



Danescroft (Kenavon Drive Project
Management) LLP

GAS HOLDER SITE, READING

Supplementary Phase 2 Geo-Environmental &
Geotechnical Site Assessment





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Supplementary Phase 2 Geo-Environmental & Geotechnical
Site Assessment

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1. INTRODUCTION

1.1. TERMS OF REFERENCE

WSP was instructed by Danescroft (Kenavon Drive Project Management) LLP (Danescroft) (“the Client”) to undertake a supplementary site investigation and assessment of contaminated land, associated liabilities and constraints to support the detailed planning application for the proposed redevelopment of the site known as Gas Holder Site at Alexander Turner Close, Reading (“the Site”). The work was undertaken in accordance with our proposal dated 22 October 2018 (ref. 70031882-P01).

The Site location and current layout are presented in Drawings 70031882-001 and 70031882-002 in **Appendix A**.

1.2. CLIENT AIMS

Danescroft is working on behalf of Scotia Gas Networks (SGN) and is submitting a detailed planning application for a high density residential development on behalf of SGN. Draft planning conditions have been submitted by the Environmental Health Officer at Reading Borough Council, however no formal conditions have received to date for the Site.

WSP has undertaken a supplementary geo-environmental and geotechnical ground investigation (March-April 2019) to further assess the contamination and ground constraints associated with residential development at the site.

WSP has completed a previous ground investigation (2015) along with factual and interpretative reporting for the Site on behalf of SGN. The previous investigation was undertaken on behalf of SGN for continued use of the site as a depot. SGN has provided written agreement to Danescroft that they are able to utilise this existing data for the Site, which includes the previous WSP reports.

The Client’s aims are to:

- Undertake further intrusive ground investigation to assess potential risks to receptors including human health and controlled waters based on the future residential redevelopment of the site;
- Provide information on ground contamination to support the detailed planning application;
- Understand constraints associated with ground contamination at the Site which may impact the proposed development;
- Consider the resulting implications of these in terms of the associated environmental requirements, risks and liabilities; and
- Complete a detailed quantitative risk assessment (DQRA) for controlled waters to assess the level of remediation required at the site (to be produced under separate cover).

1.3. DEVELOPMENT PLANS

The proposed development comprises demolition of existing buildings and the gas holder and the erection of new buildings ranging between two and nine storeys in height, providing 130 residential units (Class C3) with associated access, car parking, landscaping, open space and two private gardens. The proposed development plan layouts are included in **Appendix A**.

1.4. PROJECT SCOPE

To assist in meeting the Client's aims as stated in Section 1.2, the scope of the project comprised:

- Review of the existing reports available for the Site and the surrounding area;
- Assessment of the results of the supplementary ground investigation and previous ground investigation in line with current standards and based on the proposed development;
- Refinement of the preliminary Conceptual Site Model (CSM) that was developed for the Site;
- Generic Quantitative Risk Assessment (GQRA) of potentially sensitive receptors with respect to ground and groundwater contamination; and
- Provision of recommendations with respect to the management and mitigation of potential ground contamination constraints or liabilities which are identified.

This report forms part of the Health and Safety file for the Site.

1.5. LEGISLATIVE CONTEXT AND GUIDANCE

The assessment was undertaken in the legislative context of:

- Part 2A of The Environmental Protection Act (1990); and
- The National Planning Policy Framework (2019)

The following good practice and statutory guidance was considered and the assessment was undertaken in general accordance with:

- Environment Agency 'Model Procedures for the Management of Land Contamination', CLR11 (2004);
- NHBC 'Guidance for the Safe Development of Housing on Land Affected by Contamination', R&D66 (2008);
- CIRIA 'Assessing Risks Posed by Hazardous Ground Gases to Buildings', C665 (2007);
- British Standard 'Investigation of Potentially Contaminated Sites – Code of Practice', BS EN 10175:2011;
- Defra 'Environmental Protection Act 1990: Part 2A Contaminated Land Statutory Guidance', PB13735 (2012);
- British Standard 'Guidance on Investigations for Ground Gas – Permanent Gases and Volatile Organic Compounds (VOCs)' BS 8576:2013;
- British Standard 'Code of Practice for Ground Investigations', BS 5930:2015;
- CIRIA C552 Contaminated Land Risk Assessment – A Guide to Good Practice; and
- UK Water Industry Research (UKWIR) (2010). Guidance for the selection of water supply pipe to be used in brownfield sites. Report Ref. No. 10/WM/03/21.

1.6. SOURCES OF INFORMATION

The following relevant sources of previous information were used in the production of this report. Information from these sources relating to the underlying ground conditions has also been utilised in later sections this report, where appropriate:

Table 1 - Sources of Information

Source	Report
WSP Reports	WSP (2016) Factual Site Investigation Report, Gasholder No. 4, Kenavon Drive, Reading, May 2016, Project No. 287642I, Revision 1 (for SGN). WSP (2016) Interpretative Site Investigation Report, Gasholder No. 4, Kenavon Drive, Reading, May 2016, Project No. 287642I, Revision 1 (for SGN). WSP (2017) Off-Site Environmental Liability Assessment, Reading Gasholder No. 4, June 2017, Project No. 70031882 (for Danescroft). WSP (2019) Phase 2 Site Assessment, Gas Holder Site, Reading, April 2019, Project No. 70031882 (for Danescroft).
Third Party Reports	Factual Environmental Desk Study (March 2005). Atkins Ltd. From an original report titled: Kenavon Drive, Reading (Mentor No.9005) Environmental Assessment Desk Study: Final Interpretative Report. November 1997. WS Atkins Consultants Limited. Factual Environmental Site Investigation Report (March 2005). Atkins Ltd. From an original report titled: Kenavon Drive, Reading (Mentor No.9005) Environmental Site Investigation: Interpretative Report Final. October 1998. WS Atkins Consultants Limited.
Public Information	Environment Agency, 'What's in your Backyard?' (http://apps.environment-agency.gov.uk/wiyby/default.aspx), accessed 22 January 2016. Envirocheck® Report (ref 72752172_1_1) September 2015. BGS 'Geology of Britain' online viewer accessed on 23 May 2018 (http://mapapps.bgs.ac.uk/geologyofbritain/home.html). Zetica 'Unexploded Bomb Risk Map' website accessed 23 May 2018 (https://zeticauxo.com/downloads-and-resources/risk-maps/).
Notes:	The report contains British Geological Survey materials ©NERC 2018 and Environment Agency information ©Environment Agency and database right.

1.7. CONFIDENTIALITY STATEMENT AND LIMITATIONS

This report is addressed to and may be relied upon by Danescroft (Kenavon Drive Project Management) LLP. It may not be relied upon or transferred to any other parties without the express agreement of WSP UK Limited in writing. The report should be read and used in full. No responsibility will be accepted where this report is used, either in its entirety or in part, by any other party.

Third party information not directly commissioned by WSP UK Limited and used in the production of this report has been relied upon as being accurate. WSP UK Limited cannot and will not accept any liability for errors and/or omissions in data provided by others in these cases and cannot warrant that works. Report limitations are presented in **Appendix B**.

2. SITE SETTING

2.1. SITE DESCRIPTION AND CURRENT USE

Table 2 summarises the Site details based on site visits conducted in 2015 and 2019 and obtained over the course of the project.

Table 2 – Summary of Site Details

Detail	Comment
Name and Address of Site	Gas Holder Site at Alexander Turner Close, Reading
National Grid reference	472925, 173675
Site Description and Current Use	The Site is approximately triangular in shape and is classified as operational gas land, comprising a decommissioned gas holder (gas holder No.4) within a separate palisade fence compound in the west of the Site and an asphalt yard in the east of the Site utilised by SGN as a manned storage depot. The Site is accessed via a new housing development to the west. Access to the SGN depot yard is gained through a gate in the southwest corner. The palisade compound which houses the gas holder is accessed through the SGN depot yard via double gates in the palisade compound. Gas holder No.4 is a 2,000,000 cubic foot (cu ft) capacity, oil filmed, column guided holder with an above ground tank which is decommissioned and has been purged to air. The holder is constructed on a raft foundation with cast concrete simplex piles. The depot is manned and is utilised primarily for storage of plant and equipment. The yard has an asphalt surface cover and contains three portable offices which are located along the southern site boundary and a metal storage container. Signage, lights, barriers and plant are stored within the yard area. A small palisade fenced compound area is located adjacent to the northern Site boundary (accessed through the yard) which contains a disused concrete water tower and seven metal storage containers. Two small single-storey brick buildings are present within the gas holder compound. These comprise: a former boiler house which is currently used to store red diesel, which is located in the northwest corner; and an equipment store to the west of the compound. The red diesel stored in the former of these buildings is used to fuel plant within a small substation present to the east of the building. Plant and equipment (including bowzers, traffic lights, gas pipes and barriers) are stored externally within the compound.
Area	Approximately 1.0 ha.
Site Setting and Surrounding Area	The Site is located within a mixed residential and commercial area, east of Reading town centre, and approximately 1.3 km east of Reading Train Station. Notable trade directory entries include an active scrap yard 334 m west of the Site, which is classified as a car breakers and dismantlers, and an active photographic processors, Kodak Processing, located 370 m west of the Site.

Detail	Comment
Topography	The Site is generally flat with levels slightly increasing to the west. A topographical survey plan is provided in Appendix A (70031882-002).
Boundaries	Railway lines bound the Site to the north. The River Kennet is present to the southeast of the Site with residential houses beyond. A newly constructed residential development is present beyond the western Site boundary.
Drainage & Flooding	Drainage is present across the Site as detailed in the services plan in Appendix A (70031882-003). According to the 'Flood map for planning' ¹ , the Site is within Flood Zone 2. This zone relates to "Land having between a 1 in 100 and 1 in 1,000 annual probability of river flooding".
Embankments & Slopes	Embankments are present along the northern and south-eastern boundaries of the Site by the railway line and river respectively.
Trees & Vegetation (including invasive species)	Trees and vegetation bound the northern and south-eastern boundaries of the Site.
Fauna	Anecdotal evidence (circa 2015) suggests that peregrine falcons could be present nesting on gas holder No.4.

2.2. HISTORY OF SITE AND SURROUNDING AREA

The Site history has been reviewed with reference to the Envirocheck report (Appendix C) and previous reports produced for the Site. A composite plan of the historical Site structures is shown on Drawing 70031882-004 in **Appendix A**.

Earliest mapping from 1879 shows the Site to be undeveloped, with residential properties located beyond the River Kennet to the south of the Site (flowing in a north easterly direction towards the River Thames); a railway line present to the north; and a gravel pit to the east (approximately 175 m from Site).

By 1899 a gasworks has been developed to the west of the Site, with structures situated on the northern Site boundary, and railway lines passing through the centre of the Site. These structures appear to be the liquor tank, purifiers and sulphate of ammonia plant. At this time the gravel pit to the east had been backfilled and a steam laundry is present in the area, although another gravel pit is present further east (350 m from Site), which was later backfilled in the 1910s.

A cross-boundary gas holder was constructed in 1901 which comprised a frame-guided two-lift gas holder with a partially below ground tank of steel construction and expansion of the western

¹ <https://flood-map-for-planning.service.gov.uk/confirm-location?easting=472934&northing=173627&placeOrPostcode=RG1%203EA> (viewed 23 May 2018)

gasworks has occurred. A plan of the gasworks from 1905 shows the configuration of the gasworks to the west of the Site which notably comprises two gasholders (one being the cross-boundary gas holder), a tar tank, oil storage tank, a relief holder and a carburetted water gas (CWG) plant. Tar mains are visible which cross onto Site along the western Site boundary and connect to the on-site liquor tank.

Gas holder No.4, located in the centre of the western portion of the Site, is first shown on mapping from 1931, along with further expansion of the western gasworks and another gasworks is also shown beyond the railway line to the north east. By 1950s, a water tower is recorded in the eastern corner of the Site and additional buildings have been constructed in the north-western corner. Structures in the north of the Site have been subject to alteration or demolition with the liquor tank and sulphate of ammonia tank no longer shown.

By the 1970s the cross-boundary gas holder is no longer shown and depots with tanks are shown to the north of the Site beyond the railway line, which by the 1980s was replaced by a superstore. A depot is shown on the site of the former gasworks to the west of the Site on historical mapping between 1989 and 2006. The desk study produced by Atkins in 1998 details this as a car leasing depot, however no trade directory entries have been noted associated with this land use.

By 1990 the buildings in the north of the subject Site have been demolished and the Site is shown in its current layout. Palisade fencing and the addition of portacabins are not shown on historical mapping, but are known to have been installed in the early 1990s.

On the 2015 map the western adjacent gasworks is no longer shown.

The Envirocheck report details two historical landfill sites which were present to the north and north east of the Site. Napier Road landfill was present 129 m north of the Site, beyond the railway tracks. The landfill accepted inert and industrial waste (historical maps also show a depot in this area). A superstore is now present on this land which was constructed by 1982. Deans Farm historical landfill was located 293 m north east of the Site beyond the River Thames. It is assumed that this landfill was utilised for the disposal of river dredgings from the Thames due to an associated inactive licenced waste management facility entry.

2.3. ENVIRONMENTAL SETTING

The Envirocheck report is provided in **Appendix C**, however a summary of key information is provided below.

Table 3 – Summary from Envirocheck report

Detail	Comment
Discharge consent	There are four discharge consents within 250 m with one being on Site (British Gas Plc Southern; discharge of other matter-surface water to the River Kennet; revoked 1 Oct 1996) and the closest off-site consent was 28 m to the south west related to the discharge of surface water to the River Kennet (Rosehaugh Estates Plc).

Detail	Comment
Pollution Incidents to Controlled Waters	There has been one incident on-site and 39 incidents within 250 m of the Site. The on-site incident was classified as a minor incident and occurred in 1997, although no further details are available. The off-site incidents were generally classified as minor; however a significant incident was recorded 145 m northeast of the Site.
River Quality	The quality of the River Kennet was recorded as B (Good) and the River Thames as A and B (Very Good and Good).
Control of Major Accident Hazards Sites (COMAH)	The Site and the adjacent western gasworks were recorded as COMAH sites.
Notification of Installations Handling Hazardous Substances (NIHHS)	This related to the gasworks to the west of the Site.
Planning Hazardous Substance Consents	This consent was granted for the Site and related to liquefied extremely flammable gas (including LPG) and natural gas.
Natural Cavities	The closest natural cavity recorded is approximately 436 m to the south of the Site and it relates to three solution pipes, likely to be present in the Chalk.
Radon	The Site is in an area where less than 1% of homes are above the action level and therefore radon protection for new dwellings is not required.
Contemporary Trade Directory Entries	Notable trade directory entries include an active car breakdown and recovery service 223 m to the south west and an active scrap yard 334 m west of the Site, which is classified as a car breakers and dismantlers and an in active photographic processors, Kodak Processing, located 370 m west of the Site. Within 250 m of the Site there was a site which manufactured and assembled electronic equipment (now inactive)
Fuel Station Entries	The closest fuel station is 321 m north west of the Site.

2.4. UNEXPLODED BOMB (UXB) RISK

The Zetica unexploded bomb risk map indicates that the Site is in an area with a low risk from UXBs. The map is presented in **Appendix D**.

2.5. GEOLOGY

Superficial deposits at the Site comprise Alluvium overlying Kempton Park Gravel Member (River Terrace Gravels), comprising sand and gravel.

The solid geology beneath the superficial deposits comprises the Seaford Chalk Formation and Newhaven Chalk Formation (undifferentiated).

Ground investigation reports indicate Made Ground to be present on Site, recorded to a maximum depth of 3.8 m below ground level (bgl).

2.6. HYDROGEOLOGY

The superficial deposits are classified as a Secondary A aquifer, while the Chalk bedrock is classified as a Principal aquifer. The Site is within a groundwater Source Protection Zone (SPZ 3, Total Catchment).

The Environment Agency website identifies the SPZ to be associated with a potable groundwater abstraction located approximately 2 km south of the Site adjacent to Reading University operated by Thames Groundwater. The maximum daily abstraction is 30,000 m³, with an annual abstraction of 1,500,000 m³. The Envirocheck report details two groundwater abstractions operated by University of Reading located 1,939 m and 1,942 m south of the Site; the yearly rate of abstraction is 240,000 m³ for the former and utilised for 'general use', the latter is utilised for drinking, cooking and washing. During a meeting with the Environment Agency in September 2018, it was stated that the abstraction licence for the University of Reading has been revoked and the Royal Berkshire Hospital, approximately 1km south west of the Site, has a potable water abstraction point.

Four further groundwater abstractions are present within 1 km of the Site. One abstraction licence was associated with the former gasworks to the west of the Site when remediation works (involving pump and treat from five boreholes) were undertaken in 2000. One abstraction licence, located 619 m east of the Site, is held by Wokingham Waterside Centre and utilised for drinking, among other uses.

Review of hydrogeological mapping has confirmed regional groundwater flow to be in an approximate south easterly direction, however local surface water controls from the River Thames and the River Kennet are likely to influence localised groundwater flow, potentially creating a more easterly flow. The river to the south of the Site is partially canalised with a concrete river bank between the Site and the river along the majority of the boundary. This may impede shallow groundwater flow on Site.

2.7. HYDROLOGY

The Site is located within a Flood Zone 2 and historical mapping indicated the area to be 'liable to floods'. The River Kennet is situated adjacent to the southern Site boundary and flows in a west to east direction. The River Kennet is classified as a Primary River by the Environment Agency and is a tributary of the River Thames converging approximately 200 m north north-east of the Site. The river is partially canalised adjacent to the Site, which becomes a natural river bank along the southern boundary in the east of the Site.

A dry drainage ditch is present adjacent to the Site's northern boundary.

2.8. PREVIOUS REPORTS FOR SITE AND SURROUNDING AREA

Details of the previous assessments and reports undertaken at the Site and provided to WSP for review are factually summarised within **Table 4** below. Seven further reports on investigations and monitoring undertaken at the Site between 1985 and 1995 are listed below from the Factual Environmental Desk Study, Atkins (1995); however, these reports were not available for review:

- Site investigation No 463/85 for Proposed Development at Reading Gasworks - Main Site. By G Percy Trentham Ltd. 1985. (Geotechnical and contamination investigation) (later made available by the Environment Agency and discussed in Section 2.11);
- Geotechnical report at Reading Gas Works. By Ground Explorations Limited. July 1991. Report no. 10873. (Geotechnical investigation);
- Monitoring of Boreholes at Reading Gas Works. By Severn Trent Laboratories. February 1992. Letter Ref. 9DC199/ SS. (Groundwater quality monitoring);
- Monitoring of Boreholes Reading Gas Works. By Severn Trent Laboratories. April 1992. Ref. 2725 & 2775. Report No. PM367. (Groundwater quality monitoring);
- Boundary Soil Survey Results at the British Gas Southern Reading No.4 Gas Works Site. By Komex Clarke Bond. January 1993. Ref. K192—36I9. (Contamination assessment);
- Groundwater Monitoring at Kenavon Drive. By Severn Trent Laboratories. July 1994. Ref. TH/300/94. (Groundwater quality monitoring); and
- Environmental Monitoring at Kenavon Drive. By Severn Trent Laboratories. January 1995. Ref. TH/61298/95 (Groundwater monitoring).

Table 4 – Previous reports for the Site

Report	Date	Factual Summary of Findings
Factual Environmental Desk Study. Atkins Ltd. From an original report titled: Kenavon Drive, Reading (Mentor No.9005) Environmental Assessment Desk Study: Final Interpretative Report. November 1997. WS Atkins Consultants Limited.	March 2005 (November 1997)	The report covers the factual information contained within the original Environmental Desk Study dated November 1997. The Environmental Desk Study was undertaken to identify the potential risks to human health and the environment. The environmental assessment was based on geological and hydrological reports, historical information and historical Ordnance Survey maps.
Factual Environmental Site Investigation Report. Atkins Ltd. From an original report titled: Kenavon Drive, Reading (Mentor No.9005) Environmental Site Investigation: Interpretative Report Final. October 1998. WS Atkins Consultants Limited.	March 2005 (October 1998)	This report covers the factual information contained within the original intrusive site investigation report dated October 1998. The 1998 intrusive site investigation was undertaken to determine the nature of ground conditions beneath the Site, review and verify previous findings, and complete further groundwater monitoring rounds. The investigation was conducted between the 20 January and 04 February 1998 and comprised four boreholes, five window sample locations, one trial trench (undertaken within the cross-boundary gas holder), and six trial pits with associated soils, soil leachate, and groundwater testing. The historical exploratory hole locations are presented on Drawing 70031882/004 in Appendix A. The report concluded that the Site is underlain by a variable thickness of Made Ground to a

Report	Date	Factual Summary of Findings
		maximum proved depth of 3.8 m bgl, underlain by Alluvial Deposits and River Terrace Gravels. Fractured Chalk rock was found beneath the River Terrace Gravels at proven depths of 7.0 to 8.5 m bgl. Groundwater was identified between 1.80 and 8.01 m bgl. (35.24 and 35.31 m AOD). Metals, inorganic and organic compounds were detected at concentrations above the method of detection limit in soils, soil leachate and groundwater samples and tarry material was identified. Surface water samples were not collected. The concrete base of an ammoniacal liquor tank was located within TP4 with associated effluent pipework. Concrete foundations and stantions were identified in TP3, and a vertical brick wall was noted in TP6 to 1.5 m bgl.

Following review of previous available reports undertaken for the Site, it is understood that an intrusive site investigation was carried out on-site in 1985 with subsequent monitoring reports over the proceeding decade; however, copies of these reports have not been provided to WSP.

2.9. PREVIOUS REPORTS FOR THE SURROUNDING AREA

Various reports (between 2002 and 2009) are available for the former gasworks site immediately adjacent to the west of the Site and a detailed summary of these results is within the WSP Off-Site Environmental Liability Assessment report. A brief overview of these results is provided below.

Hydrocarbons and other gasworks contaminants were noted across the site. Hydrocarbon contamination was largely noted in the upper layers of the soil horizon in the unsaturated zone above the groundwater table. Contamination was also noted within shallow groundwater within the River Terrace Gravels, comprising benzene, hydrocarbons, ammonia and cyanide. Limited hydrocarbon contamination was identified in the Chalk Principal aquifer. Elevated concentrations of carbon dioxide were noted during monitoring works at the site.

Atkins undertook remediation works between 1999 and 2002 in the east of the site in proximity to the shared boundary with the subject Site. Some further detail on the proposed remediation scheme is included below in Section 2.11. WSP has not had access to validation reports detailing the completed remediation works.

Caswell and Provectus undertook soil and groundwater remediation works respectively across the site in 2008. The remediation works were concluded by the Environment Agency and the Local Authority to be adequate for the proposed development and the protection of the identified environmental receptors. The remediation met with current legislation at the time of the works.

In addition to the remediation works, recommendations were made to provide passive ground gas protection measures into new developments on site.

The WSP Off-Site Environmental Liability Assessment report concluded that although there may be residual liability to groundwater and to future human health receptors on the subject Site from off-site contaminated groundwater, ground gases and vapours, it was considered that contaminant sources on the Site presented a greater risk to the identified receptors.

2.10. COUNCIL DATABASE

A review of the Reading Borough's Council's planning website² provided additional information relating to the adjacent site as detailed below:

2.10.1. WILSON BAILEY GEOTECHNICAL & ENVIRONMENTAL LETTER DATED 22 APRIL 2014

- A ground investigation was completed by Wilson Bailey Geotechnical & Environmental on behalf of the developer Bellway to re-assess the site based on the current re-development scheme.
- The investigation comprised eight new soil gas and groundwater monitoring standpipes across the site with a limited programme of soil gas (four rounds) and groundwater (two rounds) monitoring and sampling. Trial pitting and probing was also completed at select locations.
- Wilson Bailey Geotechnical & Environmental reported that a wide range of potential soil contaminants were not generally detected with the soil samples. Elevated concentrations of polycyclic aromatic hydrocarbon (PAH) compounds were encountered in most of the samples and asbestos fibres was encountered within a number of samples of remediated Made Ground from within the western part of the site. Elevated concentrations of the majority of the determinants were not encountered in the groundwater, with the majority measured at concentrations below the laboratory limit of detection, although elevated concentrations of ammonia were consistently detected.
- The gas monitoring carried out in low and falling atmospheric conditions did not indicate the presence of significantly elevated concentrations of carbon dioxide or methane. However, Wilson Bailey Geotechnical & Environmental recommended gas protection measures were required in the central and eastern parts of the site. No further information is available on the website to suggest whether these gas protection measures were installed and validated.

2.11. INFORMATION PROVIDED BY THE ENVIRONMENT AGENCY

- Various reports were provided by the Environment Agency, primarily relating to the former gasworks to the west and south west of the Site. The reports date from 1985 to 2002 and relate to ground investigations, detailed quantitative risk assessments, remediation strategies and long-term groundwater monitoring.

² http://planning.reading.gov.uk/fastweb_PL/welcome.asp (viewed 13 June 2018)

- Due to the age of the data and as the information relates to the area off-site, a detailed summary of these reports has not been provided. However, information from a key report is provided below.

