M58 Link Road

Ground Investigation Report

Wigan Council

July 2021
Version **C01**

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Document history

Document title: **Ground Investigation Report**

Document reference: **M58Link-ATK-HGT-XX-RP-CE-000004**

Revision	Status	Purpose description	Originated	Checked	Reviewed	Authorised	Date
C01	**A1**	**First Draft**	**CH**	**CH**	**JH**	**SA**	**13/07/21**

Client signoff

Client	Wigan Council
Project	M58 Link Road
Job number	5195745
Client signature / date	

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1. Introduction

1.1. Background

Atkins have been appointed by Balfour Beatty, under the SCAPE Framework, to undertake pre-construction activities which involves the detailed design of the proposed M58 to Pemberton link road. The M58 Link Road scheme will provide a new road link from the M58 Junction 6/M6 Junction 26 to the A49 Link Road (currently under construction) to the east of the former Pemberton Colliery. The M58 to Pemberton Link is a 2.3km single carriageway with two main junctions along the route at Kilshaw Street at Billinge Road. The three main scheme objectives of this project are:

- To enhance connectivity from the M58 and M6 at Junction 26 through to Wigan Town Centre and west Wigan, in conjunction with the A49 link Road.
- To reduce congestion on the existing road network, specifically on Ormskirk Road (A577).
- To facilitate economic growth, by connecting several strategic development sites to the highway network.

The overall scheme comprises upgrade to motorway roundabouts, widening of the M6, sections of completely new road, a section of widened road along Leopold Street, and a new overline bridge to avoid the existing Network Rail's Pemberton Bridge (overline).

The link road provides direct access to the Pemberton Park Development (former Pemberton Colliery and open-cast site) within which the eastern most section of the route lies. The existing Pemberton Bridge is to be retained for local traffic.

The scheme comprises 4 sections, indicated in Figure 1-1 and shown in attached General Arrangement Drawings in Appendix G. This Ground Investigation Report covers sections 2 and 3 indicated in Figure 1-1. Section 1 containing the J26 motorway roundabouts will be investigated as part of the programme of drilling and grouting due to occur at a later date. Section 4 which crosses the former Pemberton Colliery has previously been remediated and a validation report for Phase 3 of the remediation works has been made available to Atkins. For Section 4 confirmatory chemical and in-situ testing is expected to be required during detailed design and/or construction which will be reported on separately.

Figure 1-1 - Overview of scheme sections

1.2. Scope of Work

The aim of the ground investigation is to provide further understanding of the current ground and groundwater conditions to enable a design and build contractor to construct the new link road. Atkins' scope of works included:

- to obtain geo-environmental and geotechnical information for Sections 2 & 3 to inform the design and construction of new road, including road widening works, and retaining structures
- provide limited further information on the presence of shallow mine workings

- provide ground information to be used in the design of the new Pemberton Bridge
- Preparation of a geo-environmental assessment for Sections 2 & 3 detailing the GI findings and assessment of results including the production of a generic quantitative risk assessment (GQRA) to assess potential risks to human health and controlled waters for the proposed end use using the GI data obtained for Atkins;
- Development of a Conceptual Site Model (CSM) for Sections 2 & 3 identifying potential contaminant sources, pathways and receptors;
- further ground investigation may be required for specific structures at detailed design stage, and will be required as part of any mine workings treatment strategy. The GI was not designed to give detailed information on the mine workings.
- Section 1 was not included in the GI as this area is to be investigated as part of a programme of ground treatment works due to commence at a later date. This is with the exception of two GI locations which fall just inside the eastern most extent of section 1. For the purposes of this report they will be included within Section 2
- For Section 4 additional chemical testing and confirmatory in-situ testing is expected to be required as part of detailed design and construction in this area.
- Planned borehole BH018 on the southern side of the railway near the footprint of the proposed foundation could not be drilled due to service and utility constraints and therefore ground investigation data is limited in this area. Access to this area was also restricted by two bungalows.
- A Trial Excavation (TT001) was undertaken after the GI for the main purpose of understanding the excavatability of the bedrock in the area of Pemberton Bridge. The findings of this trial excavation have been included in this report for completeness. The log for this excavation has been included within the Factual Report.

1.3. Information Sources

The following existing site-specific information has been consulted in the preparation of this report:

- Mott MacDonald (2015), M58 Link Road. ES Volume 2 Appendix 2F. HD22/08 Preliminary Sources Study Report. Wigan Council. [1]
- Mott MacDonald (2015), Pemberton Link Road. ES Volume 2 Appendix 2G. HD22/08 Preliminary Sources Study Report. Wigan Council. [2]
- Mott MacDonald "ES Volume 2 Appendix 2H Coal Authority Mining Report.pdf" 2013 [3]
- Mott MacDonald, Environmental Statement Volume 2 Appendix 2C-5 Geology and Soils: Technical Information 350184/KWN/SA/08/A, March 2016 [4]
- Consultants Coal Mining Report, October 2021 reference 51002312984001 – Offline bridge option [5]
- Forster A, Stewart M, Lawrence D J D, Arrick A, Cheney C S, Ward R S, Appleton J D, Highley D E, MacDonald A M and Roberts P D (1995), A geological background for planning and development in Wigan, British Geological Survey Technical Report No WN/95/3, eds. Forster A, Arrick A, Culshaw M G and Johnston M [6]
- Wardell Armstrong (2013), Phase 3 Remediation Works Validation Report, Former Pemberton Colliery, Wigan [7]
- Geotechnics Limited, Factual Ground Investigation Report, 2021 [8].
- Atkins Limited, Pemberton Bridge Geo-environmental Desk Study, 2020 [9].
- M58 Link Road Mining Risk Assessment, October 2020 [10]

The open source data listed in Table 1-1 has been consulted in the preparation of this report:

Table 1-1 Open source data

Information	Sources of Information	Details
Geological mapping	British Geological Survey (BGS)	BGS Online GeoIndex [11]
		1:50,000 mapping sheets [12]

Information	Sources of Information	Details
		British Geological Survey Technical Report No WN/95/3
Historical mapping	Landmark Information Group	Envirocheck Report [13]
	old-maps.co.uk	Free online resource for historical maps [14]
Existing ground investigations	British Geological Survey (BGS)	Borehole records obtained from BGS Online GeoIndex [11] including M6 J26 Historical Records.pdf.
Mining and quarrying	The Coal Authority	Coal Authority Online Viewer [15]
	British Geological Survey (BGS)	BGS Online GeoIndex [11]
Satellite and terrestrial imagery	Microsoft Corporation	Bing Maps [16]
	Google	Google Street View [17]
Unexploded Bombs	Zetica UXO	Zetica UXB Risk Map [18]

1.4. Reporting approach

The information provided in this report will be presented in-line with the proposed scheme chainage sections 2 and 3 as shown in Figure 1-1.

- Section 2: = Chainage 55 to 1465 m
- Section 3: = Chainage 1465 to 1825 m

Section 1 (motorway roundabout upgrade) will be investigated with respect to an intrusive ground investigation as part of a programme of drilling and grouting due to occur at a later date and detailed within the Atkins drilling and grouting specification (M58Link-ATK-VGT-XX_BH-SP-CE-000003). Section 1 is not discussed further within this report.

Section 4 which crosses the former Pemberton Colliery has previously been remediated and a validation report for Phase 3 of the remediation works has been provided to Atkins for information. For Section 4 confirmatory chemical and in-situ testing is expected to be required during detailed design and/or construction which will be reported on separately.

1.5. Limitations

This Ground Investigation Report only covers sections 2 and 3 indicated in Figure 1-1.

Atkins is responsible for selecting and summarising the data supplied by the client or other parties but cannot be held for any mistakes or inaccuracies or the completeness of third-party data on which it has relied. As with any point data, ground conditions can only be inferred between test locations and as such localised conditions on site may vary between point locations. Ground gas and groundwater conditions are based on observations made at the time of the Atkins designed 2021 ground investigation and monitoring programme, and may be subject to variation due to atmospheric, seasonal or other effects. Therefore, this report cannot guarantee against unexpected ground conditions occurring between the sampling points.

This report presents the preliminary findings of geo-environmental and geotechnical ground investigation and risk assessment to inform the client about potential contamination and geotechnical hazards & constraints relating to the proposed scheme. Once details of the design (e.g. layout, levels loadings, etc) is known, further development-specific ground investigation and assessment may be required by the Client/Developer/Contractor to inform design. Constraints relating to ecology, heritage, flooding/drainage, utilities, air quality and noise are beyond the remit of this report.

The Conceptual Site Model (CSM) developed and Generic Quantitative Risk Assessment (GQRA) carried out were based on the current scheme design as shown upon the General Arrangement Drawings (Drawing Nos. M58Link-ATK-HGN-XX-DR-CH-100002 to 100008). Any changes to the proposed design/layout may require revision of the CSM and reassessment of the risk assessment findings if the final development differs substantially from these assumptions.

This report does not advise on measures to deal with asbestos. Detailed advice should be sought from a specialist contractor.

This report should be read considering the legislation, statutory requirements and/or industry good practice applicable at the time the report was written. Any subsequent changes in legislation or guidance may necessitate the findings to be reassessed in light of these circumstances.

2. Environmental Setting & Site Characterisation

A review of publicly available information and previous reports have been used to describe the environmental setting, including the following key information:

Atkins Limited, Pemberton Bridge Geo-environmental Desk Study, 2020 [9];

Mott MacDonald, Environmental Statement Volume 2 Appendix 2C-5 Geology and Soils: Technical Information 350184/KWN/SA/08/A, March 2016 [4];

- Including Landmark Information Group Envirocheck Report Order No. 64347475_1_1 Obtained in February 2015 [13]

BGS online viewer [19]; and,

Defra MAGIC Map [20].

2.1. Location and Description

The proposed road scheme forms a linear site spanning a distance of approximately 2.3km between M58 Junction 6/Junction 26 of the M6 in the west, and the A49 Link Road in the east (currently under construction). The route is located between grid reference E354070 N404460 in the west, and E356080 N403760 in the east.

The proposed alignment is shown on the General Arrangement Drawings (M58Link-ATK-HGN-XX-DR-CH-100002 – 100008) included within Appendix G.

The Site is located east of the Orrell Interchange and adjacent to an area of recreational land currently used by Orrell St James Amateur Rugby League Football Club (ARLFC) on its northern boundary. At its eastern end is the former Pemberton Colliery site.

The existing ground level along the proposed alignment falls from approximately 78m AOD at the M58 Junction 2 roundabout to approximately 60m at the tie-in to A571 Billinge Road. The first 450m of the alignment, before merging with Leopold Street, passes over hummocky arable land typically with poor drainage and Smithy Brook located along the southern boundary. At approximate chainage 1300m the alignment diverges SE of Leopold Street and continues over undulating scrub land until approximate chainage 1600m. Two low features in relation to the alignment are Smithy Brook at 63m AOD, which meanders approximately 350m south of the alignment from chainage 0–750m and a railway cutting. The latter serves Pemberton Station at the eastern end of the proposed highway alignment. The final 200m of the highway alignment runs close to the crest of the northern slope of the railway cutting

Section 3 includes the proposed offline Pemberton Bridge and connects the alignment to the A571 Billinge Road. The alignment passes over the rail line immediately west of Pemberton station. The rail line is situated in an approximately 8m deep cutting bound by densely vegetated slopes. The existing slopes stand at and approximate gradient of 1:2.5. A narrow masonry footbridge crosses the railway at this location and is scheduled for demolition as part of the road scheme.

2.2. Key Historical Land uses

A review of the historical setting of the site has been provided within the Mott MacDonald PSSR, a summary of which has been provided below. The following historical land uses on and within 250 m of the site boundary have been indicated:

Table 2-1 - Summary of Key Historical Land Uses

On-site/off-site and orientation	Land Use	Dates Present (from – until)	Distance from site (m)
On-site	Yorkshire Railway Track in a cutting	1849 - Present	n/a

	Railway sidings associated with Pemberton Collieries	1893 – 1976	
	Excavation	1929 – 1951	
	New Venture Pit	1929 – 1951	
	Infilled Reservoir	1929 – 1951	
	Electrical Sub station	1954	
North	Industrial Estate	1951 – present	Adjacent to boundary
	Works, Mill, chimneys and sub stations	1967 – 1992	Adjacent to boundary
	New Venture Pit shaft and workings	1929 – 1938	100
	Sand Pit and Quarry	1894	175
East	Pemberton Station	1849 – present	Adjacent to boundary
	Pemberton Colliery Sidings	1894 - 1974	175
	Pemberton Colliery	1849 – 1955	Adjacent to boundary
	Opencast Coal Disposal Centre	1982 – 1992	250
South	Liverpool, Bolton and Bury Line of the Lancashire and Yorkshire Railway/London, Midland and Scottish Railway	1849 – Present	Adjacent to boundary
	Bankees Siding/Winstanley's Colliery Siding	1894 – 1951	100
	Old Mine Shafts	1894 – 1984	170
	Old Coal Pit	1849 – 1894	200
West	M58 Roundabout	1982 – present	Adjacent to boundary
	M6 Motorway	1967 – present	Adjacent to boundary

A Geohazard summary plan is presented within the Mott MacDonald PSSR (Drawing No. MMD-350184-C-DR-00-XX-0009) which shows the location of key sources of contamination.

2.3. Geology

The BGS online GeoIndex and the published BGS Geological Mapping (Solid and Drift), Wigan, Sheet 84, indicates the proposed alignment to be underlain by Glacial Till deposits between chainage 55m to 625m. Beyond chainage 625m, superficial deposits are no longer indicated.

Between chainage 55m to approximate chainage 1350m, bedrock geology is indicated to comprise interbedded mudstone, siltstone and sandstone of the Pennine Lower Coal Measures. Coal seams are indicated to subcrop beneath glacial till and outcrop where superficial deposits are shown to be absent. The Smith seam is shown to subcrop beneath the eastern circulatory at J26 of the M6and the Half Yard seam is indicated to subcrop on a SSW trending line that intersects the alignment at approximate chainage 150m.

Further seams are indicated to intersect the alignment between approximate chainages 600m to 1000m; from west to east these are Flaggy Delft, Sir John and Thin Coal.

A marked change in solid geology is indicated at chainage 1350m by the down-throwing of the Pemberton Rock Member by the NW to SE trending Pemberton Fault. The Pemberton Rock Member is indicated to comprise cross-bedded sandstone and subordinate mudstones. The alignment remains on the Pemberton Rock until approximate chainage 1580m where a NE to SW trending fault brings the Ravenhead Rock Member alongside the Pemberton Rock. The Ravenhead Rock is described as predominantly pebbly sandstone with subordinate mudstone.

At approximate chainage 1650m another NW to SE trending fault known as the East Pemberton Fault brings the Pennine Middle Coal Measures formation alongside the Ravenhead Rock Member. The Pennine Middle Coal Measures comprise interbedded grey mudstone, siltstone, pale grey sandstone and commonly coal seams, with a bed of mudstone containing marine fossils at the base, and several such marine fossil-bearing mudstones in the upper half of the unit.

2.4. Hydrogeology

The Defra MAGIC online map viewer indicates that Aquifers underlying the site are classified as:

- Superficial: Glacial Till – Unproductive Strata
- Bedrock: Pennine Lower Coal Measures and Pemberton Rock Member – Secondary A Aquifers

The Environmental Agency (EA) defines Secondary A Aquifers as "permeable layers capable of supporting water supplies at a local rather than strategic scale (forming an important source of base flow to rivers). These are generally aquifers formerly classified as minor aquifers". Unproductive Strata are rock layers or drift deposits with low permeability that have negligible significance for water supply or river base flow.

No Source Protection Zones (SPZs) are present on site or within 1 km of the site [21].

A Coal Authority operated groundwater abstraction is located approximately 270 m south of the site from the underlying coal measures for pump and treat purposes (remediation). As recorded in the Mott MacDonald ES, there is also understood to be a pump and treat abstraction at the Pemberton Colliery Drainage Sough to the east of the site (400 m).

As recorded in the Mott MacDonald ES, the western extent of the site is indicated to have the potential for groundwater flooding of property located below ground level.

2.5. Hydrology

The nearest watercourse/water feature is a small unnamed stream which flows north to south from south of the Orrell St James ARLFC playing fields across the site towards Smithy Brook. This unnamed stream is a tributary of Smithy Brook, which flows west to east to the south of the site.

According to the Environment Agency Catchment Data Explorer Website [22], Smithy Brook has been given a chemical rating of "fail" and an ecological rating of "moderate" in 2019 with an overall waterbody classification of "moderate".

The site is not indicated to be within an area liable to flooding from either surface water courses or the sea [23]

There are no surface water abstractions within 250 m of the site.

2.6. Landfills and Waste

According to the Mott MacDonald ES there are three historic landfill sites located within 500 m of the site:

Lamberhead Industrial Estate, to the immediate north of Leopold Street;

Edge Hall Road, 415 m west of the site to the south west of the Orrell Interchange; and

Little Lane, Goose Green, to the north-east of the former Pemberton Colliery site – The full operating history of the Site is unknown but the landfill pre-dates the Control of Pollution Act 1974 (COPA) and was a former backfilled stone quarry (approximately 120m from the eastern end of the Scheme). Records indicate that the landfill was unlined and received unlicensed mixed waste.

A single licensed waste management facility, KWS Tyre Recycling, is located on site on Leopold Street.

2.7. Discharge consents

According to the Envirocheck Report a discharge consent for the Coal Authority pump and treat groundwater abstraction is present to the south of the site into Smithy Brook (just to the north of the abstraction point, 220 m south). A discharge consent is also present upstream along the Smithy Brook relating to United Utilities pumping station sewage discharge, approximately 83 m west of the site.

2.8. Pollution incidents

The Envirocheck contained within the Mott MacDonald ES indicates that there are four current Integrated Pollution Prevention Controls (IPPC)/Local Authority Pollution Prevention and Controls (LAPPC) in the vicinity of the Site:

Bitrez Ltd: Pemberton Polymers (organic chemicals, plastic materials) approximately 110 m north from the Site in the Lamberhead Industrial Estate;

Bitrex Ltd: Bitumen and tar processes on Leopold Street to the north of the site;

Easmix Concrete Ltd: Concrete blending and packing approximately 90m north from the Site; and

Pemberton Service Station: Active approximately 465 m to the north of the Site.

Lapsed IPPCs/LAPPSs include activities such as road vehicle re-spraying, production of offal products (370 m south).

Pollution incidents to controlled waters in the vicinity of the Site include historic discharges relating to diesel spillage at the adjacent Orrell Interchange, and sewage wastes/domestic wastes/oil/unknown pollution discharged to the Smithy Brook (to the west of the former Pemberton Colliery site). A prosecution relating to controlled waters is recorded from 1997 when sludge from reservoir infilling entered Smithy Brook at Foundry Lane. In 2013, the Substantiated Pollution Incident Register records a significant incident to water and air adjacent to Leopold Street associated with firefighting runoff (located adjacent to the northern site boundary). (Envirocheck contained within the Mott MacDonald ES.)

