PROPOSED RESIDENTIAL DEVELOPMENT
GENE METALS, TREFOREST

WATERSTONE HOMES LTD

GEO-ENVIRONMENTAL AND GEOTECHNICAL ASSESSMENT

Prepared for:
Waterstone Homes Ltd
Number One
Waterton Park
Bridgend
CF31 3PH

Prepared by:
Earth Science Partnership
33 Cardiff Road
Taff's Well
Cardiff CF15 7RB
Tel: 029 2081 3385
Fax: 029 2081 3386
e-mail: enquiries@earthsciencepartnership.com
Website: www.earthsciencepartnership.com

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Date	Status	Written By	Checked By	Approved By
September 2016	First Issue – Draft	Matthew Elcock	Jeremy Hucker	Matthew Eynon
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		BEng (Hons) FGS	BSc (Hons) CGeol FGS UK Registered Ground Engineering Adviser	BSc (Hons) MSc CGeol EurGeol FGS UK Registered Ground Engineering Specialist
Signature				

SUMMARY

Waterstone Homes Ltd is considering the purchase of the subject site for redevelopment as a residential development. ESP have undertaken a geo-environmental and geotechnical assessment, comprising a desk study, intrusive investigation, laboratory testing and assessment of data. This report includes the Preliminary Risk Assessment and Generic Quantitative Risk Assessment (for human health and controlled waters) elements of CLR11. The key potential land quality issues identified by the assessment are summarised below:

	Potential Hazard	Anticipated Risk	Discussion
Site Setting	***Current Site Status.*** *(Section 2.1)*	-	*The site is occupied by a derelict metal recycling/scrap yard, with some on-going low key skip management.*
	Identified Ground Conditions. *(Section 5.0)*	-	*The investigation indicated significant and variable thicknesses of Made Ground over fine-grained glacial Diamicton and, at very shallow depth in places, the Brithdir Sandstone (Coal Measures) bedrock.*
	Groundwater Conditions. *(Section 5.2)*	-	*The site is underlain by a Secondary A Aquifer. Perched groundwater bodies have been identified within the shallow soils.*
	Historical Land Use. *(Section 2.3)*	-	*The surrounding land uses include an iron and steel works and railway sidings. A former quarry lies immediately to the south-east. The site possibly appears to have been developed as a recycling works/scrap yard in the late 1940s.*
Geo-environmental	***Potential Contamination Sources*** *(Section 3.1.2)*	***High***	*The site was a former scrap yard, with an above ground (possibly fuel) tank formerly next to one of the buildings. Scrap waste, including asbestos materials, is present within the shallow soils.*
	Chronic Risks to Human Health *(Section 7.2 and 7.3)*	***High***	*Elevated levels of metals, polyaromatic and petroleum hydrocarbons and PCBs have been identified above the GAC in the shallow soils. Asbestos has also been identified in the shallow soils.*
	Risks to Controlled Waters *(Section 7.4)*	***High***	*Elevated levels of leachable metals, polyaromatic and petroleum hydrocarbons, and solvents have been identified within the Made Ground.*
	Hazardous Ground Gas *(Section 7.5)*	To be confirmed	*Gas monitoring is ongoing and will be reported on completion.*
	Remedial Works (Sections 7.1 to 7.4)		*The proposed earthworks will partly mitigate the above risks, but remedial works will also be required.*
Geotechnical	***Abandoned Mine Workings and/or Old Mine Entries*** *(Section 2.9.2)*	*Low*	*The coal mining risk is low.*
	Weak/Compressible Ground, requiring non-traditional foundations *(Section 8.5)*	***High***	*Due to the variation in the ground conditions across the site, and the proposed earthworks, foundation options are complex.*
	Shrinkage or Swelling *(Section 8.4.2)*	*Low*	*Hazards associated with shrinkage and swelling are not likely to be realised once earthworks have been completed.*
	Sulphate Attack on Buried Concrete *(Section 7.6.2)*	*Moderate*	*Laboratory testing has indicated the site is classed as AC-2z in terms of sulphate attack on buried concrete.*
	Soakaway Feasibility *(Section 8.10)*	-	*Soakaways will be feasible constructed in the sandstone bedrock, however, there are likely to be limitations in their location and depth.*
	Other Hazards *(Section 8.2.5 and 8.3.3)*	***High***	*The south-eastern boundary comprises a former quarry face. The slopes to the west of the access road comprise apparent loose end tipped materials. The stability of these areas requires careful consideration. Expansive slag has been identified.*
Others	***UXO*** *(Section2.9.9)*	*Low*	*The site is in an area of low UXO risk.*
	Flooding *(Section 2.4.3)*	*Low*	*The site is not in a flood risk zone.*
	Invasive Plants *(Section 8.1.1)*	-	*None visually identified during site works.*
	Further Investigation Required?	***Yes***	*See Section 9.0.*

