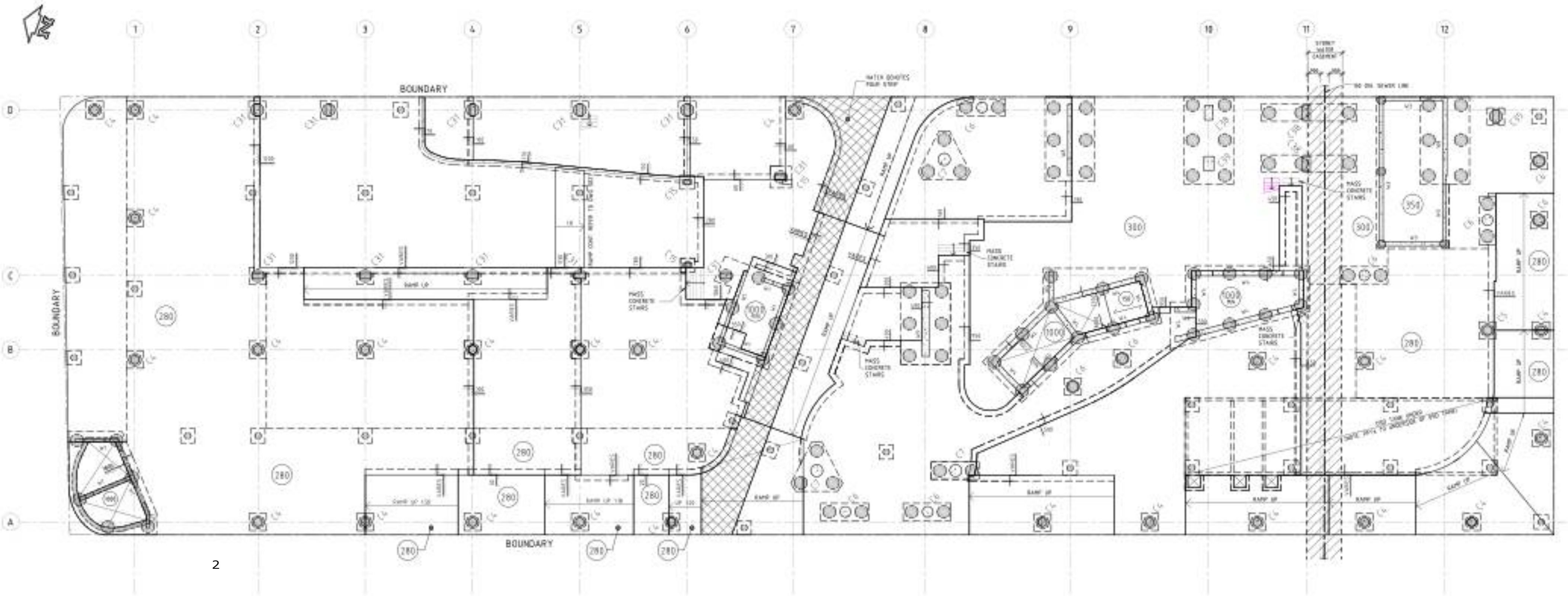
Aspects	Hazards	Pathways	Receptors	Potential Impacts	Categories		Ranking (LxC) of risk before control measures	Potential control measures	Categories		Ranking (LxC) of residual risk following implementation of control measures
					Likelihood (L)	Consequence (C)			Likelihood (L)	Consequence (C)	
Land	Entry of LFG into building or site	Gas migration through unsaturated Soil under building	Occupants of the development	Death or serious injury due to explosion	3	4	Very high risk	Natural attenuation and oxidation of methane and LFG in the landfill cap Implementation of LFG monitoring program Hot work permits and restricted areas for hot work/potential ignition sources. Installation of low permeability layer and passive ventilation system under building	1	4	Low risk
				Asphyxiation due to low oxygen and high carbon dioxide	2	4	Moderate risk	Material under depot will have low permeability to LFG Indoor monitoring in the building and passive venitilation system allowing LFG to vent freely to the surface where it will be oxidised	1	4	Low risk
			Residential dwellings off-site	Death or injury due to fire or explosion (presence of methane and ignition sources	2	4	Moderate risk	LFG monitoring bores and monitoring program. Release of any potential accumulation of LFG and migration by advective pressure as high permeability site surface proposed (gravel and crushed rock)	1	4	Low risk
				Asphyxiation due to low oxygen and high carbon dioxide	1	4	Low risk				
	Gas entry to underground services or in the ground.	Gas migration via underground service trenches and incoming feeders through the landfill	Occupants of the development	Death or serious injury due to explosion	4	4	Very high risk	Low permeability seal around pipes and in service ducts/trenches. Periodic and regular monitoring of pits Grates and venting of service pits	1	4	Low risk
			Construction workers excavating trenches	Death or serious injury due to explosion	1	4	Low risk	Accumulation is not likely to occur as trenches are open to atmosphere and LFG will be diluted to acceptable concentrations. Hot work permits and restricted areas for hot work/potential ignition sources. No smoking on-site and LEL monitors used with Construction Environmental Management (CEMP)/Environmental Management Plan (EMP)	1	4	Low risk
				Asphyxiation due to low oxygen and high CO2	1	4	Low risk	Personal LEL monitors and no entry into pits or trenches greater than 1.2m deep Implementation and enforcement of Environmental Management Plan (EMP) and construction plan	1	4	Very low risk
			Support infrastructure	Corrosion of in piers, walls and ground infrastructure due to acidic LFG or condensate	1	2	Low risk	Gas membrane and tanking membrane will prevent exposure to any potential leachate. Concrete resistant to attack from acidic LFG and leachate	1	1	Very low risk
Air	Presence of toxic gases in air	Ambient air	Workers on site and residents	Chronic health risk to nearby residents and site occupants	1	4		Landfill capping, high permeability site surface, sub slab and ambient LEL monitors. Management plans	1	1	Very low risk
	Emission of greenhouse gases		Atmosphere	Contribution to GHG and global warming	1	1	Very low risk	Oxidation of methane in landfill capping	1	1	Very low risk
	Odour		Site visitors and residents off-site	Aesthetic impact	2	2	Low risk	Cap walkover & odour monitoring	1	2	Very low risk
			Construction and depot workers	Aesthetic impact							
Groundwater and leachate	Partitioning of LFG from groundwater & leachate into soil gas	Gas migration through unsaturated soil	Residents in buildings off site	Death or serious injury due to explosion or asphyxiation	1	4	Low risk	None	1	4	Very low risk
			Construction/depot workers in trench & pits	Death or serious injury due to explosion or asphyxiation				Staff should receive confined space training and take appropriate precautions entering confined spaces. LEL monitors			
			Residents in buildings off-site	Death or serious injury due to explosion or asphyxiation				None			
		Gas migration through Unsaturated Soil Zone and via underground services	Residents in buildings off site	Death or serious injury due to explosion or asphyxiation				Seals on pipes and services that run through trenches			
			Construction/depot workers in trench & pits	Death or serious injury due to explosion or asphyxiation				Depot staff should receive confined space training and take appropriate precautions if entering confined spaces. LEL monitors			
			Flora and Fauna	Vegetation die-back	1	2	Very low risk	Visual site inspections	1	2	Very low risk