2.9. Trade Directory Entries and Fuel Stations

Contemporary Trade Directory Entries active in the vicinity of the Site include (predominantly relating to the Lamberhead Industrial Estate) the following entries: Builders merchants, office furniture and equipment, joiners, precision engineers, car breakdown and recovery, tyre manufacture and distribution, valve manufacturers, distribution services, firefighting equipment, car engine repairs and recycling services. Inactive entries include plastics (injection moulding), concrete and mortar, leather product manufacture, garage services, pump servicing and repairs, telecommunications equipment and systems, hygiene and cleansing services, electrical goods manufacture, and wholesale.

The Envirocheck Report indicates that an open fuel station, operated by Esso, is present 465 m north east of the site.

2.10. Sensitive Land Uses

The Envirocheck Report and MAGIC maps online indicate that the site is not located within 1 km of any statutory designated land uses (e.g. Sites of Special Scientific Interest (SSSI), Ramsar sites, Conservation areas, etc).

2.11. Radon

The site is located within an intermediate radon area where between 1% and 3% of properties are estimated to be at or above the action level [24]. Therefore, no radon protection measures are required on new dwellings.

2.12. Unexploded Bomb (UXB) Risk

The site is classified as having a Low Risk with respect to UXB according to Zetica UXO (online). [18]

3. Existing Information

A number of ground investigations have been undertaken within the vicinity of the proposed M58 Link Road, existing Pemberton Tunnel and proposed Pemberton Link Road areas.

These are;

- Exploration Associates Phase 1 Ground Investigation, 1991
- Soil Mechanics Phase 4 Ground Investigation, 1993
- A5225 Ground Investigation M6 Junction 26 to Dangerous Corner (Section B), Hyder Consulting; 2004
- Colas Rail RD149 Pemberton Tunnel Ground Investigation, 2017

For further information on these investigations refer to the Mott MacDonald PSSRs [1] and [2].

4. Initial Conceptual Site Model

4.1. Introduction

Primary guidance for assessing and managing risks posed by land contamination is presented in Land Contamination: Risk Management (LCRM) published by the Environment Agency on 20 October 2020 [25]. LCRM provides a technical framework (and signposts other key guidance) for identifying and remediating contamination through the application of a risk management process. The question of whether a risk is unacceptable in any particular case involves not only scientific and technical assessments, but also appropriate criteria by which to judge the risk and conclude exactly what risk would be unacceptable.

An Initial Conceptual Site Model (CSM) describes the relationship between potential sources of contamination (resulting from both on- and off-site historical and recent activities) and receptors to the potential contamination. As part of the CSM development, three elements are identified and assessed:

Source of contamination and associated contaminants;

Receptors – human beings, controlled waters (surface water/groundwater), ecological systems and property, to that contamination; and

Pathways between the sources and receptors.

Where all three elements are present or are likely to be present, they are described as potential contaminant linkages (PCLs), which can then be subjected to the risk assessment and risk management process.

4.2. Initial Conceptual Site Model

The preliminary risk categorisations presented are based on an assessment of the potential consequence of each PCL occurring along with the likelihood that each PCL will occur in accordance with the framework provided in Appendix A. Potential contamination that might be present has been identified through knowledge of historical land uses on or adjoining the site.

Under current health and safety legislation, construction and maintenance staff are required to carry out their own appropriate risk assessments and mitigation to protect their staff, other human receptors and the environment from potential contamination. Such risks must be adequately mitigated by law, specifically the Construction Design Management (CDM) Regulations [26], that require potential risks to human health and the environment from construction activities are appropriately identified and all necessary steps taken to eliminate/manage that risk. Therefore, construction/maintenance workers have been discounted as human receptors from the CSM.

Chemical attack to buried structures as a pathway has not been included within the Initial CSM as this will be covered by the Geotechnical Assessment and mitigated in the design process. Also, as the scheme does not include the construction of buildings, it is unlikely that water supply pipes would be installed.

As no sensitive land uses have been identified within 250 m of the site, ecological receptors have not been considered as part of the Initial CSM.

The initial CSM for the scheme (sections 2 and 3 only) is presented in Table 4-1.

Table 4-1 - Initial Conceptual Site Model and Preliminary Risk Assessment for Sections 1, 2 & 3

Sources	Pathway	Receptor	(Consequence/Probability) Classification of Risk
Potential contaminants in soil/groundwater on-site, originating from the following on-site sources: Made Ground across the site associated with the historical site use Infilled Land Infilled Reservoir Waste Management Facilities Mine Workings Fill associated with existing roads on site. Electrical Sub Stations *Potential Contaminants include:* *Asbestos* *Heavy Metals* *Polychlorinated biphenyls (PCBs)* *Polycyclic Aromatic Hydrocarbons (PAHs)* *Fuels* *Organic Compounds* *Ground Gases* *Mine Gas*	Inhalation, ingestion and dermal contact with contaminants in soil and soil derived dust. Organic contaminants in soil migrating into water supply pipes.	Future site users (road users). Adjacent site users.	(*Medium/Unlikely*) **Low Risk** Based on the current and historical use of the site, it is possible that contamination may be present in the soils and shallow groundwater. The site is likely to be covered in hardstanding and vegetated verges that would prevent exposure of the public to the underlying soils. It should be noted that future construction/maintenance workers involved in excavations would come in contact with Made Ground and appropriate health and safety assessments and PPE would be required to minimise contact with soils.
	Inhalation of airborne asbestos fibres.		(*Severe/Unlikely*) **Moderate/Low Risk** Due to the past historical uses of the site/the potential for Made Ground there may be asbestos present on site. However, as the site will be covered in hardstanding and vegetated verges it is unlikely that asbestos would be exposed at surface. However, the risk to construction and maintenance workers might require further assessment by a specialist asbestos contractor.
	Migration of gases/vapours into confined spaces/buildings and accumulation (explosion). Inhalation of vapours or ground gas (asphyxiation).	Future site users and property (road users).	(*Medium/Unlikely*) **Low Risk** Although potential sources of ground gas (Made Ground and infilled land) and mine gas have been identified from desk study information; the development will not be introducing any buildings or significant enclosed spaces for site users to enter therefore there will not be a receptor. During construction (including for the temporary works) and during operation (including maintenance of culverts/drainage etc) risks associated with the possible accumulation of ground gas in inspection chambers etc should be mitigated through standard health and safety practises (i.e. monitoring of confined spaces before entry etc).
		Adjacent land users and property (Playing fields, commercial/industrial and residential).	(*Medium/Low likelihood*) **Moderate/Low Risk** Potential sources of ground gas (Made Ground and infilled land) and mine gas have been identified based on desk study information. The construction of new drainage service trenches have the potential to create new migration pathways, which could result in gases migrating off site and impacting upon surrounding land uses.
	Leaching of contaminants to groundwater in superficial deposits and to bedrock. Lateral migration beneath the site to surface water receptors. Also, via preferential pathways (e.g. service trench backfill, piled foundations).	Secondary A Bedrock Aquifers underlying the site. Surface Water Receptors (Smithy Brook and tributary).	(*Medium/Low Likelihood*) **Moderate/Low Risk** There is potential for leaching of contaminants into groundwater in the superficial deposits and bedrock however the Site will predominately be covered in hardstanding which will reduce leaching potential. The Site is not located in a source protection zone and there are no active groundwater abstraction licences within 250 m of the Site. Ground investigation (GI) would be required to characterise the risk posed by potential contamination in the soil and groundwater. Should piled foundations be required they should be designed to mitigate the creation of a migration pathways for potential contamination.
Potential contaminants in soil/groundwater on-site originating from the following off-site sources: Made Ground Railway & sidings & station Infilled Land Pemberton Colliery, mine workings & seams Infilled Opencast mine Opencast Coal Disposal Centre Electrical Substations Industrial Estate &Tanks Landfills Bitumen Works Firefighting Runoff *Potential Contaminants include:* *Asbestos* *Heavy Metals*	Inhalation, ingestion and dermal contact with contaminants in soil and soil derived dust.	Future site users (road users).	(*Medium/Unlikely*) **Low Risk** The majority of the surrounding area is currently covered in either hardstanding (roads/buildings) or vegetation, which would limit exposure to underlying soils and thus dust generation. It is assumed that surrounding commercial units are currently following best practice in their operations.
	Inhalation of airborne asbestos fibres.		(*Severe/Unlikely*) **Moderate/Low Risk** Asbestos may have been present within historical buildings which surrounded the site, therefore demolition of these buildings may have resulted in asbestos being present within Made Ground across the surrounding area and on site (e.g. wind-blown deposition).
	Migration of gases/vapours into confined spaces/buildings and accumulation (explosion). Inhalation of vapours or ground gas (asphyxiation).	Future site users and property (road users).	(*Medium/Unlikely*) **Low Risk** There is the potential for the off-site generation of ground gas, however, the development will not be introducing any buildings or significant enclosed spaces therefore there will not be a receptor. During construction (including for the temporary works) and during operation (including maintenance of culverts/drainage etc) risks associated with the possible accumulation of ground gas in inspection chambers etc should be mitigated through standard health and safety practises (i.e. monitoring of confined spaces before entry etc).
	Leaching of contaminants to groundwater in superficial deposits and bedrock. Lateral	Secondary A Bedrock Aquifers underlying the site	(*Medium/Low likelihood*) Moderate/**Low Risk**

Polychlorinated biphenyls (PCBs) *PAHs* *Total Petroleum Hydrocarbons (TPHs)* *PCBs* *Organic Compounds* *Ground, landfill & mine gases*	migration beneath the site to surface water receptors. Also, via preferential pathways.	Surface Water Receptors (Smithy Brook and tributary).	There are a variety of historical and current land uses up-hydraulic gradient of the scheme. However, the probability of new foundations/service trenches creating any new potential pathways for contaminant migration that might result in an unacceptable risk to controlled waters, will depend on degree of dissolved contamination, permeability of deposits and depths/routes of the structures.

5. Field and Laboratory Studies

5.1. Introduction

Geotechnics Limited were commissioned by Atkins to undertake a ground investigation within Sections 2 and 3 of the M58 Link Road alignment as described in Section 1 of this report. The ground investigation was designed by Atkins and carried out by Geotechnics Ltd between 20th January and 3rd March 2021, with full time technical supervision by an Atkins Geotechnical Engineer.

The aims of the investigation were to:

- inform the ground and groundwater conditions beneath the site;
- collect soil and groundwater samples for laboratory analysis of potential contaminants of concern (identified from desk-based information);
- collect soil and bedrock samples for geotechnical laboratory testing to inform the geotechnical assessment and to assist with material classification for reuse within the enabling works;
- collect soil samples to be screened against generic assessment criteria to provide an indication of degree of risk posed to end users/environment from reuse of materials;
- collection of surface water samples to inform selection of generic assessment criteria;
- undertake post field work ground gas and groundwater level monitoring to provide data to inform gas assessment; and
- provide general GI coverage across the site to allow the subsequent geotechnical design .

Following consideration of service plans from utility providers, the proposed exploratory hole locations were cleared for buried services by Avoin Maa Surveys (subcontractor hired by ground investigation contractor Geotechnics Ltd.) using ground penetrating radar (GPR) and by a Balfour Beatty Engineer using a cable avoidance tool (CAT). Permits to dig were issued by Balfour Beatty before setting up on a GI location and breaking any ground.

5.2. Scope of Works

Exploratory holes were positioned across site at locations to reduce data gaps identified from review of previous ground investigations. The holes were positioned to target potential sources of contamination and provided information on overall site conditions.

The environmental chemical testing suite was designed based on contaminants of concern identified during a review of desk-based information, including the historical uses of the site and current adjacent site uses. Volatile head space testing using a photoionisation detector (PID) was undertaken by Geotechnics Ltd. on environmental samples to assess the risk posed by volatile contaminants within soil.

The ground investigation was designed by Atkins and carried out in general accordance with i) Institute of Civil Engineers (ICE) guidance [27]; ii) British Standard (BS) 10175 [28]; iii) BS5930 [29]; iv) BS8576:2013 [30].

A total of 18 boreholes, 19 machine-dug trail pits, and 1 hand-dug trial pit was carried out during the investigation. In addition, a total of five soakaway tests were also conducted. A location plan for the GI is presented in Appendix B and in Appendix C.

Some investigative positions required relocation or omission due to constraints encountered during the investigation; additional positions were also added where necessary. Planned borehole BH018 on the southern side of the railway near the footprint of the proposed foundation could not be drilled due to service and utility constraints and therefore ground investigation data is limited in this area. Access to this area was also constrained due to the presence of two properties into which access was not possible.

A trial excavation was carried out shortly after the main ground investigation under a separate commission and was supervised by an Atkins engineer. The trial excavation was carried out to further enhance the understanding of the excavatability of the weathered bedrock around the area of the Pemberton Bridge. The log for this excavation can be found in the Factual Report presented in Appendix B and a description of the findings has been included in this report for completeness.

A summary of the works undertaken during the Geotechnics Ltd. ground investigation is provided in Table 5-1 below and the Factual Report is presented in Appendix B.:

Table 5-1 - Summary of Intrusive Locations

Exploratory Hole Type	Exploratory Hole Number	Termination Depth (m bgl)	Comment
Cable percussive with rotary core follow-on**	BH002 – BH007, BH015 - BH017 and BH019-BH022*	13.80-25.00	
Cable percussive only	BH010, BH011, BH013 and BH014	3.35-6.45	
Dynamic sample with rotary follow-on	BH024 and BH025	15.00-17.20	Rotary coring started at 2.0 m BGL (BH024) and 3.70 m BGL (BH025)
Machine-dug trial pits	TP001-TP003 and TP006-TP020	2.00-4.00	
Hand-dug trial pit	TP004	1.00	
Soakaway tests	TP003, TP014, TP015, TP019 and TP020	0.10-1.50	

*BH021 has incorrectly been labelled as BH022 in the Factual Report.

** Planned borehole BH018 on the southern side of the railway near the footprint of the proposed foundation could not be drilled due to service and utility constraints and therefore ground investigation data is limited in this area.

The following additional works were also undertaken: photo-ionisation detector (PID) testing of samples on site; installation of gas/groundwater monitoring standpipes within all borehole locations; collection of both geo-environmental and geotechnical samples, with associated testing; and four rounds of post site works gas/groundwater monitoring.

The trial excavation carried after the main GI works (TT01), was excavated to a depth of 5.0m bgl.

5.2.1. Geophysics

As part of the surveys undertaken for the project, a limited geophysical survey was undertaken to investigate the presence of historical mine entries for the purposes of gaining heritage information rather than geotechnical or environmental information.

The geophysical survey report (see Appendix F) has indicated the following;

- The area investigated was limited to 0.4 ha due to overgrown vegetation. Therefore, the majority of the site has not been assessed by the survey.
- In the area investigated 'There is no evidence for post-medieval industrial activity, such as mine shafts'.
- The area that could be surveyed is dominated by an increased magnetic response. This is likely caused by modern spread of foreign material associated with landscaping of the area. This strong magnetic response has the potential to mask any weak archaeological anomalies that may be in the area.

5.3. Environmental Sampling

5.3.1. Soil Sampling

Environmental soil samples were collected during the ground investigation and transported to ALS Life Sciences Limited (ALS) for chemical analysis. ALS is a United Kingdom Accreditation Service (UKAS) and Monitoring Certification Scheme (MCERTS) accredited laboratory. Soil samples were collected by a Geotechnics Ltd engineer and stored within cool boxes with ice packs before being transported to the laboratory within 24 hours of collection under Geotechnics Ltd's chain of custody delivery process.

5.3.2. PID Testing

All environmental soil samples were screened on-site by a Geotechnics Ltd engineer with a photo-ionisation detector (PID). This test provides an indication of the presence and concentration of Volatile Organic Compounds (VOCs) in soil vapour and informs the appropriate selection of laboratory analysis. In-situ testing results from each exploratory hole are presented on their respective logs.

5.3.3. Groundwater Sampling

Two sets of groundwater samples were collected from seven exploratory holes across the site. Wells were developed by a Geotechnics engineer following well installation during the site works, prior to sampling being undertaken on 19 to 21 April 2021 and 12 to 14 May 2021. The samples were sent to the laboratory for chemical analysis indicated in Section 5.6.3. During groundwater sampling, in-situ testing of samples was undertaken to monitor certain parameters to ensure that samples of groundwater were representative of conditions within the ground. The parameters recorded included pH, temperature, electrical conductivity, redox potential and dissolved oxygen. Full results of this testing are presented within the Geotechnics Ltd Factual Report.

5.3.4. Surface Water Sampling

Four surface water samples were collected by a Geotechnics engineer from surface water features across the site as indicated on drawing #.

5.4. In-situ Geotechnical Testing

In-situ geotechnical testing was undertaken by Geotechnics Ltd. during the 2021 GI and is summarised in Table 5 -2. These are detailed further in Section 6.

Table 5 -2 – In-situ tests

Tests	No of Tests
Hand Vane	23
Soakaway Tests	6
Standard Penetration Tests (SPTs)	74

5.5. Geotechnical Laboratory Testing

The programme of laboratory testing was carried out in accordance with Eurocode 7 and, where no conflict exists, with British Standards. The testing was undertaken at a United Kingdom Accredited Service (UKAS) testing laboratory. Atkins scheduled the testing. The numbers of tests undertaken are listed in Table 5 -3. These are detailed further in Section 5.

Table 5 -3 - Laboratory Tests

Tests	No of Tests
Water Content	54
Atterberg Limits	54
Compaction Test (2.5kg Rammer)	7
Single Stage Quick Undrained Triaxial Test	12
California Bearing Ration	14
Moisture condition value at its natural moisture content (MCV spot)	1
Particle Size Distribution by sieving method	33
Particle Size Distribution by pipette method	12
BRE SD1 Suite D 2005	36
Unconfined Compressive Strength tests	9
Point Load tests	72

5.6. Geo-environmental Laboratory Chemical Analysis

Chemical analysis of environmental samples was scheduled by Atkins and carried out by ALS under the UKAS and MCERTS accreditation schemes. Chemical analysis was based on contaminants of concern (CoC) identified in the CSM from consideration of historical and current land uses, in-situ PID testing and ground conditions encountered on site. In total 43 soil samples were scheduled for chemical analysis with depths ranging from 0.20 m bgl to 2.00 m bgl. Samples consisted of the following:

- Topsoil: Five samples;
- Made Ground: 24 samples:
- Glacial Till, Clay: 10 samples: and
- Glacial Till, Sand: four samples.