Note: The above is intended to provide a brief summary of the conclusions of the assessment. It does not provide a definitive assessment and must not be referenced as a separate document. Refer to the main body of the report for details.

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1.0 INTRODUCTION AND OBJECTIVES

1.1 Background

Waterstone Homes Ltd (hereafter known as the Client) are proposing to redevelop the subject site for residential purposes. The Earth Science Partnership Ltd (ESP), Consulting Engineers, Geologists and Environmental Scientists, were instructed by the Client to undertake an integrated geotechnical and geo-environmental investigation and assessment to identify and evaluate potential ground hazards which could impact on the proposed development. The site location is shown on Figure 1.

The proposed development will comprise 34 one and two-storey residential properties with private gardens within three blocks as shown on Figure 2. A development platform will be created in the centre of the site by cutting into the existing slopes by around 2 to 3m to the west, and filling over the lower lying areas in the east by up to 3m. Little or no level change will be realised in the centre of the site. Based on the above, we understand that the proposed structures would be classified as Geotechnical Category 2 (BS5930:2015).

For the purposes of this assessment, we have designated the eastern filled area as Zone A, the central, grade area as Zone B, and the western area (where the cut will occur) as Zone C, as shown on Figure 3.

In addition to the development on the site, we understand that the existing access track, alongside the Treforest FC football pitch, is to be widened by cutting into steeply sided, vegetated, northern slope – see Figure 2.

ESP completed a Preliminary Geotechnical and Geo-environmental Assessment at the site for the Client in May 2015, which comprised a desk study and preliminary investigation (trail pitting), but no laboratory testing (ESP, 2015). The findings of this preliminary assessment have been incorporated into this current report.

1.2 Objective and Scope of Works

We understand that planning permission has yet to be sought for the development, therefore, there are no planning conditions relevant to this assessment.

The objective of this investigation was to establish a conceptual model of the site in terms of ground conditions to provide information for the design and construction of the proposed development, and to establish whether or not there are any potentially unacceptable ground hazard related risks to the development.

The scope of works for the investigation was mutually developed with the Client by ESP within an agreed budget, and comprised the incorporation of the previous desk study and investigation information (ESP, 2015), the supervision and direction of windowless sample boreholes, trial pits, soakaway infiltration testing, a preliminary stability assessment of the former quarry face on the south-eastern boundary, geotechnical and geo-environmental laboratory testing, assessment of foundation options, an appraisal of contamination risks to human health and controlled waters, and reporting.

The contract was awarded on the basis of a competitive tender quotation. The terms of reference for the assessment are as laid down in the Earth Science Partnership proposal of 5th August 2015 (ref: jph/5902b.02.lt1 proposal). This investigation and assessment was undertaken in August and September 2016.