APPENDIX D – CONCEPT DESIGN DRAWINGS

DRAWING REGISTER

Figure	Description	NOTE
1	SLAB DESIGN	
2	MEMBRANE, 50MM DRAINAGE CELL EXTENT AND SUBSLAB MONITORING POINTS	
3	TYPICAL CROSS SECTION	CETCO STANDARD DRAWING
4	INLET DETAILS - MUSHROOM AND Z TYPE	CETCO STANDARD DRAWING
5	OUTLET DETAIL AND TURBINE VENTILATOR DETAIL	CETCO STANDARD DRAWING
6	GAS VAPOUR BARRIER DETAILS	CETCO STANDARD DRAWING
7	RETAINING WALL DETAIL	CETCO STANDARD DRAWING
8	LIFT PIT AND STORMWATER PIT DETAIL	CETCO STANDARD DRAWING
9	INLET AND OUTLET DETAILS	
10	LEVEL 2 VERTICAL INLETS SOUTH TOWER	
11	LEVEL 7 DISCHARGE OUTLETS PLAN	
12	LEVEL 7 DISCHARGE OUTLETS SECTION	
13	SERVICES NORTH TOWER	INSYNC SERVICES
14	SERVICES SOUTH TOWER	INSYNC SERVICES

APPENDIX D FIGURE 1 – SLAB DESIGN



2

GENERAL ARRANGEMENT PLAN
250 THICK SLAB ON GROUND U.N.O

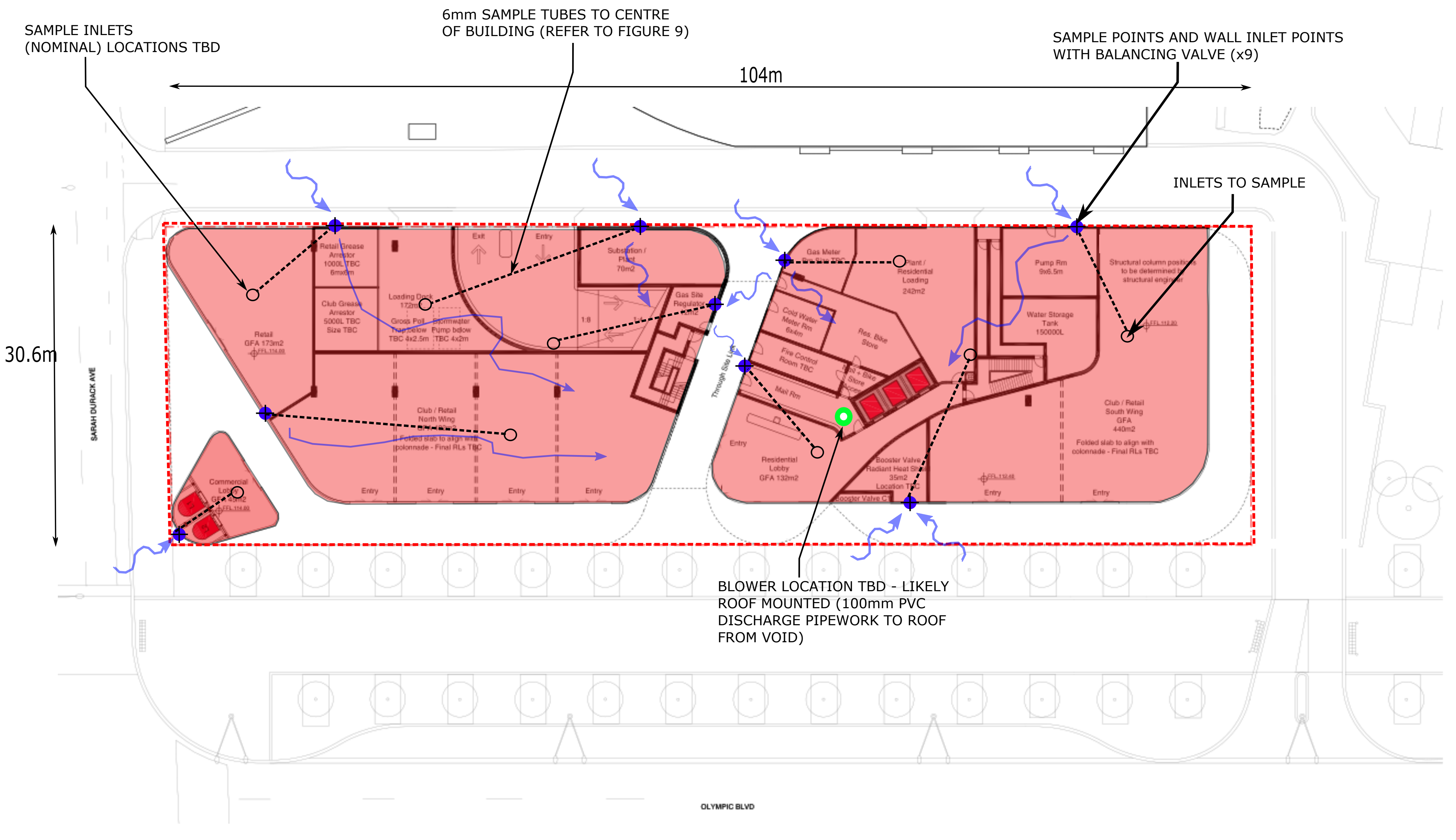
DLA Environmental Services
A Pacific Environment company