5.6.1. Soils

Selected soil samples were scheduled for soil analysis comprising the following determinands:

Table 5-4 - Soil testing suite

Determinand	Number of samples tested
Metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, vanadium, water soluble boron, zinc)	43
Polycyclic Aromatic Hydrocarbons (PAHs)	42
Total Petroleum Hydrocarbons (aliphatic/aromatic fractions) (TPH)	11
Polychlorinated biphenyls (PCBs)	11
Cyanide (free & total)	42
Total Organic Carbon/Fraction Organic Carbon/Soil Organic Matter	43
pH	43
Asbestos Identification	43
Asbestos Quantification	1
Volatile Organic Compounds (VOCs)	27
Semi-volatile organic compounds (SVOCs)	7
Waste Acceptance Criteria (WAC) Analysis (Full Suite)	6

5.6.2. Soil-leachate

Selected soil samples were scheduled for leachate analysis (2:1 leachate preparation) comprising the following determinands:

Table 5-5 - Soil-leachate testing suite

Determinand	Number of samples tested
Dissolved metals (arsenic, boron, cadmium, chromium, copper, lead, mercury, nickel, selenium, vanadium, zinc)	18
PAHs	18
Cyanide (total)	18
pH	18
Sulphate	18
Ammoniacal Nitrogen as NH3	18

5.6.3. Groundwater

Groundwater samples were scheduled for a range of determinands comprising the following:

Table 5-6 - Groundwater testing suite

Determinand	Number of samples tested
Dissolved metals (arsenic, boron, cadmium, chromium, copper, hexavalent chromium, iron, lead, mercury, nickel, selenium, zinc)	12
PAHs	12
Cyanide (free, complex & total)	12
pH	12
Sulphate	12
Chloride	12
Ammoniacal Nitrogen as NH3	12
VOCs	5
SVOCs	5
TPH (aliphatic/aromatic split)	5
PCBs	5

5.6.4. Surface Water

Surface water samples were scheduled for the following determinands:

Determinand	Number of samples tested
Organic Carbon	4
Calcium	4
Hardness, Total as CaCO3	4
pH	4

5.6.5. Ground Gas and Groundwater Level Monitoring

Geotechnics Ltd. monitored the installations on four occasions as outlined in Table 5-# below. Methane, carbon dioxide, carbon monoxide, hydrogen sulphide, oxygen and gas flow rate were recorded. For the first three rounds a GA5000 monitor was utilised, for the final round a GFM436 monitor was used. Calibration certificates are provided alongside the Geotechnics Factual Report within Appendix B.

Table 5-7 - Ground Gas Monitoring Dates and Conditions

Date	Pressure	Trend*
25/03/2021	1006	Falling
19/04/2021	1012	Falling
06/05/2021	999	Rising
03/06/2021	1012	Fluctuating

*Trend on lead up to the monitoring round interpreted from atmospheric pressure conditions obtained from on-line resources.

Groundwater levels were measured on five occasions utilising a 50 mm oil interface probe as detailed below:

- 25 March 2021;
- 19 – 20 April 2021;
- 6 May 2021;
- 12 – 14 May 2021; and
- 3 June 2021.

6. Ground Summary

6.1. Summary of Ground Conditions

Ground conditions have been summarised below using data gathered from the 2021 Ground Investigation and supported by data from previous ground investigations where applicable. Olfactory and visual signs of contamination along with PID results are discussed in Section 5.3. The Factual Report produced by Geotechnics is presented in Appendix B, and geological cross sections are presented in Appendix D.

6.1.1. Made Ground

Artificial/ Made Ground is only mapped by the BGS to the east of scheme in the Pemberton Colliery area, however Made Ground was encountered across the site within the 2021 GI and is recorded in the historical boreholes. It has been assumed that the Made Ground is associated with the construction of the railway line and historical coal mining activity in the local area. Made Ground across the site is discussed in sections 6.1.1.1 to 6.1.1.5 of this report. Made Ground has been categorised into Made Ground Hardstanding, Made Ground (Granular), Made Ground (Cohesive), mine workings and open cast backfill material.

6.1.1.1. Topsoil

Topsoil was encountered in the majority of the 2021 GI exploratory holes across the site, and ranges from 0.0 to 0.5 m thick.

It is anticipated that Topsoil will be stripped prior to construction and therefore is not considered further in this report. There is the potential that topsoil may be reused on site within verge areas across the scheme. This will be subject to analysis against suitable reuse criteria.

6.1.1.2. Hardstanding

Hardstanding was encountered in Section 2 of the scheme. During the 2021 GI, BH019 encountered '*black tarmacadam*' from 0.0 to 0.05 m bgl. Black tarmacadam was also encountered in BH010 and BH014 at a depth which ranged from 0.10 to 0.50 m bgl and is interpreted to be part of a former road.

Hardstanding was also found in Section 3 in historical borehole SD50SE307 from 0.0 to 0.10 m bgl, and it was described as '*loosely laid red bricks with grass and weeds above (old yard floor).*'

6.1.1.3. Granular Made Ground

During the 2021 GI, Made Ground (Granular) was encountered in a total of 23 exploratory holes to a maximum depth of 3 m bgl (61.21m OD) in BH014. Made Ground (Granular) deposits across site were variable and are described in Table 6-1.

Table 6-1 - Description of Made Ground (Granular)

Type	Locations	Typical description	Thickness range (m)	Depth (m bgl)
Section 2	BH003, BH010, BH012A, BH013, BH014, TP001, TP002, TP006, TP008, TP009, TP011, TP012, TP014, TP018, TP019, and TP020	Dark brown gravelly silty/clayey fine to medium SAND. Gravel is angular to subangular fine to coarse of mudstone, siltstone, sandstone, glass, concrete, ash and brick fragments	0.1-3.0	0.1-3.0
Section 3	BH017, BH019, BH020, BH021, BH022, BH025 and TP015.	Black slightly silty, slightly gravelly SAND. Gravel is angular to subangular fine to coarse of sandstone, mudstone and brick fragments	0.2-1.0	0.0-1.20

During previous investigations Made Ground (Granular) material was encountered from and to a similar depth up to a maximum depth of 1.5m bgl (57.40m OD) in Section 3. In Section 2, the maximum depth of Made Ground (Granular) was encountered in GEL_BH02A (5.20 m bgl, 69.6m OD) which is located in between the roads leading to the southern arm of the eastern roundabout. Across all sections, there was no significant variation in composition from that described during the recent investigation.

6.1.1.4. Cohesive Made Ground

During the 2021 GI, Made Ground (Cohesive) was encountered in a total of 16 exploratory holes across all sections to a maximum depth of 3.8 m bgl (61.21m OD) in TP008. Made Ground (Cohesive) deposits across site were variable and are described in Table 6-2

Table 6-2 - Description of Made Ground (Cohesive)

Type	Locations	Typical description	Thickness range (m)	Depth (m bgl)
Section 2	BH003, BH006, BH011, TP001, TP002, TP003, TP008, TP009, TP011, TP012, TP018, TP019 and TP020	Soft to firm slightly sandy gravelly CLAY. Gravel is subangular to subrounded fine to coarse mudstone, sandstone, siltstone and coal.	0.5-3.88	0.0-4.0
Section 3	BH019, BH020, BH021, TP015	Firm to stiff sandy gravelly CLAY. Gravel is angular to subrounded fine to coarse of mudstone, sandstone and brick fragments.	0.05-2.7	0.2-3.5

6.1.1.5. Mine workings

Evidence of historical mining activity was encountered in the 2021 GI and is summarised in Table 6-3. The depth of the workings correlates with historical GI information which is further interrogated in the coal mining risk assessment produced by Atkins in May 2021 [10].

Evidence of historical mining activity at the site broadly fell into three categories:

1. Probable shallow underground coal workings
    - Probable shallow underground workings were encountered within BH002 to BH007 inclusive, and were generally defined by competent rock above and below a unit of non-intact disturbed material. The disturbed material generally included fragmented bedrock recovered as a soft to firm gravelly clay often containing coal fragments and commonly with a thin residual layer of coal above the floor of the suspected former working.
2. Localised surface extraction of shallow coal or crop mining
    - Evidence of workings encountered in BH012A and TP020 are considered to be surface extraction of shallow coal subcropping at this location as indicated on the geological map.
3. Deposits associated with historical underground mining or excavation within the local area
    - The material encountered within TP002, TP003, TP009, TP018 and TP019 took the form of variably weathered often iron stained angular gravel of siltstone and mudstone assumed to be of the Pennine Middle Coal Measures formation, lying directly on top of bedrock. The gravel contained frequent large coal fragments and intact tabular coal with occasional pyrite. The material is not considered to be associated with surface extraction of coal as there is no coal seam indicated to subcrop near surface within these areas. The material may however be associated with underground extraction of coal within the local area, or, excavation of nearby features such as the Brook Lane cutting and railway cutting.

Table 6-3 - Description of material recovered from potential mine workings

Locations	Typical description	Thickness (m)	Depth range (m bgl)
1. Probable shallow underground mine workings			
BH002	Very weak to weak MUDSTONE recovered as clayey gravel of mudstone and occasional coal	3.1	8.20-11.30
BH003	Extremely weak MUDSTONE	2.7	8.40-11.10
BH004	Extremely weak MUDSTONE, recovered as a gravelly clay with occasional brown staining	2.4	11.6-14.0

BH005	Weak to extremely weak COAL and MUDSTONE	5.7	11.10-16.8
BH006	Extremely weak COAL and grey MUDSTONE	4.9	8.7-13.6
BH007	Weak to moderately weak MUDSTONE and COAL with carbonaceous lenses	3.1	8.7-11.8
2. Probable surface extraction of shallow subcropping seam			
BH012A	Extremely weak COAL and grey MUDSTONE with occasional carbonaceous lenses	2.8	2.2-5.0
TP020	Dark grey very gravelly slightly silty fine to coarse sand. Gravel is angular to subangular fine to coarse of mudstone and coal. Occasional pockets (up to 300mm) of soft greyish brown clay	2.00	2.0-4.0
3. Deposits associated with historical underground mining and extraction within the local area			
TP002	Grey mottled orangish brown slightly sandy slightly silty angular to subangular fine to coarse gravel of mudstone and coal	0.5	3.0-3.5
TP003	Brownish grey sandy clayey angular to subangular fine to coarse gravel of mudstone, coal and pyrite	2.0	2.0-4.0
TP009	Orangish brown mottled grey sandy slightly silty angular to subangular fine to coarse gravel of mudstone, coal and pyrite	1.1	2.3-3.2
TP018	Brown slightly sandy gravelly clay. Gravel of mudstone, coal and pyrite. High cobble content of tabular coal.	3.35	0.35-3.70
TP019	Grey mottled orangish brown sandy clayey angular to subangular fine to coarse gravel of mudstone and coal.	1.80	2-3.2

A Mott MacDonald PSSR [31] reports the following; however, this secondary information source was incomplete during Atkins' review as several plans were missing:

"Historical ground investigation works undertaken as part of the then A5225 Scheme identified a number of potential mine workings in the form of voids, loose drilling and loss of flush, suggesting that in areas, collapse of old workings may have already taken place. Indicators of former workings were encountered at depths of between 2.3–10mbgl. Evidence of workings was encountered at greater depth, 17.7m bgl, in one borehole (BH210). None of the boreholes were sunk deeper than 30m below ground level and hence deep workings and seams were not penetrated"

6.2. Opencast Backfill

Backfill associated with the former Pemberton Colliery and later opencast workings were encountered in Section 3 during the 2021 GI and is described in Table 6-4.

Table 6-4 - Description of Made Ground (Cohesive)

Locations	Typical description	Thickness (m)	Depth (m bgl)
BH022	Firm grey silty gravelly clay with a low cobble content. Gravel is angular, fine to coarse of mudstone, sandstone and coal	3.3	0.1-3.4

BH022	Extremely weak black coal (opencast backfill).	3.4	4.4
BH022	Extremely weak to weak grey mudstone with bands of clay, recovered as slightly sandy slightly gravelly clay (opencast backfill)	4.4	7.7

Borehole 22 appears to be located within an area of backfilled opencast, however the historical plans are unclear with respect to the extent of the former opencast.

6.2.1. Superficial Deposits

6.2.1.1. Glacial Till

The Glacial Till deposits are generally described as '*firm to stiff brown slightly gravelly sandy clay'* and were encountered in both Section 2 and 3.

The maximum recorded thickness of the unit was 4.3 m within BH005. The glacial till directly overlies the Pemberton Rock, Pennine Lower Coal Measures and Pennine Middle Coal Measures. Gravel generally comprises mudstone, siltstone and sandstone.

Granular bands were encountered within the Glacial Till (Cohesive) unit comprising loose to dense slightly clayey fine to coarse gravel of mudstone and sandstone. The bands were encountered in Section 2 from a depth of 0.1-3.40m bgl (74.69 – 64.54m OD). A summary of the superficial deposits is presented in Table 6-5.

Table 6-5 - Description of superficial deposits

Section	Locations	Typical description	Thickness range (m)	Depth (mBGL)
2	BH002, BH003, BH004, BH005, BH007, BH010, BH011, BH012A, BH013, BH014, TP001, TP004, TP006, TP007, TP010, TP013, TP016, and TP017	Soft to firm grey slightly gravelly CLAY. Gravel is subangular to subrounded fine to coarse of mudstone, siltstone and sandstone.	0.3-3.6	0.0-3.3
3	BH020, BH021, TT001 and TP015	Firm to stiff brown mottled grey gravelly sandy CLAY. Gravel is angular to subangular fine to medium of mudstone, siltstone and coal.	0.5-1.5	1.8-4.0

During previous investigations Glacial Till deposits were encountered at a similar depth across all sections, and there was no significant variation in composition from those described during the recent investigation.

6.2.2. Bedrock

The bedrock encountered along the alignment comprised sandstone, mudstone, and siltstone of the Pennine Lower Coal Measures (PLCM), Pennine Middle Coal Measures (PMCM), the Pemberton Rock and the Ravenhead Rock.

Table 6-6 - Description of bedrock deposits

Section	Section	Location	Typical description	Thickness range (m)	Depth (mBGL)
Weathered PLCM	2	BH002, BH003, BH004, BH005, BH006, BH007, BH011, BH014, BH016, TP004, TP009, TP010, TP012, and TP017	Extremely weak sandy gravelly slightly clayey MUDSTONE/SAND with a medium cobble content. Gravel of sandstone, mudstone and siltstone	0.1-2.72	0.95 – 4.20
PLCM			Weak to moderately weak light grey MUDSTONE with occasional bands of coal	>10.95	2.7 - 19.90 (Depth not proven)

			and black carboniferous clasts		
Weathered Pemberton Rock	2	BH015, BH016, TP013 and TP014	Extremely weak light brown mottled light grey SANDSTONE, recovered as clayey sand/gravel	0.7-1.1	0.4 - 2.00
Pemberton Rock			Weak to moderately weak grey fine to coarse SANDSTONE. Discontinuities are sub horizontal to inclined, closely to medium spaced, rough, clean	>17.1	2.90 - 24.10 (Depth not proven)
Cohesive material associated with potential fault zone	3	BH025	Firm to stiff sandy gravelly CLAY with low cobble content of sandstone. Gravel is fine to coarse of mudstone, siltstone, sandstone with fragments of coal	7.10	0.2 - 7.30
Weathered Raven Head Rock	3	BH017, BH019, and BH024	Soft greyish brown very gravelly CLAY/ Extremely weak brownish grey MUDSTONE, recovered as sandy gravel	0.40-1.4	1.5 - 4.5
Ravenhead Rock	3	BH017, BH019, BH024, and BH025	Weak to moderately weak grey fine to coarse grained SANDSTONE. Discontinuities are randomly orientated and extremely close to closely spaced.	>22.4	2.00 - 23.45 (Depth not proven)
Weathered PMCM	3	BH020, BH021, BH022	Extremely weak grey MUDSTONE/SANDSTONE	1.8-2.20	2.4 -6.60
PMCM	3		Weak to medium strong grey and brown fine grained MUDSTONE and SANDSTONE	>10	3.80 – 17.10 (Depth not proven)

6.2.3. Groundwater recorded during the 2021 investigation

Groundwater encountered during the recent ground investigation is summarised in Table 6-7 and Table 6-8. Groundwater strikes were not recorded within bedrock due to the use of water flush during drilling. In Section 3, groundwater was encountered in historical exploratory hole SD50SW125 at a depth of 15.40m bgl within the Weathered Pennine Lower Coal Measures and is noted as having a ‘rapid inflow’.

Table 6-7 - Summary of groundwater strikes in Section 2 during the 2021 ground investigation

Exploratory hole	Depth of water strike (m bgl)	Deposit	Water level after 20 min (m bgl) (Potentiometric surface)	Total rise in 20 mins (m)
BH002	1.8	Glacial Till	1.70	0.10
BH005	1.5	Glacial Till	1.10	0.40
BH005	2.5	Glacial Till	1.90	0.60
BH014	1.1	Made Ground (Granular)	0.90	0.20

TP001	0.8	Topsoil	No rise
TP003	2.2	Topsoil	No rise
TP007	4	Glacial Till	No rise
TP008	3.5	Topsoil	No rise
TP009	3	Topsoil	No rise
TP011	1	Topsoil	No rise
TP012	1.1	Topsoil	No rise
TP017	1.2	Topsoil	No rise
TP018	0.2	Topsoil	No rise
TP020	2.1	Topsoil	No rise

Table 6-8 - Summary of groundwater strikes in Section 3 during the 2021 ground investigation

Exploratory hole	Depth of water strike (m bgl)	Deposit	Water level after 20 min (m bgl) (Potentiometric surface)	Total rise in 20 mins (m)
BH020	3.70	Weathered Pennine Middle Coal Measures	3.60	0.10
TP015	1.80	Topsoil	No rise	

6.2.4. Groundwater levels

Groundwater levels have been monitored on five occasions during the monitoring regime by a Geotechnics Ltd engineer. The groundwater levels recorded are summarised in Table 6-6.