2.11.1. WS ATKINS CONSULTANTS LTD – STAGE 5 REMEDIATION DETAILED DESIGN AND METHOD STATEMENT, AUGUST 1999

- The report excluded the Site and relates to the area to the west.
- Investigations at the western site identified contamination relating to the historical gas works.
- Elevated concentrations of chlorinated solvents were detected within the gravel and Chalk aquifers, although this was attributed to an off-site source given the lack of a known historical context or source. As the source was likely offsite the chlorinated solvent contamination was not within the scope of statutory liability for BG plc. It is understood from this report that it was agreed in principle with the Environment Agency that the chlorinated solvents would not be considered further, however the concentrations of the solvents would be monitored during groundwater monitoring.
- The proposed remediation scheme included general civil works (demolition, site clearance, etc.), excavation and disposal of soil contamination (including the contents of the former gas holders, tanks and pipelines), treatment and disposal of extracted groundwater (via excavation dewatering of perched water), replacement with clean backfill and reinstatement of hardstanding; with groundwater monitoring before, during and after the remediation works.
- Due to the substantial size and anticipated structural integrity of the holder bases (Gas holders No.2 and No. 3) it was proposed to excavate the contaminated fill material, remove residual contamination from the surfaces, backfill and the structures would remain unbroken and in-situ.
- A clay cut-off wall (as discussed above in Section 2.9) was said to have been necessary to allow effective perched water dewatering of the excavations adjacent to the southern boundary of the neighbouring site and to minimise cross boundary migration of contaminated perched water.
- Due to the presence of a brick telecoms building on the base of Gas holder No. 3 (cross boundary gas holder), which is still located on the subject Site, it was proposed that an injected grout curtain and below ground stability grouting was undertaken to allow minimal disturbance to the building during the adjacent excavation of contaminated fill within the base of Gas holder No. 3. It is understood that approximately 730 m³ of contaminated material was anticipated to remain below the building, within the holder base. The grouting would therefore also isolate and contain this contaminated material within the structure.
- No further details are provided regarding the clay or grouting walls as the validation reports for the completed remedial works have not been made available to WSP.

2.11.2. REMEDIATION WORKS

Reports provided by the Environment Agency include details of the remediation and long-term groundwater monitoring that was completed at the adjoining site by CELTIC Technologies Limited (CELTIC) and VHE Construction (verified by Environ), with validation reports provided in 2001^{3,4,5}.

The groundwater remediation completed by CELTIC included removal of free product, in-situ air sparging and groundwater monitoring. CELTIC concluded that the mass of contamination migrating off-site had been significantly reduced and that there was sufficient evidence to demonstrate that the boundary concentrations do not represent a significant risk to off-site receptors. In addition, conditions at the site boundary should continue to improve.

The work completed by VHE Construction included excavation of contamination hotspots, installation of a medium term biological system for the treatment of contaminated groundwater, removal of below ground structures, encapsulation of residual contamination and design of foundations to protect the Chalk aquifer.

Upon completion of the remediation works, long term groundwater monitoring continued, which was completed in 2002. Based on the report provided by Environ the Environment Agency (in a letter dated 29 August 2002) accepted that the agreed period of monitoring had been completed and that there had been some improvement in the groundwater quality.

³ CELTIC Technologies Limited (2001). Kenavon Drive Redevelopment, Reading, Berkshire, Remediation Validation Report. Report No. R513F/00/1315 (FINAL). February 2001

⁴ Environ (2001) Final Remediation Validation Report, Former Gasworks Site, Kenavon Drive, Reading, Volumes 1 to 3. July 2001

⁵ Environ (2002) Post Remediation Groundwater Monitoring, Draft, June 2002

3. PRELIMINARY CONCEPTUAL SITE MODEL (CSM)

3.1. INTRODUCTION

In the context of current UK Government guidance issued in connection with Part 2A of the Environmental Protection Act 1990, qualitative risks should be assessed using a 'source-pathway-receptor' assessment approach. Such an approach recognises that risks from site-based contaminants can only exist where all three components are present (constituting a complete 'contaminant linkage').

The Site has been assessed in the context of the proposed residential use.

3.2. SOURCES

Potential contaminant sources have been identified following review of historical information, historical mapping, site plans and observations from previous site investigations. The structures referenced below are shown in Drawing 70031882-004 in **Appendix A**.

3.2.1. ON-SITE SOURCES: HISTORICAL SITE USE

- **Made Ground** – associated with the demolition of gasworks structures, deposited wastes and historical levelling of the Site. Contaminants may include: asbestos, hydrocarbons, metals, spent oxide (cyanide), ammonia, ground gas/vapours, polychlorinated biphenyls (PCBs).
- **Cross-Boundary Gas Holder** – former gas holder partially located on-site straddling the western Site boundary (Structure 7).
- **Gasworks Structures** – a number of former gasworks structures were identified on historical plans, which include an above-ground liquor tank adjacent to the northern Site boundary (Structure 1), lime store (Structure 4), acid tanks (Structure 5), purifiers (Structure 2), separating pits (Structure 6), sulphate of ammonia works (Structure 3), and a liquor and sulphate plant (Structure 11).
- **Contaminated Groundwater** – potentially contaminated groundwater may be associated from leachable contaminants within the Made Ground or off-site sources.
- **NAPL** – potential presence of tar/DNAPL/LNAPL within ground and groundwater from on-site sources including liquor tank (Structure 1) and associated tar mains, and a concentrated liquor and sulphate tank (Structure 11). A tar tank structure was discovered during the 2015 site investigation as shown on Drawing 7003182-004, which is potentially the concentrated liquor and sulphate tank (Structure 11), which was uncovered to the south of Structure 11.

3.2.2. ON-SITE SOURCES: CURRENT SITE USE

- **Electricity Sub-station** – small sub-station in the northwest corner of the Site, situated adjacent to the east of the brick store building in the north-west corner of the Site.

Red diesel storage cans were observed on-site within the brick building (former boiler house) in the north-west corner of the Site, utilised for fuelling SGN plant and machinery. The fuel cans were stored on wooden pallets on hardstanding with absorbent matting beneath. No evidence of spillage was noted. These fuel cans have not been considered as a relevant source due to the appropriate standards of storage, and absence of evidence of previous spillages.

3.2.3. OFF-SITE SOURCES

- **Gas Works** – potential sources of contamination associated with former off-site gasworks structures to the west of the Site.
- **NAPL** – Tar/DNAPL/NAPL within ground and groundwater from off-site sources associated with the former gasworks including a tar tank and associated tar mains, an oil storage tank, a carburetted water gas (CWG) plant and a relief holder.

Commercial land uses were present to the west of the site following decommissioning of the gas works, including photographic processors, car leasing depot and a car breakers. However, these historic off-site land uses have not been considered as a significant source due to the distance from site and the nature of the premises adjacent to site.

An historical landfill, Napier Road Landfill, is located within 250 m to the north of the Site beyond the railway lines. Due to the distance from Site and nature of waste disposed of (inert & industrial), the landfill has been discounted as a significant source. Other potential off-site sources included the landfill to the north east (Deans Farm) and the infilled gravel pits to the east. However, given the distance from Site, the inferred groundwater flow direction and the waste disposed (assumed to be river dredging's) these sources have also been discounted.

3.3. RECEPTOR

3.3.1. HUMAN HEALTH

Principal human health receptors have been identified as:

- Future Site users (residents);
- Construction workers or maintenance workers; and
- Neighbouring site users (neighbouring residents to the west of the Site).

3.3.2. CONTROLLED WATERS

Principal controlled water receptors have been identified as:

- Surface water features; the River Kennet which runs adjacent to the south-eastern Site boundary and flows into the River Thames, and the River Thames which is located 200m to the north of the Site;
- Groundwater beneath Site within superficial deposits designated as a Secondary A Aquifer; and
- Groundwater beneath the Site within the Chalk designated as a Principal aquifer (SPZ 3).

3.3.3. PROPERTY

- On-site buildings and structures (e.g. buried concrete and water supply pipes); and
- Off-site buildings and structures.

3.3.4. ECOLOGY

No designated ecological receptors have been identified on or within the vicinity of the Site. Anecdotal evidence suggests a pair of peregrine falcons have been using gas holder No.4 as a nest site.

However, these are considered to be a development constraint only and have not been further assessed with regards to contaminated land.

3.4. PATHWAYS

The primary human health exposure pathways of concern at the Site are:

- Inhalation of asbestos fibres;
- Ingestion, inhalation and dermal contact with contaminated soil, dust and groundwater; and
- Inhalation of hazardous ground gases and vapours.

The primary controlled waters exposure pathways of concern at the Site are:

- Vertical and lateral migration of free-product and leachable contaminants to groundwater;
- Lateral migration of free-product and leachable contaminants in groundwater to off-site groundwater receptors and surface waters;
- Migration via drainage and discharge to surface water; and
- Migration of leachable contaminants / free product in perched water to groundwater via overtopping, leaking or failure of below ground structures.

The primary property pathways of concern at the Site are:

- Direct contact with contaminated soil or groundwater causing chemical attack; and
- Migration of explosive ground gas.

3.5. POTENTIAL CONTAMINANT LINKAGES

Potential contaminant linkages at the Site are presented in **Table 5**. It should be noted that the identification of potential 'contaminant linkages' does not indicate that they are significant or that Site is unsuitable for its future use. It does however act as a way of focusing data collection at the Site and risk evaluation.

Table 5 – Preliminary Conceptual Site Model

Source	Pathway	Receptor
On-site: Made Ground Former gasworks structures Cross boundary gas holder Electrical substation Contaminated groundwater Tars/NAPL	Ingestion, inhalation and dermal contact with contaminated soil, dust, groundwater and free product.	Human Health: Future Site users Neighbouring site users Construction/maintenance workers
	Inhalation of asbestos fibres.	
	Inhalation of hazardous ground gases and soil/groundwater vapours.	
	Vertical and lateral migration of free-product and leachable contaminants to groundwater.	Groundwater: Secondary A Aquifers (Alluvium & River Terrace Gravels) Principal Aquifer (Seaford Chalk Formation and Newhaven Chalk)
	Lateral migration of free-product and leachable contaminants in groundwater to surface waters.	Surface Waters: River Kennet

Source	Pathway	Receptor
	Migration via drainage and discharge to surface water.	River Thames
	Direct contact with contaminated soil or groundwater causing chemical attack and migration of explosive ground gas.	Property Receptors: Site buildings and structures
Off-site: Former gasworks adjacent to the western Site boundary.	Ingestion and inhalation of wind-blown dust.	Human Health: Future Site users
	Lateral migration and inhalation of hazardous ground gases and soil/groundwater vapours.	Construction/maintenance workers
	Lateral migration of free-product and leachable contaminants to groundwater.	Groundwater: Secondary A Aquifers (Alluvium & River Terrace Gravels) Principal Aquifer (Seaford Chalk Formation and Newhaven Chalk)

Based on the desk study review and information from previous investigations, the risk to receptors is considered to be **moderate to high** based on the conceptual site model discussed above.

The risk categories is based on guidance presented in CIRIA Publication C552, Contaminated Land Risk Assessment – A Guide to Good Practice. CIRIA states that the risk levels should be based on an understanding of both the probability (likelihood) of a risk occurring and the magnitude of the potential consequence (severity) of a risk. CIRIA defines four levels of probability and four levels of severity with relation to contaminated land, as presented in **Appendix E**.

4. RATIONALE FOR GROUND INVESTIGATIONS

4.1. INTRODUCTION

The rationale for the ground investigations were scoped to refine the preliminary CSM and risk assessments. The supplementary ground investigation was recommended to:

- Sample areas not previously investigated (i.e. non-targeted investigation across the site).
- Further investigate nature and extent solvent concentrations in the west of the Site.
- Install additional gas and vapour monitoring wells to enable additional data to be gathered to more appropriately assess the risk to residential occupants on and off-site (i.e. beneath proposed building footprint and along western boundary). Based on CIRIA C665, a minimum of six gas monitoring visits are required, therefore an additional two rounds were recommended following the supplementary site investigation (four rounds completed during first phase of investigation).
- Install additional groundwater monitoring wells, particularly along the southern and western boundaries, with subsequent groundwater monitoring and sampling.
- Obtain additional surface water samples.
- Obtain samples for a preliminary waste classification of the underlying soils including Waste Acceptance Criteria (WAC) testing.

4.2. RATIONALE

The ground investigations which were undertaken in 2015 and 2019 comprised the excavation of trial pits and trial trenches, drilling and installation of boreholes for gas and groundwater monitoring, and hand excavation of pits for overall coverage and in areas difficult to access. A rationale for the individual investigation locations is detailed in **Table 6** below, with further details on the scope of works detailed in **Appendix F** (including the laboratory analysis completed). The exploratory hole locations are presented in Drawing 70031882-004 in **Appendix A**.

Table 6 – Summary of Site Investigation Rationale

Exploratory hole	Location ID	Rationale
Boreholes (2015)	BH101	To be undertaken within the cross-boundary gas holder (following excavation TP101 undertaken to confirm wall of gas holder). [NOTE: due to service constraints TP101 could not be undertaken, however gas holder wall was traced at surface with ground penetrating radar (GPR)] Borehole was scheduled to categorise and assess gas holder backfill, identify depth, thickness and construction of holder base, and categorise ground conditions below the gas holder (depending on visual and olfactory observation of contamination within the holder). Clean drilling techniques were implemented coring through gas holder base. Installed above base of holder as groundwater monitoring well to establish groundwater depth (to assess continuity with surrounding groundwater) and groundwater quality within the holder.

Exploratory hole	Location ID	Rationale
	BH102-104	Three shallow boreholes targeting historical gasworks structures, characterise ground conditions across the Site and to establish groundwater depth, quality and flow direction in shallow aquifer. All three shallow boreholes were installed as dual gas and groundwater installations to monitor ground gas regime on Site. BH102 was located to target the sulphate of ammonia works, and BH103 was located to target an unknown structure to the south of the concentrated liquor and sulphate plant. BH104 was located on the southern Site boundary to capture down-gradient water quality data and for coverage in the ground gas assessment. Standard Penetration Tests (SPTs) undertaken at selected centres, appropriate to ground conditions at a total of four borehole locations across Site during the 2015 investigation.
	BH105-107	Three deep boreholes to establish groundwater quality and groundwater flow within Chalk aquifer at depth (minimum of three boreholes required to triangulate groundwater flow), and characterise ground conditions across the Site. BH106 and BH107 positioned down-gradient (assumed) of gasworks structures. SPTs undertaken at selected centres, appropriate to ground conditions at a total of four borehole locations across Site during the 2015 investigation.
Trial pits (2015)	TP101	One trial pit undertaken to identify / confirm the wall of former cross-boundary gas holder, and to characterise ground conditions within and outside gas holder.
	TP102-106	Five trial pits undertaken across the Site targeting historical below ground structures, target areas of potential contamination and to characterise ground conditions. TP102 was located to target the separating pits; TP103 the liquor tank; TP104 the concentrated liquor and sulphate plant; TP105 the concentrated liquor and sulphate plant and overhead acid tanks; and, TP106 the lime store.
Trial trenches (2015)	TT101-102	Two trial trenches were undertaken to confirm the location of historical structures (including sulphate of ammonia plant and other unnamed historical structures); investigate potential for below ground tanks, target areas of potential contamination, and characterise ground conditions.
Hand dug inspection pits (2015)	HP101-104	Four non-targeted Site wide inspection pits were excavated by hand in areas difficult to reach with mechanical plant. Undertaken to characterise ground conditions across Site.
Boreholes (2019)	BH201-204	Four deep boreholes to establish groundwater quality, groundwater flow and hydraulic connectivity within the Chalk (BH202) and river terrace gravels aquifer (BH201, BH203 and BH204). BH204 was drilled into the Chalk to establish ground conditions and obtain geotechnical information, but was installed as a groundwater well within river terrace gravels. SPTs and U100's (when ground conditions allow) undertaken at selected centres, appropriate to ground conditions within all four deep borehole locations (BH210-204) across Site.
Window Sample Locations (2019)	WS201-202	To aid with characterising the gas regime across the Site and establish ground conditions. Installed as gas wells within the Made Ground.
	WS203-204	Establish ground conditions within areas not previously investigated. Window samples not installed.

Exploratory hole	Location ID	Rationale
	WS205–206	To determine shallow groundwater quality across the Site and establish ground conditions.
Vapor Monitoring Locations (2019)	VW201	To determine vapour assessment in area with previously identified VOCs.
	VW202–203	To determine vapour egress within the vicinity of previously identified tar tank.

The findings are discussed in the following sections and support the refined conceptual site model which is presented in **Section 7**.

5. SITE INVESTIGATION & MONITORING WORKS

5.1. GROUND CONDITIONS ENCOUNTERED ON-SITE

Ground conditions have been logged in accordance with BS5930:1999+A2:2010 and ES EN ISO 14688 Part 1 where applicable. Detailed logs for all exploratory holes are provided in **Appendix G**, and a photographic record of ground conditions is included as **Appendix H**.

A summary of the strata encountered across the Site is provided in **Table 7**.

Table 7 – Summary of Strata Encountered During Investigation

Stratum	Depth to Top of Stratum (m bgl)	Thickness (m)	Typical Description
Made Ground	0.0	0.53 – 3.2a	Made Ground deposits were highly variable across Site, with the main constituents ranging from concrete/tarmac, silty, sandy gravel to sandy gravelly clay.
Alluvium	0.75 – 3.2	1.0 – 3.64b	Black to grey soft silt, which varied to a sandy gravelly clay in some locations, with some inclusions of calcareous shell fragments.
River Terrace Gravels	3.7 – 5.14	3.05 – 4.30b	Black sand and gravel, which varied to light brown sandy gravel and gravelly sand.
Chalk	6.95 – 8.15	(17.70) Not proven	White clayey gravelly sand or sandy gravelly silt with Chalk and flint cobbles and gravel (weathered head of Chalk). Competent Chalk generally white with grey or orange discolouration with rare black speckles, very weak to weak medium density, fractures ranging from vertical to horizontal, generally clean close to very closely spaced. With rare flint gravel.

a Base of Made Ground not proven in all locations where refusals were encountered

b Base of strata not proven in shallow borehole locations

5.1.1. SURFACE COVER

The Site comprises of two sections, the western half contains the gas holder structure within a palisade fenced compound; this area is largely covered by concrete hardstanding and crushed stone (90%), with soft standing present in localised areas. The localised areas of soft standing are highlighted on the topographical plan as 'unmade ground' and vegetation around the north and east of the gas holder and along the northern Site boundary. In addition, the 'rubble stockpile' and area beneath the 'stacked material' as shown on the topographical plan are also areas of soft standing.

The eastern half of the Site houses an operational storage yard for SGN contractors; this area of the Site is covered by hardstanding comprising tarmac (75%) and concrete (25%).

Concrete and tarmac hardstanding varied in depth between 0.08m and 0.9m bgl. Refusals in the hardstanding were encountered during coring in two locations (BH106_R and BH103A_R) on metal contained within the concrete.

5.1.2. MADE GROUND

Made Ground was identified within each exploratory holes excavated across the Site. The proven thickness of Made Ground varied between 0.53-3.2 m outside of structures, with an average thickness of approximately 1.4 m. The greatest thickness of Made Ground outside of structures was identified in WS204 at a thickness of 3.2 m.

BH101 is located on the western half of Site within the footprint of the former cross-boundary gas holder; Made Ground was identified in this location to the base of the gas holder at 3.7 m bgl. The base comprised a 0.6 m thick concrete slab and a layer of red brick beneath the concrete. Made Ground deposits in BH101 appear to be reworked natural ground which have been used to backfill the gas holder base. WS206 was positioned adjacent but outside the former cross-boundary gas holder; Made Ground was identified in this location to a depth of 3.1m bgl.

Made Ground typically comprised sandy, gravelly clay with occasional cobbles. The gravel comprised flints, concrete and red brick with some occasional Chalk. Cobbles comprised of brick and concrete. Coal inclusions were present in several of the Made Ground deposits from across the Site area while ashy and clinker deposits were only occasionally present. Other anthropogenic inclusions such as metal, timber and redundant pipe work were encountered within the Made Ground in various locations. Brick back fill was identified in WS201A to a depth of 1.2m bgl when the location refused.

Evidence of contamination within the Made Ground was identified across the site, but consistently in the northern central areas of the Site. Made Ground comprised a mixture of black clayey gravels and gravelly clays with pockets of tarry material and evidence of staining. Evidence of tar and hydrocarbon contamination was present on the arisings from TT102 and on the drill equipment and on arisings from BH102B. Tarry residues within soils and hydrocarbon odours were also observed in Made Ground from TT102 and TT101 in the north of the Site, and HP103 adjacent to the southeast of gas holder No. 4. Evidence of contamination was also noted within TP102, TP103 and TP105 in the north of the Site. A strong hydrocarbon odour and dark blue or black staining was noted within the Made Ground of BH202 and from HP104A in the southwest of the Site. Made Ground in WS204, WS205 and BH204 (all located within the storage yard in the central area of the site) also reported hydrocarbon odours, a sheen was also noted on the arisings in WS204.

Evidence from the arisings of BH103 indicates the investigated structure to be a tar tank; the borehole was situated to investigate an unidentified historical structure which was identified at the surface with the ground penetration radar (GPR) device during the service clearance works. Strong tarry and hydrocarbon odours and tar coated material (bricks, and gravel) were noted from 0.25 m bgl at BH103. Black tarry coating on material, sheens and strong odours were noted from 0.25-1.26 m bgl.

5.1.3. CONCRETE & UNDERGROUND STRUCTURES

Buried structures were exposed in several locations across the Site. The concrete was identified to be 0.9 m thick within BH106, located in the northern part of the Site within the storage yard; this is

suspected to be a part of some historical foundations. TP104 also encountered a large thickness of concrete, with layers of concrete and red brick walls. Concrete and brick foundations were also encountered in TP105. A steel ring was identified within WS201 at 0.15m bgl. A brick path / structure was identified within BH204 at 0.4m bgl. VW203 was terminated at 0.15m bgl on a brick structure potential a wall of a former brick building.

Locations which refused on solid subsurface structures include BH103A_R and BH106_R (coring refused on metal within concrete), BH103, TP103, TP103A, HP101, HP101A, HP104, HP104A. BH103 was terminated at 1.26 m bgl on a concrete base of the tar tank.

Unmarked services were identified within BH102A, BH105_R, WS201B, WS201C, BH203, BH203A, BH203B and WS201D hand excavations during the intrusive investigation. Where services were encountered they were treated as live and the location terminated and backfilled. The identified structures and services are detailed within **Table 8**.

Table 8 – Structures and Services Encountered

Exploratory Hole ID	Depth Encountered (mbgl)	Description
BH101	3.7-4.3	Concrete base of cross-boundary gas holder encountered - confirmed to be 0.6 m thick. Structure 7 on Drawing 70031882/004.
BH102A	0.64	Two black metal corroded pipes (5-10 cm diameter) forming a t-junction.
BH103	1.26	Concrete base of tank encountered at 1.26 m bgl. Base not breached. Historical structure identified on Drawing 70031882/004 as 'Tar Tank'.
BH103A_R	0.45	Metal plate contained within concrete. Metal shaving noted during coring.
BH105_R	0.35	Edge of large diameter black metal pipe identified running east to west.
BH106_R	0.2	Top of brick wall and metal plate. Borehole located within Structure 11 (concentrated sulphate and liquor plant) on Drawing 70031882/004.
BH106	0.0-0.9	Concrete cored from the surface, full thickness revealed to be 0.9 m. Concrete assumed to be part of historical foundation. Borehole located within Structure 11 (concentrated sulphate and liquor plant) on Drawing 70031882/004.
TT102	1	Trench refused on solid platform at base. Excavation located within Structure 3 (sulphate of ammonia works) on Drawing 70031882/004.
TP103	0.8	Trial pit terminated at 0.8 m bgl on brick base of liquor tank, identified as Structure 1 on Drawing 70031882/004.
TP103A	0.35	Black pipe exposed in trial pit. Trial pit extended in western side of pit to avoid exposed service.
TP103A	0.55	Trial pit extended in western side of pit to avoid exposed service. Terminated at 0.55 m bgl on brick base.
TP104	0.0-1.0	Thick layer of concrete at surface. Excavation located within Structure 11 (concentrated sulphate and liquor plant) on Drawing 70031882/004.