Sydney Office
Phone (02) 9476 1765
Fax (02) 9476 1557

Maitland Office
Phone (02) 4933 0001

Title: SLAB DESIGN			
Client: ECOVE	Project No.: DL 3620	Figure No: 1	Date: 11/10/2016
	Scale: As Shown	Compiled: AP	Revision: R00

APPENDIX D FIGURE 2 – MEMBRANE AND DRAINAGE CELL EXTENT



Legend

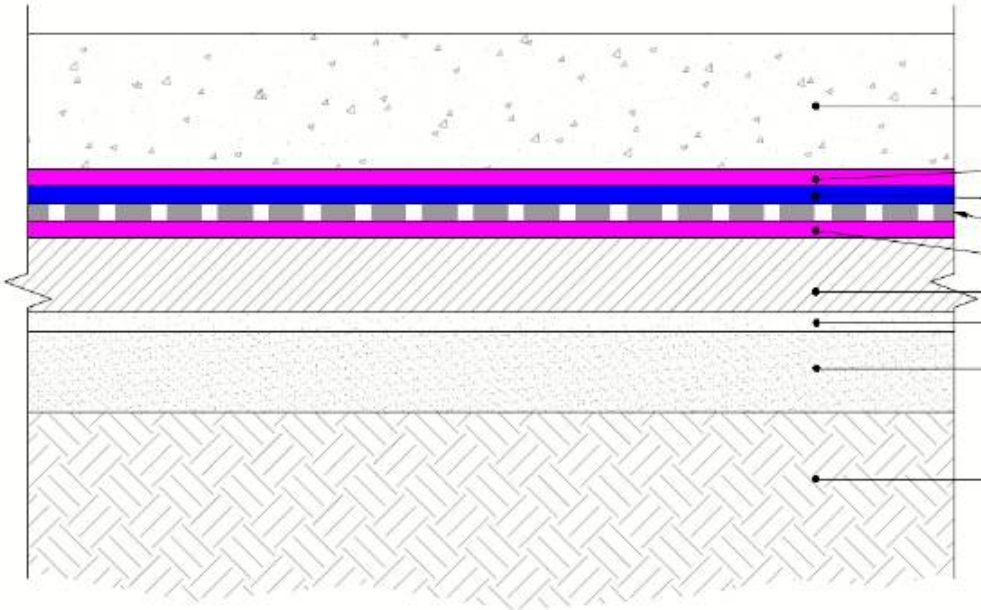
- 50mm Drainage Cell and membrane barrier extent
- SAMPLE OPENING
- SITE BOUNDARY
- INLET SUBSLAB MONITORING POINT
- BLOWER LOCATION (TBD)
- AIR IN

DLA Environmental Services
A Pacific Environment company

Sydney Office
Phone (02) 9476 1765
Fax (02) 9476 1557
Maitland Office
Phone (02) 4933 0001

Title	Drainage Cell, Membrane Barrier Extent and Inlet Subslab Monitoring Points		
Client	Project No.	Figure No	Date
ECOVE	DL 3620	2	2/12/2016
	Scale	Compiled	Revision
	As Shown	SB	R00

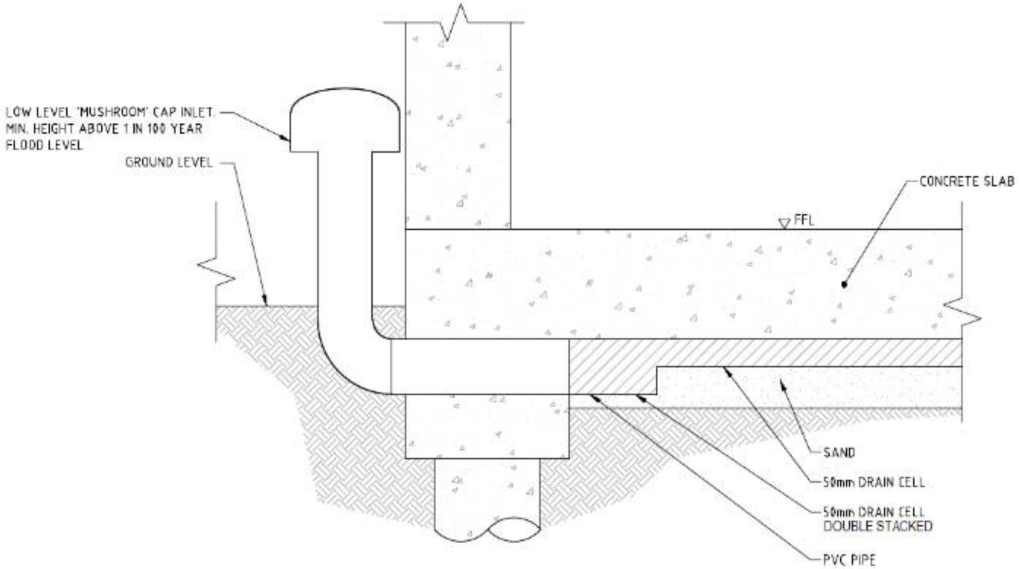
APPENDIX D FIGURE 3 – TYPICAL CROSS SECTION