Table 6-9 - Summary of groundwater levels during Geotechnics monitoring rounds

Exploratory hole	Well screen range (m bgl)	Screened Deposits	Water Depth (m bgl)						
			25/03/2021	19 - 21/04/2021	06/05/2021	12 - 14/05/2021	03/06/2021	Min	Max
BH002	0.50 to 4.00	Glacial Till (Clay)	0.80	1.20	1.23	0.78	0.97	0.78	1.23
BH003	0.30 to 2.80	Made Ground	1.79	1.82	1.80	n/a	1.80	1.79	1.82
BH004	0.50 to 2.30	Glacial Till (Clay and Sand)	1.70	1.70	1.70	n/a	1.83	1.70	1.83
BH005	0.50 to 3.00	Glacial Till (Clay) and Mudstone	1.46	1.84	1.81	1.10	1.58	1.10	1.84
BH006	3.50 to 15.00	Mudstone and Coal	9.61	9.82	9.82	n/a	9.65	9.61	9.82
BH007	0.50 to 4.00	Glacial Till (Clay) and Mudstone	n/a*	3.15	2.95	n/a*	n/a*	2.95	3.15
BH010	1.50 to 3.50	Glacial Till (Clay)	1.10	1.20	1.15	1.10	1.11	1.10	1.20
BH011	1.30 to 3.30	Glacial Till (Clay) and Mudstone	Dry	Dry	Dry	n/a	Dry	Dry	Dry
BH012A	2.00 to 4.90	Coal and Mudstone	Dry	Dry	Dry	n/a	n/a	Dry	Dry
BH013	1.40 to 2.90	Glacial Till (Clay and Gravel)	2.04	2.23	2.20	n/a	2.08	2.04	2.23
BH014	1.00 to 3.00	Made Ground	1.46	1.61	1.59	n/a	1.47	1.46	1.61
BH015	2.00 to 4.90	Glacial Till (Gravel) and Sandstone	Dry	Dry	Dry	n/a	Dry	Dry	Dry
BH016	1.00 to 13.00	Glacial Till (Gravel) and Sandstone	8.53	8.70	8.65	n/a	n/a	8.53	8.70
BH017	1.00 to 13.00	Glacial Till (Clay and Sand) and Mudstone	6.85	6.97	7.10	7.13	7.00	6.85	7.13
BH019	1.00 to 13.00	Glacial Till (Clay) and Mudstone	n/a	4.48	4.50	4.41	4.47	4.41	4.47
BH020	2.00 to 5.00	Glacial Till (Clay) and Sandstone	3.40	3.60	3.61	2.85	2.86	2.85	3.61
BH021	0.50 to 2.00	Made Ground and Glacial Till (Clay)	0.90	1.11	1.10	1.12	0.88	0.88	1.12
BH022	3.40 to 8.00	Coal and Mudstone	n/a	3.76	3.79	n/a	3.70	3.70	3.79
BH024	0.50 to 2.50	Glacial Till (Clay) and Mudstone	1.59	1.97	1.87	n/a	1.88	1.59	1.97
BH025	1.00 to 6.60	Glacial Till (Clay)	0.60	0.90	0.44	0.92	0.55	0.44	0.92

*Geotechnics note protective cover could not be opened.

Based on water level data obtained during excavation/drilling and subsequent monitoring visits, the following hydrogeological regime is considered likely to be present:

Groundwater within the superficial deposits (Glacial Till);

Groundwater within Bedrock.

Groundwater levels across the site remained constant during all monitoring rounds.

6.3. Ground Gas Monitoring Results

Four rounds of ground gas monitoring have been undertaken by a Geotechnics Engineer from the installed monitoring wells. Details of the pressure trends of the monitoring rounds undertaken are presented in Table 6-12 below. The results are summarised in Table 6-9, with maximum or minimum concentration values and steady flows taken from across the whole monitoring period presented. A ground gas risk assessment is presented within Section 7.5.

Table 6-10 - Ground Gas Monitoring Pressure Trends

Monitoring Round	Pressure	Trend
15/03/2021	1006	Falling
19/04/2021	1012	Falling
06/05/2021	999	Rising
03/06/2021	1013	Falling

Table 6-11 - Summary of ground gas results from the Geotechnics monitoring

Exploratory Hole	Flow (l/hr)		Methane (% v/v)		Carbon Dioxide (% v/v)		Oxygen (% v/v)		Max hydrogen sulphide (ppm)	Max carbon monoxide (ppm)	Deposits Screened	Response Zone flooded? (no. visits)
	Max	Max steady	Max	Max steady	Max	Max steady	Min	Min steady				
BH002	<0.1	<0.1	<0.1	<0.1	4.80	4.20	13.70	13.70	<0.1	1	Clay	N
BH003	<0.1	<0.1	<0.1	<0.1	6.90	6.90	13.80	13.80	<0.1	1	Made Ground	N
BH004	<0.1	<0.1	<0.1	<0.1	2.10	2.10	0.80	0.80	1	1	Clay and Sand	N
BH005*	<0.1	<0.1	<0.1	<0.1	3.20	2.10	18.20	18.20	1	<0.1	Clay and Mudstone	N
BH006	<0.1	<0.1	<0.1	<0.1	3.90	3.90	10.70	10.70	<0.1	<0.1	Mudstone and Coal	N
BH007*	<0.1	<0.1	<0.1	<0.1	10.50	10.50	0.80	0.80	<0.1	3	Clay and Mudstone	N
BH010	<0.1	<0.1	0.1	0.1	1.00	0.50	19.50	19.50	1	<0.1	Clay	Y (3)
BH011	<0.1	<0.1	<0.1	<0.1	8.30	8.00	3.30	3.30	1	<0.1	Clay and Mudstone	N
BH012A**	<0.1	<0.1	<0.1	<0.1	4.00	4.00	6.70	6.70	1	<0.1	Coal and Mudstone	N
BH013	<0.1	<0.1	0.1	<0.1	3.20	2.80	16.10	16.10	1	1	Clay and Gravel	N
BH014	0.1	0.1	<0.1	<0.1	3.20	2.80	17.90	17.90	1	1	Made Ground	N
BH015	<0.1	<0.1	<0.1	<0.1	1.10	1.10	19.50	19.50	<0.1	1	Gravel and Sandstone	N
BH016**	<0.1	<0.1	<0.1	<0.1	1.30	1.30	19.10	19.10	1	1	Gravel and Sandstone	N
BH017	<0.1	<0.1	<0.1	<0.1	1.30	0.80	19.30	19.30	1	2	Clay, Sand and Mudstone	N
BH019**	0.1	0.1	0.1	<0.1	8.60	8.60	6.30	6.30	1	<0.1	Clay and Mudstone	N
BH020	<0.1	<0.1	<0.1	<0.1	1.40	1.40	18.90	18.90	1	7	Clay and Sandstone	N
BH021	<0.1	<0.1	<0.1	<0.1	3.30	3.30	17.40	17.40	<0.1	2	Made Ground and Clay	N
BH022**	<0.1	<0.1	<0.1	<0.1	3.50	2.40	18.60	18.60	<0.1	0	Coal and Mudstone	Y (2)
BH024	<0.1	<0.1	<0.1	<0.1	1.00	0.80	19.70	19.70	<0.1	1	Clay and Mudstone	N
BH025	<0.1	<0.1	<0.1	<0.1	0.70	0.40	19.90	19.90	1	2	Clay	Y (3)

*Measured on two occasions

**Measured on three occasions

6.4. Olfactory and Visual Records of Contamination

6.4.1. Soils

The majority of exploratory holes across the site encountered Made Ground which included ash, concrete, brick, glass, plastic, ceramic and coal. A summary of the other records of contamination observed during ground investigations undertaken at the site are summarised in Table 6-11 below.

Table 6-12 - Summary of visual/olfactory records of contamination

Exploratory Holes	Depth (m bgl)	Strata	Record of contamination
TP002	0.10 to 0.50	Made Ground	Strong organic odour
TP015	0.80 to 3.00	Made Ground	Slight organic odour
	3.50 to 4.00	Clay	Slight organic odour
TP019	2.00 to 3.80	Made Ground	Strong hydrocarbon odour
BH014	0.50 to 3.10	Made Ground	Clinker
TP001	0.40 to 1.00	Made Ground	Clinker

No other visual or olfactory signs of contamination were recorded during any of the phases of ground investigation.

6.4.2. Soil Vapour Headspace Results for Soils

Photo-ionisation detector (PID) screening for volatile organic compounds (VOCs) was conducted on environmental soil samples during the ground investigation. The photo-ionisation (PID) tests conducted in the field did not record VOC levels of concern, with concentrations consistently measured below the limit of detection (<0.1 ppm) with values ranging from <0.1 ppm to 0.8 ppm.

Soil samples which were not subjected to PID screening in the field (12 samples from five locations including BH013, BH014, BH012A, TP007 and TP008) due to an instrument not being available on site, underwent laboratory analysis for volatile organic compounds as a substitute analysis to check for potential VOC contamination. No elevated concentrations were recorded.

6.5. In-situ Geotechnical Testing

6.5.1. Standard Penetration Tests

A total of 76 Standard Penetration Tests (SPTs) were performed at various depth intervals across the site during the 2021 GI, and a total of 105 SPTs were recorded within the historical exploratory holes. A summary of the SPT results for the various strata is given in Table 6-13. A plot of SPT 'N60' value against depth is provided in Appendix E. The general trend of the SPT plots shows increasing SPT N60 values with depth. There are the occasional anomalous values where a soft pocket or gravel/cobbles may have been encountered.

Table 6-13 – Standard Penetration Test data

Strata	No of Tests	SPT 'N60' Value		
		Minimum	Maximum	Average
Made Ground (Granular)	4	0	26	16.8
Made Ground (Cohesive)	6	2	18	10
Glacial Till	11	4	49 (54)	21.6
Weathered PLCM	8	50	50+	50+
PLCM	11	16	50+	50+
Potential Fault Zone	5	12	29	22.4
Weathered Raven Head Rock	4	13	50+	37.7
Raven Head Rock	5	28	50+	45.6
Mine workings	7	16	50+	29.4
Opencast backfill	4	11	50+	40.3
Weathered PMCM	3	4	50+	34.7
PMCM	2	50+		
Weathered Pemberton Rock	5	24	50+	40
Pemberton Rock	1	50+		

6.5.2. Hand vane tests

A total of 23 hand shear vane tests were undertaken during the 2021 GI. The results are summarised in Table 6-14.

Table 6-14 – Summary of hand shear vane tests

	Exploratory Holes	Number of tests	Depth range	Shear strength kN/m2
Made Ground (Cohesive)	TP002, TP003, TP018, TP019, and, TP020	16	0.50-2.00	49-76
Glacial Till	TP010	4	0.5-1.80	42-71
Mine workings	TP019	1	2.00	52
Opencast Backfill	TP018	2	0.5-1.00	64-67

6.5.3. Soakaway tests

A total of 6 soakaway tests were carried out during the 2021 GI and are summarised in Table 6-14. The tests were generally carried out in accordance with BRE Digest 365 "Soakaway Design", 2016. However, due to slow soakage the tests were not repeated three times at each location.

Table 6-15 – Summary of hand shear vane tests

Ground Investigation	Number of tests	Depth range	Infiltration rate
TP003	1	4.00	N/A*
TP014	1	2.70	8.82E-005
TP014	1	2.20	1.15E-004
TP015	1	4.00	N/A*
TP019	1	3.80	-2.83E-005
TP020	1	0.90	-2.36E-005

*it was not possible to calculate the infiltration rate due to insufficient change in effective head in TP003 and TP015.

6.6. Laboratory soil and rock testing

The following laboratory testing was undertaken in accordance with BS 1377: Part 2: 1990. For the detailed information and full results of each test refer to the ground investigation factual report, Geotechnics Ltd, 2021 which is presented in Appendix B. The data below summarises the results.

6.6.1. Moisture content

A total of 54 moisture content tests have been conducted as part of the ground investigation. A summary of these results can be seen in Table 6-16. A plot of moisture content against depth is given in Appendix E.

Table 6-16 - Moisture content of strata from laboratory data Section 2

Strata	No of Tests	Moisture Content (%)		
		Minimum	Maximum	Average
Made Ground (Cohesive)	19	13	26	21.6
Made Ground (Granular)	1	33		
Glacial Till	28	14	39	19.6
Weathered PLCM	2	22	24	23
Ravenhead Rock (Weathered)	1	18		
Potential Fault Zone	1	14		
Mine workings	1	12		
Opencast Backfill	1	21		

6.6.2. Atterberg Limits

A total of 54 Atterberg limit tests have been conducted as part of the ground investigation. A summary of the results of these tests is presented in Table 6-17. A plot showing plasticity index against depth is presented in Appendix E.

Table 6-17 - Consistency Limits

Stratum	No of Tests	Liquid Limit %		Plastic Limit %		Plasticity Index %	
		Min	Max	Min	Max	Min	Max

Made Ground (Cohesive) (typically a low to high plasticity clay)	20	30	59	16	26	13	33
Glacial Till (low to intermediate plasticity clay)	28	26	43	14	22	12	23
Weathered PLCM (low to intermediate plasticity clay)	2	33	38	17	19	16	19
Potential Fault Zone (*low plasticity clay*)	1	36		18		18	
Ravenhead Rock (Weathered) (*intermediate plasticity clay*)	1	33		16		17	
Mine workings	1	32		16		16	
Opencast Backfill	1	38		19		19	

6.6.3. Strength Tests

A total of twelve unconsolidated, undrained triaxial tests were undertaken by as part of the 2021 GI. A summary of the results of these tests is provided in Table 6-18. In BH019 (Section 3) one test was conducted within Ravenhead Rock (weathered), and the material was found to have an undrained shear strength of 117 kPa. In Section 4 there was one undrained shear strength from triaxial tests within Glacial Till which had an undrained shear strength of 140 kPa.

Table 6-18 - Undrained shear strength from triaxial tests Section 2

	No of Tests	Undrained Shear Strength (kPa)		
		Minimum	Maximum	Average
Made Ground (Cohesive)	1	58		
Glacial Till	9	58	140	94.12
Weathered PLCM	1	29		
Weathered Ravenhead Rock	1	117		

6.6.4. Compaction Tests

A total of 7 compaction tests have been conducted as part of the 2021 GI, all of which were undertaken in Section 2. A summary of the results of these tests is presented in Table 6-19.

Table 6-19 - Section 2 Maximum Dry Density and Optimum Moisture Content

	No of Tests	Maximum Dry Density (Mg/m^3)			Optimum Moisture Content (%)		
		Min.	Max.	Av.	Min.	Max.	Av.
Made Ground (Cohesive)	2	1.59	1.78	1.7	12	25	18.6
Glacial Till	4	1.57	1.90	1.8	7.3	22	15.7
Opencast backfill	1	1.59	1.74	1.7	13	25	19

6.6.5. CBR testing

A total of 13 remoulded CBR tests were carried out as part of the 2021 GI. A summary of the results of these tests is presented in Table 6-20 and Table 6-21.Table 6-20 –Remoulded CBR test results

Table 6-20 –Remoulded CBR test results

	No of Tests	Average CBR value (%)			Moisture Content (%)
		Min.	Max.	Av.	
Made Ground (Cohesive)	2	0.6	2.8	1.5	24-29
Glacial Till	11	0.1	6.6	2.3	16-32

Table 6-21 –CBR test results in relation to the scheme chainage

Location ID	Closest mainline chainage (approximate)	Depth Specimen Top (m)	CBR Top (%)	CBR Base (%)	Moisture Content Top (%)	Moisture Content Base (%)	Moisture Content Initial (%)
BH002	30	2	0.1	0.2	25	25	25
BH005	350	0.5	1.3	1.2	22	22	22
BH005	350	1.2	1.3	1.4	26	26	26
BH010	675	1.2	3.6	3.5	17	17	17
BH011	790	0.6	4.3	4.6	22	22	22
BH012A	1030	0.5	1.4	1.4	20	20	20
BH013	1220	0.2	1.3	1.2	26	26	26
TP006	580	0.7	1.6	1.7	18	18	18
TP007	640	1	2.4	2.2	20	20	20
TP009	840	0.7	2.1	2.8	24	24	24
TP010	910	0.5	6.6	5.4	16	16	16
TP011	1100	0.8	0.7	0.6	26	26	26
TP013	1450	0.25	1.4	1.7	32	31	31
TP015	1680	1	1.7	1.6	29	29	29

6.6.6. Moisture Condition Value / Moisture Content Relationship

One remoulded Moisture Condition Value / Moisture Content Relationship tests was carried out in BH005 (Section 2) as part of the 2021 GI. A summary of the results of this test is presented in Table 6-22.

Table 6-22 - Moisture condition value / moisture content relationship

	No of Tests	Moisture Condition Value		Moisture Content (%)	
		Min.	Max.	Min.	Max.
Glacial Till	1	4.0	11.8	11.0	20

6.6.7. Particle Size Distribution

During the 2021 GI, 33 PSD tests were undertaken in Section 2 (29 tests) and Section 4 (4 tests). No PSD tests were undertaken in Section 3.

Based on the PSD data collected during the investigation a typical description can be made for the following units:

- Made Ground (Granular): “fine to coarse silty gravelly sand with cobbles”
- Open cast backfill: “slightly clayey sandy gravel with cobbles”
- Mine workings (where granular): “slightly clayey, silty, sandy gravel”
- Weathered PMCM: “gravelly sandy clay/silt”
- Weathered PLCM: “clayey gravelly sand/silt with cobbles”
- Weathered Pemberton rock: “slightly silty sandy gravel with cobbles”.

6.6.8. Rock density tests

A total of 9 rock density tests were undertaken in the 2021 GI. The results are summarised in Table 6-23.

Table 6-23 – Rock porosity and density tests

	Exploratory Hole	Number of tests	Section	Depth	Dry Density (kg/m^3)	Bulk Density (kg/m^3)
Pemberton Rock	BH015, and BH016	2	2	10.56 - 12.00	24- 24.5	23- 25
Raven Head Rock	BH017, BH024, and BH025	7	3	4.75- 14.40	21-25.5	23-27

6.6.9. Rock strength testing

A total of 9 Unconfined Compressive Strength (UCS) tests and 72 Point Load tests were carried out on samples of rock obtained from exploratory holes across site. The results of the testing are presented in Table 6-24 and Table 6-25.

Table 6-24 - UCS test results

	Exploratory Hole	Number of Tests	Moisture Content (%)		UCS (MPa)	
			Min.	Max.	Min.	Max.
Pemberton Rock	BH015 and BH016	2	4.8	5.0	16.5	19.3
Ravenhead Rock	BH017, BH024, and BH025	6	2.7	5.1	6.00	31.9
Potential fault zone	BH025	1	9.4		0.83	

Table 6-25 - Point Load test results

	No of Tests	Point load strength index Is(50)		UCS (MPa)***
		Min.	Max.	
Pennine Lower Coal Measures*	19	0.13	4.81	2.86 - 105.82
Pemberton Rock	12	0.20	1.36	4.4 - 29.92
Ravenhead Rock	34	0.00	4.12	0-90 - 64
Pennine Middle Coal Measures**	5	0.02	1.01	0.44 - 22.22

*within the Pennine Lower Coal Measures, point load tests were carried out on samples of mudstone, siltstone, and sandstone.

**within the Pennine Middle Coal Measures, point load tests were carried out on samples of mudstone and sandstone.

***a suitable multiplication factor can be applied to the point load test results to calculate an equivalent UCS value. The results in Table 6-28 were determined by using a multiplication factor of 22 as suggested by Carter and Sneddon (1977).