Exploratory Hole ID	Depth Encountered (mbgl)	Description
	1.9-2.1	A layer of concrete was exposed on the eastern side of the trial pit at 1.9 m bgl. Total thickness not proven; concrete continued down the east of the trial pit to the base of the excavation at 2.1 m. Excavation located within Structure 11 (concentrated sulphate and liquor plant) on Drawing 70031882/004.
TP105	0.45	Red brick and concrete base exposed on southern edge of pit. Base presumed to be base of 'carpenters shop' as identified as Structure 5 on Drawing 70031882/004.
HP101	0.25	Hand pit terminated on concrete base. Base presumed to be base of 'purifiers' or 'sulphate of ammonia works' as identified as Structure 5 on Drawing 70031882/004.
HP101A	0.28	Hand pit terminated on concrete base. Base presumed to be base of 'purifiers' or 'sulphate of ammonia works' as identified as Structure 5 on Drawing 70031882/004.
HP104	0.49	Hand pit terminated on concrete base. Potentially unidentified small square structure to southwest of gas holder as shown on Drawing 70031882/004.
HP104A	0.15	Course of red bricks revealed to be part of wall. Potentially unidentified small square structure to southwest of gas holder as shown on Drawing 70031882/004.
HP104A	0.78	Hand pit terminated on concrete base. Potentially unidentified small square structure to southwest of gas holder as shown on Drawing 70031882/004.
WS201	0.15	Terminated on a steel structure below ground
WS201B	0.46	Plastic pipe approximately 250mm diameter running south west
WS201C	0.52	Terminated on metal pipe
WS201D	0.60	Terminated on yellow plastic pipe (presumed gas) running north.
WS202	1.35	Unidentified service potentially a brick drain
BH203	0.78	Metal pipe running north east
BH203A	0.50	Metal pipe approximately 150mm diameter running north
BH203B	0.60	Metal pipe approximately 150mm diameter running north
BH204	0.40 – 0.55	Brick structure identified - potentially a previous floor or path
VW203	0.15	Terminated on a brick wall - potentially part of a former building

5.1.4. ALLUVIUM

Alluvium was observed below the Made Ground in the majority of the borehole locations, with the exception of BH101 which was undertaken within the footprint former cross-boundary gas holder.

The Alluvium generally comprised black to grey soft silt with occasional to abundant white calcareous shell fragments, which varied to a sandy gravelly clay in some locations. Peat bands

were identified within the Alluvium generally consisting of brown to grey sandy clay with numerous wood decaying wood fragments. Clayey sand layers were identified within the Alluvial deposits.

Evidence of contamination within the Alluvium was identified at within BH201, BH202, BH203C and WS204. Generally, evidence of contamination consisted of hydrocarbon odour with some black staining notably within BH202 and BH203.

5.1.5. RIVER TERRACE GRAVELS

River Terrace Gravels were generally identified beneath the Alluvium in the borehole locations, with the exception of BH101 where it was encountered below the base of the gas holder at 4.3 m bgl and WS204 where the hole was terminated within the Alluvium at 5.0m bgl.

The top of the River Terrace Gravels varied between 3.7 - 5.14 m bgl. The strata comprised a black sand and gravel, which varied to a light brown to grey sandy gravel and gravelly sand. Gravels were noted to predominantly feature sub-rounded to sub-angular flint and Chalk.

Although visual or olfactory evidence of contamination was identified within natural ground at several locations across the Site, the most notable evidence of contamination was present within the granular strata of the River Terrace Gravels. Notably within BH201 and BH202 the gravels were stained black, had a strong hydrocarbon odour and a sheen.

5.1.6. CHALK

The upper boundary of the weathered Chalk was noted in the deep boreholes from 6.95 m bgl in BH105, to 8.25 m bgl in BH101. The Chalk comprised structureless white clayey gravelly sand or sandy gravelly clay/silt with Chalk and flint cobbles and gravels. Chalk was noted to the base of the deep boreholes to a maximum depth 17.7m bgl.

Hydrocarbon odours and visual staining were noted in the Chalk in BH101 below the base of the cross boundary holder; here the base of the River Terrace Gravels was also contaminated.

Strong hydrocarbon odours, visual staining and globules of product were also observed in the Chalk in BH202 to a depth of ~16.7m bgl along the fractures (see photo no. 50 within **Appendix H**). Slight staining and slight hydrocarbon odour were noted between 16.7m and the base of the borehole at 17.7m bgl. Clean drilling techniques were used in both these locations during drilling works when progressing from the River Terrace Gravels to the Chalk.

Within BH201 a sulphur/ammoniacal odour was noted within the Chalk.

5.1.7. VISUAL AND OLFATORY EVIDENCE OF CONTAMINATION

A summary of visual and olfactory evidence of contamination identified within Made Ground and natural ground is summarised below in **Table 9**.

Table 9 – Visual and Olfactory Evidence of Contamination

ID	Detail	Depth (mbgl)	Strata	Visual Evidence	Olfactory Evidence	Max PID reading(s) (ppm)
BH101	Located within footprint of former cross-boundary gas holder.	3.3-3.7	Made Ground	Dark grey staining.	Slight hydrocarbon odour.	NT ^a

ID	Detail	Depth (mbgl)	Strata	Visual Evidence	Olfactory Evidence	Max PID reading(s) (ppm)
	Located within footprint of former cross-boundary gas holder, below holder base.	7.30-8.25	River Terrace Gravels	Dark blue/black staining of sand and gravel.	Strong hydrocarbon odour, particularly at base of strata.	31.7 (8.20 m)
		8.25-8.80	Chalk	Grey staining throughout.	Strong hydrocarbon odour, particularly at the top of the strata.	NT
BH102	Located adjacent to historical liquor tank and sulphate of ammonia works in the north of the Site.	0.75-0.90	Made Ground	Some blue-black staining.	Faint hydrocarbon odour.	NT
		0.90-1.50	Made Ground	No visual evidence.	Hydrocarbon odour.	0.7 (1.2 m)
		1.50-4.15	Alluvium	Band of grey clay with black staining at 2.75-3.00 m bgl. Staining evident on drill equipment.	Very strong hydrocarbon odour.	33.6 (1.55 m)
		4.15-4.50	River Terrace Gravels	Sheen present on gravels.	Very strong hydrocarbon odour.	257 (4.15 m)
BH103	Situating within tar tank. Located adjacent to the concentrated liquor and sulphate tank.	0.25-0.70	Made Ground	Pockets of black tarry and black standing.	Strong tarry odour.	469 (0.3 m)
		0.70-1.26	Made Ground	Material coated in tars. Black tarry gravels and sheen on arisings.	Strong tarry odour.	500.8 (0.9 m)
BH103A	Located adjacent to tar tank.	1.60-4.00	Alluvium	No visual evidence of contamination.	Possible hydrocarbon odour.	25.9 (2.0 m)
		1.60-4.00	Alluvium	No visual evidence of contamination.	Possible hydrocarbon odour.	25.9 (2.0 m)
		4.00-4.50	River Terrace Gravels	No visual evidence of contamination.	Hydrocarbon odour.	24 (4.30 m)
BH106	Located adjacent to northern Site boundary within liquor and sulphate plant.	1.60-2.40	Alluvium	No visual evidence of contamination.	Possible hydrocarbon odour.	NT
		2.4-3.85	Alluvium	No visual evidence of contamination.	Possible hydrocarbon odour. Elevated PID reading.	51.8 (3.6 m)

ID	Detail	Depth (mbgl)	Strata	Visual Evidence	Olfactory Evidence	Max PID reading(s) (ppm)
TP102	Located within former separating pits, north of gas holder	1.90-2.65	Alluvium	Dark blue seams of staining.	No olfactory evidence of contamination.	12 (1.8 m) 7.5 (2.20 m)
TP103	Located within former liquor tank north of the gas holder.	0.60-0.80	Made Ground	Black staining evident on soil.	No olfactory evidence of contamination.	38.3 (0.80 m)
TP105	Located adjacent to overhead acid tanks and liquor and sulphate plant.	1.60-3.00	Alluvium	Occasional black staining on grey soils.	No olfactory evidence of contamination.	26 (1.70 m)
TT101	Located with sulphate of ammonia plant and adjacent to purifiers.	0.20-1.00	Made Ground	Some black staining.	Slight hydrocarbon odour on arisings.	16.5 (0.50 m)
TT102	Located with sulphate of ammonia plant and adjacent to purifiers.	0.70-1.00	Made Ground	No evidence of contamination.	Slight to moderate tar odour.	6 (0.70 m)
HP103	Located to the southeast of the gas holder within the palisade fence compound.	0.20-1.20	Made Ground	Made Ground consisting of coal and possible coke fragments.	Moderate hydrocarbon odour	63.8 (0.30 m)
HP104A	Located near western boundary to the south-west of the current gas holder.	0.15-0.78	Made Ground	Heavy black staining	Strong hydrocarbon odour	118.6 (0.70 m)
BH201	Located to the south of the chemical store and north west of gas holder.	4.9	River Terrace Gravels	Hydrocarbon staining	No olfactory evidence of contamination.	1.6 (4.9 m)
		7.10	Chalk	No visual evidence of contamination.	Sulphur / ammonia odour	0.7 (7.90 m)
BH202	Located between the cross-boundary gas holder and the above ground gas holder close to the western site boundary.	0.20	Made Ground	No visual evidence of contamination.	Strong Hydrocarbon odour	1.6 (0.30 m)
		2.50	Alluvium	dark grey scattered inclusions	Hydrocarbon odour on	40 (2.00 m)
		3.00	Alluvium	Oily concentration at 3.4m where flint gravel is noted.	Hydrocarbon odour	5
		4.10	Alluvium	No visual evidence of contamination.	Hydrocarbon odour remains	11 (4.50 m)

ID	Detail	Depth (mbgl)	Strata	Visual Evidence	Olfactory Evidence	Max PID reading(s) (ppm)
		6.60	River Terrace Gravels	Oily sheen on gravels recovered	Hydrocarbon odour remains	4 (6.30 m)
		13.00	Chalk	Grey staining of Chalk	Very pungent hydrocarbon odour	4 (12.30)
BH203C	Located to the south east of the gas holder.	1.60	Made Ground	Black hydrocarbon staining	No olfactory evidence of contamination.	0.40 (1.70)
		2.45	Alluvium	Sheen on core	No olfactory evidence of contamination.	7.20 (2.50)
BH204	Located within the storage yard.	4.70	River Terrace Gravels	No visual evidence of contamination.	Slight hydrocarbon odour	1.10 (4.90 m)
		5.00	River Terrace Gravels	No visual evidence of contamination.	Very strong Hydrocarbon odour	1.20
WS202	Located in eastern corner.	1.20	Made Ground	No visual evidence of contamination.	Slight odour (burnt)	-
WS203	Located north east of gas holder.	4.20	River Terrace Gravels	No visual evidence of contamination.	Slight hydrocarbon odour	<0.1 (4.50 m)
WS204	Located south east of gas holder.	0.60	Made Ground	Sheen on core run	Slight hydrocarbon odour	9.00
		1.80	Made Ground	No visual evidence of contamination.	Slight hydrocarbon odour	<0.1 (1.90 m)
WS205	Located within storage yard.	0.40		No visual evidence of contamination.	Hydrocarbon odour	-

a Not tested due to defective equipment

5.1.8. TAR & NAPL

Non-aqueous phase liquid (NAPL) was encountered during the site investigation within Chalk fissures in BH202 to a depth of ~16.7m bgl. In addition, whilst developing BH202, a brown product was abstracted from the borehole as discussed in Section 5.2 below.

Tarry coated soils and backfill materials were noted within the tar tank. In addition, 5 cm of tarry waters were noted within this vacuum excavation pit (BH103) at the base of tar tank produced by the water lance during vacuum excavation procedures.

5.2. GROUNDWATER

During the ground investigations, groundwater strikes were recorded in the Made Ground and Alluvium and the levels are detailed in the logs in **Appendix G**. Seven exploratory holes were installed at the Site for groundwater monitoring in 2015 (BH101-BH107) and six installed in 2019 (BH201-204 and WS205-206). In total, three rounds of groundwater monitoring and sampling were undertaken on 24 November 2015 (Round 1) and 15 December 2015 (Round 2) where boreholes installed in 2015 were monitored, and between 10 – 17 April 2019 (Round 3) where all wells installed in 2015 & 2019 were monitored.

The full results of the groundwater monitoring are presented within **Appendix I**, and a summary of the data is provided below in **Table 10**.

Visual & Olfactory Evidence of Contamination

Hydrocarbon odours were noted on the water from BH102B and BH103A during the first two monitoring rounds in 2015.

During the well development of BH202, where three well volumes of water were purged prior to sampling, a brown product was purged from the well (shown in photograph no. 49 within **Appendix H**). This had a very strong creosote / hydrocarbon odour and was emulsified with groundwater. Due to the presence of NAPL in this well, groundwater from this location was not monitored. Due to the NAPL creating an emulsion with the groundwater the thickness could not be determined with the oil/water interface probe, and the NAPL is assumed to be a DNAPL. A sample of the purged water containing the NAPL was analysed which is discussed below, however a pure product sample could not be retrieved for chemical fingerprint testing.

No other sheens or non-aqueous phase liquid (NAPL) were not noted at other locations during any of the monitoring rounds.

Product Analysis

A sample of water was taken from the IBC (intermediate bulk container) on site which contained purged groundwater from boreholes across the site and the product purged from BH202. Although product analysis could not be undertaken on the NAPL, the analysis results from the purged water in the IBC indicate high concentrations of naphthalene (4,010 µg/l), benzene (3,040 µg/l) and toluene (1,760 µg/l) which were significantly higher than concentrations detected in groundwater samples across the site and indicative of gas works derived contaminants, potentially from a creosote coal tar product (DNAPL).

Table 10 – Measured Groundwater Elevations

BH ID	Response Zone (m bgl)	Response Strata	Groundwater Level (Round 3 - April 2019)		Observations
			m bgl	m AOD	
BH101	1.00 – 3.60	Made Ground	1.28	36.56	No odour or sheen
BH102B	1.00 – 4.50	Alluvium / River Terrace Gravels	1.01	36.19	Hydrocarbon / sulphuric odour (Rounds 1 & 2)

BH ID	Response Zone (m bgl)	Response Strata	Groundwater Level (Round 3 - April 2019)		Observations
			m bgl	m AOD	
BH103A	1.00 – 4.50	Alluvium / River Terrace Gravels	1.33	35.81	Hydrocarbon odour (Rounds 1 & 2)
BH104	1.00 – 4.50	Made Ground / Alluvium / River Terrace Gravels	2.06	35.35	No odour or sheen
BH105	8.30 – 10.70	Chalk	1.89	35.38	No odour or sheen
BH106	9.00 – 10.50	Chalk	1.97	35.30	No odour or sheen
BH107	9.00 – 10.50	Chalk	1.98	35.36	No odour or sheen
BH201	5.00 – 7.00	River Terrace Gravels	1.94	35.30	No odour or sheen
BH202	14.70 – 17.70	Chalk	1.90	35.38	Product on dip tape, strong creosote / hydrocarbon odour from well
BH203C	5.30 – 7.30	River Terrace Gravels	1.71	35.45	No odour or sheen
BH204	5.00 – 7.00	River Terrace Gravels	2.01	35.29	No odour or sheen
WS205	0.50 – 1.50	Made Ground	1.37	35.77	Not enough water for a sample
WS206	1.00 – 3.00	Made Ground	1.36	36.22	No odour or sheen

*Above Ordnance Datum

Groundwater data gathered from boreholes screened within the RTG deposits indicate that groundwater flow is to the north or north west towards the River Thames located 200 m north and away from the River Kennet adjacent to the southeast boundary of the site. Given the proximity of the River Kennet a more easterly direction was expected, however the River Kennet is canalised and underground services, structures or unknown water abstractions could also have an effect on the groundwater flow. A hydraulic gradient of approximately 0.005 (0.1 m head difference over 20 m distance) has been calculated based on the 9 April 2019 level data.

Groundwater data from the boreholes screened within the Chalk indicate a groundwater flow direction towards the east with a hydraulic gradient of approximately 0.0013 (0.1 m head difference over 75 m distance).

Groundwater configuration plans are presented in Drawing 70031882-009A & 009B.

5.2.1. IN-SITU GEOCHEMISTRY MEASUREMENTS

Geochemical parameters were recorded during low flow purging prior to groundwater sampling. **Table 11** summarises the conditions observed in the groundwater.

Table 11 – Recorded Range of In-Situ Geochemistry Measurements

Stratum	Temperature (°C)	Dissolved Oxygen (mg/l)	Electrical Conductivity (µS/m)	pH	Redox Potential (mV)
Made Ground/Alluvium/River Terrace Deposits	7.0 to 13.5*	0.25 to 8.10	445 to 1960	6.9 to 8.42	-286 to 199.3
Chalk	9.1 to 13.3*	0.32 to 4.03	707 to 1290	7.04 to 8.49	-287 to -22.6

* It is likely that the readings of 13°C are anomalous, and the instrumentation probes which recorded these readings could have been in direct sun.

5.2.2. HYDRAULIC CONDUCTIVITY TESTS

In-situ conductivity tests were carried out on six boreholes on 8 and 9 May 2019. A solid slug of known volume was introduced in the boreholes and the subsequent water level response was recorded with a logger at 1 and 0.125 second intervals.

The groundwater recovery data was analysed using the aquifer property software package AQTESOLV (HydroSOLV, Inc.). Hydraulic conductivity was estimated from the in-situ tests by fitting mathematical models to the observed displacement data. The Bower and Rice (1976) straight-line and the Spring-Gelhar underdamped methodology were applied. The data analysis is presented in **Appendix I** and a summary of the calculated hydraulic conductivities is presented in **Table 12**.

Table 12 – Hydraulic Conductivity Results per Borehole

Location	Response Zone	Screen Interval (m bgl)	Static Water Level (m bgl)	Geomean Hydraulic Conductivity (m/d)
BH103A	Silt (Alluvium)	1.6 – 4.5	1.06	0.37
BH106	Structureless Chalk	9.0 – 10.5	1.78	10.60
BH107	Structureless Chalk	9.0 – 10.5	1.98	3.73
BH201	Sandy gravels (RTG)	5.0 – 7.0	2.23	145.2
BH204	Coarse sand and sandy clayey gravels (RTG)	5.0 – 7.0	1.98	58.37

Results of the tests analysis provided different hydraulic conductivity for each of the lithologies beneath the site. The calculated hydraulic conductivities are consistent and within the range of literature based values as shown in **Table 13**.

Table 13 - Hydraulic Conductivity Results and Literature Values

Lithology	Calculated Hydraulic Conductivity (m/d)			Literature Hydraulic Conductivity (m/d)		
	min	mean	max	min	max	reference
Chalk	3.52	6.29	12.11	0.76*	500*	The physical properties of major aquifers in England and Wales (Chilterns Area, pg68) Mean value of 17.2 m/d
River Terrace Gravels	41.56	105.9	177.5	25.92	2592	Domenico & Schwartz 1990 for gravels
Alluvium	0.15	0.37	0.96	8.64E-5	1.73	Domenico & Schwartz 1990 for silt

* Based on transmissivity values along 50 m saturated Chalk aquifer.

5.2.3. REFINED HYDROGEOLOGICAL MODEL

Based on the desk-based information and the ground conditions that were encountered during the two phases of investigation, the preliminary hydrogeological model that was provided earlier in the report has been refined.

The ground conditions encountered comprised Made Ground, Alluvium, River Terrace Gravels and Chalk. Numerous obstructions were encountered in the Made Ground associated with former structures, foundations and services. The cross-boundary gas holder is also present to a depth of 4.3m bgl; these below ground features may have an influence of localised groundwater flow.

Groundwater in the Made Ground is considered to be perched and given the impermeable nature of the alluvial deposits, the perched groundwater should not be in continuity with the groundwater in the River Terrace Gravels and Chalk, unless buried structures provide a pathway. Although cohesive structureless Chalk was recorded at one location (BH105), this does not appear to be consistent across the Site and therefore the groundwater in the River Terrace Gravels may be in continuity with the groundwater in the Chalk. In addition, groundwater data indicates that both the RTG and the Chalk aquifer are confined by the Alluvium.

Current groundwater data gathered during two monitoring rounds (9 and 15 April 2019) in the intermediate boreholes (response zone in the River Terrace Gravels) suggests a north or northwest flow direction towards the River Thames located 200 m north and away from the River Kennet. Based on the location of the surface waters and previous investigations carried out on the site (1998 monitoring) the groundwater flow within the RTG was expected to be to the southeast or north east towards the River Kennet. This direction however is plausible given that the River Kennet is canalised in the site area.

Groundwater data from the boreholes installed within the Chalk indicate that the groundwater flow in the Chalk is towards the north east. This is consistent with previous investigations and groundwater flow indicated in the BGS hydrogeological maps.

Groundwater configuration plans for the River Terrace Gravels and the Chalk are contained within **Appendix A** as Drawings 70031882-009A and 70031882-009B.

5.3. GROUND GAS MONITORING

A total of five shallow boreholes (BH102B, BH103A, BH104, WS201 and WS202) and three vapour wells (VW201A, VW202 and VW203) were installed as ground gas monitoring locations, with response zones in the Made Ground. Following the completion of the intrusive investigation, four rounds of gas monitoring were undertaken in 2015 and a further two rounds in 2019 to enable a preliminary assessment of the ground gas regime at the Site. Three of the monitoring rounds were undertaken in periods of falling atmospheric pressure which is considered to demonstrate worst-case conditions, however all rounds were undertaken during periods of high pressure (>1,000mb).

The full results of the monitoring and a summary of atmospheric conditions during the monitoring round are presented within **Appendix I**. A summary of the highest (and lowest in the case of oxygen) recorded gas monitoring results of unflooded wells is also presented in **Table 14** below.

Table 14 – Summary of Ground Gas Monitoring Results

BH ID	Response zone (m bgl)	Max flow rate (l/hr)	Atmospheric pressure range	Max Methane (%) (peak)	Max Carbon dioxide (%) (steady)	Min Oxygen (steady)	Max Hydrogen sulphide (pm)	Max Carbon monoxide (ppm)
BH102B	1.0-1.2	0.5	1008 to 1020	0.1	0.2	19.9	0	0
BH103A	1.0-1.5	0	1008 to 1020	0.1	3.7	1.8	0	0
BH104	1.0-1.5	0	1008 to 1020	0.1	6.6	11.4	1	0
BH202	0.5 -1.0	0	1008 – 1017	0.1	0.9	9.2	0	0
WS201A	0.6 – 1.1	0	1008 – 1017	0	0.5	18.8	0	0
WS202	0.5 – 1.3	0	1008 – 1017	0	2.2	15.3	0	0
WS205	0.5 – 1.5	0	1008 – 1017	2.8	6.3	0	0	0
WS206	1.0 – 3.0	0	1008 – 1017	0	0.9	17.7	0	0
VW201A	0.75 – 1.0	0.4	1008 – 1017	0	0.4	17.8	0	0
VW202	0.75 – 1.0	0	1008 – 1017	0	1.9	13.4	0	0
VW203A	0.75 – 1.0	0	1008 – 1017	0	3.6	13.3	0	8

5.4. VAPOUR SAMPLING

A total of three shallow wells (VW201A, VW202 and VW203A) were installed as soil vapour monitoring locations in 2019, with response zones in the Made Ground to further assess risks posed by vapours to off-site receptors and future on-site residents. Following the completion of the intrusive investigation in 2019, three rounds of vapour sampling were undertaken on 15th April, 13th

June and 20st June 2019 using summa vacuum canisters. Results of the vapour sampling are discussed in Section 6.2.

6. CONTAMINATION ASSESSMENT

6.1. HUMAN HEALTH RISK ASSESSMENT

6.1.1. RATIONALE

Legislation and guidance on the assessment of contaminated sites, consistent with European Union best practice, acknowledges the need for a tiered risk based approach. This human health risk assessment represents a generic quantitative risk assessment (GQRA) and involves comparison of Site contaminant levels against generic standards and compliance criteria including an assessment of risk using the source-pathway-receptor model.

WSP has derived a set of Generic Assessment Criteria (GAC) for the generic land use scenarios following the CLEA methodology and using the CLEA Workbook V1.071 computer modelling tool. Further details on the assumptions and methodologies adopted by WSP are provided in **Appendix J**.

Based on the proposed development plans, a residential without plant uptake scenario has been used to assess the risk to human health from soils, which is relevant for the vast majority of the site. The average soil organic matter (SOM) content of the soil samples varied based on the strata and an appropriate representative SOM has been used in the risk assessment as follows:

- **Made Ground:** 6% SOM (recorded values ranged between <0.35 % and 40.7%; average of 11%)
- **Alluvium:** 2.5% SOM (recorded values ranged between <0.35% and 9.96%; average 3.4%)
- **River Terrace Gravel:** 1% SOM (recorded values ranged between <0.35% and 1.56%; average 0.6%)
- **Chalk:** 1% SOM (<0.35% recorded)

To assess the risk to human health from groundwater (through vapour inhalation), a residential land use scenario has been assumed.

For some contaminants of concern, direct contact will be the dominant pathway for exposure. In order to support the soil reuse option, human exposure to unsaturated soils, irrespective of depth, was assumed possible for the purpose of this assessment. This will maximise the information available to the design team on the suitability of unsaturated material and can support their materials management options. Laboratory certificates of the chemical analysis are provided in **Appendix K** and screening tables that presents an assessment of the analytical data is provided in **Appendix L**.

6.1.2. SOIL ASSESSMENT

A total of 89 samples, including four duplicate samples and three skip samples, from across the site from the 2015 and 2019 site investigation were analysed for a range of determinands (as detailed within **Appendix F**). A summary of the contaminant exceedances above the GAC which may pose a risk to human health are summarised in **Table 15** below, with full results within **Appendix L**.