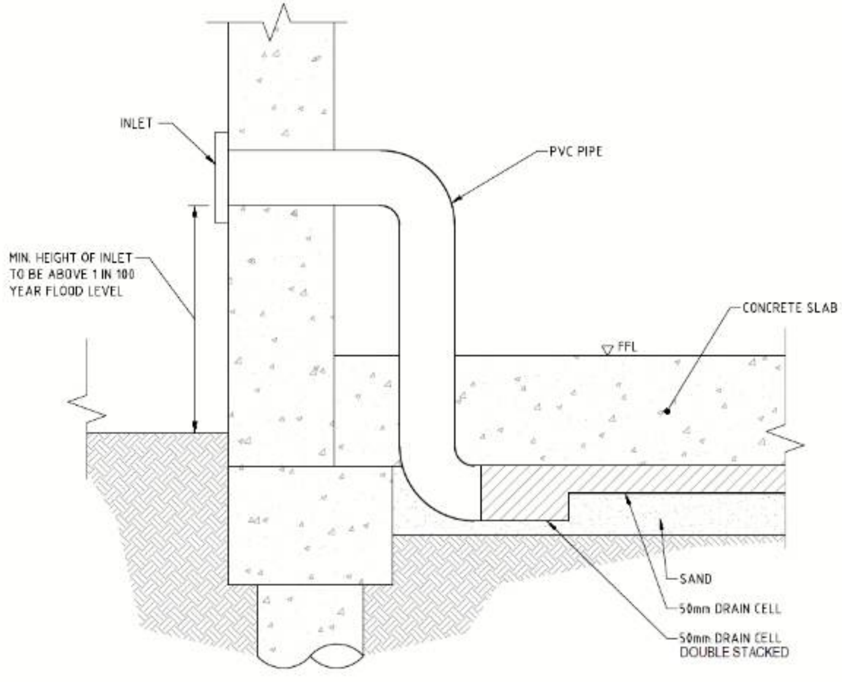
TYPICAL CROSS SECTION
N.T.S

DLA Environmental Services A Pacific Environment company	Title TYPICAL CROSS SECTION			
	Client ECOVE	Project No. DL 3620	Figure No 3	Date 21/11/2016
Sydney Office Phone (02) 9476 1765 Fax (02) 9476 1557 Maitland Office Phone (02) 4933 0001		Scale As Shown	Compiled SB	Revision R00

APPENDIX D FIGURE 4 – INLET DETAIL MUSHROOM AND Z TYPE



INLET DETAIL - MUSHROOM
N.T.S



INLET DETAIL - Z TYPE
N.T.S

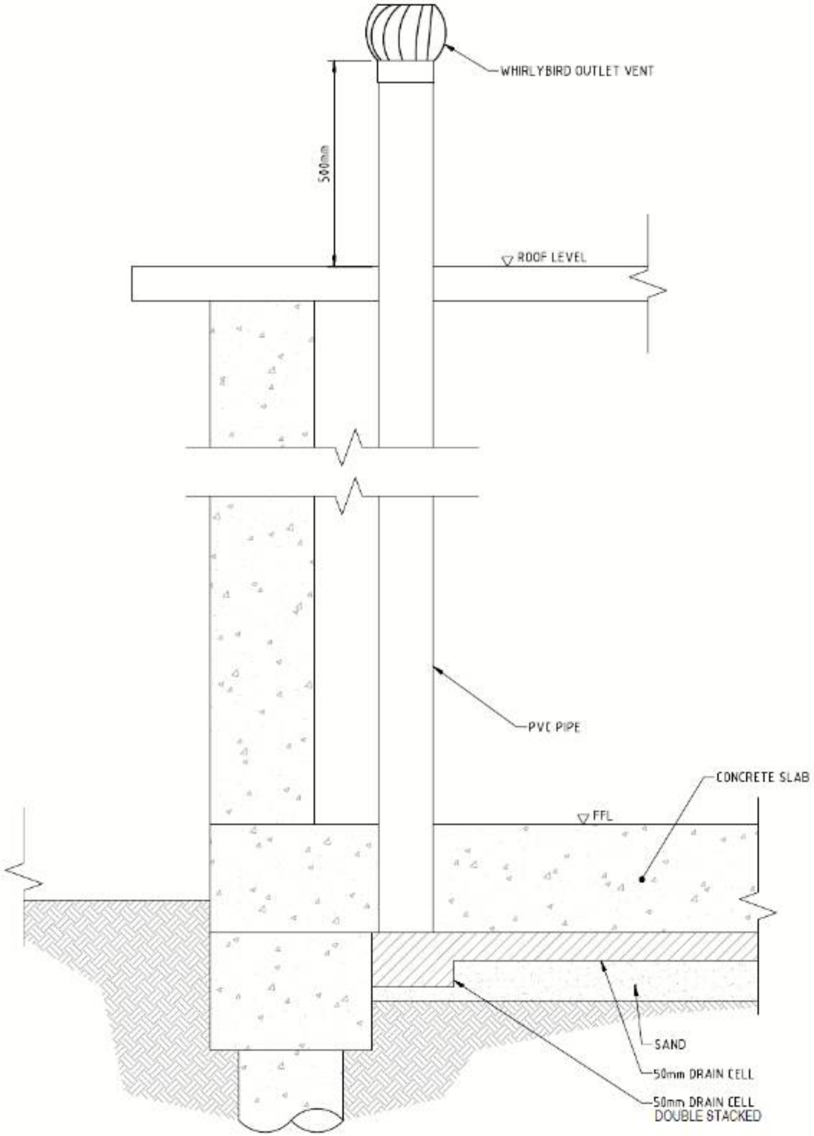
DLA Environmental Services
A Pacific Environment company

Sydney Office
Phone (02) 9476 1765
Fax (02) 9476 1557

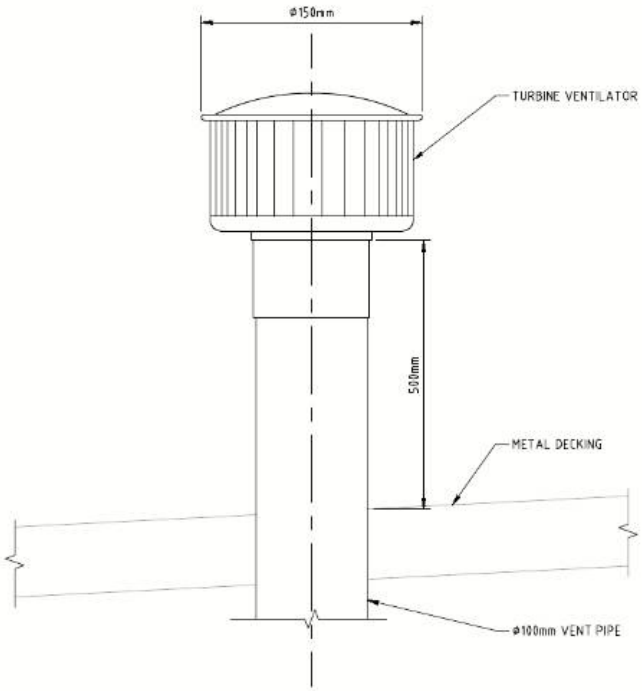
Maitland Office
Phone (02) 4933 0001

Title: INLET DETAILS			
Client: ECOVE	Project No.: DL 3620	Figure No: 4	Date: 21/11/2016
	Scale: As Shown	Compiled: AP	Revision: R00