1.3 Report Format

This report includes the desk study and field reconnaissance reports (Section 2), and details of the investigation undertaken of Eurocode EC7 and BS5930:2015 (Section 4), along with the Preliminary Risk Assessment stage (Section 3) and Generic Quantitative Risk Assessment (Section 5) of CLR11. A preliminary evaluation of the resulting risks and any remedial measures potentially required to mitigate identified unacceptable risks from contamination and hazardous ground gas is included in Sections 6 and 7. However, it should be appreciated that this is a preliminary evaluation only, and will not generally meet the requirements of the Options Appraisal report of CLR11.

A preliminary risk register, identifying potential geotechnical hazards from the desk study review, is presented as Section 2.9, with a full assessment of the geotechnical conditions including a discussion on foundation and floor slab options, the feasibility of soakaways, etc. in Section 8 – this comprises the relevant elements of the Geotechnical Design Report of BS EN 1997-2 (Eurocode 7) and BS5930:2015. The geotechnical risk register is updated using the findings of the intrusive investigation and assessment in Section 8.2. The report concludes with a summary of any further surveys/ investigations/ assessments recommended (Section 9).

The assessment of the potential for hazardous substances (contamination) or conditions to exist on, at or near the site at levels or in a situation likely to warrant mitigation or consideration appropriate to the proposed end use has been undertaken using the guidance published by CIRIA (2001). This is discussed in more detail in Section 3.2.1.

1.4 Limitations of Report

This report represents the findings of the brief relating to the proposed end use and geotechnical category of structure(s) as detailed in Section 1.1. The brief did not require an assessment of the implications for any other end use or structures, nor is the report a comprehensive site characterisation and should not be construed as such. Should an alternative end use or structure be considered, the findings of the assessment should be re-examined relating to the new proposals.

The site has an active environmental permit from its past use as a waste facility. Whilst the information within this report would assist in the surrender of this permit, this is not an objective of this report and a further assessment/report would be required. This present assessment was not designed to investigate the impact on the groundwater beneath the site due to the past use of the site.

Where preventative, ameliorative or remediation works are required, professional judgement will be used to make recommendations that satisfy the site specific requirements in accordance with good practice guidance.

Consultation with regulatory authorities will be required with respect to proposed works as there may be overriding regional or policy requirements which demand additional work to be undertaken. It should be noted that both regulations and their interpretation by statutory authorities are continually changing.

This report represents the findings and opinions of experienced geo-environmental and geotechnical specialists. Earth Science Partnership does not provide legal advice and the advice of lawyers may also be required.

1.5 Digital Copy of Report

This report is published in digital pdf format only.

2.0 DESK STUDY AND FIELD RECONNAISSANCE VISIT

As discussed in Section 1.1, a desk study for the site was undertaken as part of the preliminary assessment in 2015. Much of the information discussed in this section was obtained at that time, but is considered still relevant. Copies of historical maps are presented in Appendix B, an environmental data report in Appendix C, a mining report obtained from the Coal Authority in Appendix D, and information provided by the Local Authority in Appendix E.

The site description is based on recent field reconnaissance visits made to the site between 20th and 22nd July 2016, during predominantly dry and sunny weather, and general views of the site are included as a series of photographs within the Plates section of this report.

2.1 Site Location and Description

The site is located on the western side of the village of Treforest, just to the south of Pontypridd in the County Borough of Rhondda Cynon Taff. The National Grid Reference of the centre of the site is 307850 189030. A Site Location Plan is presented as Figure 1.

It comprises an irregular shaped parcel of land some 140m in length (east-west) and between 30 and 70m in width (north-south), and occupying an area of some 0.7ha. It is bounded by:

- To the north and west: open agricultural land, partly overgrown with some ruins of masonry walls and scrap vehicles to the west;
- To the north-east: a steep, heavily vegetated slope up to a football pitch on an elevated plateau;
- To the east: a small enclosure with structures used to keep pigeons, followed by the ground of Treforest Football Club, at a lower level to the site; and
- To the south/south-east: residential properties at a considerably lower level within a former quarry, on Birchley Close.