Polychlorinated biphenyls (PCBs) are a potential contaminant of concern given the presence of a substation on-site. PCB concentrations in the Made Ground analysed in the vicinity of the substation were below the laboratory limit of detection and GAC.

Table 15 – Summary of Exceedances in the Made Ground

Determinant	GAC (mg/kg)	Max Concentration (mg/kg)	Number of Samples Exceeding GAC	Location of Maximum Exceedance
Arsenic	35	268	21 of 50	WS204 (1.05 – 1.10 m)
Beryllium	1.72	2.85	5 of 50	HP101 (0.1 m)
Lead	188	31,000	33 of 50	WS204 (0.60 – 0.70 m)
Mercury	55.7	278	1 of 50	WS204 (1.05 – 1.10 m)
Benzene	1.4	9.68	2 of 50	BH103 (0.9 m)
TPH Aliphatic >12-16	3491	4,990	1 of 50	BH103 (0.9 m)
TPH Aromatics >EC12-EC16	1,732	5,800	3 of 50	BH103 (0.9 m)
TPH Aromatics >EC16-EC21	1,336	6,570	5 of 50	HP103 (0.3 m)
TPH Aromatics >EC21-EC35	1,336	9,710	11 of 50	HP103 (0.3 m)
TPH Aromatics >EC35-EC44	1,336	1,510	2 of 50	BH103 (0.3m)
TPH Hazard Index*	1	-	15 of 35	BH103 (0.9m)
Naphthalene	13.2	2,350	6 of 50	BH103 (0.9 m)
Benzo(a)pyrene	1.7	382	36 of 50	HP103 (0.3 m)
2,4 - Dimethylphenol	150.4	922	2 of 20	BH103 (0.9 m)
Carbon disulphide	0.622	4.67	6 of 20	TT101 (0.5 m)
1,2,4-Trimethylbenzene	34.5	88.4	1 of 20	BH103 (0.9 m)

* Where TPH Hazard Index is > 1.0, it means the GAC is exceeded for TPH for that sample

Metals, total petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAH), semi-volatile organic compounds (SVOC) and volatile organic compounds (VOCs) were recorded above the relevant GAC in samples from Made Ground.

The elevated organic contamination was identified across the Site, as would be expected from its history. Maximum concentrations were generally encountered where visual or olfactory evidence of contamination was identified and/or near sources (e.g. BH101 – cross boundary gas holder, BH103 – tar tank, HP101 – purifiers, HP103 – gas holder No. 4, TT101 - purifiers). Locations where

exceedances were recorded in the Made Ground are shown on Drawing 70031882-005 in **Appendix A**.

Elevated concentrations of the following contaminants have been identified in approximately 50% or more of the soil samples and may be representative of Site wide conditions: arsenic, lead, TPH (based on the hazard index) and benzo(a)pyrene.

An outlier test has not been completed as part of the statistical analysis as it is not considered to be appropriate given the investigation was generally targeted to areas of potential concern. For some contaminants, an exceedance was only recorded at isolated locations and therefore may be representative of a contaminant hotspot: nickel, TPH aliphatic >12-16 and VOCs.

The results for arsenic, benzene, benzo(a)pyrene and lead have been compared against C4SL, as shown in **Table 16**. C4SL values are considered to be pragmatic criteria to apply in the instance of GAC exceedances.

Table 16 – Summary of Exceedances of C4SL Criteria

Determinate	Number of samples exceeding GAC	C4SL (mg/kg)	Number of samples exceeding C4SL
Arsenic	21	40	18
Benzo(a)pyrene	35	5.3	29
Benzene	3	3.3	1
Lead	34	310	28

6.1.2.1. Statistics

Fifteen contaminants exceeded their relevant GAC or CS4L and therefore statistical test have been undertaken in accordance with CIEH / CL:AIRE guidance. The aim of the assessment is to investigate whether individual results are problematic or whether the dataset as a whole represents a potential risk.

The Site has been investigated for the purposes of planning. Therefore, the statistical assessment has been undertaken under the 'planning' scenario. In this case, the key question is 'is there sufficient evidence that the true mean concentration of the contaminant (μ) is less than the critical concentration (C_c , in this instance the GAC or C4SL)?'. Under the planning scenario, an evidence level of 95% is required to reject the null hypothesis. **Table 17** summarises the evidence level against the null hypothesis for all exceedances across the Site.

Table 17 – Results of Statistical Analysis of Exceedances of Determinants

Determinant	No. of Samples	GAC (mg/kg)	Mean (mg/kg)	UCL95 (mg/kg)	Evidence Against Null Hypothesis	Result
Arsenic	51	35	54.1	90.4	0%	$\mu \geq C_c$
Beryllium	51	1.72	1.0	1.4	99%	$\mu < C_c$
Lead	51	188	1591.7	4670.3	0%	$\mu \geq C_c$
Mercury	51	55.7	7.8	31.5	99%	$\mu < C_c$
Benzene	46	0.38	0.3	1.2	100%	$\mu < C_c$
TPH Aliphatic >EC12-16	50	3491	215.9	694.2	100%	$\mu < C_c$
TPH Aromatics >EC12-EC16	50	1,732	292.8	895.6	99%	$\mu < C_c$
TPH Aromatics >EC16-EC21	50	1,336	535.7	1325.8	95%	$\mu < C_c$
TPH Aromatics >EC21-EC35	50	1,336	922.7	1964.0	75%	$\mu \geq C_c$
TPH Aromatics >EC35-EC44	50	1,336	214.0	431.0	100%	$\mu < C_c$
Naphthalene	51	13.2	117.8	405.9	0%	$\mu \geq C_c$
Benzo(a)pyrene	51	1.7	27.5	63.2	0%	$\mu \geq C_c$
2,4 - Dimethylphenol	20	881	79.3	317.3	100%	$\mu < C_c$
Carbon disulphide	20	0.622	0.4	1.4	54%	$\mu \geq C_c$
1,2,4-Trimethylbenzene	20	34.5	5.5	24.7	98%	$\mu < C_c$

Of the exceedance identified across the Site there is sufficient evidence (95%) to dismiss the null hypothesis for beryllium, mercury, benzene, TPH aliphatic >EC12-16, TPH aromatics >EC12-16, >EC16-EC21 >EC35-EC44, 2,4 – Dimethylphenol and 1,2,4-Trimethylbenzene. The true mean concentrations for these contaminants within the Made Ground are therefore likely to be less than the critical concentrations.

However, for arsenic, lead, aromatic >C21 – 35, naphthalene, benzo(a)pyrene and carbon disulphide the null hypothesis cannot be rejected and the true mean concentrations for these contaminants are likely to exceed the GAC across the Site. A summary of the statistical analysis is presented included within **Appendix L**.

6.1.2.2. Soil Assessment: Residential with Plant Uptake

Two small private gardens are proposed for ground floor flats in the west of the site; in addition to the assessment above, a residential with plant uptake scenario has been used to assess the risk to human health from soils in this area. BH101 is situated within the area of the proposed gardens, and WS206, VW210A and BH201 are within proximity to the north. A total of nine soil samples from these locations (7 no. Made Ground, 1 no. Alluvium and 1 no. RTG) were screened against the derived 'residential with plant uptake' criteria. A summary of the contaminant exceedances above the GAC which may pose a risk to human health are summarised in **Table 18**.

Table 18 – Summary of Exceedances within Proposed Garden Areas

Determinate	GAC (mg/kg)	Max Concentration (mg/kg)	Number of Samples Exceeding GAC	Location of Maximum Exceedance
Arsenic	35	262	2	BH201 (0.3-0.4 m bgl)
Lead	188	1270	3	BH201 (0.3-0.4 m bgl)
Benzo(a)pyrene	1.6	16.9	3	BH201 (0.3-0.4 m bgl)
Carbon Disulphide	0.62	4.67	1	VW201A (0.8-1.0 m bgl)
Asbestos	Present	Detected	1	WS206 (0.3-0.4 n bgl)

Exceedances of metals (arsenic and lead), benzo(a)pyrene and carbon disulphide exceeded the GAC within the top 1.2 meters of Made Ground. Asbestos fibres (chrysotile) were also detected in one sample from WS206 at 0.3 m bgl. Soils within and adjacent to the proposed garden areas are not suitable for a residential scenario with plant uptake. It is therefore recommended that clean soils (between 0.6-1.0 m in depth) are imported in to the garden areas; Site won soils from elsewhere on site would not be suitable for re-use.

6.1.2.3. Asbestos

Asbestos was analysed in 46 samples and was identified in 19 samples as detailed below in **Table 18**. In the majority of locations, the asbestos quantities were above the laboratory limit of detection.

Table 19 – Locations with Asbestos in the Made Ground

Location	Asbestos Type	Asbestos quantification (%)
BH102 (0.8 m)	Loose fibres - Chrysotile	0.0087
BH103 (0.9 m)	ACM* debris and loose fibres – Chrysotile and Amosite	19.2
BH104 (0.4 m)	Loose fibres - Chrysotile	0.0026
BH103A (0.4 m)	Loose fibres - Chrysotile	0.0015

Location	Asbestos Type	Asbestos quantification (%)
BH102B (0.3 m)	Loose fibres - Chrysotile	<0.001
HP101 (0.1 m)	ACM debris - Chrysotile and Amosite	2.91
HP103 (0.3 m)	Loose fibres - Chrysotile	<0.001
HP104 (0.4 m)	Fibre bundles – Amosite	0.0073
HP101A (0.2 m)	Loose fibres and fibre bundles - Chrysotile and Amosite	<0.001
TT101 (0.5 m)	Loose fibres – Chrysotile, Amosite, Crocidolite	0.0022
TT102 (0.35 m)	Loose fibres - Chrysotile	0.0031
TT102 (0.7 m)	Loose fibres – Amosite, Crocidolite	0.0012
BH202 (0.3 m) – 2019	Loose fibres - Chrysotile	<0.001
BH203C (0.5 – 0.6 m) – 2019	Loose fibres – Crocidolite	0.0111
WS204 (0.5 – 0.6 m) – 2019	Loose fibres - Chrysotile	ACM debris
WS204 (2.3 – 2.4 m) - 2019	Loose fibres – Chrysotile	-
WS206 (0.3 – 0.4 m) – 2019	Loose fibres - Chrysotile	<0.001
VW203 (0.3 – 0.4 m) – 2019	Soil containing material typical of lagging – Chrysotile and Amosite	2.99
VW203A (0.8 – 1.0 m) – 2019	Loose fibres - Chrysotile	0.0408

*Asbestos Containing Material

6.1.2.4. Natural Ground

Elevated concentrations of contaminants that may pose a risk to human health were recorded at isolated locations in the Alluvium as detailed below in **Table 19**. Locations where exceedances were recorded in the natural soil are shown on Drawing 70031882-005b in **Appendix A**.

Table 20 – Summary of Exceedances in the Natural Ground

Determinant	GAC (mg/kg)	Max Concentration (mg/kg)	Number of Samples Exceeding GAC	Location of Maximum Exceedance	Stratum
Benzene	0.69	0.878	1	BH106 (3.6 m bgl)	Alluvium
Naphthalene	5.6	9.32	2	BH203C (3.5 m bgl)	Alluvium
				WS203 (3.4 m bgl)	Alluvium

The organic contamination in the natural soil has been encountered in areas where visual/olfactory evidence of contamination was identified, where elevated PID readings were recorded, or within the vicinity of historic gas work structures.

6.1.2.5. Uncertainties

GACs are not available for each of the contaminants analysed and some contaminants where GACs are not available were also above the laboratory limit of detection including some phenols, PAH, SVOC, VOC and inorganic compounds (e.g. ammonia). Naphthalene and benzo(a)pyrene have been used as a marker for PAH compounds and it is considered that the risk from the VOC, SVOC and phenol compounds will be managed via the assessment of the organic compounds and ammonia via other inorganic compounds, which have GACs available.

6.1.2.6. Historical lab data 1998 investigation

The laboratory analytical data reported from the historical investigation undertaken in 1998 has been reviewed with reference to the derived human health GAC. Similar contamination, to that encountered in 2015, was recorded in the soil during the 1998 investigation including elevated concentrations of benzo(a)pyrene, naphthalene, benzene, arsenic and lead, which may pose a risk to human health.

Limited analysis was undertaken during these investigations. Analysis for asbestos, VOCs, speciated TPH was not undertaken on the soil samples from this phase of investigation.

6.2. VAPOUR ASSESSMENT

6.2.1. GROUNDWATER VAPOUR

Elevated concentrations of chlorinated solvents were recorded in the groundwater at BH101, BH201, WS206 and BH105A that may pose a risk to human health via vapour migration (see **Table 20** below and Drawing 70031882-006 in **Appendix A.**). All four locations are within the northwest of the site. BH101 is located within the cross-boundary gas holder with a response zone in the Made Ground (i.e. material used to backfill the gas holder). The response zone of WS206 is within the Made Ground, BH201 within the River Terrace Gravels, and BH105A within the Chalk. It should be noted that the GACs are conservative for the Site setting as they are based on groundwater being 1 m bgl. However, they provide an indication that a vapour risk from the groundwater may be present.

Table 21 – Summary of Vapour Exceedances in the Groundwater

Determinant	GAC (µg/l)	Max Concentration (µg/l)	Number of Samples Exceeding GAC	Location of Maximum Exceedance	Groundwater depth (mbgl) [stratum]
Vinyl chloride	3	1,160	1 of 11	WS206	1.53 – 1.65 [Made Ground]
Trichloroethene (TCE)	29	155	1 of 11	BH101	2.38-2.4 [Made Ground]
Tetrachloroethene (PCE)	177	293	1 of 11	BH101	2.38-2.4 [Made Ground]

Table 15 also indicates that a potential vapour risk could be present due to elevated concentrations of volatile and semi-volatile compounds in the Made Ground and natural ground, with maximum concentrations generally encountered within the top one metre, these include: benzene, benzo(a)pyrene, naphthalene, 2,4 – dimethylphenol, carbon disulphide, tetrachloroethene, 1,3,5-trimethylbenzene and 1,2,4-trimethylbenzene.

6.2.2. SOIL VAPOUR

The detections of chlorinated solvents in groundwater in 2015 from BH101 exceeded the GAC as discussed above. The groundwater vapour GACs are conservative for the Site setting, therefore, it was recommended that specialist vapour wells were installed in the 2019 to accurately assess risk from vapours.

WSP installed three vapour wells in 2019 (VW201A-VW203A) to further assess vapours adjacent to the western site boundary and adjacent to the identified former tar tank in the central northern area of the Site.

Chlorinated solvents were detected in vapour samples from all three rounds from VW201A which is located adjacent to the western Site boundary and from VW203A from the first round on sampling only. However, it should be noted that during the first round of vapour sampling the laboratory reported issues with the sampling equipment, so this result may be anomalous. All results were screen against the soil vapour GAC for a sandy loam, indicative of site conditions. Although elevated levels of chlorinated solvents were detected, no determinands exceeded the GAC. The GAC for tetrachloroethene and trichloroethene are 56,056 and 5,339 µg/m³ respectively. The highest recorded concentration of tetrachloroethene was 36,886 µg/m³ and trichloroethene was 4,257 µg/m³ which were both recorded in VW201A on 13th June.

Therefore, it can be concluded that no significant risks from vapours to off-site residents and future on-site human health receptors are presented from the on-site concentrations. The gas risk assessment has characterised the site as Characteristic Situation 2 where basic gas protection measures are required. Passive ground gas protection measures were recommended into new developments on site the adjacent residential development site to the west. Therefore, although protection measures are not required for vapours, their presence will provide an additional level of

satisfaction that vapours will not pose a risk to off-site or on-site human health receptors (however, WSP has not been provided with information on whether these gas protection measures were installed and validated on the adjacent site).

6.3. CONTROLLED WATERS GENERIC QUANTITATIVE RISK ASSESSMENT

6.3.1. RATIONALE

The generic controlled waters risk assessment was conducted in accordance with the principles of The Environment Agency's 'Remedial Targets Methodology: Hydrogeological Risk Assessment for Land Contamination' 2006 (2006) and the 'prevent and limit' approach of the Water Framework Directive (2000/60/EC).

Generic controlled waters risk assessments compare directly measured concentrations with generic assessment criteria (GAC). GAC are selected based on both a hierarchy of relevance to England and the receptor. In this case, the controlled water receptors identified in the CSM were the Secondary A and Principal aquifers and the River Thames. The following hierarchies of GAC were therefore considered to be appropriate:

For the protection of the Aquifers

- UK Drinking Water Quality Standards (DWS) from The Water Supply (Water Quality) Regulations 2000 (amended 2004).
- World Health Organisation Guidelines for Drinking Water Quality, Fourth Edition, Volume 1, (2011).
- World Health Organisation Petroleum Products in Drinking Water (2008).

For the protection of the Surface Waters

- Environmental Quality Standards (EQS) from The Water Framework Directive (Standards and Classification) Directions (England and Wales) 2015.

All available groundwater and leachate data have been screened against the appropriate GAC including:

- Three rounds of groundwater sampling, November and December 2015 and April 2019; and
- Two rounds of leachate sampling in November 2015 (CEN 10:1) and March 2019 (CEN 2:1).

A summary of the screening results is presented in the following sections. It should be noted that different leachate solid-liquid ratios were used in the leachate analysis from the 2015 and 2019 rounds, therefore, the screening results are shown separately.

6.3.2. LEACHATE

Tables 21 and 22 summarise the exceedances recorded in the leachate samples. Concentrations of sulphate, cyanide, ammoniacal nitrogen, metals, TPH, PAH, VOC and phenol exceeded the relevant GAC and indicate that these contaminants have the potential to leach from the soil and pose a potential risk to groundwater beneath the Site and nearby surface water. The elevated concentrations have generally been recorded at locations that are in close proximity to potential sources at the Site or where visual/olfactory evidence of hydrocarbon contamination was recorded during site works.

Maximum concentrations were generally recorded at HP103, which is located adjacent to gas holder No. 4, TP103 located within the former footprint of liquor tank (Structure 1 on 70031882-004) located

to the north of the gas holder No. 4, and WS203 and BH104 which are non-targeted locations within the central areas of the Site which detected high concentrations of leachable TPH compounds.

Locations where exceedances were recorded in the leachate samples are shown on Drawing 70031882-007A & B in **Appendix A**.

Table 22 – Summary of Exceedances in Leachate Samples against the DWS/WHO

Determinant	GAC (µg/l)	Max Concentration (µg/l)	Number of Samples Exceeding GAC	Location of Exceedances
2015 data CEN 10:1				
Sulphate	250000	1,570,000	8 of 12	BH106 (1.1m, MG); BH102B (1m, MG); HP103 (0.3m, MG); TP102 (0.9m, MG); TP103 (0.8m, MG); TP104 (1.1m, MG); TP105 (1.7m, ALV); TP103A (0.4m, MG)
Total cyanide	50	4170	8 of 12	BH107 (0.35m, MG); BH102B (1m, MG); HP103 (0.3m, MG); HP104A (0.7m, MG); TP102 (0.9m, MG); TP103 (0.8m, MG); TP104 (1.1m, MG); TP103A (0.4m, MG)
Ammoniacal Nitrogen as N	500	142333	6 of 12	BH106 (1.1m, MG); BH102B (1m, MG); TP102 (0.9m, MG); TP103 (0.8m, MG); TP104 (1.1m, MG); TP105 (1.5m, ALV); TP103A (0.4m, MG)
Arsenic	10	56.7	2 of 12	BH106 (1.1 m, MG); TP104 (1.1m, MG)
Aliphatics >C10-C12	300	1,010	3 of 12	HP103 (0.3 m, MG); HP104 (0.7m, MG); TP103 (0.8m, MG)
Aromatics >EC10-EC12	90	674	3 of 12	HP103 (0.3 m, MG); HP104 (0.7m, MG); TP103 (0.8m, MG)
Aromatics >EC12-EC16	90	3,030	3 of 12	HP103 (0.3 m, MG); HP104 (0.7m, MG); TP103 (0.8m, MG)
Aromatics >EC16-EC21	90	694	3 of 12	HP103 (0.3 m, MG); HP104 (0.7m, MG); TP103 (0.8m, MG)
Benzo(a)pyrene	0.01	0.201	5 of 12	BH107 (0.35m, MG); HP103 (0.3 m, MG); HP104 (0.7m, MG); TP103 (0.8m, MG); TP103A (0.4m, MG)
PAH (sum of 4)	0.1	0.247	4 of 12	BH107 (0.35m, MG); HP104 (0.7m, MG); TP103A (0.4m, MG)
Benzene	1	3.07	1 of 12	TP103 (0.8 m, MG)
2019 data CEN 2:1				
Sulphate	250000	513000	2 of 12	VW203A (0.8m, MG); WS204 (0.6m, MG)
Ammoniacal Nitrogen as N	500	68200	5 of 10	BH201 (5.1m, RTG); BH203C (2.2m, ALV); WS203 (3.5 m, ALV); WS204 (0.6m, MG); WS206 (4.2m, ALV)

Determinant	GAC (µg/l)	Max Concentration (µg/l)	Number of Samples Exceeding GAC	Location of Exceedances
Arsenic	10	192	5 of 10	BH202 (0.3m, MG); BH203C (2.2m, ALV); WS203A (0.3 m, MG); WS203 (3.4m, ALV); WS204 (0.6m, MG);
Lead	10	43.9	1 of 10	WS204 (0.6 m, MG)
Selenium	10	55.6	3 of 10	WS203A (0.3 m, MG); WS203 (3.4m, ALV); WS204 (0.6m, MG);
Aliphatics >C8-C10	300	322	1 of 10	WS203 (3.5 m, ALV);
Aliphatics >C10-C12	300	1080	3 of 10	BH202 (0.3m, MG); WS203 (3.5 m, ALV); WS204 (0.6m, MG);
Aromatics >EC10-EC12	90	722	3 of 10	BH202 (0.3m, MG); WS203 (3.5 m, ALV); WS204 (0.6m, MG);
Aromatics >EC12-EC16	90	727	2 of 10	BH202 (0.3m, MG); WS204 (0.6m, MG);
Aromatics >EC16-EC21	90	821	3 of 10	BH204 (0.6 m, MG); BH202 (0.3m, MG); WS204 (0.6m, MG);
Aromatics >EC21-EC35	90	513,000	1 of 10	BH204 (0.6 m, MG)

Table 23 – Summary of Exceedances in Leachate Samples against the EQS

Determinant	GAC (µg/l)	Max Concentration (µg/l)	Number of Samples Exceeding GAC	Location of Exceedances
2015 data CEN 10:1				
Free Ammonia	600	1498	1 of 12	TP105 (1.7m, ALV);
Arsenic	50	56.7	2 of 12	BH106 (1.1 m, MG); TP104 (1.1m, MG)
Cadmium	0.25	0.436	1 of 12	HP103 (0.3 m, MG)
Copper	1	21.7	12 of 12	Throughout
Lead	1.2	5.96	5 of 12	BH107 (0.35 m, MG); HP104 (0.7m, MG); TP103 (0.8 m, MG); TP106 (0.5m, MG); TP103A (0.4m, MG)
Nickel	4	17.8	8 of 12	BH106 (1.1m, MG); BH107 (0.35 m, MG); HP103 (0.3m, MG); TP102 (0.9m, MG); TP103 (0.8m, MG); TP104 (1.1m, MG); TP105 (1.7m, ALV); TP103A (0.4m, MG)

Determinant	GAC (µg/l)	Max Concentration (µg/l)	Number of Samples Exceeding GAC	Location of Exceedances
Zinc	10.9	29.1	1 of 12	HP103 (0.3 m, MG)
Phenol	7.7	290	1 of 12	TP103 (0.8 m, MG)
Xylenes	30	41	1 of 12	TP103 (0.8 m, MG)
Naphthalene	2	2,170	2 of 12	TP103 (0.8 m, MG); TP105 (1.7m, ALV)
Fluoranthene	0.0063	23.9	11 of 12	Throughout
Anthracene	0.1	36.1	7 of 12	BH106 (1.1m, MG); BH107 (0.35 m, MG); BH102B (1m, MG); HP103 (0.3m, MG); HP104A (0.7m, MG); TP103 (0.8m, MG); TP103A (0.4m, MG)
Benzo(a)pyrene	0.00017	0.201	5 of 12	BH107 (0.35 m, MG); HP103 (0.3m, MG); HP104A (0.7m, MG); TP103 (0.8m, MG); TP103A (0.4m, MG)
Aromatics >EC8-EC10	20	94	4 of 12	BH107 (0.35 m, MG); HP103 (0.3m, MG); HP104A (0.7m, MG); TP103 (0.8m, MG);
Aromatics >EC10-EC12	2	674	4 of 12	BH107 (0.35 m, MG); HP103 (0.3m, MG); HP104A (0.7m, MG); TP103 (0.8m, MG);
Aromatics >EC12-EC16	2	3030	6 of 12	BH107 (0.35 m, MG); HP103 (0.3m, MG); HP104A (0.7m, MG); TP103 (0.8m, MG); TP103A (0.4m, MG); TP105 (1.7 m, ALV)
Aromatics >EC16-EC21	0.1	694	6 of 12	BH107 (0.35 m, MG); HP103 (0.3m, MG); HP104A (0.7m, MG); TP103 (0.8m, MG); TP103A (0.4m, MG); TP104 (1.1 m MG)
Aromatics >EC21-EC35	0.00017	77	6 of 12	HP103 (0.3m, MG); HP104A (0.7m, MG); TP103 (0.8m, MG); TP103A (0.4m, MG); TP104 (1.1 m MG); TP102 (0.9 m MG)
2019 data CEN 2:1				
Free ammonia	600	718	1 of 10	WS203 (3.5 m, ALV)
Arsenic	50	192	2 of 10	BH202 (0.3m, MG); WS203 (3.5 m, ALV)
Cadmium	0.25	0.37	1 of 10	WS203 (0.8 m, MG)
Copper	1	52.2	9 of 10	Throughout
Lead	1.2	43.9	3 of 10	BH202 (0.3 m, MG); WS203 (3.5 m, ALV); WS204 (0.6 m, MG)
Nickel	4	19.7	5 of 10	BH202 (0.3 m, MG); WS203 (3.5 m, ALV); WS204 (0.6 m, MG); BH203C (2.2m, ALV); VW203A (0.8m, MG)