APPENDIX D FIGURE 5 – OUTLET DETAIL AND TURBINE VENTILATOR



OUTLET DETAIL
N.T.S

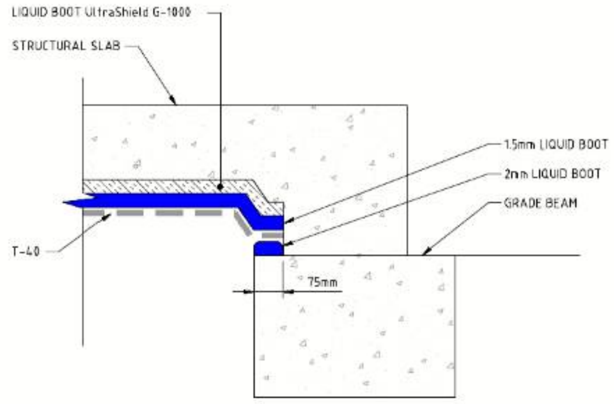


TURBINE VENTILATOR TYPICAL DETAIL
N.T.S

DLA Environmental Services
A Pacific Environment company
Sydney Office
Phone (02) 9476 1765
Fax (02) 9476 1557
Maitland Office
Phone (02) 4933 0001

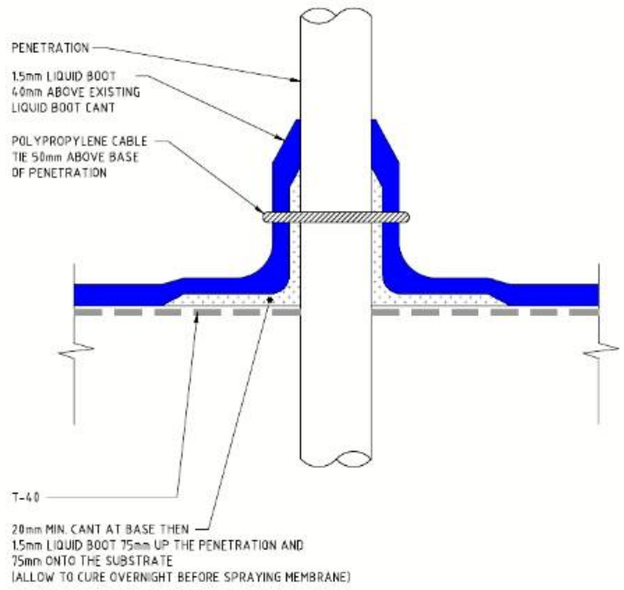
Title: OUTLET DETAILS			
Client: ECOVE	Project No.: DL 3620	Figure No: 5	Date: 21/11/2016
	Scale: As Shown	Compiled: AP	Revision: R00

APPENDIX D FIGURE 6 – GAS VAPOUR BARRIER DETAIL



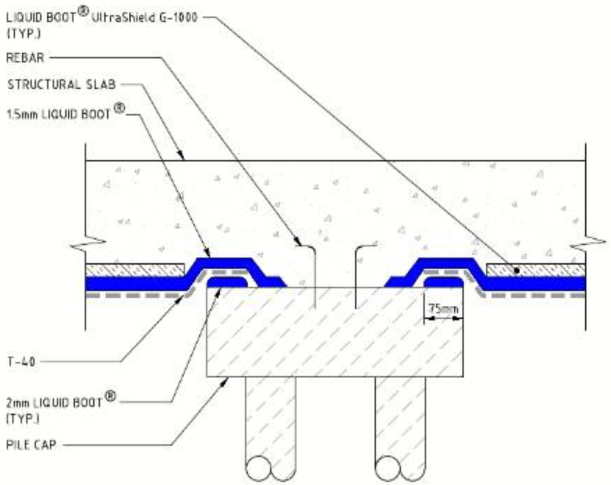
GAS VAPOR BARRIER
OVER FOOTING AND GRADE BEAMS
N.T.S

NOTE:
BRING THE MEMBRANE 75mm ONTO THE FOOTINGS, THE GEOTEXTILE IS THEN ENCAPSULATED IN THE MEMBRANE.

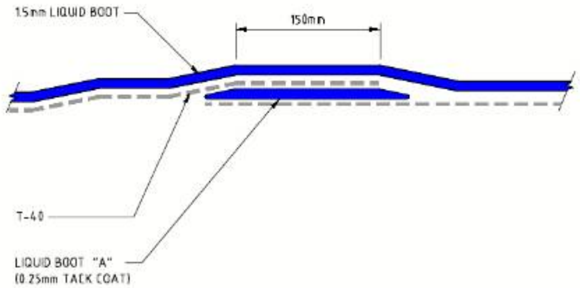


GAS VAPOR BARRIER
PENETRATIONS ON EARTH OR GRAVEL SUBGRADE
N.T.S

NOTE:
ALL PENETRATIONS SHALL BE CLEANED AS PER SPECIFICATIONS BEFORE LIQUID BOOT IS APPLIED.