The site lies on the upper, east-facing slopes of the valley of the River Taff, and has until recently been used as the premises of Gene Metals (a metal recycling company). Recent (and historical) maps indicate the site was formerly a scrap yard. It appears to be currently derelict, apart from the storage of waste skips by an unknown third party in the south-eastern margins.

The site comprises three basic zones, as shown on Figure 3:

- **Zone A:** a lower-lying area in the east of the site, indicated to be generally at between 97 and 100m OD (based on a topographic survey provided by the Client), and comprising a plateau partly used for the storage of skips – see Plates 2, 3, 4, 5 and 13. A large, now derelict, steel sheet-clad former industrial building (Building A) is located in this area (Plates 4 and 5) with smaller buildings to the south-west, outside the site boundary. Building A contains an open vehicle inspection pit and evidence (bedding and clothing) of recent human habitation.
- **Zone B:** a central plateau area is currently undeveloped apart from a now derelict, large steel-clad, industrial building in the north-east (Building B), and forms a plateau at between 101 and 102m OD (based on the topographic survey) – see Plates 6, 7 and 8. A concrete slab is located near the centre of the Zone B. A brick and concrete bund is located immediately to the south-west of Building B, but the associated former tank appears to have been removed (Plate 14).

- **Zone C:** the western area is more elevated than the remainder of the site and comprises an undeveloped flat plateau area at around 105m OD in the south, with slopes up to around 109m OD in the north – see Plates 9 and 10.

The overgrown banks between Zones B and C, and between Zones A and B are both generally between 1 and 2m in height. A number of retaining walls are present around Zone A, including one of around 1m height supporting Building A, and one of around 2m height supporting the ground around Building B, on the boundary of Zones A and B in the north of the site (Plate 3). Further retaining walls of up to around 1.5m height support the ground in the north of Zone A, above the site entrance. A lower retaining wall is present in the south-west of Zone A, supporting the level ground to the north-west. The south-eastern boundary comprises the crest of a former quarry, and appears to be formed by a sub-vertical face, which is heavily overgrown.

The current ground surface across the site comprises predominantly loose gravel with fragments of metal and other scrap debris evident. Old concrete slabs indicate the former presence of external hardstandings, but also apparent former building floor slabs. A now-backfilled, former weighbridge is located immediately to the south-east of Building B. The site is predominantly overgrown with grass and scrub vegetation, and stockpiles of vegetation including large wooden timbers also present in Zones A and B (Plate 4).

A stream is present in the west of the site (Zone C – see Figure 3 and Plate 11). It appears to flow from a culvert to the north, collecting in a pool, before being further culverted beneath the majority of the site width. This culvert empties into a further pool outside the southern boundary, where the stream then enters a further culvert carrying it further downhill to the south-east. Ochre coloured staining in the base of the pools suggests some contamination of the water by acid mine drainage (from abandoned coal workings), however the water flowing from the culverts did not appear discoloured at this time – see Plate 11.

Further standing water in the west of the site may indicate the presence of a spring in this area – some of this water flows into the pool in the north of Zone C.

The site is presently accessed via a locked gate at the end of a narrow track which runs between the ground of Treforest FC (some 4m below the track to the south), and an overgrown slope to the north – see Plates 1 and 12. The slope angle varies along the length of the track, being relatively shallow immediately adjacent to the track along part, but at angles visually estimated as around 20 to 30° immediately adjacent to the track in places.

Site observations and the utility plans indicate that the site is crossed by the following services:

- An underground electricity cable crosses the access track and then follows the track towards the site, where, at a pole near the entrance, overhead lines service the buildings on site; and
- From an electricity pole to the east of Building A, an underground electric cable runs to the south of Building A and crosses the site toward a telephone mast to the west.

2.2 Previous Investigations and Assessments

Earth Science Partnership (ESP) undertook a preliminary assessment for the Client at the site in May 2015 (ESP, 2015). This preliminary investigation included a review of desk study information, and the excavation of fifteen trial pits (TP1 to TP15) to a maximum depth of 2.2m. No laboratory testing was undertaken at that time.