Determinant	GAC (µg/l)	Max Concentration (µg/l)	Number of Samples Exceeding GAC	Location of Exceedances
Zinc	10.9	21	3 of 10	WS204 (0.6 m, MG); BH203C (2.2m, ALV); VW203A (0.8m, MG)
Phenol	7.7	10	1 of 10	WS203 (3.5 m, ALV)
Naphthalene	2	51.7	4 of 10	BH201 (5.1m, RTG); BH202 (0.3 m, MG); WS203 (3.5 m, ALV); WS204 (0.6 m, MG)
Fluoranthene	0.0063	8.27	10 of 10	Throughout
Anthracene	0.1	8.94	2 of 10	BH202 (0.3 m, MG); WS204 (0.6 m, MG)
Benzo(a)pyrene	0.00017	0.283	5 of 10	BH202 (0.3 m, MG); BH204 (0.6m, MG); VW202 (0.4m, MG); WS203 (3.4m, ALV); WS204 (0.6m, MG)
Aromatics >EC8-EC10	20	314	5 of 10	BH201 (1.1m, MG); BH202 (0.3 m, MG); WS203 (3.5 m, ALV); WS204 (0.6 m, MG); WS206 (4.2 m ALV)
Aromatics >EC10-EC12	2	722	5 of 10	BH201 (1.1m, MG); BH202 (0.3 m, MG); WS203 (3.5 m, ALV); WS204 (0.6 m, MG); WS206 (4.2 m ALV)
Aromatics >EC12-EC16	2	727	3 of 10	BH202 (0.3 m, MG); WS203 (3.5 m, ALV); WS204 (0.6 m, MG)
Aromatics >EC16-EC21	0.1	821	3 of 10	BH202 (0.3 m, MG); BH204 (0.6 m MG); WS204 (0.6 m, MG)
Aromatics >EC21-EC35	0.00017	513000	3 of 10	BH202 (0.3 m, MG); BH204 (0.6 m MG); WS204 (0.6 m, MG)

6.3.3. GROUNDWATER

Tables 23 and 24 summarise the contaminants in the groundwater (from three rounds of sampling) which exceeded the relevant GAC. Generally, concentrations of contaminants identified as leachable in the soil (**Table 20 and 21**) have been recorded in the groundwater. The locations of the maximum concentrations were typically encountered at BH202 located southwest of the gas holder and screened in the Chalk and consistent with NAPL observed during monitoring. Relatively high concentrations were also observed at BH102B, which is located adjacent to the historical liquor tank and sulphate & ammonia works in the north of the Site and is screened within the drift deposits, and within WS206 located northwest of gas holder No. 4 in the west of the Site and screened in the Made Ground.

The groundwater exceedances are typically located within the superficial deposits. However, elevated concentrations of PAH and benzene have also been encountered in the Chalk aquifer specially within BH202 suggesting that migration is occurring into the Chalk and indicating that the superficial and bedrock aquifers are likely to be hydraulically linked.

Elevated concentrations of chlorinated solvents were recorded in groundwater at five boreholes, which exceeded the relevant GAC. Trichlorethene (TCE), cis-1,2-dichloroethene (DCE) and vinyl chloride are all degradation products of Tetrachloroethene (PCE). These contaminants have only been recorded in the groundwater above the laboratory limit of detection in boreholes BH101, BH105, BH202, BH201 and WS206, all of which are located along the west boundary or in the northwest of the Site. Soil concentrations of these contaminants were limited to marginal detections of DCE in two samples and single detection of PCE (31.9 mg/kg at VW201A). Therefore, although chlorinated solvents are not typically encountered at gaswork sites, it is considered likely that there is an on-site source located within the western area of the site. However, given the relatively high concentrations in groundwater, their locations and the limited soil concentrations it is considered that an off-site source is likely to exist. Elevated concentrations of chlorinated solvents were detected within the RTG and Chalk aquifers off-site during previous investigation works in 1998/1999, although the source could not be determined.

Locations where exceedances were recorded in the groundwater are shown on Drawing 70031882-008A & B in **Appendix A**.

Table 24 – Summary of Exceedances in Groundwater Samples against the DWS/WHO

Determinant	GAC (µg/l)	Max Concentration (µg/l)	Number of Samples Exceeding GAC	Location of Exceedances
Nitrite	500	2360	5 of 14	BH105A (CLK); BH106 (CLK); BH107 (CLK)
Sulphate	250000	635000	5 of 14	BH102B (ALV); BH106 (CLK); BH104(ALV/RTG)
Ammoniacal Nitrogen as N	500	44177	22 of 26	Throughout
Total cyanide	50	2160	13 of 26	BH102B (ALV/RTG); BH103A (ALV/RTG); BH105A (CLK); BH101 (MG); WS206 (MG); BH104 (ALV/RTG); BH201 (RTG), BH202 (CLK)
Nitrate as NO3	50000	72500	2 of 15	BH105A (CLK)
Arsenic	10	68.5	7 of 26	BH105A (CLK); BH102B (ALV/RTG); BH104 (ALV/RTG); BH201 (RTG), BH202 (CLK)
Manganese	50	3,800	12 of 14	BH102B (ALV/RTG); BH103A (ALV/RTG); BH106 (CLK); BH107 (CLK); BH101 (MG); BH104 (ALV/RTG)
Iron	200	34600	9 of 26	BH102B (ALV/RTG); BH103A (ALV/RTG); BH105A (CLK); WS206 (MG); BH104 (ALV/RTG); BH203C (RTG); BH202(CLK)
Nickel	20	27.3	2 of 26	BH106 (CLK); BH101 (MG)
Selenium	10	20.8	2 of 17	BH105 (CLK)
Aliphatics >C8-C10	300	840	1 of 26	BH202(CLK)

Determinant	GAC (µg/l)	Max Concentration (µg/l)	Number of Samples Exceeding GAC	Location of Exceedances
Aliphatics >C10-C12	300	2570	1 of 26	BH202(CLK)
Aromatics >EC5-EC7	1	803	3 of 26	WS206 (MG); BH201 (RTG)
Aromatics >EC8-EC10	500	1070	1 of 26	BH202(CLK)
Aromatics >EC10-EC12	90	1710	2 of 26	BH102B (ALV/RTG); BH202(CLK)
Aromatics >EC12-EC16	90	1710	3 of 26	BH102B (ALV/RTG); BH202(CLK)
Aromatics >EC16-EC21	90	134	2 of 26	BH102B (ALV/RTG); BH202(CLK)
Aromatics >EC21-EC35	90	155	3 of 26	BH102B (ALV/RTG); BH105A (CLK); BH202(CLK)
Benzo(a)pyrene	0.01	1.09	11 of 26	BH102B (ALV/RTG); BH103A (ALV/RTG); BH105 (CLK); WS206 (MG); BH104 (ALV/RTG); BH202(CLK)
PAH (sum of 4)	0.1	2.25	6 of 26	BH102B (ALV/RTG); BH103A (ALV/RTG); BH105 (CLK); WS206 (MG); BH104 (ALV/RTG); BH202(CLK)
Benzene	1	712	10 of 26	BH102B (ALV/RTG); BH105 (CLK); BH106 (CLK); BH101 (MG); WS206 (MG); BH201 (RTG); BH202(CLK)
Vinyl chloride	0.5	2750	7 of 22	BH105 (CLK); BH101 (MG); WS206 (MG); BH201 (RTG); BH202(CLK)
cis-1,2-Dichloroethene	50	5610	4 of 22	BH101 (MG); WS206 (MG); BH201 (RTG)
Trichloroethene (TCE)	10	155	3 of 22	BH101 (MG); WS206 (MG)
Tetrachloroethene	10	956	3 of 22	BH101 (MG); WS206 (MG)

Table 25 – Summary of Exceedances in Groundwater Samples against the EQS

Determinant	GAC (µg/l)	Max Concentration (µg/l)	Number of Samples Exceeding GAC	Location of Exceedances
Arsenic	50	68.5	1 of 26	BH104 (ALV/RTG)

Determinant	GAC (µg/l)	Max Concentration (µg/l)	Number of Samples Exceeding GAC	Location of Exceedances
Iron	1000	34600	6 of 26	BH102B (ALV/RTG); BH105 (CLK); WS206 (MG); BH202(CLK)
Copper	1	4.93	14 of 26	BH102B (ALV/RTG); BH103A (ALV/RTG); BH105 (CLK); BH106 (CLK); BH107 (CLK); BH101 (MG); BH104 (ALV/RTG)
Manganese	123	3,800	12 of 14	BH102B (ALV/RTG); BH103A (ALV/RTG); BH106 (CLK); BH107 (CLK); BH101 (MG); BH104 (ALV/RTG)
Nickel	4	27.3	13 of 26	BH102B (ALV/RTG); BH103A (ALV/RTG); BH106 (CLK); BH107 (CLK); BH101 (MG); BH104 (ALV/RTG); WS206 (MG)
Phenol	7.7	10	1 of 18	BH102B (ALV/RTG)
Fluoranthene	0.0063	3.45	19 of 26	BH102B (ALV/RTG); BH103A (ALV/RTG); BH105 (CLK); BH104 (ALV/RTG); WS206 (MG); BH201 (RTG); BH202(CLK)
Anthracene	0.1	5.05	3 of 26	BH102B (ALV/RTG); BH202(CLK)
Benzo(a)pyrene	0.00017	1.09	11 of 26	BH102B (ALV/RTG); BH103A (ALV/RTG); BH105 (CLK); BH104 (ALV/RTG); WS206 (MG); BH201 (RTG); BH202(CLK)
Benzene	10	712	3 of 26	WS206 (MG); BH201 (RTG) ; BH202(CLK)
Ethylbenzene	20	23	1 of 26	BH102B (ALV/RTG)
Xylene (total)	30	442	3 of 26	BH102B (ALV/RTG) ; BH202(CLK)
Trichloroethene	10	155	3 of 12	BH101 (MG); WS206 (MG)
Tetrachloroethene	10	956	3 of 22	BH101 (MG); WS206 (MG)
Aromatics >EC5-EC7	10	803	3 of 22	BH201 (ALV); WS206 (MG) ; BH202(CLK)
Aromatics >EC8-EC10	20	1070	6 of 22	BH102B (AL/RTG); BH101 (MG); WS206 (MG) ; BH202(CLK)
Aromatics >EC10-EC12	2	1710	3 of 22	BH102 B (ALV/RTG);, BH202(CLK)
Aromatics >EC12-EC16	2	478	6 of 22	BH102 B (ALV/RTG); BH103A (ALV/RTG); BH106 (CLK) ; BH202(CLK)
Aromatics >EC16-EC21	0.1	134	5 of 22	BH102 B (ALV/RTG); BH103A (ALV/RTG); BH105 A (CLK) ; BH202(CLK)
Aromatics >EC21-EC35	0.00017	155	5 of 22	BH102 B (ALV/RTG); BH105 A (CLK) ; BH202(CLK)

6.3.4. SURFACE WATER

Four upstream and downstream samples were taken from the River Kennet during the monitoring visits carried out in November and December 2015, and April 2019. Concentrations of three contaminants (copper, fluoranthene and benzo(a)pyrene) were recorded in exceedance of the EQS (**Table 26**), however, concentrations were typically lower than those recorded in the groundwater samples. In addition, concentrations were recorded in both the downstream and upstream samples indicating that the source likely to be upgradient of the River Kennet.

Table 26 – Summary of Exceedances in Surface Water Samples

Determinant	GAC (µg/l)	Max Concentration (µg/l)	Number of Samples Exceeding GAC	Location of Exceedance
Copper	1	2.15	4 of 6	Downstream and Upstream (November and December 2015)
Fluoranthene	0.0063	0.0412	3 of 6	Upstream (November 2015 and April 2019); Downstream (April 2019)
Benzo(a)pyrene	0.00017	0.037	2 of 6	Upstream (November 2015); Downstream (April 2019)

6.3.5. HISTORICAL LAB DATA 1998 INVESTIGATION

The laboratory analytical data reported from the 1998 investigation has been reviewed with reference to the GAC. Again, similar contamination was encountered in the groundwater and leachate in the 1998 and 2015 investigations. The 1998 investigation encountered elevated concentrations of metals, cyanide, sulphate, ammonium, chlorinated solvents, benzene and xylene in the groundwater and metals in the leachate that posed a potential risk to controlled waters.

Limited analysis was undertaken during the 1998 investigation; analysis for VOCs and speciated TPH was not undertaken on the groundwater/leachate samples from this phase of investigation (leachate testing was restricted to only metals).

6.3.6. SUMMARY OF CONTROLLED WATERS GQRA RESULTS

Groundwater and leachate concentrations of several CoCs exceeded the relevant GAC for the protection of groundwater sources and surface waters. Groundwater exceedances were mainly located within the superficial deposits however, samples taken within the Chalk also recorded exceedances of ammoniacal nitrogen, PAH, TPH, benzene and chlorinated solvents. Generally exceedances were related to the southwest area (BH202), northwest adjacent to the cross-boundary gas holder (WS206, BH101, BH201), north of the current gas holder (gas holder no. 4) and adjacent to the above ground liquor tank (BH102B, BH105) and north-eastern area of the Site, in proximity of the identified tar tank (BH103).

Laboratory results of the water samples taken from the River Kennet reveal limited impact in the water quality, likely from an upgradient source. This result is consistent with the CSM which considers the River Thames as the main surface water receptor based on the groundwater flow direction within the RTG towards the north.

Nonetheless, all determinands with recorded exceedances will be further assessed in a subsequent detailed qualitative risk assessment.

6.4. GROUND GAS ASSESSMENT

Potential risks posed by hazardous ground gases at the site have been assessed following the guidance contained within CIRIA C665 Report. This method requires use of both gas concentrations (carbon dioxide and methane) and standpipe flow rates to calculate a gas screening value (GSV).

In-situ gas monitoring data was collected on six occasions between 2015 and 2019 and is summarised in Section 5.1.13. A full record of the data is presented in **Appendix I**. A maximum methane concentration of 2.8% (WS205) and a maximum carbon dioxide concentration of 6.6% (BH104) were recorded at the Site. However, the screened section within the gas well in WS205 was partially flooded potentially giving inaccurate gas readings. Excluding the 2.8% methane concentration from WS205, methane was detected to a maximum concentration of 0.1%.

The Typical Maximum Concentrations and GSVs recorded during the ground gas monitoring rounds undertaken at the site are summarised in **Table 26** below.

Table 27 – Typical Maximum Concentrations and GSVs

	Maximum Flow Rate	Methane		Carbon Dioxide	
		Typical Maximum Concentrations (%)	Gas Screening Value* (l/hr)	Typical Maximum Concentrations (%)	Gas Screening Value* (l/hr)
Measured Concentration	+0.5	2.8	0.014	6.6	0.033

*Gas screening value (GSV) is calculated by multiplying the maximum gas concentration (%) by the maximum measured borehole flow rate (l/hr) as per CIRIA C665; methane trigger value is 1%; carbon dioxide trigger value is 5%. Where gas flow rates were recorded as <0.1l/hr (GMF 485 LOD), a conservative flow rate estimate of 0.1 l/hr is assumed for the calculation of gas screening values.

The gas risk assessment for the site is driven by the concentrations of carbon dioxide. The GSV (0.033 l/hr) and low flow rates recorded alone would characterise the site as a Characteristic Situation 1. However, owing to the concentrations of carbon dioxide recorded in BH104 and WS205 on two occasions at >5%, the classification should be increased to Characteristic Situation 2 (Low Risk) where basic gas protection measures should be included as follows:

Situation A:

Characteristic Situation 2 (low risk).

2 levels of protection are required for a residential building.
Typical scope of protective measures:

- a) Reinforced concrete cast in-situ floor slab (suspended, non-suspended or raft) with at least 1200 g DPM² and underfloor venting.
 - b) Beam and block or pre-cast concrete slab and minimum 2000 g DPM/reinforced gas membrane.
- All joints and penetrations sealed.

6.4.1. GROUND GAS DATA QUALITY

Although three rounds of monitoring were completed during falling atmospheric pressure conditions, none of the monitoring was completed during low pressure conditions (i.e. <1000 mb). Six rounds of gas monitoring have been completed, in line with CIRIA C665 where a minimum of six visits would be required for this type of site and the proposed development.

6.5. UNDERGROUND SERVICES RISK ASSESSMENT

The UKWIR document⁶ provides guidance on threshold values above which water supply pipes made of certain material may be at risk. Based on the threshold concentrations for polyethylene (PE) and Poly Vinyl Chloride (PVC) pipe material the concentrations of hydrocarbons in the shallow soil across the Site may potentially pose a risk to water supply pipes. Such contaminants may degrade or infiltrate the pipe affecting the quality of the water. The hydrocarbon contaminants in the shallow groundwater may also pose a risk to water supply pipes. Screening of the soil data to 4 m bgl has been undertaken and is summarised in **Table 27** below.

Table 28 – Details of Pipe Material Threshold Exceedances

Parameter	Polyethylene (PE) material threshold (mg/kg)	Polyvinyl chloride (PVC) material threshold (mg/kg)	Maximum concentration on Site* (mg/kg)
VOC	0.5	0.125	938.57 (Made Ground) (HP103 0.3m bgl) 337.639 (Alluvium) (WS203 3.4-3.5m bgl)
BTEX & MTBE	0.1	0.03	41.5 (Made Ground) (BH103 0.9m bgl) 1.93 (Alluvium) (BH106 3.6m bgl)

⁶ UKWIR (2010). Guidance for the selection of water supply pipe to be used in brownfield sites. Report Ref. No. 10/WM/03/21

Parameter	Polyethylene (PE) material threshold (mg/kg)	Polyvinyl chloride (PVC) material threshold (mg/kg)	Maximum concentration on Site* (mg/kg)
SVOC	2	1.4	6,423.4 (Made Ground) (BH103 0.9m bgl) 66.5 (Alluvium) (BH106 3.6m bgl)
Phenols	2	0.4	2560 (Made Ground) (BH103 0.9m bgl) 191 (Natural) (BH106 3.6m bgl)
Creosols and chlorinated phenols	2	0.04	2560 (Made Ground) (BH103 0.9m bgl) 191 (Natural) (BH106 3.6m bgl)
Mineral oil C11-20	10	-	21,808.9 (Made Ground) (BH103 0.9m bgl) 32.59 (Alluvium) (BH203 3.50-3.60m bgl)
Mineral oil C21-40	500	-	12780 (Made Ground) (BH103 0.3m bgl) 67 (Alluvium) (BH203 3.50-3.60m bgl)

*Samples from the top 4m

Water supply pipes will require upgrading to protect against the potentially aggressive effects of residual hydrocarbons within the shallow soils. When the proposed route of potable water supply pipes has been finalised, a water supply pipe risk assessment should be undertaken on the basis of information obtained in all (current and future) phases of investigation. Water supply pipe material selection should be in accordance with current recommendations set out in UKWIR6.

6.6. AREAS OF POTENTIAL CONCERN

An evaluation of the areas of potential concern that were identified in the preliminary CSM and that have been assessed above are detailed in **Table 28**.

With the exception of the electrical substation, elevated concentrations of contaminants of concern have been encountered at all of the potential areas of concern and across the Site.

Table 29 – Summary of Contamination Impacts by Area of Potential Concern

Area of Potential Concern	Exploratory Locations	Field Evidence of Impact	Summary of PID Readings (>1 ppm)	Summary of Findings
Cross-boundary gas holder & Chlorinated solvent impact in west of Site	BH101 (within holder) VW201A, WS206, BH201 (adjacent to holder)	Visual and olfactory evidence of contamination in Made Ground, River Terrace Gravels and Chalk.	BH101: 31.7 ppm (8. 2m) VW201A: 11 ppm (0.8 m), 4.1 ppm (0.8 m)	Chlorinated solvents were detected within groundwater, however a soil vapour risk assessment has been undertaken which has determined there to be no significant risk to human health receptors. Contaminants in the groundwater may pose a risk to controlled waters (ammonia, cyanide, benzene, manganese, nickel, chlorinated solvents, cis-1,2-dichloroethene, aromatics C5-C7. Leachable ammonia, copper, fluoranthene, naphthalene that may pose a risk to controlled waters.
Sulphate of ammonia works	BH102, BH102A, BH102B	Visual and olfactory evidence of contamination in soil (Made Ground, Alluvium, River Terrace Gravels) and groundwater	BH102: 5.6 ppm (0.8 m), 33.6 ppm (1.55 m) 257 ppm (4.15 m)	Asbestos present in Made Ground. Arsenic, lead, TPH and benzo(a)pyrene present in the Made Ground that may pose a risk to human health. Leachable ammonia, copper, fluoranthene, anthracene, sulphate, and cyanide that may pose a risk to controlled waters. Elevated concentrations of sulphate, ammonia, cyanide, arsenic, copper, nickel, manganese, TPH, PAH, phenol, ethylbenzene and xylene in the groundwater that may pose a risk to controlled waters.
Tar Tank	BH103, BH103A, BH103AR VW202 VW203	Visual and olfactory evidence of contamination in soil (Made Ground, Alluvium, River Terrace Gravels) and groundwater	BH103: 469 ppm (0.3 m), 500.8 ppm (0.9 m), 24.1 (0.4 m), 25.9 ppm (2 m), 24 ppm (4.3 m)	Asbestos present in the Made Ground. Arsenic, lead, beryllium, benzene, TPH, naphthalene, benzo(a)pyrene, and VOC in the Made Ground which may pose a risk to human health. Ammonia, manganese, PAH, copper, iron, nickel, cyanide, TPH and PAH in the groundwater that may pose a risk to controlled waters. Leachable sulphate, arsenic, selenium and benzo(a)pyrene that may pose a risk to controlled waters. Soils vapour wells screened in the Made Ground adjacent to the tar tank did not detect vapour in excess of the soil vapour GAC.

Area of Potential Concern	Exploratory Locations	Field Evidence of Impact	Summary of PID Readings (>1 ppm)	Summary of Findings
Separating tank	TP101, TP102	Visual evidence of contamination in Alluvium	TP102: 2.5 ppm (0.9 m), 12 ppm (1.8 m), 7.5 ppm (2.2 m)	Leachable copper, nickel, sulphate and cyanide that may pose a risk to controlled waters.
Liquor tank & Tar Mains	TP103, TP103A	Visual evidence of contamination in Made Ground	38.3 ppm (0.8 m) 0 ppm (0.4 m)	Arsenic, lead, benzene, TPH, benzo(a)pyrene and naphthalene in the Made Ground that may pose a risk to human health. Leachable ammonia, metals, sulphate, cyanide, phenol, xylene, benzene, TPH and PAH that may pose a risk to controlled waters.
Concentrated liquor and sulphate plant and overhead acid tanks	TP104 & TP105	Visual evidence of contamination in Alluvium (TP105)	TP104: 5.2 ppm (1.1 m), 44.3 ppm (2 m) TP105: 13.1 ppm (0.5 m), 26.7 ppm (1.7 m)	Arsenic, TPH, benzo(a)pyrene and naphthalene in the Made Ground that may pose a risk to human health. Leachable ammonia, sulphate, cyanide, metals, TPH, PAH and bis(2-ethylhexyl) phthalate that may pose a risk to controlled waters.
Sulphate of ammonia plant (and other unidentified structures in north of Site)	TT101-102	Visual and olfactory evidence of contamination in Made Ground	TT01: 6.8 ppm (0.2 m), 16.5 ppm (0.5 m), 16.5 ppm (1 m) TT02: 2.9ppm (0.35m), 6ppm (0.7m)	Asbestos present in Made Ground. Arsenic, lead, TPH, benzo(a)pyrene and carbon disulphide in the Made Ground that may pose a risk to human health.
Electrical substation	BH105 & TP102	Visual evidence of contamination (TP102)	BH105: 0.2 ppm (0.2 m), 0 ppm (0.9 m), 22ppm (2.4m), 29.2 ppm (9.2 m) TP102 :2.5 ppm (0.9m), 12 ppm (1. 8m), 7.5 ppm (2.2 m)	PCB concentrations do not exceed the laboratory limit of detection or GAC.