GAS VAPOR BARRIER
PILE CAP
N.T.S



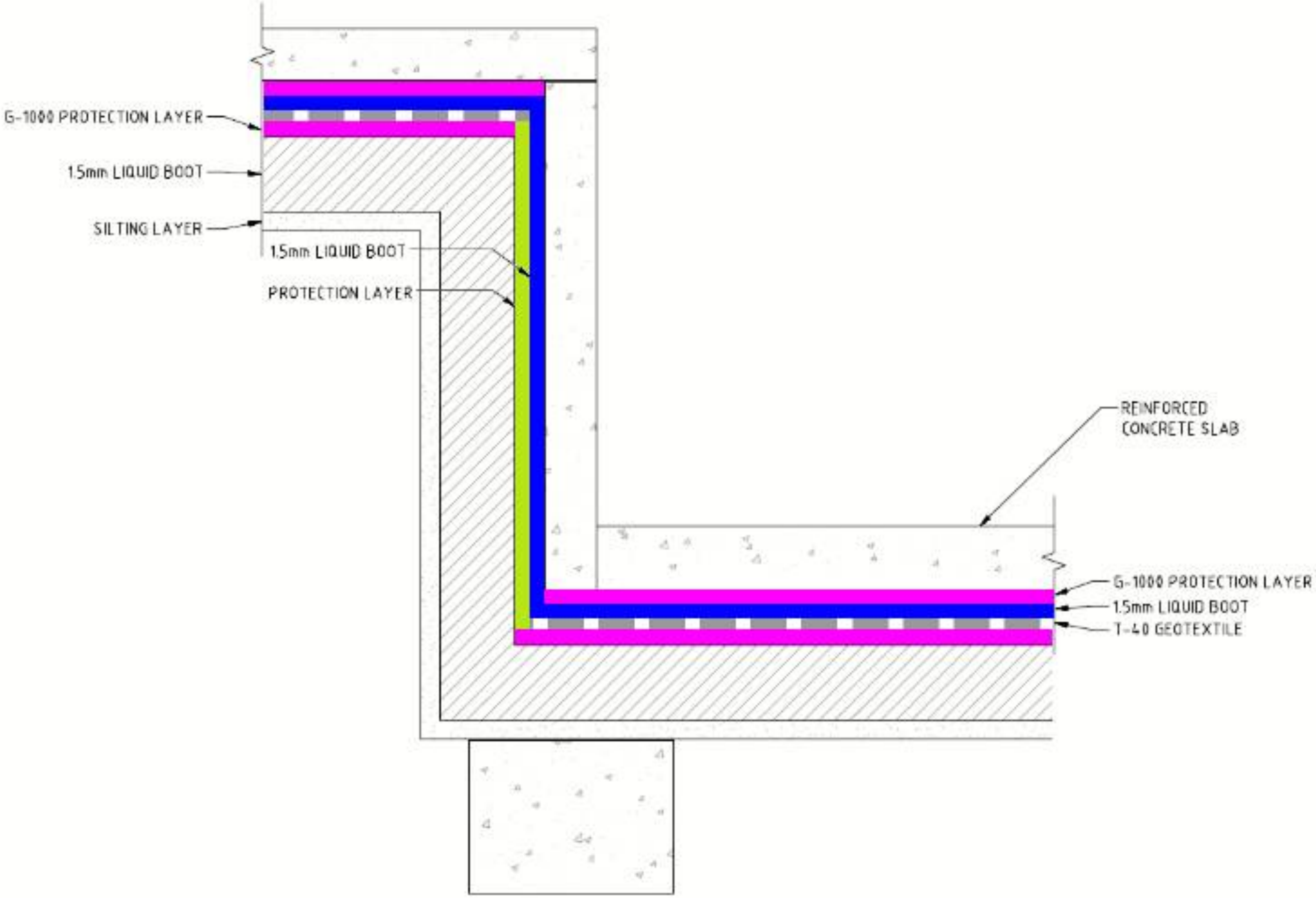
GAS VAPOR BARRIER
MEMBRANE LAP JOINTS ON GEOTEXTILE
N.T.S

DLA Environmental Services
A Pacific Environment company
Sydney Office
Phone (02) 9476 1765
Fax (02) 9476 1557
Maitland Office
Phone (02) 4933 0001

Title
GAS VAPOR BARRIER DETAILS

Client	Project No.	Figure No	Date
ECOVE	DL 3620	6	21/11/2016
	Scale: As Shown	Compiled: AP	Revision: R00

APPENDIX D FIGURE 7 – RETAINING WALL DETAIL



RETAINING WALL

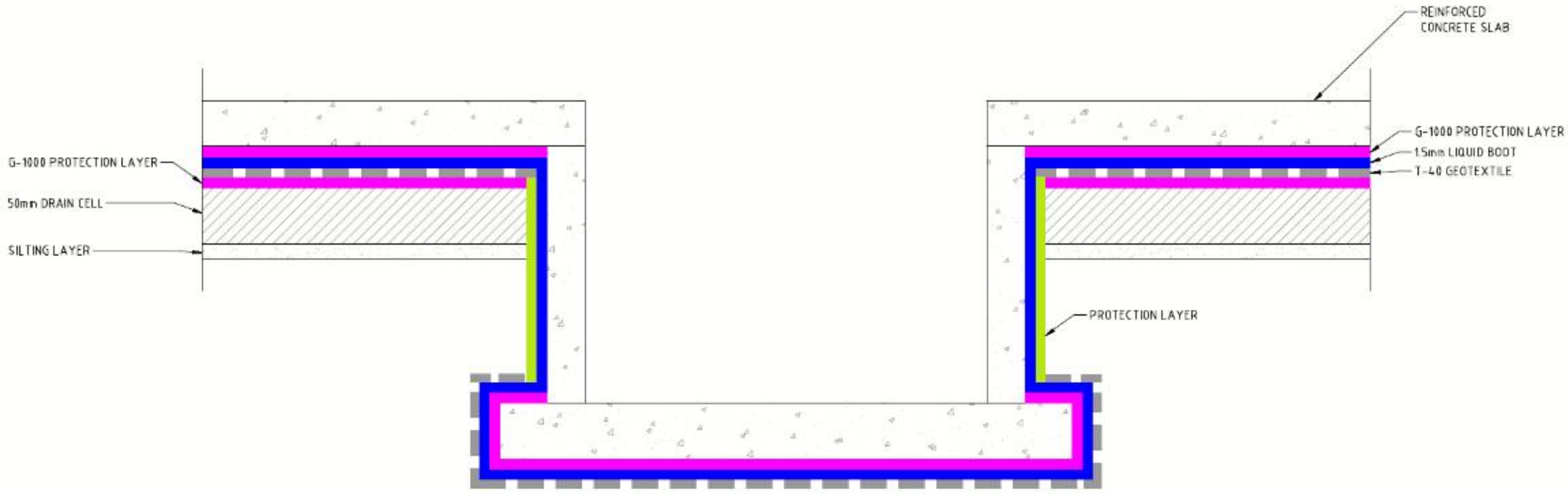
DLA Environmental Services
A Pacific Environment company