7. Ground Model and Material Properties

The following section presents the ground models and provides a summary of geotechnical parameters and concrete design sulphate classification derived from laboratory and in-situ testing.

7.1. Geotechnical Properties

Geotechnical properties for each stratum are summarised in Table 7-10. These have been derived from in-situ tests, laboratory tests, published literature and soil descriptions; the methodology used to derive these are outlined in the sub-sections below and supported by plots contained within Appendix E.

7.1.1. Unit Weight

Characteristic values of unit weight have been derived from literature sources supplemented by testing results. Characteristic weight values were obtained from suggested values within Figures 1 and 2 in BS8002 with additional information gathered from Table 2.14 in Barnes (2010) [32]; values have been inferred from strata descriptions and SPT values.

Table 7-1 – Bulk Unit Weight and Dry Unit Weight

Strata	Bulk Unit Weight γ (kN/m^3)	Dry Unit Weight γ_d (kN/m^3)
Made Ground (Cohesive)	17-19	16-19
Made Ground (Granular)	18-20	16-19
Opencast backfill	17-20	16-19
Glacial Till	20-22	18-20
Potential fault zone	17-19	16-19
Weathered Bedrock	19-21	17-19
Bedrock	21-23	19-21

The unit weights given for the Glacial Till apply for both granular and cohesive material, since these are expected to be broadly similar.

7.1.2. Stiffness

Values for drained Young's modulus (E') have been derived from the SPT data using correlations such as those provided in CIRIA C143 [33] which for granular strata is conservatively calculated based on the following equation E' (MN/m^2) = SPT N and for cohesive strata E' (MN/m^2) = 0.9 SPT N (based on Stroud, 1989) [34]. These multipliers can be reviewed by the designer during detailed design if appropriate.

Values of undrained Young's modulus (Eu) have been derived from SPT data using CIRIA C143 [33] assuming a Poisson's ratio of 0.5 a conservative relationship of $E_u/N = 1.0$ is established.

The results are summarised in Table 7-2.

Table 7-2 - Summary of SPT N60, E' and Eu

Strata	SPT N60 (2021 GI)	SPT N (Historical exploratory holes)	Drained Young's modulus range, E' (MPa)	Undrained Young's modulus range, E_u (MPa)
Opencast backfill	11-50	None recorded	11-50	N/A
Glacial Till	4-50+	8-71 (50)	4-45	4-50
Weathered PLCM	50+	30-121 (50+)	50	N/A

PLCM	16-50+	12-176 (50+)	-	N/A
Weathered PMCM	50+	24-124 (50+)	50	N/A
PMCM	50+	28-90 (50+)	-	N/A
Weathered Pemberton Rock	24-50+	None recorded	24-50	N/A
Pemberton Rock	50+	None recorded	-	N/A
Potential Fault Zone	12-29	None recorded	9-26	12-29
Weathered Ravenhead Rock	13-50+	None recorded	13-50	N/A
Ravenhead Rock	28-50	None recorded	-	N/A
Weathered bedrock (overall)	13-50+	12-124 (50+)	13-50	N/A
Bedrock (overall)	16-50+	28-176 (50+)	-	N/A

A plot showing the change in stiffness with depth is provided in Appendix E.

7.1.3. Angle of shearing resistance

7.1.3.1. Granular Material

The angle of shearing resistance (Φ) for granular materials can be derived from the angularity of the particles, the uniformity coefficient and the density index of the material within the stratum, as detailed in BS8002 [10]. The angle of shearing resistance for each granular stratum was correlated using Table 1 and equations 3 and 4 in BS8002 [35].The angle of shearing resistance can also be determined by utilising the relationship between SPT and Φ established by Peck et al. 1967 [36] presented as Figure 2.13, Tomlinson, 2001 [37]. Representative angle of shearing resistance for each stratum has been calculated and presented in Table 7-3.

Table 7-3 - Angle of Shearing Resistance for Granular Material

Strata	**2021 GI SPT N**	**Angle of shearing resistance range using BS8002** (°)	**Angle of shearing resistance range using Peck et al. 1967** (°)
Made Ground (granular)	0-26	30	30
Weathered bedrock	13-50	32-36	32-36

7.1.3.2. Cohesive Material

The peak angle of shearing resistance (Φ) for cohesive materials has been derived from a relationship with the plasticity index (I_p) of the stratum stated as equation 7 in BS8002: The critical angle of shearing resistance ϕ' for the Glacial Till was derived from a relationship with the plasticity index (I_p) of the stratum stated as equation 7 in BS8002 [4]:

$$\phi_c = (42° - 12.5 \log_{10} I_p)$$

The peak angle of shearing resistance can be calculated by accounting for the soil dilatancy (adding 0-4° depending on over-consolidation). A soil dilatancy of 2° has been assumed for Glacial Till. The critical and peak angles of shearing resistance calculated are listed in Table 7-4 below.

The weathered mudstone is assumed to behave as a high strength clay. CIRIA C181 suggests a plasticity index of between 12-19% for weathered mudstone in the coal measures.

Table 7-4 - Angle of Shearing Resistance for Cohesive Material

Strata	Plasticity index range (%)	Critical angle of shearing resistance range (°)
Made Ground (Cohesive)	13-33	23 - 28
Glacial Till	12-23	25 - 29
Potential Fault Zone	17	27
Weathered bedrock	16-19	27 - 29

7.1.4. Undrained Shear Strength

A total of twelve unconsolidated, undrained triaxial tests were undertaken by as part of the 2021 GI. A summary of the results of these tests is provided in Table 7-5.

Table 7-5 - Undrained shear strength from triaxial tests

	Number of tests	**Moisture content**	**Undrained shear strength (kPa)**		
			Minimum	**Maximum**	**Average**
Made Ground (Cohesive)	1	19	58		
Glacial Till	9	13 -19	62	280	199
PLCM Weathered	1	24	58		
Ravenhead Rock Weathered	1	18	234		

A total of 23 hand shear vane tests were undertaken during the 2021 GI. The results are summarised in Table 7-6.

Table 7-6 - Undrained shear strength from hand shear vane tests

	Exploratory Holes	Number of tests	Depth range	Shear strength kN/m^2
Made Ground (Cohesive)	TP002, TP003, TP018, TP019, and, TP020	19	0.50 - 3.8	49 -76
Glacial Till	TP010	4	0.5 - 1.80	42 - 71

Additionally, an estimation of the undrained shear strength (c_u) of the cohesive material has been calculated using the Stroud and Stroud & Butler expression:

$$c_u = f_1 \times N_{60}$$

The value of f_1 in this equation is correlated from the plasticity index of the soil. The weathered rock is assumed to act as a clay and so in line with CIRIA 143, the c_u has been estimated by multiplying the N60 value by 5.

CIRIA C181 [6] suggests an undrained shear strength of between 15-335 kN/m^3 for weathered mudstone in coal measures.

The results obtained from the SPT tests are given in Table 7-7.

Table 7-7 - Undrained Shear Strength from SPTs

Strata	SPT N60 (2021 GI)	f_1	Multiplication factor	Undrained Shear Strength (kPa)
Made Ground (Cohesive)	2-21	4.5	N/A	9-90
Opencast backfill	11-50	4.5	N/A	50-225
Glacial Till	4-50	4.5	N/A	20-225
Weathered Pemberton Rock	24-50	N/A	5	120-250
Potential Fault Zone	12-29	4.5	N/A	54-130
Weathered Ravenhead Rock	13-50	N/A	5	65-250
Weathered PMCM	50	N/A	5	250
Weathered bedrock (overall)	13-50	N/A	5	65-250

7.1.5. Solid Core Recovery and Rock Quality Designation

The solid core recovery (SCR) values and the rock quality designation (RQD) ranges are presented in Table 7-8. The RQD of the bedrock typically increases with depth.

Table 7-8 – SCR and RQD summary for bedrock

Stratum	Rock type	SCR range (%)	RQD range (%)	RQD Average (%)
PLCM	Mudstone	0-100	0-83	26
	Siltstone	9-100	0-83	29
	Sandstone	22-100	0-90	28
	Coal	48-69	0	0
Pemberton Rock	Mudstone	86-96	68-92	80
	Siltstone	26-96	7-92	53
	Sandstone	0-100	0-91	58
Ravenhead Rock	Mudstone	0-80	0-63	31
	Siltstone	0-100	0-76	29
	Sandstone	10-96	0-92	42
PMCM	Mudstone	37-83	0-35	7
	Sandstone	0-100	0-50	19

7.2. Excavatability

A Trial Excavation (TT001) was undertaken after completion of the ground investigation in Section 3 of the scheme for the main purpose of investigating the excavatability of rock. The excavation was completed using a 21 Tonne 360 excavator (SY215c) to a depth of 5 m bgl, Groundwater was not encountered. The findings of the excavation are included within the Geotechnics Ltd. factual report and are presented in Table 7-9:

Table 7-9 Trial Excavation summary

Typical description	Thickness range (m)	Depth (m bgl)
Grass over TOPSOIL: Soft dark brown sandy clay with many rootlets.	0.25	0.0-0.25
Firm to stiff CLAY Gravel is angular to subangular fine to coarse of mudstone and sandstone (possible Glacial Till)	1.45	0.25-1.70
Extremely weak to weak MUDSTONE. Recovered as gravel. (Weathered bedrock)	2.00	1.70-3.70
Extremely weak to weak bluish grey thinly bedded fine grained SANDSTONE. Recovered as angular fine to coarse gravel and cobbles. (Ravenhead Rock) (Assessed as weak to medium strong by Atkins Site Engineer).	1.30	3.70-5.00

7.2.1. Characteristic geotechnical properties

The characteristic geotechnical properties for the strata encountered are presented in Table 7-10.

Table 7-10 - Summary of Characteristic Geotechnical Properties

Stratum	γ (kN/m^3)	c_u (kN/m^2)	Angle of shearing resistance, ϕ' (°)	Eu (MPa)	E' (MPa)	UCS (MPa)
Made Ground (Cohesive)	19-21	-	23-25	18-21	18	-
Made Ground (Granular)	17-19	-	28-30	-	19-21	-
Opencast backfill	17-20	70	22-24	-	24-27	-
Glacial Till	19-21	70-75	27-29	20-44	11-31	-
Potential Fault Zone	17-19	60-70	25-27	18-22	20-24	-
Pemberton Rock	21-23	-	28-30	-	28-45	19-24
Weathered Pennine Lower Coal Measures	19-21	-		-	24-32	-
Pennine Lower Coal Measures	21-23	-	28-30	-	-	17-20
Weathered Pennine Middle Coal Measures	19-21	-	27-29	-	24-32	-
Pennine Middle Coal Measures	21-23	-	28-30	-	-	15-19
Weathered Ravenhead Rock	19-21	-	27-29	-	24-32	-
Ravenhead Rock	21-23	-	28-30	-	-	17-40

7.2.2. Preliminary ground models

The tables below provide preliminary ground models for the two proposed main structures along the alignment. These are:

- retaining wall proposed at Brook Lane, and the
- offline Pemberton Bridge Structure.

A.1.1.1. Retaining wall at Brook Lane

The proposed retaining wall is located at 354512 (X), 404234 (Y), in Pemberton, Wigan. The proposed M58 Link Road highway alignment crosses the existing Brook Lane, which runs north to south. Brook Lane is an unclassified non-surfaced track constructed in cutting. The existing Brook Lane will be terminated where the Link Road intersects it. Hall Lane and associated properties, which were previously accessed from Brook Lane, will be connected directly to the new Link Road via a new junction further to the west. The proposed retaining wall will be 16 m in length, between chainages 471 and 487 on the proposed link road. The wall will be on the south side of the proposed Link Road and will be parallel to the carriageway.

Following a review of stratigraphy identified within draft logs from the 2021 GI boreholes and the historical BGS boreholes, a preliminary ground model has been determined for the Brook Lane site area and is presented in Table 7-11.

Table 7-11 - Preliminary ground model for Brook Lane

Stratum	Exploratory holes encountered	General Material Description	Top Depth Range (m BGL)	Top Depth Range (m OD)	Thickness Range (m)
Topsoil	TP004, BH006, BH007, SD50SW142, SD50SW125	Dark brown silty fine to medium sand with many rootlets.	0.0	73.39 - 74.9	0.1-0.55
Cohesive Made Ground	BH006	Soft brownish grey slightly gravelly sandy CLAY.	0.1	74.8	0.4
Glacial Till	TP004, BH006, BH007, SD50SW142, SD50SW125	Soft to stiff reddish brown mottled grey CLAY	0.3 - 0.55	73.6 - 73.08	0.65 - 2.35
PLCM	TP004, BH006, BH007, SD50SW142, SD50SW125	Weak to moderately weak light grey MUDSTONE with occasional bands of coal and black carboniferous clasts	0.95 - 2.5	72.44 - 71.1	>28.5 (thickness not proven)
Mine workings	BH006, BH007, SD50SW125	Weak grey fragmented MUDSTONE recovered as clayey GRAVEL with occasional bands of coal and fragments of carbonaceous mudstone	7.0 - 8.7	67.0 - 66.1	3.1 - 4.9

A.1.1.2. Pemberton Bridge structure

The proposed bridge will be located at 355535 (X), 403933 (Y), in Pemberton, Wigan and comprise a single skew-span of 35 m (21.1 m square span). The proposed M58 Link Road alignment will cross the railway connecting Leopold Street (to the north) to Billinge Road (to the south) and is circa 150 m south-west of Pemberton Railway Station. The proposed bridge will be at the site of an existing masonry arch footbridge, Highfield bridge (WKL2/27), which is located at chainage 19m 725yds on the WKL2 railway line and will require demolition prior to construction of the new bridge. At this location the railway corridor is constructed in cutting, with the track level approximately 7.5 m below the crest of the cutting slopes, which are spaced approximately 32 m apart. The cutting slopes are densely vegetated along the railway corridor and have varying slope profiles with angles ranging between 20° and 45°

Planned borehole BH018 on the southern side of the railway near the footprint of the proposed bridge foundations could not be drilled due to service and utility constraints and therefore ground investigation data is limited in this area. Boreholes could not be drilled within the footprints of the proposed foundations on either side of the bridge as the foundations will be within the slopes of the rail cutting. Due to the relatively complex geology in a small area, and in particular the faulting, different rock units and engineering characteristics of these rock units, the ground conditions may vary across the Pemberton Bridge foundation location:

Following a review of stratigraphy identified within draft logs from the 2021 GI boreholes and the historical BGS boreholes, a preliminary ground model has been determined for proposed Pemberton Bridge site area and is presented in Table 7-12.

Table 7-12 - Preliminary ground model for Pemberton Bridge

Stratum	Exploratory holes encountered	General Material Description	Top Depth Range	Top Depth Range	Thickness Range
			(m BGL)	(m OD)	(m)
Topsoil	BH024, TT01 SD50SE184, SD50SE813, SD50SE814.	Grass over TOPSOIL: Dark brown slightly gravelly slightly sandy CLAY. Gravel of mudstone, siltstone, and sandstone.	0	63.9 – 61.2	0 - 0.4
Made Ground	BH017, BH019, BH025, SD50SE184, SD50SE185, SD50SE307.	Soft and firm to stiff slightly silty clayey gravelly SAND. Gravel comprises coal fragments, ash, sandstone, mudstone, and brick fragments.	0 - 0.2	63.7 – 60.9	0.2 - 1.2
Cohesive material /Glacial Till)	BH017, BH019, BH024, BH025. TT01, SD50SE184, SD50SE185, SD50SE307, SD50SE813, SD50SE814.	Soft to firm slightly silty slightly sandy gravelly CLAY. Gravel is fine to coarse mudstone, siltstone, sandstone and coal. Organic material present.	0.2 – 0.8	63.6 - 59.7	0.2 – 1.7
Cohesive material (Potential fault zone)	BH025	Firm to stiff sandy gravelly CLAY with low cobble content of sandstone. Gravel is fine to coarse of mudstone, siltstone, sandstone with fragments of coal.	0.5	61.9	6.8
Weathered bedrock	BH017, BH019, BH024, TT01, SD50SE184, SD50SE185, SD50SE307, SD50SE813, SD50SE814.	Destructured to distinctly weathered MUDSTONE, SILTSTONE and SANDSTONE	0.5 – 1.5	62.2 – 59.2	0.5 – 2.2
Bedrock (Ravenhead Rock Formation)	BH017, BH019, BH024, BH025, TT01, SD50SE184, SD50SE185, SDSE307, SD50SE813, SD50SE814.	SILTSTONE, SANDSTONE and MUDSTONE.	2.5 – 4.0 (7.4 in BH025)	61.4 – 58.4 (55.1 in BH025)	>22.5m (Thickness not proven)

Made Ground within the Pemberton Bridge area is assumed to be removed and replaced with engineering fill.

7.3. Aggressive Chemical Environment for Concrete (ACEC)

A total of 38 soil samples were analysed for sulphates and pH Testing was conducted in accordance with BRE SD1 guidance [38].

The design sulphate and ACEC classifications have been determined in accordance with BRE SD1 for a brownfield site with pyrite and mobile groundwater conditions have been assumed.

Table 7-13 – Characteristic values from BRE SD1 testing

Strata	No. of tests	Water soluble sulphate, 2:1 water/soil extract (mg/l SO4)	Total potential sulphate (%)	pH	DS / AC Class
Made Ground (Cohesive)	3	79.25-1600*	0.06-2.31	8.1-6.52	DS-1/AC-1 *(DS-3/AC-2)
Made Ground (Granular)	2	74 -110	0.18- 0.27	6.7-6.8	DS-1 / AC-1
Glacial Till	6	11.99 –1502*	0.02 -0.51	6.69-8.25	DS-1/AC-1 *(DS-3/ AC-2)
Pennine Lower Coal Measures (Mudstone)	2	17.86 – 121.94	0.02 – 0.51	7.2 - 7.6	DS-1 / AC-1
Potential Fault Zone	1	62.92	0.03	8.07	DS-1/AC-1
Pemberton Rock	8	10.39-153	0.01	6.5-8.34	DS-1 / AC-2
Ravenhead Rock (Siltstone)	1	14.85- 29.69	0.01-0.02	8 – 8.70	DS-1 / AC-1
Ravenhead Rock (Sandstone)	4	23.94-34.55	0.03	6.9 – 8.13	DS-1 / AC-1
Pennine Middle Coal Measures (Sandstone)	2	31.60-33.54	2.3	7.78-7.80	DS-2 / AC-1

*based on a small sample size (TP004) and (BH021 and BH022) so may not be representative of the whole unit (i.e. may be linked to discreet areas of contamination). Further BRE SD1 testing may indicate a lower classification.

8. Generic Quantitative Risk Assessment

8.1. Human Health Risk Assessment

8.1.1. Introduction

A generic quantitative risk assessment (GQRA) has been carried out to assess the potential long-term risks to human health receptors in relation to the proposed development at the site and the identified key contaminants of concern. It is understood excavation arisings, including topsoil, might be reused beneath grassed verges, so soil data have been screened against generic assessment criteria (GAC) relating to a public open space (park) end use as a conservative measure.