Non-targeted exploratory wells investigating the Chalk aquifer (BH105-107 and BH202) identified visual and olfactory evidence of contamination in Alluvium at BH106, and within Alluvium, River Terrace Gravels and Chalk in BH202, including product within Chalk fissures and groundwater. Leachable contaminants and contaminants in groundwater at these locations may pose a risk to controlled waters. Contaminants identified in groundwater in these locations (including nitrate, nitrite, sulphate, ammonia, manganese, copper, nickel, selenium, benzo(a)pyrene, fluoranthene, TPH, vinyl chloride, chloroform and bis(2-Ethylhexyl) phthalate) that may pose a risk to controlled waters.

7. REFINED CONCEPTUAL SITE MODEL

7.1. INTRODUCTION

This section provides a refinement of the preliminary CSM which was presented in Section 3. Plausible source-pathway-receptor contaminant linkages have been refined in line with industry good practice (principally CLR11 and R&D66).

The refined CSM provides an updated understanding of the Site based on the findings of the Site investigations and analytical results and draws on the ground, hydrogeological and contamination models which are presented in Sections 5 and 6. It is based on a proposed future residential land use.

The sources of contamination have been refined below taking account of the findings of the site investigation. Due to the detections of chlorinated solvents, this contamination source is now considered in its own right. The receptors and pathways remain as per the original CSM in Section 3, however groundworkers during redevelopment and maintenance workers have been discounted from the assessment because there are legal requirements to ensure that suitable health and safety controls should be in place during works (i.e. Construction (Design and Management) Regulations 2015).

7.2. SOURCES OF CONTAMINATION CONSIDERED FOR FURTHER ASSESSMENT

- **Made Ground** – associated with the demolition of gasworks structures, deposited wastes, and historical levelling of the Site. The Site investigation confirmed Made Ground across the site, with an average thickness of 1.4 m. Visual and olfactory evidence of contamination was recorded which included hydrocarbon odours, pockets of black and tarry staining, blue staining (potentially associated with spent oxide deposits) and coal, clinker and coke fragments. No visual evidence of asbestos containing material was identified during the ground investigation, however laboratory analysis positively identified asbestos fibres within Made Ground soils. Blue staining on Made Ground soils from TP102 at 0.9 m bgl may be evidence of spent oxide contaminants in soil; this is supported by relatively high cyanide concentrations in the soil at this location (dark blue mottling and staining within BH101 and BH102 were considered associated with hydrocarbon staining and natural mottling within the alluvial deposits). Elevated concentrations of contaminants are present in the Made Ground that may pose a risk to human health and controlled waters. Carbon dioxide has been recorded in the Made Ground and the gas regime has been classified as Characteristic Situation 2. The soil vapour assessment determined that no significant risks to human health are posed soil vapours within the Made Ground.
- **Impacted Natural Ground** - Visual and olfactory evidence of contamination was recorded in the Alluvium, River Terrace Gravel and Chalk which included hydrocarbon odours and pockets of black staining. Elevated leachate concentrations (Alluvium) may pose a risk to controlled waters. Three marginal exceedances of the human health GAC were identified within the Alluvium for naphthalene (2 no.) and benzene (1 no.) at depths >3m bgl.
- **Cross-Boundary Gas Holder** – former gas holder partially located on-site straddling the western Site boundary (Structure 7). The investigation confirmed the concrete base of the partially below ground gas holder at 3.7 m bgl. The gas holder infill comprised reworked natural sands and

gravels and clay. Slight hydrocarbon odours and dark grey staining were noted at the base of the former gas holder from 3.3-3.7 m bgl. A groundwater strike was encountered at 2.2 m bgl during drilling works which correlated with groundwater levels within the Alluvium. Groundwater levels inside the structure are similar with groundwater in the Alluvium outside the cross-boundary gas holder, which suggests that the structure is not contained. Natural ground below the base of the gas holder was stained black and strong hydrocarbon odours were noted. Localised grey staining was noted to the upper boundary of the weathered Chalk at 8.25 m bgl. Chlorinated solvents were detected in groundwater within BH101.

The portion of the gas holder located off-site was remediated in 1999, and an injected grout curtain and below ground stability grouting was undertaken adjacent to the boundary. Approximately 730 m³ of contaminated material was anticipated to remain within the on site portion of the cross-boundary gas holder base, however the grouting would have isolated and contained this contaminated material. No further details are provided regarding the grouting walls as the validation reports for the completed remedial works have not been made available to WSP.

- **Tar Tank** – during the ground investigation in 2015, BH103 was targeted to investigate an unknown structure adjacent to the sulphate of ammonia works in the north of the site. A tar tank was identified in this location during the site investigation. Material backfilled into the tank was coated in tar, with strong coal tar odours. The base of the tank was discovered at 1.26 m bgl. The extent of the tank was surveyed using ground penetrating radar (GPR). The survey findings roughly correlate with the position of the liquor and sulphate plant (Structure 11) identified from historical mapping (confirmed tank labelled 'Tar Tank' on Drawing 70031882-004 in **Appendix A**).
- **Tar Mains** - Tar mains cross the site from the liquor tank (Structure 1) in the north of the site to the western site boundary. Although not identified during site investigation works, tar mains could be the source of the DNAPL detected at depth in BH202. The tar tank and tar mains have been grouped together in the CSM below.
- **NAPL / DNAPL** – Dense non-aqueous phase liquid (DNAPL) was identified within the Chalk at depth in BH202. Small globules of product were identified within Chalk fissures up to ~16.7m bgl. In addition, when BH202 was purged, an emulsion of NAPL and water were recovered. It is likely this NAPL is acting as a DNAPL. Source of the NAPL has not been determined, however it could be from both an off-site source (tar tank, CWG plant, relief holder) or an on-site source (liquor tank, tar mains, tar tank).
- **Contaminated Groundwater** – groundwater was encountered beneath the Site at depths ranging from 1.03 to 2.40 m bgl (35.37 – 36.17 m AOD), and has been impacted by gasworks derived contaminants. In addition to the DNAPL encountered in BH202, hydrocarbon odours were noted within BH102B and BH103A. The contaminated groundwater is associated with leachable contaminants within the Made Ground and natural ground, DNAPL within the groundwater, and potential off-site sources.
- **Chlorinated Solvents** – Tetrachloroethene (PCE), trichloroethene (TCE) and vinyl chloride have been identified in soil and groundwaters in the north west and west of the site, posing a risk to controlled waters. The vapour risk assessment determined there was no significant risk to human health. Highest soil concentrations of chlorinated solvents were identified in VW201A. Chlorinated solvents are used for a wide variety of commercial and industrial purposes, including degreasers, cleaning solutions, paint thinners and pesticides. These chlorinated solvents are not

typical gasworks contaminants, and following a review of the gasworks history both on and off the site, an associated specific provenance for the use of these solvents has not been identified. A car leasing depot was present on the site of the former gasworks to the west of the site between 1989 and 2006. It is unknown what activities were undertaken here, however, it is possible that chlorinated solvents were utilised in vehicle maintenance or repair. The historical landfill sites, scrapyards and photographic processors could also be a possible source, however, the distances of these land uses from site limits this possibility. As discussed in earlier sections, an on-site source cannot be discounted particularly given the concentrations present in on-site soil and leachate samples.

- **Off site sources** – Contamination from the adjacent former gasworks could be migrating onto Site (from historic sources such as tar tank, oil storage tank, CWG plant and relief holder).

7.3. SOURCES OF CONTAMINATION NOT CONSIDERED FURTHER

- **Gasworks Structures** – a number of former gasworks structures were identified on historical plans, which include an above-ground liquor tank adjacent to the northern site boundary and (Structure 1) and associated tar mains, lime store (Structure 4), acid tanks (Structure 5), purifiers (Structure 2), separating pits (Structure 6), sulphate of ammonia works (Structure 3), and a liquor and sulphate plant (Structure 11). The investigation identified no evidence of remnant structures with the exception of limited foundations. It is likely that these were above-ground structures which have been demolished and removed. Any remaining residual contamination associated with these structures, is considered as part of the Made Ground source. Therefore, gasworks structures as a contaminant source are not considered further. The in-situ below ground structures, such as the tar tank and the cross-boundary gas holder, are considered separately.
- **Electrical Substation** - Based on the results from the ground investigation, the electrical substation as a potential contaminant source is not considered further.
- **Off site sources** – with the exception of the off site gas works, all other off-site sources, including the landfills, scrap yard, photographic processors, and car leasing depot have all been discounted as significant off-site sources of contamination and are not considered further.

7.4. PLAUSIBLE CONTAMINANT LINKAGES

Table 28 provides a revised evaluation of the potential contaminant linkages that were considered to be plausible for the future use of the Site. It uses the current Site investigation findings to refine the initial assessment. The updated CSM is also presented graphically in Drawing 70031882-010 in **Appendix A**.

Table 30 – Summary of Plausible Contaminant Linkages

Source	Pathway	Receptor	Comment [current risk classification]
Made Ground	Ingestion, inhalation and dermal contact with contaminated soil and dust.	Human Health: Future Site users Neighbouring site users	Where hardstanding is present within the proposed development this would act as a barrier to the underlying soils. However, either source removal or an appropriate barrier system would be required in areas of soft landscaping and gardens. Severity = Medium Likelihood = Likely Risk Classification = <u>Moderate</u>
	Inhalation of hazardous ground gases and soil vapours.		Gas protection measures in buildings will be required as part of the proposed development. The vapour risk assessment was undertaken to further assess the risk to on and off-site receptors, and although concentrations of chlorinated solvents were detected, concentrations were below the assessment criteria. Therefore, significant risks to off-site and future on-site users can be discounted. Severity = Medium Likelihood = Low Likelihood Risk Classification = <u>Low to Moderate</u>
	Vertical and lateral migration of leachable contaminants to groundwater.	Groundwater: Secondary A Aquifers (Alluvium & River Terrace Gravels) Principal Aquifer (Seaford Chalk Formation and Newhaven Chalk)	Contaminants in the soil pose a potential risk to groundwater and off-site surface water features. Risks to these receptors need to be assessed further within a detailed quantitative risk assessment. Should piling be proposed on site this could generate preferential pathways to the aquifer. A piling works risk assessment is required to further assess these risks and propose a recommended foundation solution which will mitigate these risks. Severity = Medium Likelihood = High Likelihood Risk Classification = <u>High</u>
	Lateral migration of leachable contaminants in groundwater to surface waters.	Surface Waters (River Kennet, River Thames)	Contaminants in the soil pose a potential risk to groundwater and off-site surface water receptors. Risks to these receptors need to be assessed further within a detailed quantitative risk assessment. Severity = Medium Likelihood = High Likelihood Risk Classification = <u>High</u>
	Migration via drainage and discharge to surface water.		A surface water drain is located in the centre of the depot yard serving an area of hardstanding. The drain outfalls to a surface water drain in the north of the site which runs in westerly direction off-site where it connects with the foul sewer. Therefore, no significant risks to surface waters from preferential pathways through drains have been identified.

Source	Pathway	Receptor	Comment [current risk classification]
	Direct contact with contaminated soil causing chemical attack.	Property Receptors: Site buildings and structures	Appropriate pipe material and buried concrete design is required to mitigate this risk. Severity = Medium Likelihood = Likely Risk Classification = Moderate
	Inhalation of asbestos fibres.	Human Health: Future Site users Neighbouring site users	Where hardstanding is present within the proposed development this would act as a barrier to the underlying soils. However, either source removal or an appropriate barrier system would be required in areas of soft landscaping and gardens. Severity = Severe Likelihood = Likely Risk Classification = High
Cross boundary gas holder	Inhalation of hazardous groundwater and soil vapours.	Human Health: Future Site users Neighbouring site users	The vapour risk assessment was undertaken to further assess the risk to on and off-site receptors, and although concentrations of chlorinated solvents were detected, concentrations were below the assessment criteria. Therefore, significant risks to off-site and future on-site users can be discounted. Severity = Mild Likelihood = Low Likelihood Risk Classification = Low
	Vertical and lateral migration of contaminants in the groundwater on site to groundwater and surface water off site. Migration via drainage and discharge to surface water.	Groundwater: Secondary A Aquifers (Alluvium & River Terrace Gravels) Principal Aquifer (Seaford Chalk Formation and Newhaven Chalk) Surface Waters (River Kennet, River Thames)	Contaminants in the soil pose a potential risk to groundwater and off-site surface water features. Risks to these receptors need to be assessed further within a detailed quantitative risk assessment. Severity = Medium Likelihood = High Likelihood Risk Classification = High A surface water drain is located in the centre of the depot yard serving an area of hardstanding. The drain outfalls to a surface water drain in the north of the site which runs in westerly direction off-site where it connects with the foul sewer. Therefore, no significant risks to surface waters from preferential pathways through drains have been identified.
Tar tank	Vertical and lateral migration of tar and contaminants in groundwater to groundwater and surface waters off site. Migration of leachable contaminants in the	Groundwater: Secondary A Aquifers (Alluvium & River Terrace Gravels) Principal Aquifer (Seaford Chalk Formation and Newhaven Chalk) Surface Waters	Contaminants in the soil pose a potential risk to groundwater and off-site surface water features. Risks to these receptors need to be assessed further within a detailed quantitative risk assessment. Severity = Medium Likelihood = Likely Risk Classification = High The tar tank is covered by hardstanding so there is limited risk of the structure overtopping. Any residual risks from overtopping, leaking or failure of below ground structures are captured when addressing risks posed to controlled waters by vertical and lateral migration of tar and contaminants in groundwater.

Source	Pathway	Receptor	Comment [current risk classification]
	perched groundwater via overtopping, leaking or failure of the below ground structure.	(River Kennet, River Thames)	
	Ingestion, inhalation and dermal contact with contaminated soil and dust.	Human Health: Future Site users Neighbouring site users	Source removal of tar tank contents is likely to be required. Where hardstanding is present within the proposed development this would act as a barrier to the underlying soils. However, source removal or an appropriate barrier system would be required in areas of soft landscaping and gardens. Severity = Medium Likelihood = Likely Risk Classification = <u>Moderate</u>
	Direct contact with contaminated groundwater causing chemical attack.	Property Receptors: Site buildings and structures	Appropriate pipe material and buried concrete design is required to mitigate this risk. Source removal of tar may be required. Severity = Mild Likelihood = Likely Risk Classification = <u>Low to Moderate</u>
DNAPL	Vertical and lateral migration of DNAPL and contaminants in groundwater to groundwater and surface waters off site.	Groundwater: Secondary A Aquifers (Alluvium & River Terrace Gravels) Principal Aquifer (Seaford Chalk Formation and Newhaven Chalk) Surface Waters (River Kennet, River Thames)	NAPL in the Chalk poses a potential risk to groundwater and off-site surface water features. Risks to these receptors need to be assessed further within a detailed quantitative risk assessment. Severity = Medium Likelihood = Likely Risk Classification = <u>Moderate</u>
Contaminated groundwater	Vertical and lateral migration of contaminants in the groundwater on site to groundwater and surface water off site Migration via drainage	Groundwater: Secondary A Aquifers (Alluvium & River Terrace Gravels) Principal Aquifer (Seaford Chalk Formation and Newhaven Chalk)	Contaminants in groundwater pose a potential risk to groundwater and off-site surface water features. Risks to these receptors need to be assessed further within a detailed quantitative risk assessment. Severity = Medium Likelihood = Likely Risk Classification = <u>Moderate</u>

Source	Pathway	Receptor	Comment [current risk classification]
	and discharge to surface water.	Surface Waters (River Kennet, River Thames)	
	Ingestion and dermal contact with contaminated groundwater.	Human Health: Future Site users Neighbouring site users	Given the depth to groundwater and as it is not abstracted for potable supply within close proximity to the site the risk is considered to be low. Severity = Medium Likelihood = Low Likelihood Risk Classification = Low
	Direct contact with contaminated groundwater causing chemical attack.	Property Receptors: Site buildings and structures	Appropriate pipe material and buried concrete design is required to mitigate this risk. Severity = Moderate Likelihood = Likely Risk Classification = High [Moderate]
Chlorinated Solvents	Vertical and lateral migration of leachable contaminants to groundwater and surface waters	Surface Waters (River Kennet, River Thames) Groundwater: Secondary A Aquifers (Alluvium & River Terrace Gravels) Principal Aquifer (Seaford Chalk Formation and Newhaven Chalk)	Chlorinated Solvents contaminants in the Made Ground soil and in groundwaters in the west of the Site pose a potential risk to groundwater and off-site surface water features. Risks to these receptors need to be assessed further within a detailed quantitative risk assessment. Severity = Moderate Likelihood = Likely Risk Classification = High
	Vertical and lateral migration of contaminants in groundwater	Surface Waters (River Kennet, River Thames)	
Off-site Sources: Former gasworks adjacent to the	Lateral migration and inhalation of hazardous ground gases and soil/groundwater vapours.	Human Health: Future Site users Neighbouring site users	The WSP Off-Site Environmental Liability Assessment report concluded that although there may be residual liability to groundwater and to future human health receptors on the Site from off site contaminated groundwater, ground gases and vapours, it was considered that contaminant sources on the Site presented in greater risk to the identified receptors.

Source	Pathway	Receptor	Comment [current risk classification]
western site boundary.	Ingestion and inhalation of wind-blown dust.		Although there is a potential for DNAPL and the chlorinated solvents identified in the west of the site to have originated from an off-site source, both have been detected on site within soils and groundwater, and therefore they are being treated as an on site source. Severity = Medium Likelihood = Low Likelihood Risk Classification = <u>Low to Moderate</u>
	Lateral migration of free-product and leachable contaminants to groundwater.	Groundwater: Secondary A Aquifers (Alluvium & River Terrace Gravels) Principal Aquifer (Seaford Chalk Formation and Newhaven Chalk)	

8. GEOTECHNICAL ANALYSIS

8.1. INTRODUCTION

The following has been produced based on the in-situ and laboratory geotechnical testing undertaken on soil samples taken during the ground investigation by WSP in 2015 and 2019. Full records of the geotechnical laboratory testing are provided in **Appendix K**. Figures pertaining to the following text are collated at the end of this section.

This section constitutes a summary of preliminary geotechnical characteristics of the underlying ground conditions along with an outline of ground abnormalities and engineering constraints associated with the redevelopment.

It is expected that a further detailed geotechnical investigation is undertaken when the masterplan is fixed, and therefore information presented herein is preliminary. This section is not to be used as an interpretative report for the permanent or temporary design of the works.

8.2. WATER CONTENT AND ATTERBERG LIMITS

A total of 12 water content tests were undertaken on samples taken during the 2019 ground investigation (11 on Alluvium soil samples and one on a sample of Made Ground). **Table 31** summarises the results and **Figure 8-1** plots the water content with depth.

The plot shows a high variability in the water content results. The variations are controlled by the nature of the geology and in particular the organic material and fines content of the Alluvium. Typically, the samples with more peat and clay have higher water content. The water content test result in the Made Ground sample cannot be considered representative of the unit due to the lack of testing and the high heterogeneity of this unit.

Table 31 – Summary of Water Content Tests

Limit	Made Ground (Made Ground)	Alluvium (Alluvium)		
		Avg.	Max.	Min.
Water content (%)	26.6	60	96	41

A total of and eight Atterberg Limit tests (all on Alluvium samples) were undertaken. **Table 32** summarises the findings from these tests and **Figure 8-2** shows the Atterberg A-Line plot for Alluvium (Alluvium). This shows the Alluvium samples are classified as intermediate to high plasticity clay, or high to extremely high plasticity silt. The sample classified as extremely high plasticity silt was undertaken on a sample of peat, hence the high liquid limit.

Table 32 - Summary of Atterberg Limit Tests on Alluvium

Limit	Avg.	Max.	Min.
Liquid Limit (%)	71	119	41
Plastic Limit (%)	35	64	25

Limit	Avg.	Max.	Min.
Plasticity Index (%)	37	72	16

8.3. PARTICLE SIZE DISTRIBUTION

Particle Size Distribution (PSD) tests were undertaken on two samples of Alluvium and three samples of River Terrace Gravels. The results of these tests are plotted on **Figure 8-3** which shows the cohesive nature of the Alluvium with >50% fines. The PSD for River Terrace Gravels shows this stratum is primarily gravel and sand, with a fines content <5%. The River Terrace Gravels would likely be classified as a Class 1A/1B material as determined in the Specification for Highway Works (SHW) based on grading only.

8.4. STANDARD PENETRATION TEST (SPT) DISTRIBUTION

During the ground investigation, Standard Penetration Tests (SPTs) were undertaken one time within the Made Ground; nine times within the Alluvium; 10 times within the River Terrace Gravels; and eight times within the Chalk (six from the Structureless D_c Chalk and two in the Grade B Chalk).

A summary of the SPT N values and corrected values for test procedure and overburden stress (N_{60} and $(N_1)_{60}$ respectively) for the various strata are summarised in **Table 33**.

Table 33 - Summary of SPT N, N_{60} and $(N_1)_{60}$

Stratum	N_{SPT}	N_{60} Corrected for procedure	$(N_1)_{60}$ Corrected for overburden stress
Made Ground	4	3	6
Alluvium	1 – 19 [5]	1 – 20 [5]	Not required
River Terrace Gravels	1 – 50R* [18]	1 – 50 [20]	1 -50 [18]
Chalk	27 – 50R* [41]	28 – 50 [45]	Not required

*R = refusal (50 blows for <450 mm penetration)

[] indicates average value

Figure 8-4 plots the SPT N_{60} values against depth for all SPTs. This plot shows there is no trend with the depth within the Alluvium whereas in the River Terrace Gravels and Chalk, N_{60} values typically increase with depth and reach refusal. N_{60} values in River Terrace Gravels range from 1 to refusal (>50), increasing quickly with the depth. The Chalk N_{60} values also increase with depth, with the lower N_{60} values relating to the Structureless Chalk D_c.

8.5. UNDRAINED SHEAR STRENGTH

For the Alluvium, the SPT N_{60} values have been used to determine the undrained shear strength (c_u) of the soils based on the relationship $c_u/N_{60}=4.5$. In addition, one undrained unconsolidated triaxial test was undertaken on a sample of Alluvium.

Figure 8-5 provides a plot of undrained shear strength with elevation for the Alluvium, as determined from SPTs and the triaxial test. The plot shows consistency with the results, with an average value of 8.3 kPa and no trend indicating any changes in strength with depth. This shows the Alluvium is very low strength, with a characteristic undrained shear strength determined as approximately 4 kPa.

8.6. INTERNAL ANGLE OF FRICTION

For the granular soils (Made Ground and River Terrace Gravels), $(N_1)_{60}$ values have been used to estimate the internal angle of internal friction as per Wolff (1989) ⁽¹⁾. For the Alluvium, the method given in BS 8002: Code of practice for earth retaining structures, 2015 ⁽²⁾ has been used to estimate the internal angle of friction based on plasticity index. Results of these analysis are summarised in **Table 34**.

Table 34 - Summary of Internal Angle of Friction

Stratum	Internal angle of friction from SPT correlation (°)	Internal angle of PI correlation (°)
Made Ground	29	N/A
Alluvium	N/A	22
River Terrace Gravels	27 – 41 [32]	N/A

[] indicates average value

⁽¹⁾ Wolff, T. F, 1989. *Geotechnical Judgment In Foundation Design. Foundation Engineering: Current Principles and Practice*, Vol. 2, American Society Of Civil Engineers. Pp 903 – 917.

⁽²⁾ British Standards Institution. (2015). *British standard: Code of practice for earth retaining structures. BS 8002:2015*. London.

8.7. CONSOLIDATION

One-dimensional oedometer tests were undertaken on two samples of Alluvium. The coefficient of compressibility (m_v) was recorded as 0.61 – 0.77 m^2/MN , coefficient of consolidation (C_v) was recorded as 0.85 – 1.80 $m^2/year$ and stiffness (E') was recorded as 1.30-1.64 MPa from these tests at in-situ stresses. The results are typical for the type of soil tested.

Figure 8-6 plots the coefficient of compressibility (m_v) for Alluvium, both direct measurements (results from oedometer tests) and correlations with SPT and PI (after Stroud, 1975 ⁽³⁾) are included. Although the actual value of m_v to be selected in design will vary depending on the exact stress increase, it is anticipated a value of 0.3 – 0.5 m^2/MN would be appropriate for settlement analysis.

8.8. CHALK

8.8.1. INTACT DRY DENSITY AND SATURATION MOISTURE CONTENT

A total of three Saturation Moisture Content (SMC) tests were undertaken on samples of Grade B Chalk, with Intact Dry Density (IDD) tests also undertaken on the same samples. A further five IDD tests were undertaken without SMC tests. A summary of the results is provided in **Table 35**. The three samples with SMC and IDD indicate the Grade B Chalk is of medium density (as shown on **Figure 8-7**), when compared to the limits as outlined in CIRIA C574 Engineering in Chalk ⁽⁴⁾.