Sydney Office
Phone (02) 9476 1765
Fax (02) 9476 1557

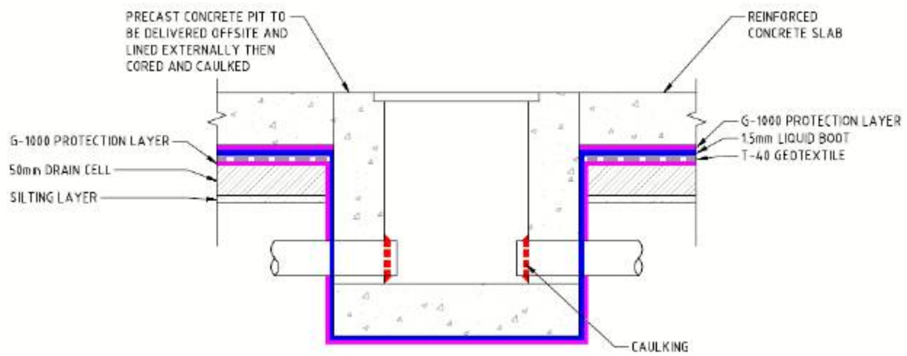
Maitland Office
Phone (02) 4933 0001

Title			
RETAINING WALL			
Client: ECOVE	Project No.: DL 3620	Figure No: 7	Date: 21/11/2016
	Scale: As Shown	Compiled: AP	Revision: R00

APPENDIX D FIGURE 8 – LIFT PIT AND STORMWATER DETAIL



LIFT PIT CORE
N.T.S



STORMWATER PIT DETAIL
N.T.S

NOTE:
HDPE PITS DO NOT REQUIRE LIQUID BOOT LINING.

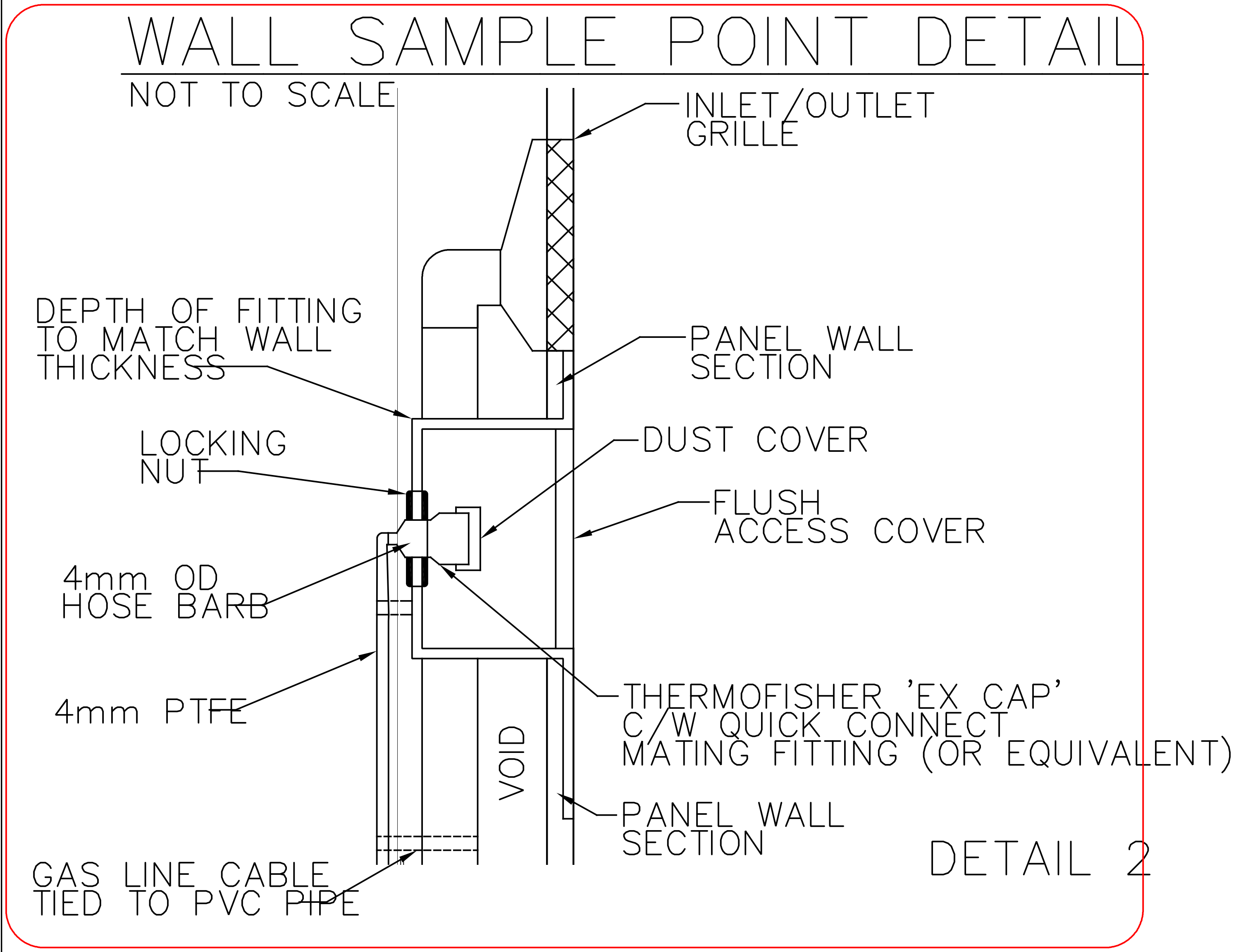
DLA Environmental Services
A Pacific Environment company