8.1.2. Methodology

In order to identify potential contaminants of concern (CoCs), the soil analytical data has been screened against GAC, e.g. Atkins' soil screening values (SSVs) or Category 4 Screening Levels (C4SLs) derived to be protective of chronic risks to human health.

Atkins has produced SSVs based on minimal toxicological risk [39] for a variety of standard land uses at 1% soil organic matter (SOM) (sand soil type) and 6% SOM (sandy loam soil type) using CLEA v1.071 in accordance with Environment Agency guidance [40].

Based on the ratio of genotoxic PAHs to benzo(a)pyrene, the surrogate marker approach for genotoxic PAHs as set out in the C4SL Project Methodology (Contaminated Land: Application in Real Environments, 2014) has been adopted.

During the Geotechnics 2021 ground investigation, samples (43 in total) were analysed for soil organic matter (SOM). The laboratory data of the soil collected from the site indicates a geometric mean SOM of 5.70 %. Therefore, it is considered that the GAC for 6% is appropriate for use at the site.

For compounds arsenic, benzene, benzo(a)pyrene, cadmium, lead, vinyl chloride, tetrachloroethene and trichloroethylene the C4SL (based on a low level of toxicological concern) for the public open space (parks) land use at 1% SOM has been selected as the assessment criterion.

For all other constituents, where available, the SSV for public open space (parks) land use has been selected as a conservative measure for the proposed development.

Due to the nature of acute risk from cyanide, the SSV for cyanide has been based on the potential for an adult to ingest a bolus of soil contaminated with free cyanide.

Due to the nature of risk from asbestos an SSV cannot be derived using CLEA. Therefore, for generic quantitative risk assessment the limit of detection at the laboratory has been selected as the assessment criterion.

At the time of writing this report the SGV for mercury has been withdrawn and therefore the S4UL has been adopted[1].

8.1.3. Comparison of Soil Concentration Data with Generic Assessment Criteria

Soil samples retrieved as part of the 2021 Geotechnics ground investigation were tested for a range of contaminants as detailed in Section 5.6.1. A full set of analytical results are included in Appendix C. These results were compared against the GAC outlined above.

A single lead exceedance of 1680 mg/kg was recorded above the GAC of 1340 mg/kg within the sample collected from BH003 at 0.50 m bgl.

Asbestos in the form of Chrysotile, was identified within TP012 at 0.20 m bgl. Quantification indicated a concentration of <0.001 %. Asbestos was not recorded in any of the other samples analysed.

8.1.4. Human Health Risk Assessment Conclusions

The single lead exceedance recorded above is deemed to be marginal, within the same order of magnitude as the GAC, and is therefore considered unlikely to pose an unacceptable risk to human health providing it is re-used beneath hardstanding or topsoil. The single exceedance, was located within BH003 and collected from within Made Ground, is situated within an area of previously infilled land. Furthermore, this area is due to be

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covered in hardstanding following development as it is located within the centre of the proposed road, reducing the likelihood of the public coming into contact with the underlying soils. Asbestos was identified in a single sample (TP012) collected from Made Ground, which was also located within an area of previously infilled ground.

Based on the investigation data used and the assumption that topsoil will be placed across landscaped areas adjacent to the road, risks to human receptors from inhalation, ingestion and dermal contact with dusts/soils are therefore considered to be low.

8.1.5. Groundwater-derived Vapour Risk Assessment

Atkins has derived a set of Water Screening Values (WSV), using the Risk-Based Corrective Action (RBCA) Toolkit Model (GSI Environmental Inc), to allow assessment of the risk posed to human health from inhalation of vapours derived from VOCs that may be present in groundwater. The WSVs are based on a groundwater body present at 1 m bgl within a sandy soil and are available for commercial and residential receptors for a range of the most typical volatile contaminants. The commercial screening values have been deemed most appropriate for this site due to the proposed end use.

With respect to potential risks to human health from groundwater, the only relevant pathways are considered to be via vapour migration and the inhalation of indoor and outdoor vapours. Therefore, only those organic contaminants with the potential to volatilise have been considered in the assessment.

The modelling used to develop assessment criteria estimates the concentration of contaminant in the soil vapour phase which may have derived from a water source. At the vapour saturation limit, the concentration of contaminant in the vapour phase cannot increase. In some cases, the calculated assessment criteria exceed the vapour saturation limit, in such instances, theoretically, the vapour concentration will never be high enough to cause an unacceptable risk to human health for that given scenario. Those contaminants for which this is the case do not have a WSV.

No WSV exceedances were recorded within groundwater samples collected from the site.

8.2. Controlled Waters Risk Assessment

8.2.1. Introduction

The controlled waters GQRA has been undertaken to assess the potential risks posed to the identified controlled waters receptors from the migration of contaminants from potential on site sources. To assess the potential risks to the identified receptors, a comparison of soil-leachate and groundwater concentrations against pertinent Water Quality Standards (WQS) has been undertaken.

8.2.2. Methodology

The ground investigation identified that the site is underlain by Glacial Till (Unproductive Strata) with a maximum thickness of 8.80 m recorded. Glacial Till is absent in parts of the east of the scheme (BH022) with Made Ground directly overlying bedrock. Bedrock consisting of the PCLM, PMCM, Pemberton Rock and Ravenhead Rock Sandstone (Secondary A Aquifers) was encountered across the site at shallow depths. A tributary of Smithy Brook runs through the site in a north to south orientation.

The WQS for the controlled waters assessment are dependent on the nature of the receptor (as identified above). Due to the close vicinity of the presence of an unnamed stream on site and shallow depth to the underlying Secondary A Aquifer, soil leachate and groundwater results have been screened against both Environment Quality Standards (EQS) and Drinking Water Standards (DWS).

The WFD Directions 2015 presents EQSs for copper, lead, zinc, manganese and nickel that relate to the bio-availability of these metals. However, the test results for these metals relate to the dissolved concentrations. An initial screen of the test data was undertaken by comparing dissolved concentrations directly against the bio-available EQS. Where concentrations exceeded the EQS (i.e. copper and lead in soil-leachate/groundwater and nickel and zinc in groundwater) the test data, together with calcium, dissolved oxygen and pH data samples collected from Smithy Brook, were input into the Metal Bioavailability Tool (M-BAT tool) in order to calculate the bio-available concentrations for samples.

Soil derived leachate tests give an indication of the concentrations at which contaminants might leach from soil into soil pore-water and thereby migrate to groundwater and thence to surface water.

Groundwater samples provide an indication of the groundwater quality and the contaminants that could migrate and discharge into surface water.

8.2.3. Results

8.2.3.1. Soil-Leachate

Eighteen soil samples ranging in depth from 0.20 to 1.00 m bgl were scheduled for soil-leachate analysis during the 2021 Geotechnics ground investigation. Samples consisted of one Topsoil sample, 15 Made Ground and two superficial (clay) samples. All soil samples scheduled for leachate analysis were collected from the unsaturated zone.

A GQRA screening of sample results has identified contaminants above the Freshwater EQS within soil derived leachate.

Table 8-1 - Controlled Waters Soil Leachate EQS Exceedances

Constituent	Unit	LOD	GAC (mg/l)	No. of Samples	Max. Value	No. of Exceedances	Locations of Exceedances
Ammoniacal Nitrogen	Mg/l	0.01	0.20	18	4.25	13	BH014, 0.5m; BH015, 0.25m; BH020, 0.25m; TP002, 0.2m; BH022, 0.5m; TP019, 0.2m; BH010, 0.25m; TP012, 0.2m; TP008, 0.20 m; TP015, 1.0 m; TP020, 0.50 m; TP006, 0.20 m; TP004, 0.50 m
Benzo(a)pyrene	mg/l	0.000002	0.00000017	18	0.0000489	7	TP002, 0.2m; TP010, 0.2m; BH003, 0.5m; BH010, 0.25m; TP008, 0.20 m; TP020, 0.50 m; TP004, 0.50 m
Copper*	mg/l	0.0003	0.001	18	0.0279	2	TP002, 0.2m; TP019, 0.2m;
Fluoranthene	mg/l	0.000005	0.0000063	18	0.000399	9	TP002, 0.2m; TP010, 0.2m; TP009, 0.5m; BH003, 0.5m; BH010, 0.25m; TP008, 0.20 m; TP020, 0.50 m; TP006, 0.20 m; TP004, 0.50 m
Iron	mg/l	0.019	1	18	6.13	3	TP015, 1.0 m; TP020, 0.50 m; BH005, 0.25 m
Hexavalent Chromium	mg/l	0.006	0.0034	18	0.0332	4	TP001, 0.5m; BH010, 0.25m; TP020, 0.50 m; BH005, 0.25 m
Nickel*	mg/l	0.0004	0.004	18	0.0336	2	BH022, 0.5m; BH003, 0.5m
pH	pH Units	1	6-9	18	10.6	2	BH014, 0.5m; TP019, 0.2m
Sulphate	mg/l	2	400	18	2160	2	BH022, 0.5m; TP010, 0.2m
Zinc*	mg/l	0.001	0.0123	18	0.865	6	TP001, 0.5m; TP002, 0.2m; TP019, 0.2m; BH003, 0.5m; TP015, 1.0 m; TP006, 0.20 m;

*following M-BAT assessment

A GQRA screening of sample results has identified contaminants above the DWS within soil derived leachate.

Table 8-2 - Controlled Waters Soil Leachate DWS Exceedances

Constituent	Unit	LOD	GAC (mg/l)	No. of Samples	Max. Value	No. of Exceedances	Locations of Exceedances
Ammoniacal Nitrogen	Mg/l	0.01	0.39	18	4.25	7	BH014, 0.5m; TP002, 0.2m; BH022, 0.5m;

							BH010, 0.25m; TP015, 1.0 m; TP006, 0.20 m; TP004, 0.50 m
Arsenic	mg/l	0.0005	0.01	18	0.0111	1	TP015, 1.0 m
Benzo(a)pyrene	mg/l	0.000002	0.00001	18	0.0000489	4	BH010, 0.25m; TP008, 0.20 m; TP020, 0.50 m; TP004, 0.50 m
Iron	mg/l	0.019	0.2	18	6.13	9	BH020, 0.25m; TP002, 0.2m; TP019, 0.2m; TP009, 0.5m; TP008, 0.20 m; TP015, 1.0 m; TP020, 0.50 m; TP006, 0.20 m; BH005, 0.25 m
Nickel	mg/l	0.0004	0.02	18	0.0336	1	BH022, 0.5m
pH	pH Units	1	6.5-9.5	18	10.6	4	BH014, 0.5m; BH015, 0.25m; TP019, 0.2m; BH003, 0.5m
Sulphate	mg/l	2	250	18	2160	3	BH014, 0.5m; BH022, 0.5m; TP010, 0.2m

The variability of the range of concentrations of metals and PAHs within the samples collected from Made Ground and superficial deposits appear similar.

Exceedances recorded above are mainly marginal (within the same or one order of magnitude of the WQS), with the exception of benzo(a)pyrene and fluoranthene EQS exceedances.

PAH exceedances recorded are generally only marginally over the limit of detection (LOD). Based on the exploratory hole logs, the Made Ground across the site appears to be underlain by clay with limited granular deposits. The majority of exceedances recorded above are recorded in areas where Glacial Till is overlying bedrock. Cohesive deposits would slow the vertical and lateral migration of leached PAHs allowing more time for natural processes such as adsorption and biodegradation to reduce concentrations.

There is the potential if piled foundations are utilised that a new migration pathway could be created to bedrock. Proposed piles in the location of Pemberton Bridge are located where minimal exceedances have been recorded. Glacial Till is indicated to underlay Made Ground across the majority of the scheme, with the exception of BH022. Glacial Till is likely to limit the vertical migration of potential contamination to the underlying low permeability mudstone. Therefore, there is a low risk of new potential pathways being created and piling is unlikely to pose an unacceptable risk to controlled waters. The potential risk to groundwater from piles should be considered by the piling Contractor as part of their piling risk assessment (if piled foundations were needed).

Overall, it is considered unlikely that the contaminants recorded within the shallow soils would pose an unacceptable risk to controlled waters.

8.2.3.2. Groundwater

Seven groundwater samples were collected from the site between 19 and 21 April 2021 by a Geotechnics Engineer and scheduled for chemical analysis by Atkins. Samples were collected from across the scheme, however, analysis was scheduled based on findings of the GI and the location of previously identified contamination sources. Groundwater samples were collected from wells which screen superficial deposits or bedrock. A further five groundwater samples were collected during a subsequent monitoring visit undertaken between 12 and 15 May 2021 and scheduled for chemical analysis.

GQRA screening of sample results has identified contaminants above the EQS within groundwater samples.

It should be noted that the majority of VOC/SVOC concentrations were measured at or below the detection limit of the laboratory. However, a number of determinands have been recorded above the detection limit where no GAC is available, including:

Dibromofluoromethane; and

4-Bromofluorobenzene.

Table 8-3 - Summary of 2021 Groundwater Controlled Waters EQS Exceedances

Constituent	Unit	LOD	GAC (mg/l)	No. of Samples	Max. Value	No. of Exceedances	Locations of Exceedances (round of monitoring)
Anthracene	Mg/l	0.000005	0.001	12	0.000162	1	**BH019 (1) (Tc & M)**
Benzo(a)pyrene	Mg/l	0.000002	0.00000017	12	0.000217	4	**BH002 (1) (Tc)** BH017 (1) (Tc, Ts & M) BH020 (1) (Tc & S) BH019 (2) (Tc & M)
Chloride	Mg/l	2	250	12	327	2	BH010 (1) (Tc) **BH010 (2) (Tc)**
Fluoranthene	Mg/l	0.000005	0.0000063	12	0.000384	8	**BH002 (1) (Tc)** BH005 (1) (Tc & M) BH017 (1) (Tc, Ts & M) BH019 (1) (Tc & M) BH010 (1) (Tc) BH020 (1) (Tc & S) BH019 (2) (Tc & M) BH025 (2) (Tc)
Hexavalent Chromium	Mg/l	0.003	0.0034	12	0.00726	2	**BH010 (1) (Tc)** BH020 (1) (Tc & S)
Total TPH	Mg/l	0.01	0.01	5	0.021	2	BH019 (2) (Tc & M) **BH010 (2) (Tc)**

*following M-BAT assessment

**Tc = Glacial Till Clay, Ts = Glacial Till Sand, M = Mudstone, S = Sandstone

Table 8-4 - Summary of 2021 Groundwater Controlled Waters DWS Exceedances

Constituent	Unit	LOD	GAC (mg/l)	No. of Samples	Max. Value	No. of Exceedances	Locations of Exceedances
Benzo(a)pyrene	Mg/l	0.000002	0.00001	12	0.000217	3	**BH002 (1)** BH017 (1) BH020 (1)
Chloride	Mg/l	2	250	12	327	2	BH010 (1) **BH010 (2)**
Iron	Mg/l	0.019	0.2	9	0.293	1	**BH005 (2)**

Exceedances recorded within groundwater samples are for similar determinands as those recorded within soil-leachate samples, indicating that soils on site may be impacting the groundwater.

Hexavalent chromium exceedances recorded within groundwater are located in similar locations as those recorded within soil leachate samples. Other heavy metals recorded to be in exceedance of the GAC in soil leachate samples are not recorded to be exceeding within groundwater samples, including arsenic, copper, nickel and zinc.

The TPH exceedances recorded within groundwater are located within BH010 and BH019. BH010 is located adjacent to industrial/commercial premises along with a historical mine entry. BH019 is located within an area which was occupied by old railway lines. Both of these may explain the presence of TPH within the groundwater at these locations.

PAH exceedances (anthracene, benzo(a)pyrene and fluoranthene), were recorded across the site, but mainly within Section 2.

Exceedances recorded are considered to be marginal, within the same or one order of magnitude of the EQS and/or DWS and are therefore unlikely to pose an unacceptable risk.

The proposed dry swales are to be lined with an impermeable membrane, as part of the drainage strategy for the scheme, are unlikely to alter the current groundwater regime at the site. Surface water run off from the scheme, collected within the swales, is to be discharged to Smithy Brook.

It is likely that exceedances recorded within groundwater across the scheme are a result of contamination from off site sources including historical mining, industrial land uses. Contamination is likely to have leached into groundwater over time (200+ years). Overall it is unlikely that the scheme will pose an unacceptable risk to controlled waters.

8.3. Preliminary Ground Gas Risk Assessment

It is understood the scheme design does not include any buildings or enclosed structures that people could enter. Risks to construction or future maintenance workers accessing service inspection chambers, etc, should be assessed/mitigated via confined space procedures that usually include consideration of air quality. However, there are residential and commercial properties located close to the proposed scheme, and so an assessment was undertaken to gain an understanding of the ground gas recorded during the monitoring period and what potential risks might be posed if the scheme were to introduce new preferential pathways via new service trenches.

The preliminary ground gas risk assessment has been undertaken in general accordance with BS 8485:2019 code of practice for design of protective measures for methane and carbon dioxide ground gases for buildings [41]. BS8485:2019 states that hazardous gas flow rates (Qhg) should be calculated for methane and carbon dioxide for every borehole for each visit and suggests the Qhgs be presented alongside the gas monitoring results in a database (which is included in Appendix C). Qhg is calculated using the maximum gas concentration recorded (unless lower values can be justified) and the steady state flow rate using the below formula:

Qhg (l/hr) = flow rate (l/hr) x [gas concentration (%) / 100]

The Gas Screening Value (GSV) is the flow rate of a specific hazardous gas considered to be representative of a site, following assessment of all borehole concentrations and gas flow rates, whilst taking account of other influencing factors. Such factors being, for example, whether a response zone was completed flooded (which can compromise gas data), the temporal/spatial nature of the data set and the acute one-off nature of the risk.

BS8485:2019 indicates that a decision must be made to determine whether the maximum Qhg in the dataset is appropriate to represent the site (and thereby be selected as the GSV), or whether maximum gas concentrations and maximum steady state flow rates should be combined from any borehole/visit to derive a “worst case GSV”.

The GSV considered representative for the site is then used to select a Characteristic Situation (CS), which is the ground gas regime assumed for design of gas protection measures for new buildings in accordance with BS8485:2019. The GSVs and CS are presented in Table 8-5 (which is based on Table 2 in BS8485:2019).

Adopting a GSV based on peak flow measurements (i.e. those measured initially after the gas tap is opened) might result in a disproportionately high gas hazard prediction and assignment of an over-precautionary GSV and Characteristic Situation (CS), leading to overly conservative gas protection measures being incorporated into a development.