The objective of this preliminary investigation was to identify the historical, environmental and geological setting of the site, the nature of the shallow soils, and the depth and composition of the Made Ground on site.

The desk study information obtained in this preliminary assessment is discussed in the following sections, and the findings of the trial pit investigation have been incorporated into the Conceptual Ground Model in Section 5.1.

2.3 Site History

2.3.1 Published Historical Maps

The site history has been assessed from a review of available historical Ordnance Survey County Series and National Grid maps. Extracts from the historical maps are presented in Appendix B and the salient features since the First Edition of the County Series maps are summarised in Table 1 below.

Table 1: Review of Historical Maps

Date	On-Site	In Vicinity of Site
1874 – 1900	The site comprises an open, undeveloped hillside, the 1900 map shows woodland to have developed over the western parts of the site (Zone C). A track is shown to cross the site.	The Forest Iron and Steel Works are shown located immediately to the south-east and east, in the location of the current football ground. The works expanded around the east and north-east of the site (i.e. north of the access road) and included buildings, tipped materials, railway sidings and infrastructure. Two engine houses are shown within 250m. Three quarries and an additional disused quarry are labelled on the map within 250m of the site. A stream is shown to flow north to south down the hillside in the west of the site (apparently now partly culverted).
1915 - 1948	The site remains unchanged.	The iron and steel works and railway sidings have been dismantled, although areas of obvious filling remain. A quarry is shown to the south of the site, with the back face along the southern site boundary. Park Joinery works are shown to the south of the quarry.
1959 - 1983	The trees have been cleared and the site is shown to have been separated into several areas with numerous buildings located in the east of the site, within Zones A and B. Given the site layout, it may have been a waste recycling facility at this time.	The quarry to the south of the site is labelled as disused. The access track to the site and football ground to the southeast are both shown. Several buildings are shown to the west of the site. The 1974 maps show the location of a tip immediately to the south of the site (within the former quarry adjacent to Birchley Close), and the football pitch to the north of the access track.
1989 - present	The site is shown in a similar layout as the present day and labelled for the first time as a scrap yard. The large buildings in Zones A and B are shown, along with further buildings in the north-east of Zone A (now evident only by their remnant floor slabs).	Housing is shown to the south of the site, in the former location of the quarry. By 2002, the present day housing along Birchley Close was developed up to the quarry face.

The historical maps show the site to have been developed with buildings between 1948 and 1959, the layout changed slightly and was first labelled as a scrap yard by 1989, although we suspect that it may have been used as a waste recycling facility before that time.

Iron and steel works, including railway sidings were present to the south and east of the site, and the maps indicate a quarry to have been located to the south, which became a tip in the 1970s.

2.3.2 Other Sources

No further relevant information on the site history has been identified as part of this assessment.

2.3.3 Archaeological Setting

A full archaeological assessment was not included within the brief, but we have not been advised of, or identified, any obvious evidence of any significant archaeological features on the site, or particular archaeological requirements.

2.4 Hydrology

2.4.1 Surface Water Features

The nearest major surface water feature to the site is the River Taff (classified as a Primary River) and flows from north to south approximately 490m to the east. A number of streams are also present in the area, including that crossing the western part of Zone C and are classified as Tertiary Rivers (see Appendix C).

The environmental data report (Appendix C) indicates that the latest data shows the water quality (in terms of biology) in the River Taff was classified as Grade C to B (good to fair) between 2005 and 2009. In terms of chemistry, the water quality was classed as Grade A (very good) between 2005 and 2008. No data is provided for the smaller stream courses, although, as discussed in Section 2.1, evidence of past impact by mine workings groundwater was observe din the stream bed in the west of the site.

2.4.2 Surface Water Abstractions

The environmental data report (Appendix C) indicates that there are no surface water abstractions within 2km of the site.