Table 35 – Summary of SMC and IDD testing

Parameter	Number of tests	Range of results [Average]
Saturation Moisture Content (%)	3	23 – 25 [24]
Porosity (%)	3	39 – 40 [39]
Intact Dry Density (Mg/m ³)	8	1.41 – 1.80 [1.56]

8.8.2. POINT LOAD TESTS

A total of five Uniaxial Compressive Strength (UCS) tests were scheduled on samples of Chalk taken from the 2019 ground investigation, however none of these samples had sufficient length to breadth ratios to complete the test. Eight Point Load Tests (PLT) were undertaken, one on a sample of Structureless Grade D_c Chalk and seven on samples of Grade B Chalk. Modified Is₅₀ values have been estimated from the correlation between Is₅₀ and UCS, as presented by Norbury, 1986 ⁽⁵⁾. In lieu of UCS results, a correlation factor of 15 has been assumed (based on a recommended factor of 10-22). A summary of the results is provided in **Table 36**. The results show the Chalk is anisotropic, with a higher UCS when loaded axially.

Table 36 – Summary of PLT results and correlation to UCS

Test orientation	Number of tests	Is(50) (MPa) [Average]	UCS equivalent (MPa) [Average]
Axial	4	0.12 – 0.26 [0.18]	1.80 – 3.90 [2.66]
Diametral	3	0.10 – 0.13 [0.12]	1.50 – 1.95 [1.75]
Irregular lump (Structureless Chalk sample)	1	0.04	0.6

⁽³⁾ Stroud M.A. and Butler F.G., The standard penetration test and the engineering properties of glacial materials, Pages 124-135, 1975.

⁽⁴⁾ CIRIA C574, Engineering in Chalk, London, 2002.

⁽⁵⁾ D R Norbury, The Point Load Test, Geological Society, London, Engineering Geology Special Publications, 2, 325-329, 1986.

8.9. SULPHATE ANALYSIS

A total of four BRE full suite test tests were undertaken. One on a sample of Made Ground and three on samples of Alluvium. Additionally, water soluble sulphate tests were undertaken on four samples of Alluvium. A summary of the sulphate and pH test results for the various strata are summarised in **Table 37**.

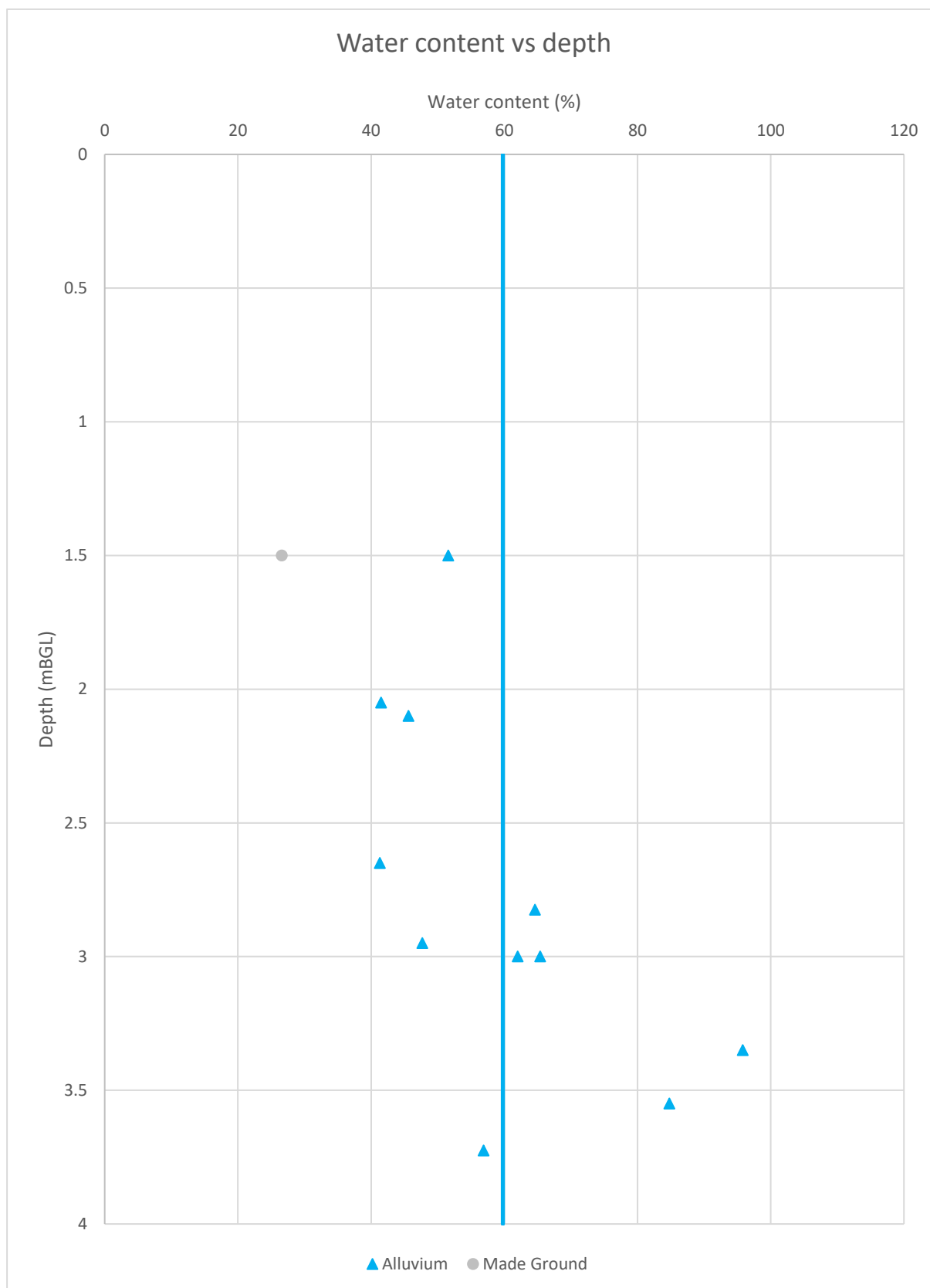
Table 37 - Summary of sulphate and pH test results

Stratum	Number of samples	Water soluble sulphate (mg/l SO ₄)	pH	TPS ⁽¹⁾ (%) SO ₄	DS Class	ACEC Class
Made Ground	1	340	7.9	0.45	DS - 1	AC-1s
Alluvium	7	46 – 1600 538 ⁽²⁾	7.2 – 8.7 7.2 ⁽²⁾	0.0.63 – 2.28 1.07 ⁽²⁾	DS - 4	AC-3s

⁽¹⁾ Total potential sulphate

⁽²⁾ Characteristic value, worst value when up to four samples. Value equal to the mean of the worst two values when there are five to nine results.

The test results indicate a Design Sulphate (DS) class of DS-4 in accordance with BRE Special Digest 1:2005 and an Aggressive Chemical Environment to Concrete (ACEC) class of AC-3s. While analysis indicates that pyrite may be present (four of the samples tested with oxidisable sulphate >0.3%), the soils present on site are not pyrite containing materials. Therefore, the high oxidisable sulphate results are likely to be due to elevated sulphate content from the Made Ground and human activities on the site. The implications of this on the design of buried concrete are discussed further in Section 8.10.