Table 8-5 - Site Characteristic GSV and Associated Characteristic Situation

CS	Hazard Potential	Site Characteristic GSV (l/hr)	Additional Factors

1	Very Low Risk	<0.07	Typical methane <1 % and/or carbon dioxide <5 %. Otherwise consider increase to Characteristic Situation 2.
2	Low Risk	<0.7	Borehole air flow rate not to exceed 70 l/hr. Otherwise consider increase to Characteristic Situation 3.
3	Moderate Risk	<3.5	-
4	Moderate to High Risk	<15	Quantitative risk assessment required to evaluate scope of protective measure.
5	High Risk	<70	-
6	Very High Risk	>70	-

BS8485:2019 does not include an approach for assessing carbon monoxide or hydrogen sulphide. The relevant Workplace Exposure Limits (WELs) as outlined within the HSE EH40/2015 (2011) document (Health and Safety Executive, 2011) have been adopted for use in a preliminary assessment of carbon monoxide and hydrogen sulphide:

- Carbon monoxide: 30 parts per million (ppm) for long-term (eight hours) exposure limit and 200 ppm for short-term (15 minutes) exposure limit.
- Hydrogen sulphide: 5 ppm for the long-term exposure limit of and 10 ppm for the short-term exposure limit.

8.3.1. Risk Assessment

8.3.1.1. Hydrogen Sulphide and Carbon Monoxide

Hydrogen sulphide concentrations were consistently measured at or below the detection limit of 1.00 ppm and recorded carbon monoxide concentrations ranged from <1.00 ppm to 7 ppm (BH020).

Concentrations recorded for both hydrogen sulphide and carbon monoxide are considerably below the WELs outlined above, and are therefore considered unlikely to pose an unacceptable risk.

8.3.1.2. Methane and Carbon Dioxide

The Qhg of each monitoring well on each visit has been calculated and is presented within the database in Appendix C. A summary using the maximum concentrations and steady state flow rates for each well is presented in Table 8-5.

Table 8-6 - Preliminary Ground Gas Risk Assessment

Exploratory Hole	Maximum Peak Carbon Dioxide (% v/v)	Maximum Peak Methane (% v/v)	Maximum Steady State Flow Rate (l/hr)	Qhg Calculated for Each Well*	Deposit/Strata Screened
BH002	4.80	<0.1**	<0.1**	0.0048	Clay
BH003	6.90	<0.1**	<0.1**	0.0069	Made Ground
BH004	2.10	<0.1**	<0.1**	0.0021	Clay and Sand
BH005*	3.20	<0.1**	<0.1**	0.0032	Clay and Mudstone
BH006	3.90	<0.1**	<0.1**	0.0039	Mudstone and Coal
BH007*	10.50	<0.1**	<0.1**	0.0105	Clay and Mudstone
BH010	1.00	0.1	<0.1**	0.0010	Clay
BH011	8.30	<0.1**	<0.1**	0.0083	Clay and Mudstone

BH012A**	4.00	<0.1**	<0.1**	0.0040	Coal and Mudstone
BH013	3.20	0.1	<0.1**	0.0032	Clay and Gravel
BH014	3.20	<0.1**	0.1	0.0032	Made Ground
BH015	1.10	<0.1**	<0.1**	0.0011	Gravel and Sandstone
BH016**	1.30	<0.1**	<0.1**	0.0013	Gravel and Sandstone
BH017	1.30	<0.1**	<0.1**	0.0013	Clay, Sand and Mudstone
BH019**	8.60	0.1	0.1	0.0086	Clay and Mudstone
BH020	1.40	<0.1**	<0.1**	0.0014	Clay and Sandstone
BH021	3.30	<0.1**	<0.1**	0.0033	Made Ground and Clay
BH022**	3.50	<0.1**	<0.1**	0.0035	Coal and Mudstone
BH024	1.00	<0.1**	<0.1**	0.0010	Clay and Mudstone
BH025	0.70	<0.1**	<0.1**	0.0007	Clay

Notes: Shading indicates flooding of response zone during all monitoring visits

*Maximum gas concentration combined with maximum steady state flow rate, recorded on any visit.

**These concentrations were recorded as not detected in the field, therefore the LOD of the GA5000 has been used in calculations.

Wells that recorded flooded response zones may not be representative of the gas regime within unsaturated soils and have therefore been disregarded from the following assessment.

A review of the pressure trends leading up to the monitoring visits indicates it is unlikely a potential "worst case" gas emission scenario (e.g. rapid fall in pressure to below 1000mb, over a short period of time) occurred immediately prior to the monitoring visits.

Methane concentrations were consistently measured at or below the monitor LOD of 0.10 % v/v. No potential sources of ground gas were identified during the ground investigation. The GI is recorded to have encountered possible shallow workings and coal, however, none of the response zines installed within the wells spanned these areas. BH021 was installed within an area noted as infilled land.

Carbon dioxide concentrations ranged from <0.10 % v/v to 10.50 % v/v (BH007). BH007s response zone screened the underlying Glacial Till (clay) and Mudstone bedrock. No sources of ground gas were recorded within the log for BH007. BH007 was measured on two occasions, with CO_2 concentrations of 9.80 % v/v and 10.50 % v/v recorded.

Carbon Dioxide was measured above 5 % v/v at four locations; BH003, BH007, BH011 and BH019. BH003 screened Made Ground deposits which contained gravels of mudstone, ash, clinker, glass and brick. The remaining boreholes all screened natural deposits with no obvious sources of ground gas present. The majority of response zones screen Glacial Till (clay) and Mudstone, both of which are relatively impermeable. The response zones which screen the more permeable deposits (Glacial Till – Sand and Sandstone bedrock) measured low levels of CO2. It is likely that CO2 concentrations are due to the natural deposits underlying the scheme.

Maximum steady state flow rates were consistently measured at or below the LOD of the instrument used (<0.1 l/hr).

If the maximum gas concentration (10.50 % v/v CO_2 BH007) and maximum steady state flow (<0.1 l/hr) are used then a Qhg of 0.0105 l/hr is calculated. This indicates a characteristic situation 1 (very low gas risk) across the site. BS8485:2019 does state that if CO_2 concentrations are above 5 % v/v then consideration must be given to whether upgrading the site to a CS2 (low risk) classification is appropriate. However, considering the minimal flow rates recorded and the majority of CO_2 recorded over 5% v/v were in wells screening clay/mudstone which would restrict lateral/vertical migration, CS2 would be disproportionate. Overall, it is unlikely the proposed scheme or installation of new service trenches would significantly alter the current ground gas risk and it is unlikely the scheme would pose an unacceptable risk to nearby properties in relation to ground gas. However, vigilance should be maintained during excavation of service trenches and if putresible/organic material, suspected old workings or a coal seam are encountered then it is recommended that the design is revisited to consider installation of clay stanks to minimise lateral gas migration.

The requirement for shallow mine stabilisation (e.g. drill and grouting) beneath the scheme is not known at the time of writing. The potential risk of displacing mine/ground gas during mine stabilisation works must be considered within the design of such activities in line with The Coal Authority's guidance.

9. Revised Conceptual Model

The findings of the recent ground investigation and GQRA have been used to update the CSM presented in Section 4.

As with the Initial CSM, future construction and ground maintenance workers are excluded from the revised CSM, as such risks should be addressed through their employers' health and safety risk assessments and work procedures. The revised CSM has been developed assuming completion of the proposed development works with no mitigation measures having been applied. The preliminary risk categorisations presented are based on an assessment of the potential consequence of each PCL occurring along with the likelihood that each PCL will occur in accordance with the framework provided in Appendix A. The revised CSM is shown in Table 9-1, together with updated risk levels.

Chemical attack to buried structures as a pathway has not been included within the CSM as it will be considered as part of the geotechnical assessment.

Table 9-1 - Revised Conceptual Model and Updated Risk Assessment for Sections 2 and 3

Sources	Pathway	Receptor	(Consequence/Probability) Classification of Risk
Potential contaminants in soil/groundwater on-site, originating from the following on and off site sources: **On-site:** Made Ground across the site associated with the historical site use Infilled Land Infilled Reservoir Waste Management Facilities Mine Workings Fill associated with existing roads on site. Electrical Sub Stations **Off – site:** Made Ground Railway & sidings & station Infilled Land Pemberton Colliery, mine workings & seams Infilled Opencast mine Opencast Coal Disposal Centre Electrical Substations Industrial Estate &Tanks Landfills Bitumen Works Firefighting Runoff **Contaminants identified during the 2019 GQRA include:** **Human Health**: Single lead exceedance within BH003 in the west of the site. Asbestos was recorded within a single location on-site (TP012). No exceedances of the WSVs were recorded in the groundwater analysed. **Controlled Waters**: Exceedances of the EQS include: ammoniacal nitrogen, anthracene, benzo(a)pyrene, chloride, copper, fluoranthene, iron, hexavalent chromium, nickel, pH, sulphate, zinc and aliphatic TPH >C21-C35 Exceedances of DWS include: arsenic, benzo(a)pyrene, chloride, iron, nickel, pH and sulphate **Ground Gas:** Characteristic Situation 1	Inhalation, ingestion and dermal contact with contaminants in soil and soil derived dust. Organic contaminants in soil migrating into water supply pipes.	Future site users (road users). Adjacent site users.	(*Mild/Low Likelihood*) **Low Risk** A single exceedance of lead is recorded within BH003 in the west of the site within the Made Ground. As the site is being redeveloped for a highway land use, the site is likely to be covered in hardstanding with minor areas of landscaping along the verges. BH003 is indicated to be located within the centre of the proposed road and therefore will be covered in hardstanding. Therefore, exposure to underlying soils is likely to be limited. Also, due to the use as a highway, exposure times are likely to be limited. If any water supply pipes require re-routing/relaying then an appropriate United Utilities Risk Assessment will need to be undertaken to assess the potential risks posed to water supply pipes and therefore future on site and off site users.
	Inhalation of airborne asbestos fibres.		(*Severe/Unlikely*) **Moderate/Low Risk** Asbestos was identified in a single location across the site, TP012 at 0.20 m bgl within the centre of the site. As the site is likely to be covered in hardstanding and/or vegetation, it is unlikely that asbestos would be exposed at surface, therefore reducing the likelihood of exposure.
	Migration of gases/vapours into confined spaces/buildings and accumulation (explosion). Inhalation of vapours or ground gas (asphyxiation).	Future site users and property (road users). Off-site residential/commercial properties.	(*Mild/Low Likelihood*) **Low Risk** No exceedances of the human health soils VOC GACs or WSVs were recorded. PID concentrations within soils ranged from 0.1 to 0.8 ppm. Following the gas assessment, the site has been classified as a CS1 as it presents a very low risk to future users/property. Minimal gas flow rates were recorded, which would suggest the gas generation potential of onsite sources is low. As no new buildings are proposed on-site and exposure times are likely to be low (site use as a road), it is unlikely that ground gas/vapours will pose an unacceptable risk as they would disperse into atmosphere. It is unlikely the proposed scheme or installation of new service trenches would significantly alter the current ground gas risk and it is unlikely the scheme would pose an unacceptable risk to nearby properties in relation to ground gas.
	Leaching of contaminants to groundwater in superficial deposits and thereby bedrock. Lateral migration beneath the site to surface water receptors. Also, via preferential pathways (e.g. service trench backfill).	Secondary A Bedrock Aquifer Surface Water Receptors (Smithy Brook).	(*Medium/Unlikely*) **Low Risk** Soil-leachate and groundwater samples indicated exceedances of heavy metals, sulphate, ammoniacal nitrogen and PAHs. The majority of recorded exceedances of the EQS for leachate samples are considered to be marginal (only a few exceedances and/or within the same or one order of magnitude of the EQS), with the exception of PAHs which exceeded EQS across most of the site. Cohesive superficial deposits were found underlying the majority of the site between the Made Ground and underlying bedrock, which would restrict vertical and lateral migration of any potential contaminants. The proposed development is unlikely to pose an unacceptable risk to controlled waters. It is likely that the exceedances recorded across the scheme are a result of wider off site sources of contamination as well as those located on site, as shallow mining and infilled ground is recorded both on and off site. The use of dry swales and impermeable liners are unlikely to alter to the current groundwater regime at the site. Surface water runoff captured within the swales is to be discharged in a controlled manner directly to Smithy Brook.

10. Preliminary Waste Characterisation

10.1. Results of CAT-Waste^{SOIL}

A preliminary waste assessment has been undertaken using the Atkins/McArdle online waste characterisation tool CAT-Waste^{SOIL} [42]. This provides an indication of whether waste fill/soils might be hazardous in accordance with current guidance within the Environment Agency's Technical Guidance WM3: Waste Classification – Guidance on the Classification and Assessment of Waste [43]. Analytical results from the on-site soil samples were uploaded into the CAT-Waste^{SOIL} tool.

A single soil sample was classified by the CAT-Waste^{SOIL} tool as having hazardous properties as detailed in Table 10-1 below. The remaining samples were classified as non-hazardous i.e. not having hazardous properties.

Table 10-1 - CAT-Waste^{SOIL} Results Summary

Exploratory Hole	Depth	Strata	Hazardous Property
BH003	0.50	Made Ground	Lead
			Zinc

10.2. Waste Acceptance Criteria

As part of the 2021 ground investigation, a total of six samples were also scheduled for waste acceptance criteria (WAC) analysis. The WAC test provides an indication of which type of landfill (inert, stable non-reactive hazardous and hazardous) might be able to accept the materials sampled. A summary of the WAC results is provided in Table 10-2 below.

Table 10-2 - Summary of WAC Testing

Exploratory Location	Depth	Deposit	WAC Result and Implication
TP016	0.20	Sand	Exceeds the WAC criteria for inert waste landfill for total organic carbon (TOC).
TP019	0.00 – 0.20	Made Ground	Exceeds the WAC criteria for stable non-reactive hazardous for pH.
TP020	0.50	Made Ground	Below WAC for an inert landfill.
TP004	0.00 – 0.50	Clay	
BH021	0.25	Made Ground	
TP010	0.00 – 00.20	Made Ground	

The client or their contractor should discuss lab results and soil descriptions with a variety of landfill operators and soil recycling operators to confirm options. Further sampling and analysis will be required during construction to ensure adequate waste classification and to inform waste disposal options.

11. Geotechnical Risk Register

Geotechnical risks and potential hazards for the project were identified and have been evaluated along with measures proposed to mitigate against the risk of these hazards occurring. The potential risks and constraints relating to land contamination and ground gas are presented in Section 13.

11.1. Preliminary Summary

The geotechnical risks identified at this stage of the project have been evaluated using a risk matrix provided in Table 7-1. As the project progresses, the geotechnical risks will be added to Table 7-2, re-considered and refined as appropriate in accordance with best practice.

Definitions :

Hazard	Something with the potential to cause harm
Consequence	Degree of harm that may be caused
Likelihood	Indicates the probability of an event occurring
Risk Rating	Consequence x Likelihood = the severity of risk

L = Likelihood : Likelihood is assessed on a scale of 1 to 5.

5. Inevitable — It is almost certain that an accident or ill-health will result if the situation continues as it is.
4. Highly Likely — It is very likely that the effects of humans or other factors will cause an accident or ill-health.
3. Likely — It is foreseeable that circumstances may combine to result in an incident.
2. Unlikely — It is unlikely that circumstances will combine to result in an incident.
1. Highly Unlikely — It is most unlikely that an incident will occur. It would require freak conditions to occur, against which it is not reasonable to protect. This should be the normal state of the workplace.

Potential severity of harm occurring:

5. Catastrophic — Catastrophic loss or damage –(multiple fatalities).
4. Major — Major damage or loss – (fatal injury).
3. Moderate — Substantial damage or loss – (serious injury or illness).
2. Minor — Minor damage or loss – (slight injury or illness).
1. Insignificant — Insignificant damage or loss – (no human injury).

Table 11-1 - Risk Matrix

Risk Level (Risk level = Severity x Likelihood)		Risk Scoring and Classification
Likelihood	Severity	

		1	2	3	4	5	
		Insignificant	Minor	Moderate	Major	Catastrophic	
5	Inevitable	L	H	H	E	E	E (>15): Extreme Risk, immediate action required to reduce/manage risk
4	Highly Likely	L	M	H	E	E	H (10-14): High Risk, to be controlled through some form of remediation
3	Likely	L	M	M	H	E	M (5-9): Major Risk, must consider some form of mitigation such as information, instruction, training
2	Unlikely	V	L	M	M	H	L (3-4): Low Risk, no further action required
1	Highly Unlikely	V	V	L	L	L	V (1-2): Very Low Risk, no further action required

Table 11-2 - Geotechnical risk register

ID	Hazard	Risk/Consequence	Phase of project	Likelihood	Severity	Overall Risk Rating	Possible Mitigation Measures	Revised Likelihood	Revised Severity	Residual Risk Rating
1	Unforeseen ground conditions during construction	Construction programme delays. Additional costs. Mobilisation of different plant.	Construction	2	5	10	Design 1. A site-specific, confirmatory ground investigation has been specified and undertaken. 2. The Series 600 specification will require hand vane testing to confirm the strength of the formation. 3. Geotechnical detailed design will take place following completion of the GIR. 4. Conservatism to detailed design taking into account all ground investigations to date.	1	5	5
2	Historical mine workings	Former historical mining activities presents a risk to the scheme, specifically the risk of sudden and catastrophic loss of support at the ground surface by the underground collapse of untreated mine shafts, adits or mine workings. Increased loading could activate	Entire project	3	5	15	Design 1. A ground investigation has been undertaken 2. A programme of drilling and grouting of the affected area has been specified (risks associated with displacement of mine gasses is to be addressed) 3. Geotechnical design of structures will take place following completion of the GIR based on the	2	5	10

		underground movement. In addition to the risk of ground collapse, colliery mining presents additional risks in the form of differential settlement of foundations in response to settlement (but not collapse) of mine workings. Displacement of mine gas and mine water.					mine workings having been treated. Construction 1. Earthworks and construction to take place after treatment of mine workings and investigation and treatment of suspected and known mineshafts			
3	Weak foundation strata	Excessive settlement of foundation strata or road pavement due to applied load (e.g. structures, embankments). Differential settlement of road pavement or structures. Unserviceability of structures. Areas of pavement become unserviceable. Failure of embankment and cutting slopes. The earthworks experience instability which could potentially	Entire Project	3	4	12	Design 1. A ground investigation has been undertaken to consider the presence of compressible soils. Compressible soils of significant depth are not anticipated on the scheme but cannot be ruled out completely prior to construction. No GI was carried out in Section 4 of the scheme as part of this phase of works. Previous validation report confirms remediation. 2. Limited laboratory CBR tests have been completed along the alignment A reasonable design CBR value has been characterised for	2	3	6

		undermine the road.					preliminary pavement design. 3. It is proposed that where soft spots are encountered, they will be excavated and replaced with well compacted granular fill. In-situ testing of all formations and inspection by a suitably qualified geotechnical engineer will be required. Construction 1. Hand shear vanes and confirmatory in-situ CBR testing is required on all formations prior to construction. 2. All formations shall be inspected by a suitably qualified geotechnical engineer to confirm that they conform with the design requirements.			
4	Presence of groundwater at shallow depth / groundwater conditions could be worse than assumed in design	Additional cost and delay associated with managing groundwater during construction. Granular deposits and surface water features likely to result in significant water ingress. Instability of excavations within granular deposits.	Construction	3	3	9	Design 1. A ground investigation has been undertaken to undertaken to gather additional information about the groundwater conditions at the site. 2. Toe drainage is likely to be required for slopes greater than 2.5m tall. 3. Geotechnical design for structures will take place following completion of the GIR.	2	3	6