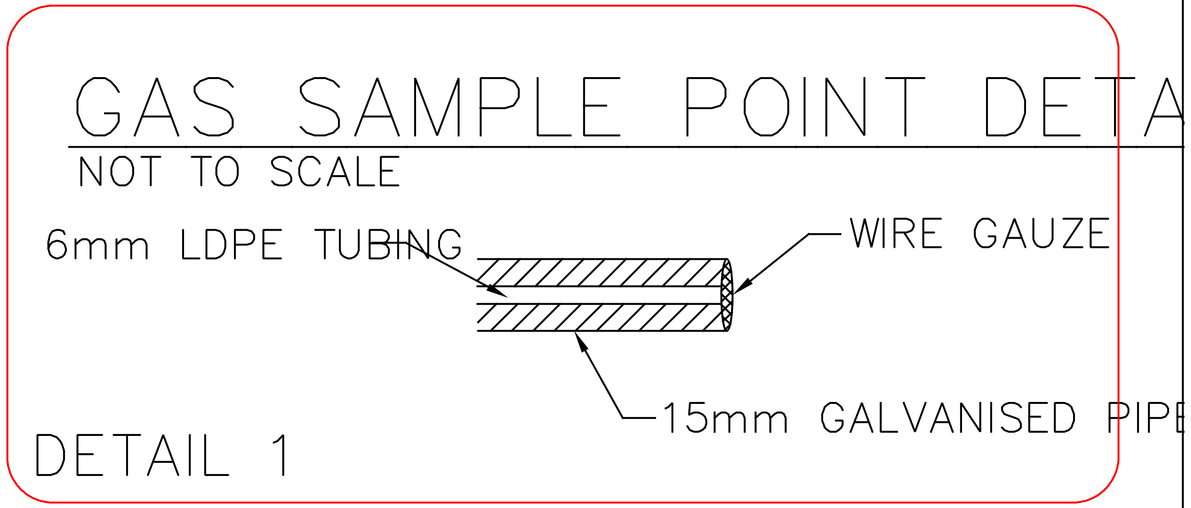
Sydney Office
Phone (02) 9476 1765
Fax (02) 9476 1557

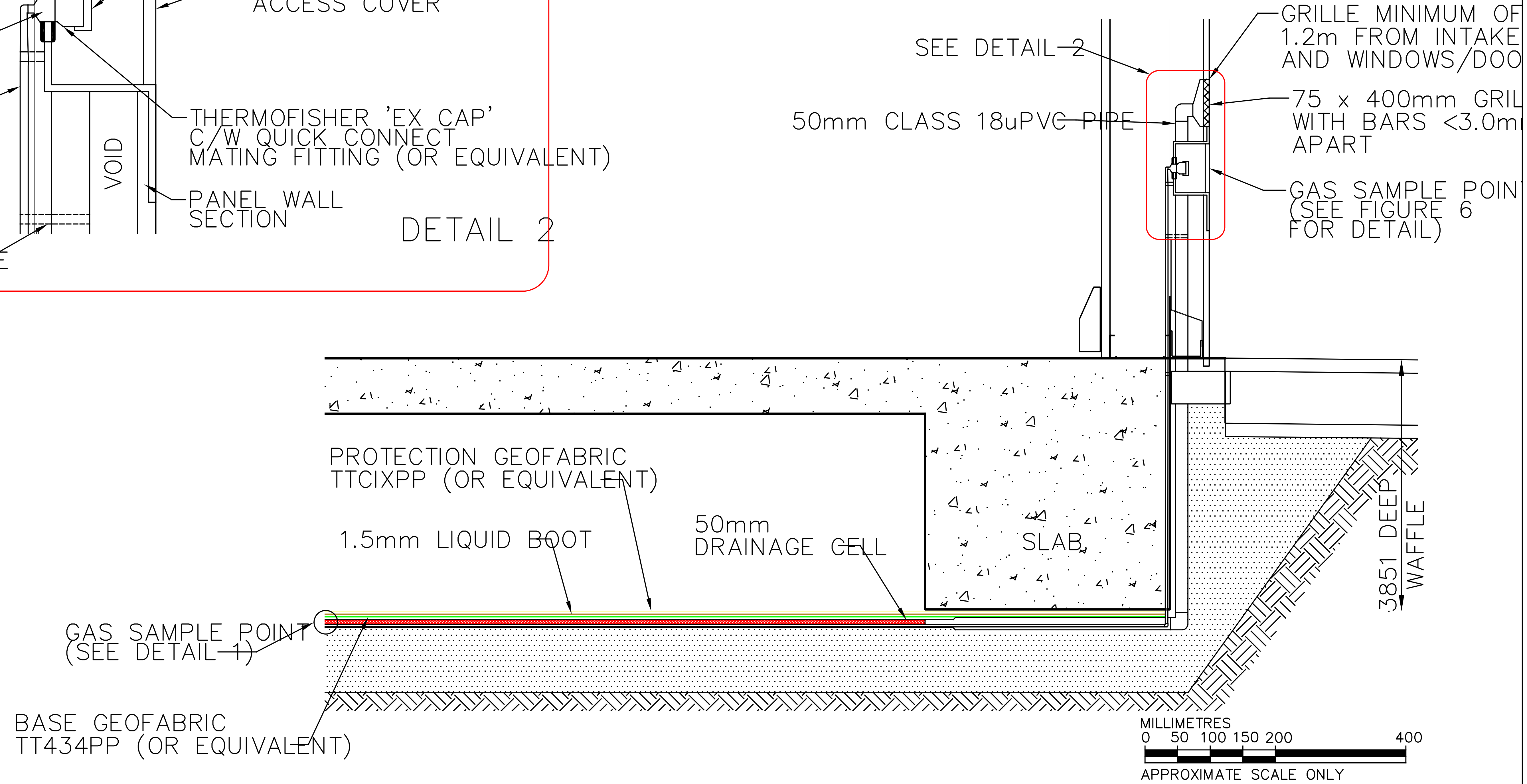
Maitland Office
Phone (02) 4933 0001

Title: Service Details			
Client: ECOVE	Project No.: DL 3620	Figure No: 8	Date: 21/11/2016
	Scale: As Shown	Compiled: AP	Revision: R00

APPENDIX D FIGURE 9 – INLET AND OUTLET DETAIL







ISSUE	DATE	AMENDMENTS	DRN	CKD
01	22.11.16	ORIGINAL ISSUE	SB	AJM

DLA ENVIRONMENTAL
UNIT 3, 38 LEIGHTON PLACE
HORNSBY, NSW 2077
TEL: 02 9476 1765
FAX:
www.dlaenvironmental.com.au

EDGE FOOTING BEAM INLET/OUTLET TO SUB-SLAB VENTILATION SYSTEM

GAS MITIGATION AREAS

SHEET SIZE: A3 | DRAWN: SB | DATE: 22/11/16 | CHECKED | APPROVED | FIG No: FIGURE 9
REV: 01 | DWG NAME:

APPENDIX D FIGURE 10 – LEVEL 2 INLET DETAIL