Line represents average value

Figure 8-1 - Water content with depth for all soils tested

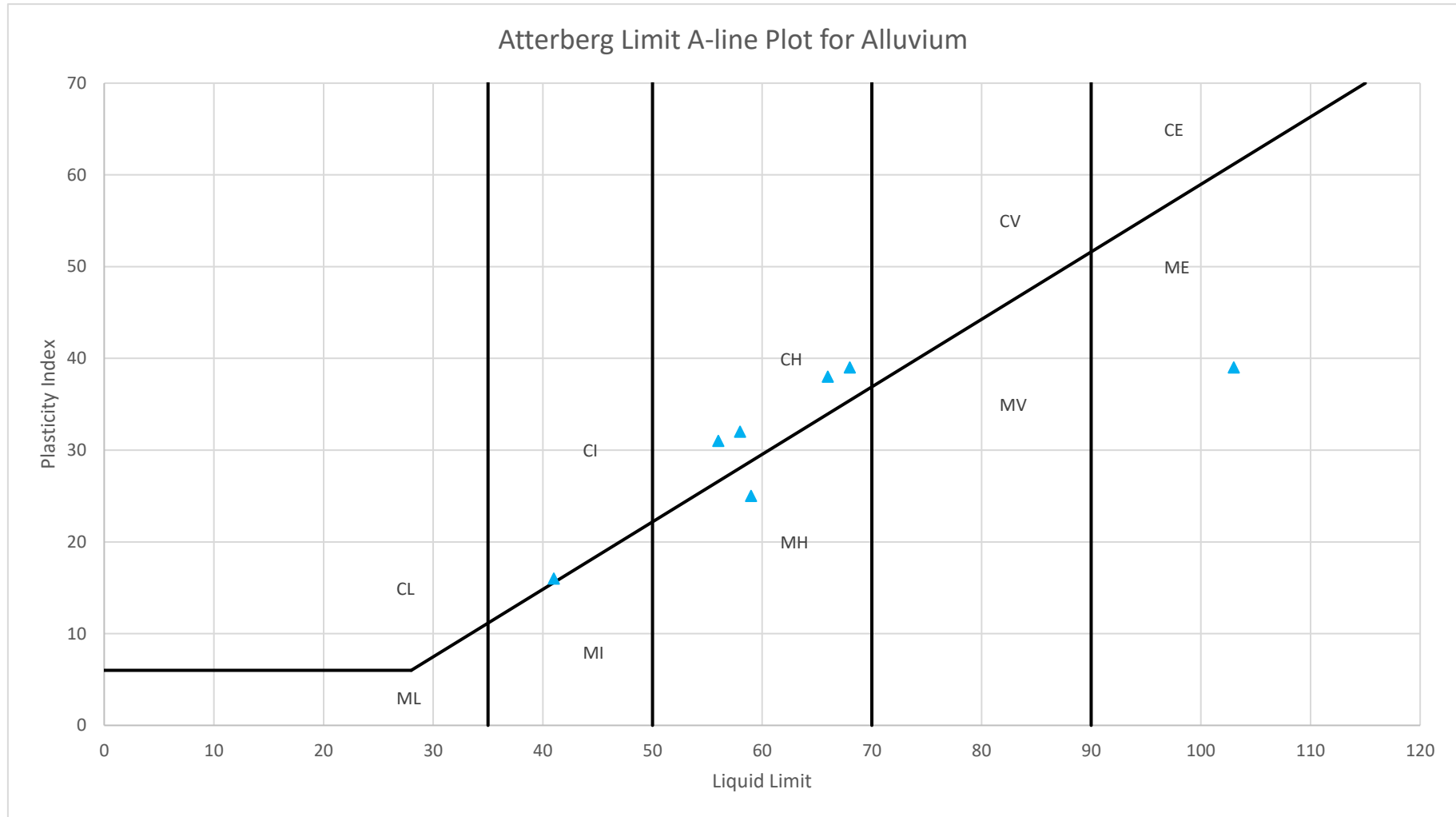


Figure 8-2 - Atterberg Limit A-Line plot for all soils tested

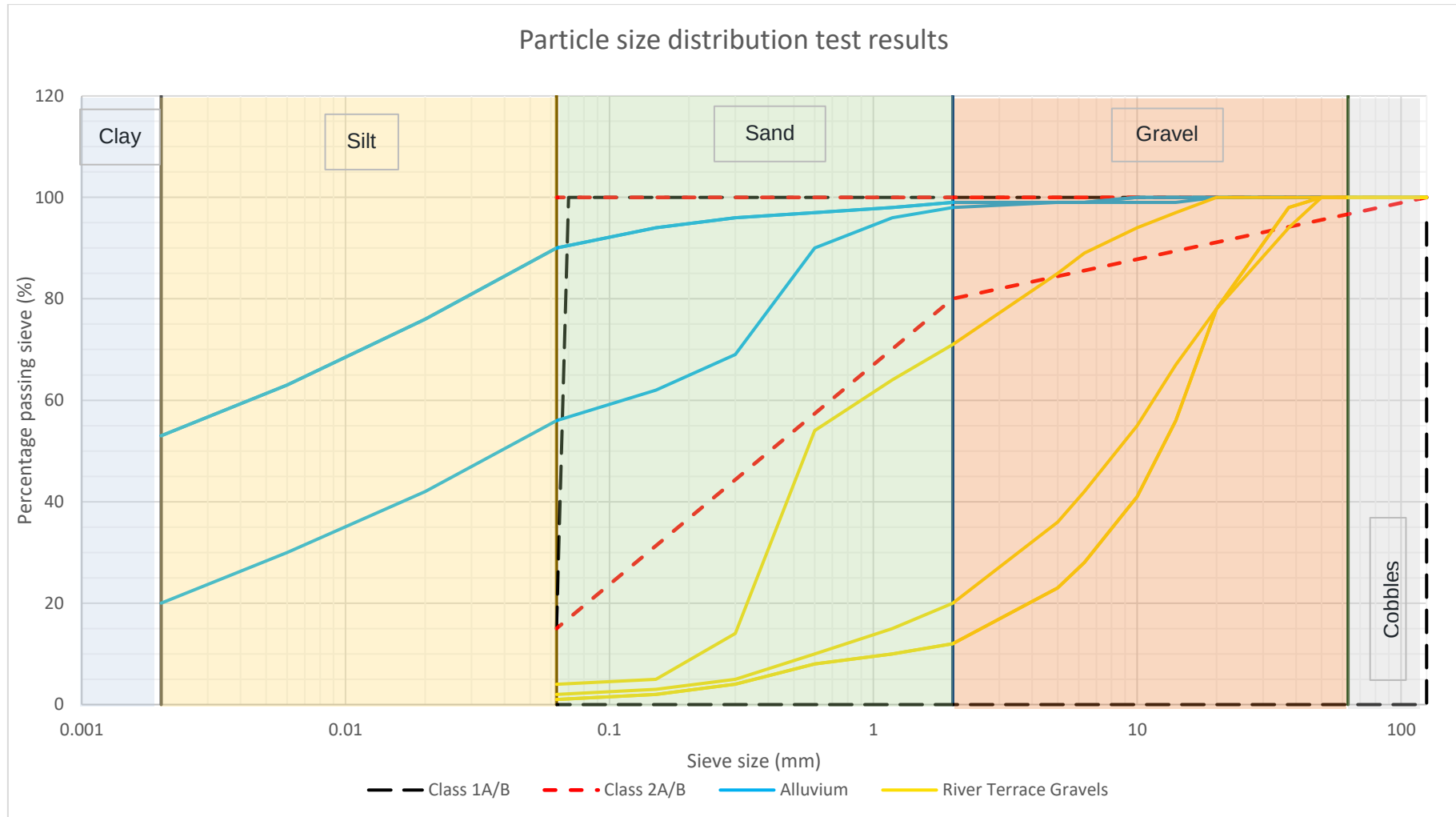


Figure 8-3 - Particle Size Distribution test results for all soils tested

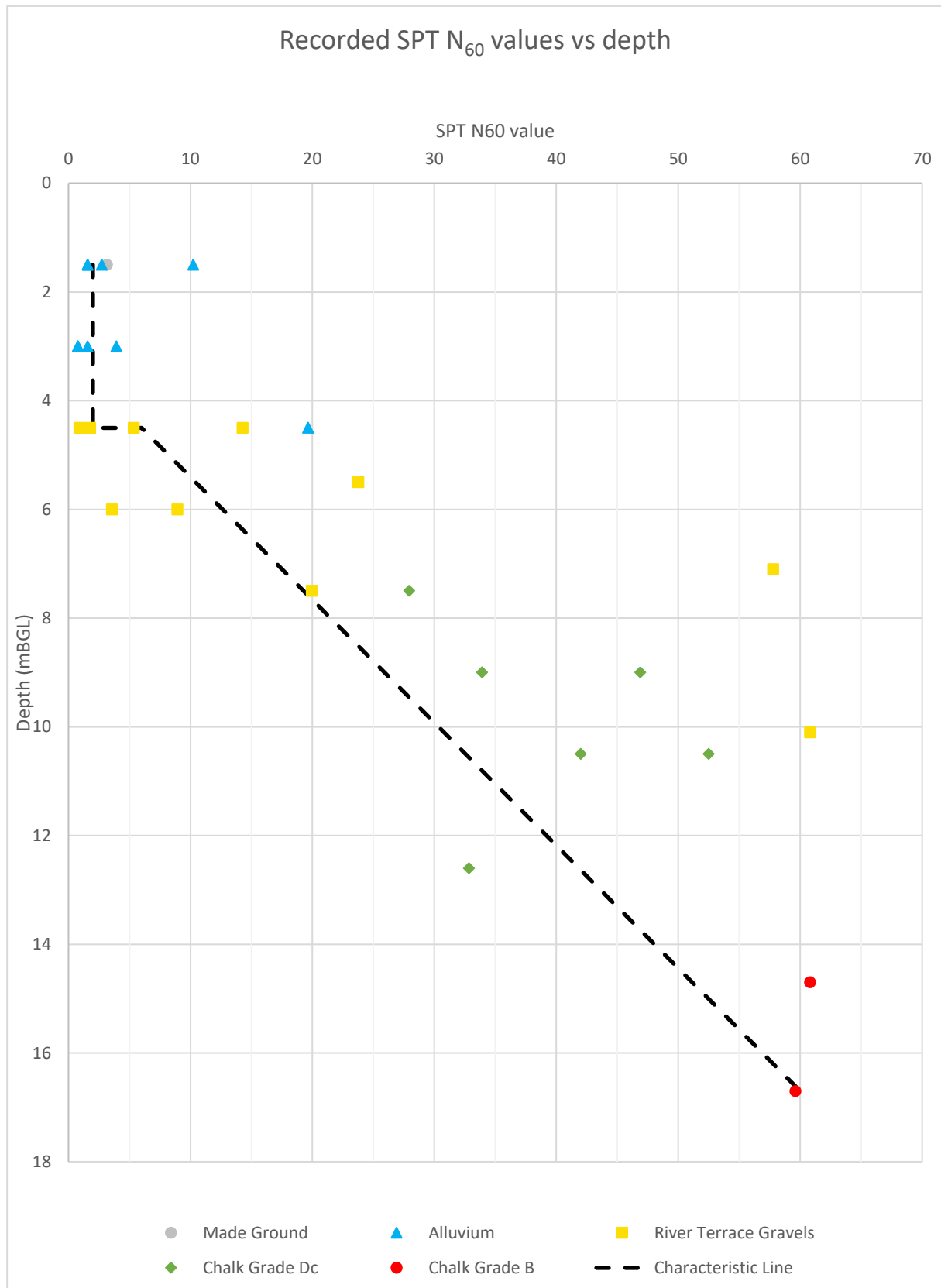


Figure 8-4 - SPT N_{60} profile for all soil types

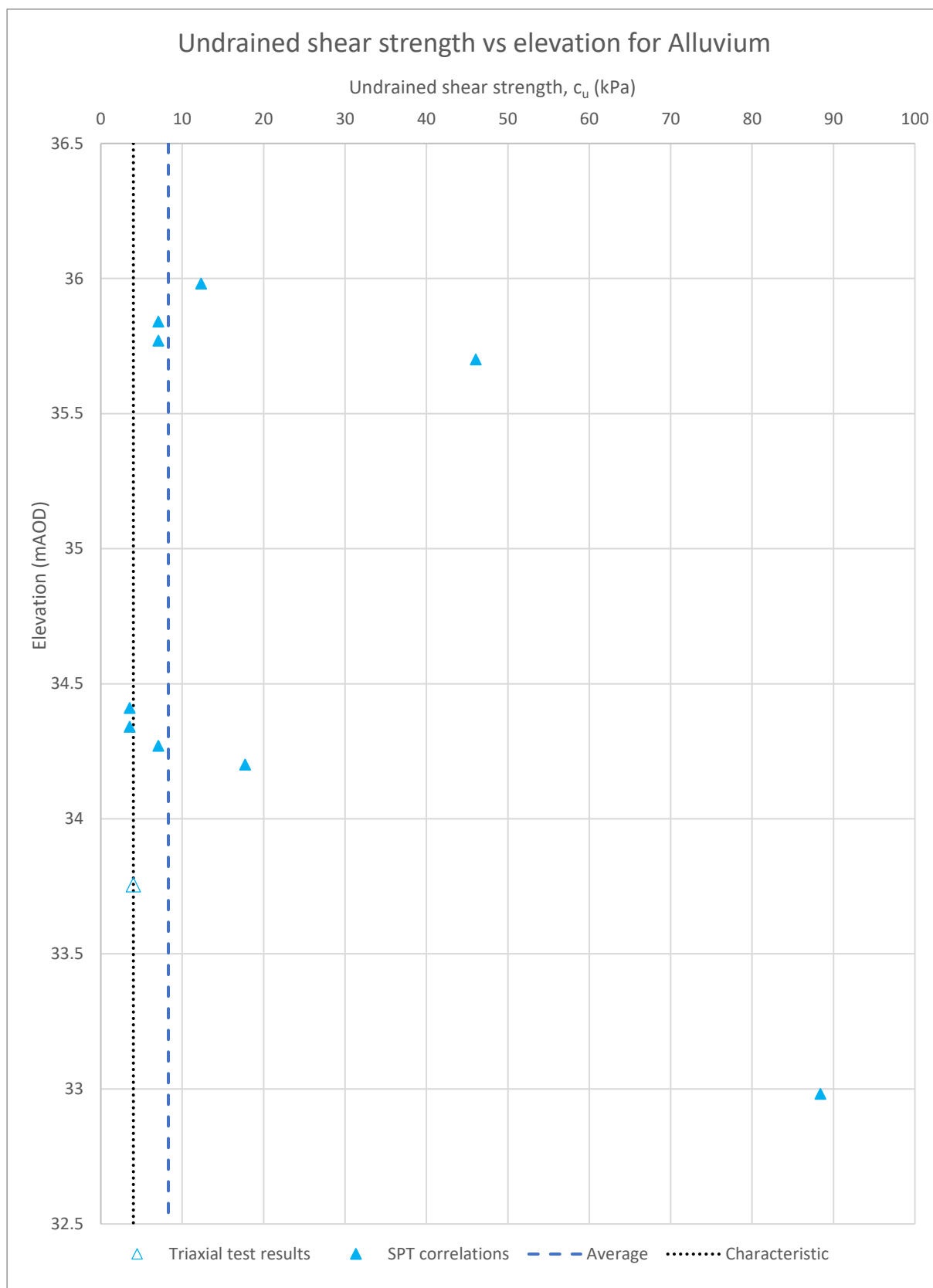


Figure 8-5 - Undrained shear strength vs elevation for Alluvium

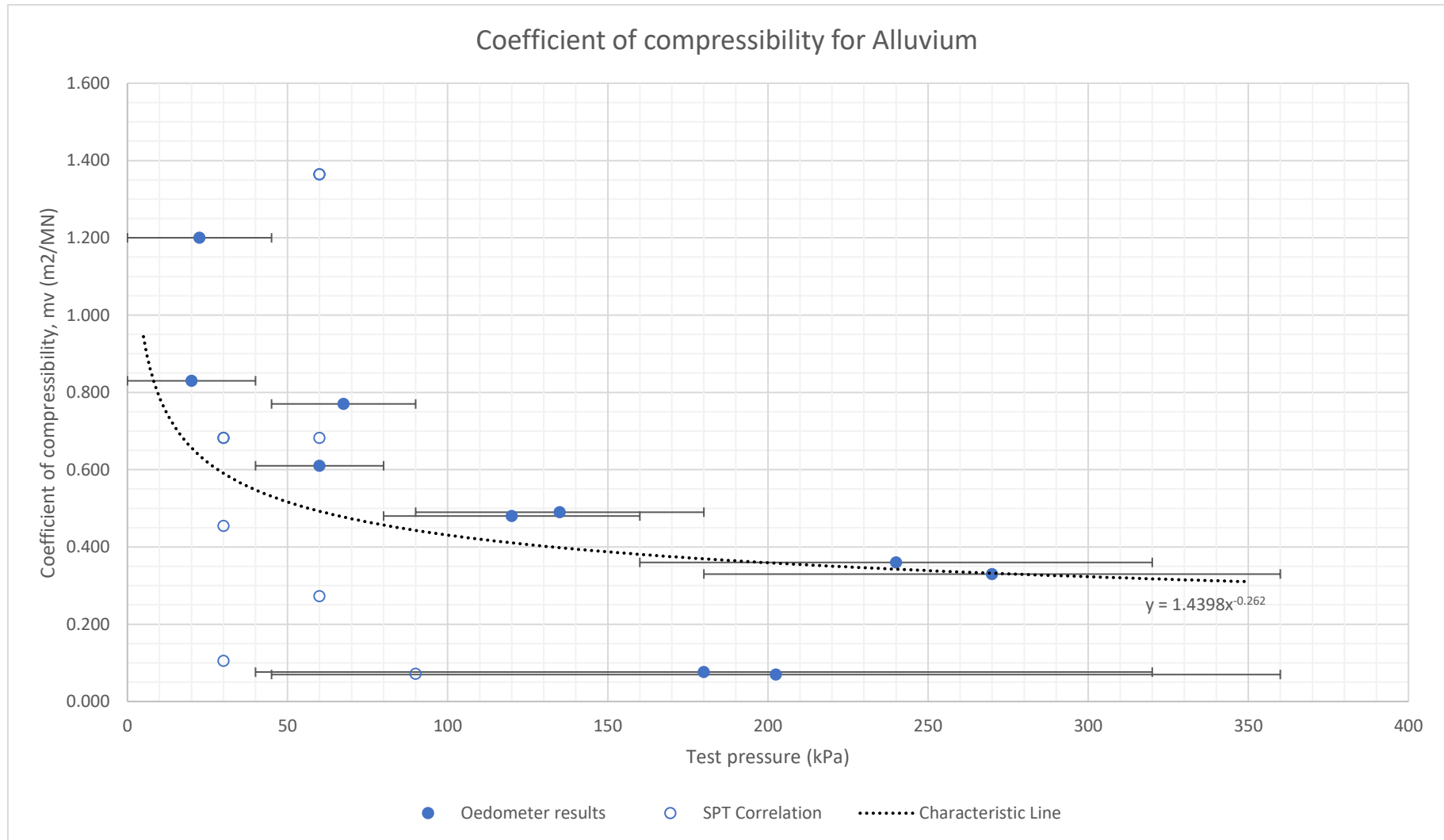


Figure 8-6 - Coefficient of compressibility for Alluvium

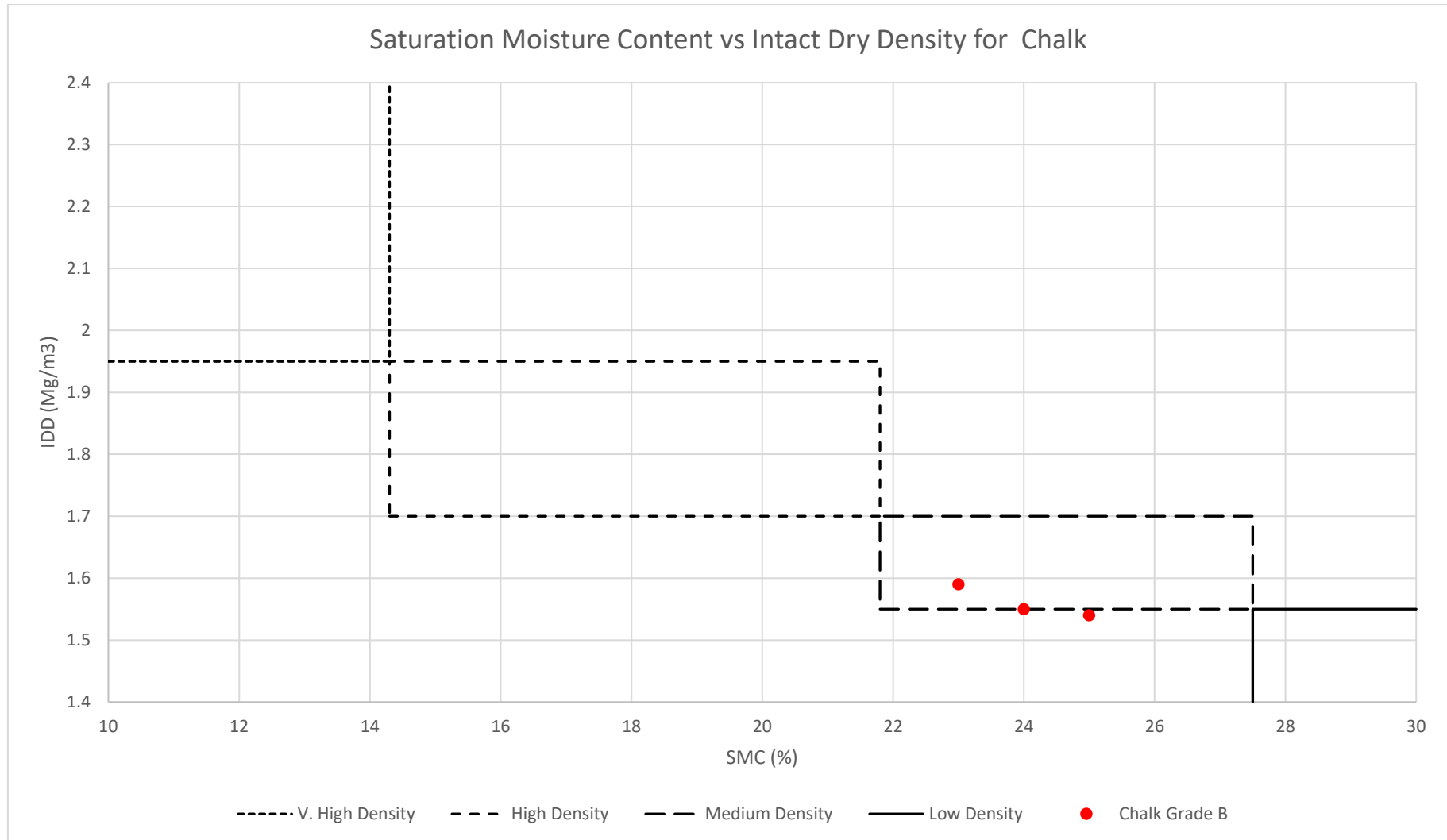


Figure 8-7 - SMC and IDD for Chalk (limits for densities taken from CIRIA C574)

8.10. ENGINEERING ASSESSMENT

8.10.1. GENERAL

At the time of writing structural loadings had not been provided. This section does not constitute a Geotechnical Design Report as detailed in Eurocode 7 (BS EN 1997-1 *Geotechnical Design*).

8.10.2. FOUNDATIONS

Made Ground and Alluvium are considered unsuitable founding materials due their low bearing capacity. Due to the size of the likely proposed buildings, piled foundations will be the most suitable solution extending into the underlying Chalk to achieve the required bearing capacity.

The presence of superficial soft cohesive layers (Alluvium) should be taken into account during design as it may induce negative skin friction.

It is envisaged Continuous Flight Auger (CFA) piles will be most suitable for the site. CFA piles reduce the impact of contaminants being driven into the ground, one of the key contamination pathway scenarios (as identified in *Piling and penetrative ground improvement methods on land affected by contamination: Guidance on pollution prevention. NGWCLC Report NC/99/73*). Additionally, CFA piles negate the need for casing or drilling mud as the bore is never left open or unsupported.

8.10.3. GROUND SLABS AND PAVEMENTS

The variability and low strength of the Made Ground and Alluvium could pose a risk to the integrity of pavements and ground slabs.

For pavements and areas of hard standing, geogrids will likely be required to reduce the effect of settlement and rutting of the pavements. Soft spots will require digging out and replacing with well compacted granular fill.

Ground slabs will likely have to be suspended to avoid issues of shrink/swell or consolidation of the Alluvium affecting the development.

8.10.4. BURIED CONCRETE

Sulphate testing indicates high levels of water soluble sulphate and TPS within the Alluvium. As a result, the DS class obtained is DS-4 and the ACEC class is AC-3s, in accordance with BRE Special Digest 1:2005.

Tests undertaken show concentrations of oxidisable sulphides (OS%) greater than 0.3% in samples of Alluvium which may indicate that pyrite is present. Therefore, construction techniques should be chosen to minimise the exposure of the ground and thus reduce the possible oxidation of pyrite, particularly where concrete is in contact with the natural ground.

8.10.5. EXCAVATIONS

Groundwater strikes recorded during the ground investigation range from 0.85 – 2.4 m bgl and occurred mainly in the Made Ground and River Terrace Gravels strata. Groundwater recorded in the Made Ground in some areas may be perched pockets of water associated with permeable lenses that will be recharged by surface water infiltration. However, further groundwater level data will be required to fully establish the hydrogeology on the Site. It is anticipated that in some areas de-watering measures may be required for excavations.

8.10.6. MATERIAL RE-USE

Particle size distribution (PSD) results show any excavated River Terrace Gravels is likely to be suitable as a Class 1A/1B material for re-use in accordance with the SHW. This is based on grading only and is subject to further testing and compliance with any earthworks specification (when produced) for the proposed development.

8.11. GEOTECHNICAL RISK REGISTER

The pertinent geotechnical risks associated with the proposed development have been identified and relevant health and safety issues have also been considered. The geotechnical risk register identifies the geotechnical hazards/ risks associated with the construction phase. A simple rating of probability and impact (1-5) has been adopted: a rating of 1 represents a negligible chance of the risk being realised or very low impact, whereas 5 would indicate a very high chance or a high impact. The geotechnical risk register is presented as **Table 37** and an explanation of how risk ratings are derived is shown below.

Risk Rating = Probability (P) x Impact (I)						
Probability (P)		Impact (I)				
		Rating		Reputation	H & S	Environment
Very likely	5	Very high	5	Threat to business survival and credibility	Fatality	Significant incident with irreversible effects and threat to public health or natural resource
Likely	4	High	4	Threat to future work and clients	Life threatening	Major incident leading to prosecution
Probable	3	Medium	3	Serious	Serious injury	Incident requiring management input
Unlikely	2	Low	2	Significant	Minor injury	Minor incident
Negligible	1	Very low	1	Very low	Negligible	Negligible

Risk Rating	1 to 4	Low Risk	Trivial, but no action required.
	5 to 10	Medium Risk	Tolerable, but must consider more costs effective solutions or improvements at no additional cost.
	12 to 16	High Risk	Substantial and work must not start until risk has been reduced.
	20 +	Critical Risk	Intolerable and work must not start on the project until risk has been reduced. If risk cannot be reduced, project should not proceed.

Table 38 - Geotechnical Risk Register

Ref.	Hazard	Pre-control Measures			Consequence	Control Measures	Post-control measures		
		P	I	Risk			P	I	Risk
1	Encountered geology different to ground investigation findings.	2	4	8	If a greater thickness of Made Ground / low strength soil is encountered, deeper excavations, and more imported materials could create an increase in the cost. If it is not detected, defects in areas of hardstanding could be generated after a short period of time.	Use of conservative parameters for the pavement design. Site supervision by a suitably qualified geotechnical engineer to identify areas of soft ground.	1	4	4
2	Different chemical conditions of the underlying geology.	3	2	6	Aggressive chemical environment to buried concrete could lead to deterioration of foundations.	Design concrete class to be determined based on BRE SD1 guidance. DS-4, AC-3s assumed as a conservative assessment. Appropriate concrete class to be chosen once proposals are confirmed. Use piling techniques which minimise exposure of the soil (e.g. continuous flight auger (CFA) piling).	2	2	4
3	High groundwater encountered.	2	3	6	Instability of excavations due to spalling of sides and flooding.	Contractor to design appropriate temporary works for excavations if required. De-watering measures such as sump pumps required in excavations.	2	1	2
4	Finding unexploded ordnance (UXO) during construction.	2	4	8	Risk to construction worker, users and potentially members of the public.	Detailed UXO desk study and consulting map.	1	4	4
5	Encountering buried services.	2	4	8	Striking existing buried services during piling / excavation works.	Latest services drawings to be obtained by the Contractor prior to breaking ground and	1	4	4

Ref.	Hazard	Pre-control Measures			Consequence	Control Measures	Post-control measures		
		P	I	Risk			P	I	Risk
						indicate where diversions may be required. Permit to dig process recommended.			
6	Extent of contaminated ground.	4	3	12	Health and safety of workforce. Financial and programme implications.	Watching brief by a suitably qualified geo-environmental engineer to identify signs of contamination, with an action plan in place if contamination encountered. Workers to wear appropriate personal protective equipment (PPE). Follow recommendations within this report with regards to contamination encountered (see Section 10).	3	3	9
7	Variability of the Made Ground	2	4	8	Excessive settlement under the ground slabs due to differing ground conditions or inappropriate foundation solution. Leading to costly repairs, disruption and programme delays. Issues with pavements post-construction.	Select appropriate design parameters during design. Design to be in accordance with Eurocodes. Suspended ground slabs to reduce the likelihood of settlement occurring.	1	4	4
8	Presence of obstructions in the Made Ground.	3	2	6	Excavation work delays. Obstruction in the pile construction.	Ensure thorough investigation of site and suitable quantity of geotechnical analysis to identify potential ground obstruction areas.	2	2	4
9	Greater than expected thickness of Structureless Chalk or Structured Chalk of	4	2	8	Inappropriate design for deep piled foundations, leading to insufficient pile capacity.	Carry out further geotechnical ground investigation with depths of boreholes in accordance with the requirements of Eurocode 7.	2	2	4

Ref.	Hazard	Pre-control Measures			Consequence	Control Measures	Post-control measures		
		P	I	Risk			P	I	Risk
	lower strength.					Carry out further UCS, PLT, Intact Dry Density (IDD) and Saturation Moisture Content (SMC) testing, to derive an accurate strength profile for use in design.			
10	Pollution of principal aquifer either by driving of contaminated material from above or through injection of concrete.	4	3	12	Contaminated groundwater at the location of a principal aquifer. Increased cost and programme overrun.	Use a piling technique which minimises the potential to drive material down (CFA piling). Carryout further and deeper ground investigation to determine the possibility or otherwise for concrete to "leak" from a CFA pile during construction. A competent piling contractor should monitor the amount of concrete being placed and ensure a minimal loss.	2	3	6
11	Natural geological hazards such as dissolution features.	2	4	8	Piles do not provide sufficient resistance. Failure of foundation system, leading to damage to property. And reputation, and cost of repairs and/or redesign.	Contractor to maintain pile installation records. Designer to be informed if ground conditions are different to design assumptions. Static pile testing to be undertaken on 1% of piles.	2	3	6
12	High to very high-density Chalk encountered during piling.	2	3	6	Proposed piling technique may not penetrate the high to very high-density Chalk. Delays to project and cost of pre-drilling and/or redesign.	Carryout further and deeper ground investigation to further confirm the Chalk grade. Assess the density of the Chalk at detailed design stage to ensure constructability of ultimate design.	2	2	4

9. CONCLUSIONS

A preliminary phase of investigation was undertaken at the Site, between November and December 2015, to allow an assessment of contaminated land and associated liabilities and constraints. A supplementary phase of site investigation was undertaken in March-June 2019 to further assess the contamination and ground constraints associated with residential development at the site. The information from both phases of investigation was assessed to support the detailed planning application for proposed residential redevelopment of the Site through the characterisation of ground, ground gas and groundwater conditions.

Investigations have confirmed that ground conditions comprise a sequence of Made Ground underlain by Alluvium, River Terrace Deposits and Chalk. Various concrete obstructions associated with former structures were encountered during the investigations.

Soil, groundwater, surface water concentrations from samples collected during the Site investigation have been compared with generic assessment criteria for the protection of human health, controlled waters and underground water pipes. Vapour and ground gas risk assessments have been undertaken with reference to soils and groundwater concentrations of VOCs/SVOCs and gas monitoring data collected during the Site investigation.

The human health generic quantitative risk assessment identified a number of contaminants, associated with the historical gasworks usage, with concentrations above the residential (without home grown produce) GAC and asbestos fibres in shallow Made Ground soils.

In addition to the risks posed by contaminant concentrations in soils, risks to human health receptors were also initially identified from a groundwater vapour source in 2015. Chlorinated solvent concentrations were identified above the GAC at the western Site boundary from groundwater samples taken from within the footprint of the cross-boundary holder during the initial investigation in 2015; however, this measure of risk is very conservative approach. Three soil vapour wells were installed on-site in 2019 to better establish risk from vapours to off-site receptors and future on-site residents. Elevated levels of chlorinated solvents were identified, however no concentrations exceeded the soil vapour GAC for human health, and therefore significant risks posed by vapour inhalation can be now be discounted.

Following the updated ground gas risk assessment, the Site has been categorized within Characteristic Situation 2 (low risk), where all new development requires gas protection to be incorporated into the design.

The controlled waters generic quantitative risk assessment identified exceedances of numerous WQs in water and leachate samples from leachable contaminants in the Made Ground/Alluvium, the tar tank, DNAPL within the Chalk and contaminated groundwater which could poses a risk to the identified receptors; groundwater (Secondary A and Principal Aquifer) and surface waters (River Thames). Risks to these receptors require further assessment in the form a Level 3 – Detailed Quantitative Risk Assessment (DQRA).

9.1. OVERALL RISK EVALUATION

Based on the GQRA the risk to the identified receptors (future residents, groundwater, surface water, neighbouring residents, buried concrete, underground services) is generally considered to be **moderate to high**.

9.2. UNCERTAINTIES & LIMITATIONS

The scope of the investigations has provided a suitable level of characterisation to develop an understanding of the constraints that must be addressed to redevelop the site for residential purposes.

Contaminants such as asbestos can be present in soil in discrete pockets and any sampling frequency cannot guarantee the absence of contaminants of this nature in areas between sample locations. The developer should ensure that suitable precautions, controls and monitoring are in place during earthworks activities and suspicious materials should be managed through appropriate procedures in accordance with the Control of Asbestos Regulations 2012, to ensure the health and safety of all workers and future Site users, and to protect the environment from contamination.

Groundwater flow within the River Terrace Gravels has been calculated from two separate rounds of groundwater level data from 2019. The direction of flow varies marginally between the two monitoring rounds from north to northwest. Only one round of groundwater sampling and analysis has been undertaken from the newly installed locations (2019).

Underlying ground conditions beneath the gas holder are currently unknown. No former gas works structures are known to be present beneath the footprint of the gas holder, with exception of the tar mains. Additional site investigation works will be required below the gas holder post demolition. There is potential that the DNAPL encountered at BH202 extend below the holder, and the source could have originated from the tar mains.

The DNAPL encountered in BH202 could not be quantified due to the product forming an emulsion with the water and was unable to be detected with the oil/water interface meter. In addition, it has not been possible to sample and analyse this product.

9.3. GEOTECHNICAL RISK

The underlying ground conditions include Made Ground to a depth of up to 4.3m bgl which could result in significant total and differential settlement due to variations in vertical and lateral composition. For this reason, shallow foundations are not considered appropriate for the site.

Groundwater is present in Made Ground and in the River Terrace Gravels deposits. Perched water pockets may be present within the Made Ground associated with permeable lenses that will be recharged by surface water infiltration.

Building foundations are anticipated to be piles founded in the Chalk, and once locations are fixed and loads are known preliminary pile calculations can be undertaken.

According with the BRE Special Digest 1:2005 a worst case buried concrete classification of Design Sulphate DS-4 and an ACEC class of AC-3s has been identified. However, this classification is based

on three samples, it is therefore recommended that further testing is undertaken across the various strata to identify if this was an isolated case.

10. RECOMMENDATIONS

10.1. FURTHER WORKS

The following further works and assessments are recommended to assess the level of remediation required at the site based on the proposed development, results of the 2015 & 2019 ground investigations and the generic quantitative risk assessments and CSM.

- A detailed quantitative risk assessment (DQRA) for controlled waters – to determine the areas requiring remediation and for generation of remedial targets where applicable (reported under separate cover)
- Additional site investigation & monitoring works are required to:
 - Delineate, sample and volumize the DNAPL identified within the Chalk aquifer at depth (2-3no. 15m wells in southwest of the Site)
 - Characterise ground conditions below the gas holder (post demolition)
 - Obtain additional gas and groundwater monitoring data to support the remediation strategy, review seasonality trends, and provide a robust data set, including an additional round of ground gas monitoring in low pressure atmospheric conditions.

A piling works risk assessment – will be required if piling is the preferred foundation solution for the development. This should be completed in accordance with Environment Agency guidance⁷. It is understood through discussions with the Environment Agency that groundwater monitoring will be required during piling.

10.2. REMEDIATION DOCUMENTS

- A Remediation Strategy will be required to be submitted to the local authorities to support sign-off of relevant planning conditions. The Strategy must include all remediation works to be undertaken, the proposed remediation objectives and remediation criteria, an appraisal of remedial options, a proposal of the preferred option(s), timetable of works, site management procedures and a verification plan.
- Remedial Design – once the remediation strategy approach has been confirmed and approved by the regulators a Remedial Design will be required which details the design of the remediation and verification works to be completed.
- Verification Report – the remediation works should be independently verified to confirm that the remedial targets have been met and a verification report, which summarises the works that have been completed, will be required to support sign-off of the relevant planning condition.

⁷ Environment Agency (2001). Piling and Penetrative Ground Improvement Methods on Land Affected by Contamination: Guidance on Pollution Prevention. May 2001. NC/99/73

10.3. OUTLINE REMEDIATION

Based on the available information mitigation measures for the proposed development may include the following, however the DQRA and remediation options appraisal will greater define remediation requirements:

- Source removal (e.g. removal of tar tanks and chlorinated solvent impacted Made Ground) or capping. Service trenches and underground obstructions may also act as preferential pathways for contaminant migration and these may need to be investigated and/or removed as part of the remediation works.
- Capping in areas of soft landscaping and gardens (between 600mm to 1m depth).
- Installation of appropriate measures to protect underground service pipes and appropriate buried concrete design; taking into account the hydrocarbon contamination present.
- Ex-situ/in-situ soil and groundwater treatment.
- Gas protection measures including subfloor ventilation and gas membranes.

10.4. ASBESTOS

On-site buildings (including the gas holder) will require demolition to facilitate remediation and redevelopment. An asbestos refurbishment and demolition survey will be required prior to building demolition.

10.5. WATER SUPPLY PIPES

Water supply pipes will require upgrading to protect against the potentially aggressive effects of residual hydrocarbons within the shallow soils. When the proposed route of potable water supply pipes has been finalised, a water supply pipe risk assessment should be undertaken on the basis of information obtained in all (current and future) phases of investigation. Water supply pipe material selection should be in accordance with current recommendations set out in UKWIR6.

10.6. DRAINAGE

Due to the level of contamination identified at the Site infiltration drainage is not recommended.

10.7. MATERIAL MANAGEMENT

Waste characterisation would need to be undertaken to determine the most appropriate disposal route, and whether any on-site treatment prior to disposal would be beneficial or required.

10.8. CONSTRAINTS

10.8.1. UNDERGROUND OBSTRUCTIONS AND SERVICES

Constraints to the remediation are likely to arise due to the presence of underground structures, in particular the foundations the gas holders and associated pipework, and current on-site structures.

The Site is very congested with services in the southern and western areas. Medium and low pressure gas mains, a high voltage electricity cable, substation, telecoms, local water, drainage and electricity cables are present on site. In addition, a number of redundant gas pipes are present across the Site associated with the former gas storage and distribution network.

Remediation of the Site will need to take into consideration the easements of operational gas mains and other live services and also obstructions posed by historical gas mains.

Although it has been assumed that the area beneath gas holder no.4 will not require significant remediation as it was an above ground tank structure, should it be demolished, there is possibility that the area beneath the gas holder base will require some remediation, particularly with regard to the tar main which crossed this area of the Site. This should be confirmed following additional sampling and testing post-demolition.

10.8.2. ECOLOGY

Anecdotal evidence circa 2015 suggests a pair of peregrine falcons had been using gas holder no.4 as a nest site. This is a potential development constraint and an ecology survey and assessment may be required prior to demolition and development.

10.8.3. TREES

It is understood that there is to be a 10m buffer area along the river front which is to be retained for open space. Trees are to be retained along this area and therefore due to root protection zones there will be restrictions on what remediation can occur in the area.

10.9. GEOTECHNICAL RECOMMENDATIONS

Due to the presence of significant thicknesses of highly variable Made Ground and soft Alluvial soils, shallow foundations are not recommended for the development of the site. To avoid the issues associated with excessive settlement and variable ground conditions, piled foundations solutions are recommended.

These will transfer loads from structures into the Chalk at depth. It is recommended CFA piles are implemented on site, as they greatly reduce the possibility of opening contamination pathways to the principal aquifer in which they will be founded, however a piling works risk assessment will be required to confirm the preferred foundation solution for the development. They also have benefits from reduced noise and vibrations during construction, and no requirement for casing through the superficial deposits.

Based on ground investigation findings, it is anticipated the Made Ground will be encountered at subgrade level across the site. It is likely that this material will have a low CBR value, therefore the use of geogrids should be considered to construct roads and areas of hardstanding to prevent settlement and rutting of the subgrade. Prior to installation, the ground beneath the geogrid should be proof rolled with a heavy roller, inspected by a suitably qualified engineer and any soft spots removed and replaced with well compacted granular fill. Voids, or low areas should be backfilled with granular fill and benched appropriately to ensure a gradual transition between the fill and surrounding ground.

It is recommended additional ground investigation is undertaken specifically for determination of geotechnical parameters and confirmation of deeper geology for geotechnical design purposes. Additional sulphate analysis and groundwater level monitoring should also be undertaken. It is recommended further ground investigation is undertaken at the location of the new buildings, when preliminary structural loads are known. This will allow preliminary pile sizing to inform the required borehole depths.