		Requirements for shallower cut slopes and/or more intensive earthworks drainage. The earthworks or structures experience instability which could potentially undermine the road.					Construction 1. The temporary works designer should consider the risk of shallow groundwater in their designs. Temporary stabilisation measures may be required for excavations. 2. Earthworks to be constructed in accordance with the construction drawings and specification. 3. All excavations to be kept dry during construction. Temporary dewatering may be required. O&M 1. Earthworks to be regularly inspected by a suitably qualified earthworks inspector. 2. Maintenance to be carried out as necessary. 3. All drainage to be inspected and maintained to prevent significant changes to the groundwater regime post construction.			
5	Difficult excavation and/or shallow obstructions	Delays to construction programme whilst appropriate equipment is mobilised. Additional costs of	Entire Project	3	2	6	Design 1. A site-specific ground investigation has been undertaken to gather information about the bedrock level at the site. Shallow bedrock may	3	1	3

		breaking out/over dig.					cause significant problems for earthworks and shallow founded structures. Construction 1. The contractor should prepare for the possibility of encountering shallow bedrock which will require additional excavation effort.			
6	Poor ground conditions and unstable excavations, i.e. localised soft cohesive deposits and variable made ground	Delays to construction programme and additional cost due to modification of designs. Health and safety of workers.	Entire Project	3	4	12	Design 1. A site-specific, confirmatory ground investigation has been specified and undertaken. 2. Geotechnical design for structures will take place following completion of the GIR. Construction 1. The temporary works designer should consider the risk of poor ground conditions in their designs. 2. The construction methodology should consider the ground conditions and potential for soft spots which may impact on movement of large machinery. 3. The earthworks should be constructed in accordance with the	2	3	6

							construction drawings and specification. 4. All formations should be inspected by a suitably qualified engineering geologist to confirm. Should conditions differ from the design assumptions, the designer should be consulted. 5. Soft spots should be treated, as shown on the construction drawings. O&M 1. The earthworks should be regularly inspected by a suitably qualified earthworks inspector. 2. Maintenance should be carried out as necessary.			
7	Potential for chemical attack on buried concrete	Deterioration of buried structural concrete by sulphate attack. Corrosion of steel reinforcement.	Entire Project	2	3	6	Design 1. The guidance from BRE SD1 has been followed and reported on in the GIR. 2. All buried structures to consider the Design Sulphate classification on a structure by structure basis. 3. Appropriate testing to confirm concrete aligns with specification shall be undertaken.	2	2	4

8	Encountering unforeseen contamination	Site won material may not be chemically suitable for reuse without remediation or mitigation. Increased waste disposal costs. Delays associated with regulatory liaison in dealing with unforeseen contamination	Entire Project	2	3	6	Design 1. A ground investigation has been undertaken to gather information on soils, soil leachate and shallow groundwater to enable a land contamination Risk Assessment (GQRA) and to refine the Conceptual Site Model. This information can be used to identify whether any remediation is required and to inform the earthworks design in the reuse of the soil under the appropriate legislation/guidance (e.g. MMP etc). Construction 1. Reuse of soils and imported material in accordance with appropriate legislation/guidance (e.g. MMP). 2. Watching brief during earthworks. 3. Site won and imported material will be subject to acceptability testing as set out in Appendix 1/5, 6/2, 6/14 & 6/15. 4. Best practice including environmental management and health and safety to avoid migration of any potential contaminants or risk to workers.	1	3	3

							5. Classification, appropriate storage, pre-treatment and duty of care for off-site disposal of waste soils. O&M 1. Details provided in an asbestos register associated with the presence of any in-ground asbestos encountered and/or a record of any elevated potential contaminants with the mitigation measures recorded.			
9	Poor compaction / unsuitable re-use material	Site won material may not achieve CBR or stability when re-used, resulting in pavement deformation or instability of the slope. Pore water pressures can build in embankments leading to mattressing when compacting.	Construction	3	2	6	Design 1. Limited material reuse testing has been completed as part of the ground investigation to provide an early indication of the acceptability of site won materials. Construction 1. The earthworks should be constructed in accordance with the construction drawings and specification. 2. Site won material will be subject to acceptability testing as set out in Appendix 1/5. A suitably qualified Engineering Geologist will review the results to ensure that the specification requirements are met.	1	3	3

							3. Material should be stockpiled correctly on site to prevent water ingress. 4. Field dry density testing will be carried out to confirm that the compaction requirements have been met, as specified in Appendix 1/5. Material which does not demonstrate conformance with the specification should be removed from the embankments.			
10	Temporary Slope Stability	Temporary slopes could become unstable if over-steep	Construction	3	3	9	Design 1. A site-specific ground investigation has been undertaken to gather additional information about the nature of material in the slope at Brook Lane and the proposed access road near BH005. This information can be used by the temporary works designers to inform their designs. 2. Permanent design must consider the likely temporary works to ensure that designs are constructible. Stability assessment of the temporary slopes has not been undertaken.	2	2	4

						Construction 1. Temporary works design should be undertaken to ensure that the slopes will remain stable during construction. 2. Should conditions on site differ from the temporary works design assumptions, the temporary works designer should be consulted.			

12. Engineering assessment

12.1. Historical mine workings

Mine workings and entries are present within and immediately adjacent to the site boundary throughout the scheme. A grouting scheme is required to infill the shallow mine workings and entries within the zone of influence of the scheme. The solution to mitigate against the coal mining risks should be developed in accordance with the abandoned mine workings manual (CIRIA C758D [44] formerly CIRIA SP32 [45]). In addition to the risk of ground collapse, colliery mining presents a risk to civil engineering infrastructure in the form of differential settlement of foundations in response to settlement of mine workings. Due consideration should be given to these issues during design.

Where existing structures and roadways are present on the proposed alignment it is recommended that detailed surveys be undertaken to identify any indication of past or present ground movements. Such locations include Leopold Street.

Where the alignment leaves the M6 eastern circulatory and crosses playing fields to the east before joining Leopold Street this is considered to be a high-risk area of the route with regards to shallow mine workings as it is previously undeveloped and recent GI indicates it is un-remediated. The change in load at the ground surface will also be most pronounced here due to new infrastructure loading ground that has previously never been loaded. The proposed retaining wall at Brook Lane is also affected by shallow mine workings. The proposed structure is a reinforced concrete retaining wall comprising modular pre-cast L-shaped panels.

In addition to risk of collapse, mine workings also pose a risk of potentially contaminated mine waters and mine gas. This must be factored when planning site works such as grouting or any further ground investigation which enter mine workings as these activities may displace potentially contaminated mine waters and mine gas. Critical receptors close to the site with respect to mine waters include Smithy Brook and nearby residential and commercial buildings.

Within Section 4, the Pemberton Colliery poses certain risks associated with the large scale historical open cast workings. At the western extents of Section 4 where the link road crosses the A571, the highwall geometry of the of the open cast pit is unconfirmed and risk of differential settlements across this transition zone are high. Due consideration should be given to carriageway design across this zone.

Remediation activities were undertaken across the Pemberton Colliery site as detailed in the Wardell Armstrong Phase 3 Remediation Validation Report [46]. These works were carried out from March to September 2012 and April to May 2013. Engineering remediation activities undertaken within the Phase 3 area of the site included;

- Excavation of made ground to 3m below final restoration level, and;
- The re-engineering of opencast backfill materials to form a development platform achieving a minimum allowable bearing capacity of 75kPa.

1.1. Excavations

Excavations within any soft or very loose to loose granular deposits are likely to be unstable, therefore positive support or battering back of excavation sides will be required. Some trial pits observed instability within pit walls, and the presence of shallow perched water may require the use of ground support in conjunction with a suitably designed dewatering system, such as sump pumps.

No person entry into excavations should take place without support of the excavation sides and no materials should be stockpiled adjacent to any open excavation.

Excavations within rock will require a suitable size of plant and ripping might be required in places.

12.2. Foundations

12.2.1. General foundation comments

The Made Ground is unlikely to be suitable for founding structures upon in its current state due to the variable nature of the deposits. It is recommended that any Made Ground, loose or compressible material be excavated and replaced with suitably compacted engineered fill. Formation inspections should be undertaken by a suitably qualified geotechnical engineer.

The Made Ground however may be a suitable formation material for access roads, though this would need to be confirmed following confirmatory targeted in-situ testing to determine the California Bearing Ratio (CBR) for design. An indicative CBR value of 2.5% may be assumed at this stage. Geogrid could be considered to reduce the risk of differential settlement within road pavement foundations.

12.2.2. Pemberton Bridge foundation considerations

Due to the relatively shallow depth to bedrock, pad or piled foundations were considered as an option for the proposed structure. The optimum foundation solution however will depend on the minimum founding depth of the structure (below the bridge deck) and should take into account the additional volume of 'hard excavation' that may be required for a pad foundation as opposed to a piled foundation.

Boreholes generally encountered 'engineering rockhead' at approximately 4m bgl on both sides of the proposed bridge. Attention should be given to the area around BH025 where bedrock was encountered at 7.3m bgl (55.1m OD) which is significantly deeper than within the surrounding boreholes. This presents a risk of differential settlement and significant variation in bearing capacity if this borehole is representative of the conditions at the foundation location. These risks should be taken into consideration when designing the founding solution and may render a shallow foundation unsuitable at this location.

As shown on the general arrangement cross-sections, re-grading of the railway cutting slopes will be required, however, these new slopes are likely to be lower in height adjacent to the railway compared to the current situation. The bedrock encountered during the recent GI was often highly fractured (likely as a result of faulting within the area) and may not be stable unsupported at steeper slope angles than are currently present. A pad foundation is more likely to adversely affect slope stability due to the surcharge effect. Piled foundations would transfer the load to a lower level and, depending on the number, location and layout of the piles, they may have a beneficial effect on the slope stability. Depending on the depth and type of foundation chosen, slope stability analyses should be carried out on the railway cutting to assess a safe angle of regrade. Due consideration should be given to the long-term monitoring and inspection requirements of the cutting.

Planned borehole BH018 on the southern side of the railway near the footprint of the proposed foundation could not be drilled due to service and utility constraints. This area was also constrained for access due to the presence of occupied bungalow residences and therefore ground investigation data is limited in this area. Boreholes could not be drilled within the footprints of the proposed foundations on either side of the bridge as they are within the slopes of the rail cutting. Due to the relatively complex geology in a small area, and in particular the faulting, different rock units and engineering characteristics of these rock units, the ground conditions may vary across the foundation location. Therefore, piled foundations are considered the lower risk foundation option at this stage

1.2. Groundwater

Shallow groundwater has been recorded during the ground investigation and subsequent monitoring rounds. Groundwater control such as sump pumping may be required during construction.

13. Land Contamination Considerations

Section 13.1 and the revised conceptual site model (RCSM) presented in Section 9 comprise the decision record for this stage of risk assessment. The Land Contamination Risk Management (LCRM) guidance states that confirmed pollutant linkages become Relevant Pollutant Linkages (RPLs). For the purpose of this report, RPLs are considered those where the risk level in the RCSM is higher than Moderate/Low and some form of mitigation before or during construction is considered likely to be required. The assessment undertaken in Section 9 has not indicated the presence of any RPLs as all pollutant linkages have been assessed as moderate/low or lower.

The following is a summary of the key findings and interpretation of the ground investigation data with respect to land contamination and ground gas. Table 13-1 includes the findings of the RCSM/GQRA and contamination constraints relating to health/safety/environment risks and waste management during construction.

The requirement for shallow mine stabilisation (e.g. drill and grouting) is not known at the time of writing. The potential risk of displacing mine/ground gas during mine stabilisation works must be considered within the design of such activities in line with The Coal Authority’s guidance.

13.1. Land Contamination Constraints and Recommendations

Table 13-1 - Contamination Constraints and Recommended Actions Before/During Construction

Item	Findings of Initial Assessments	Implications to Redevelopment
Exposure of workforce to contaminants in soils/water/air	Metals and polyaromatic hydrocarbons (PAHs) recorded within soil and groundwater. Asbestos identified on the site.	Due to the presence of Made Ground across the site it is possible that asbestos could be present elsewhere. Vigilance should be maintained during earthworks by appropriately experienced/trained staff. Advice should be obtained from an asbestos specialist on what mitigation measures are required to protect the workforce.
Exposure to workforce and displacement of mine gas towards off-site property during stabilisation of mine workings/shafts	Methane was not recorded, however carbon dioxide was recorded up to 10.95 %v/v.	Although relatively low levels of gas were recorded, there is the potential for higher concentrations of mine gas to be encountered in old workings during stablisation works. Risk assessments should be undertaken as per The Coal Authority guidance.
Re-use of site won arisings (current in-situ Made Ground and natural deposits) within the site boundary	Risk assessment indicated site won arisings might be appropriate for re-use across the site as they are unlikely to pose an unacceptable risk to human health or the environment (subject to soils containing the lead criteria exceedance and asbestos being placed under hardstanding or topsoil).	It is anticipated that arisings could be reused across the site, subject to re-use complying with requirements of a materials management plan or environmental permit. Verification that re-use complied with the MMP/permit would be required, accordingly materials should be tested and compared to re-use criteria that should be developed for the site. It is recommended this approach is agreed with the contaminated land officers at the Council and Environment Agency prior to submission of the MMP/permit.
Piling/foundations – risks to groundwater.	Leachate and groundwater recorded heavy metal and/or PAH criteria	However, as a precaution, the risk to the bedrock aquifer should be

	exceedances. Overall it is considered the scheme will pose a low risk to controlled waters.	considered further during deep foundation design (e.g. at Pemberton Bridge, where piled foundations might be needed). A piling risk assessment in accordance with Environment Agency guidance may be required.
Disposal of waste soils.	Preliminary results indicate the majority of samples from across the site might be considered non-hazardous for off-site disposal. WAC criteria for stable non-reactive hazardous waste in a non-hazardous landfill and inert landfill are exceeded within two samples.	Further sampling/analysis and waste classification will be required. Additional WAC tests might also be required. It is recommended the client/contractor discuss lab results and soil descriptions with a variety of landfill operators/soil recycling operators to confirm options.
Vapour risks (from VOCs) to end users	No exceedances of the GACs/WSVs were recorded. Groundwater vapour is unlikely to pose an unacceptable risk.	Assessment findings indicate a very low risk from groundwater and soil vapour.
Ground gas (methane and carbon dioxide) risk to end users and off-site property	Initial ground gas risk assessment indicates a characteristic situation 1 (CS1).	The gas monitoring results and assessment indicate an overall low risk from ground gas. However, vigilance should be maintained during excavation of service trenches and if putresible/organic material or suspected old workings or a coal seam are encountered then it is recommended that the design is revisited to consider installation of clay stanks to minimise lateral gas migration.
Unexpected Contamination	N/A	As with any development there is always the possibility of finding ground/gas/contamination conditions that vary from those recorded in the ground investigation. Construction team should be vigilant and if such is encountered, stop work in that area and seek advice from contamination specialists, and if specified in the planning conditions, inform the planning authority. Further sampling and assessment might be required to evaluate the risk.
Decommissioning monitoring wells	N/A	Prior to construction, all monitoring wells should be decommissioned in accordance with the Environment Agency's guidance "Good Practice for Decommissioning Redundant Boreholes and Wells" dated October 2012. This is to prevent the wells from becoming damaged during construction and inadvertently becoming pollution migration pathways.

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Appendices

Appendix A. Risk Assessment Methodology

Risk Evaluation

The contaminated land risk, a function of the probability and the consequence, has been defined using the risk matrix given in Table 1 which is taken from the NHBC and Environment Agency's guide National House-Building Council & Environment Agency, 2008, Guidance on the Safe Development of Housing on Land Affected by Contamination. London: NHBC and Environment Agency (R&D66).

Table 1 - Estimation of the Level of Risk by Comparison of Consequence and Probability

		Consequence			
		Severe	**Medium**	**Mild**	**Minor**
Probability	**High Likelihood**	Very High Risk	High Risk	Moderate Risk	Moderate/Low Risk
	Likely	High Risk	Moderate Risk	Moderate/Low Risk	Low Risk
	Low Likelihood	Moderate Risk	Moderate/Low Risk	Low Risk	Very Low Risk
	Unlikely	Moderate/Low Risk	Low Risk	Very Low Risk	Very Low Risk

The descriptions of the classified risks as given in R&D66 are as follows:

14.1.1.2. Very High Risk

There is a high probability that severe harm could arise to a designated receptor from an identified hazard at the site without remediation action OR there is evidence that severe harm to a designated receptor is already occurring. Realisation of that risk is likely to present a substantial liability to the site owner / or occupier. Investigation is required as a matter of urgency and remediation works likely to follow in the short-term.

14.1.1.3. High Risk

Harm is likely to arise to a designated receptor from an identified hazard at the site without remediation action. Realisation of the risk is likely to present a substantial liability to the site owner / occupier. Investigation is required as a matter of urgency and remediation works likely to follow in the short-term.

14.1.1.4. Moderate Risk

It is possible that harm could arise to a designated receptor from an identified hazard. However, it is either relatively unlikely that any such harm would be severe, and if any harm were to occur it is more likely that the harm would be relatively mild. Further investigative work is normally required to clarify the risk and to determine the potential liability to site owner/occupier. Some remediation works may be required in the longer term.

14.1.1.5. Low Risk

It is possible that harm could arise to a designated receptor from an identified hazard, but it is likely at worst, that this harm if realised would normally be mild. It is unlikely that the site owner/or occupier would face substantial liabilities from such a risk. Further investigative work (which is likely to be limited) to clarify the risk may be required. Any subsequent remediation works are likely to be relatively limited.

14.1.1.6. Very Low Risk

It is a low possibility that harm could arise to a designated receptor, but it is likely at worst, that this harm if realised would normally be mild or minor.

Appendix B. Geotechnics Factual Report

Appendix C. GQRA Screening Sheets

Appendix D. GI Location Plan and Geological Cross Sections

Appendix E. Geotechnical Plots

Appendix F. Geophysical Report

Appendix G. General Arrangement Drawings

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