2.4.3 Flooding

The environmental data report does not indicate that the site is at risk of flooding by rivers, reservoirs or surface water, and it does not lie within a Flood Alert or Warning Area. The site is at risk from clearwater flooding (groundwater flooding following to heavy rainfall events).

2.5 Geology

2.5.1 Published Geology

The published geological map for the area (ST08NE) indicates the site to be underlain by Glacial 'Boulder Clay' (now known as Diamicton) over bedrock of the Brithdir Beds of the Upper Coal Measures. It lies just to the north-east of the Llanwonno Fault. Recent up-to-date mapping published in the website of the British Geological Survey (BGS, August 2016) suggests that superficial deposits are absent and the bedrock to be the Brithdir Sandstone of the Coal Measures.

The geological mapping indicates the quarry face to the south of the site to comprise 40ft (12.2m) of 'massive false bedded sandstone' with a bedding dip of 18° to the south.

2.5.2 Available British Geological Survey Borehole Records

Reference to the BGS website indicates no available borehole records for the immediate vicinity of the site. However, records for boreholes in a similar geological setting to the south of the site suggest a 'grey/brown, gravelly clay' to be present above the Coal Measures bedrock. This is likely to be glacial in origin.

2.6 Hydrogeology

2.6.1 Aquifer Classification

Reference to the aquifer maps published in the environmental data report (Appendix B) indicates that the glacial superficial deposits to the south of the site are classed as Unproductive Strata, whilst the bedrock underlying the site (the Brithdir Sandstone) is classed as Secondary A Aquifer.

Secondary A Aquifers generally correspond with the previously classified minor aquifers, and comprise permeable layers capable of supporting water at a local, rather than strategic, scale and in some cases form an important base flow to rivers. Secondary A Aquifers are sensitive to pollution.

Unproductive Strata are bedrock or drift deposits of low permeability, which have negligible significance for water supply or river base flow. Unproductive Strata are the least sensitive in terms of pollution.

2.6.2 Anticipated Groundwater Bodies

Based on the available information, we consider that the shallowest main groundwater body is likely to be located within the Brithdir Sandstone bedrock.

2.6.3 Abstractions and Groundwater Vulnerability

The environmental data report indicates that there are no groundwater abstractions or Source Protection Zones within 500m of the site. The groundwater vulnerability is shown in the environmental data report to be 'minor aquifer high leaching potential.

2.6.4 Groundwater Movement

Groundwater movement within the Glacial Till will be controlled by intergranular flow whilst, in the Brithdir Sandstone, fracture flow is likely to be dominant. The Llanwonno Fault lies some 300m to the west of the site and is not likely to have any impact upon groundwater flow within the bedrock beneath the site itself.

Given the site setting, it is likely that groundwater flow will be toward the River Taff toward the east.

2.7 Contact with Regulatory Bodies & Local Information Sources

The following departments of the Local Authority (Rhondda Cynon Taff Council) have been contacted as part of this assessment:

- Environmental Services/Health/Pollution Control; and
- Trading Standards (Petroleum Officer)

Their responses are provided in Appendix E, and discussed in the following relevant sections.

2.8 Environmental Setting

2.8.1 Summary of Environmental Data

The site exists in a historically industrial, and now a rural setting. An environmental data report has been obtained for the site and is presented in Appendix C, and the data therein is summarised in Table 2 below and, where salient, discussed in Section 2.8.2.

Table 2: Summary of Environmental Data

	Item	On the Site	In the Immediate Vicinity
8	Environmentally Sensitive Sites [2]	None identified.	Ancient woodland is located within 100m of the site.
1	Potentially Contaminative Land Use	Numerous features identified, see Section 2.8.2.1.	See Section 2.8.2.1.
1	Historical Tanks, PFS, Garages, Energy Facilities	None identified.	None recorded within 150m of the site.
1	Potentially Infilled Land	Numerous features identified, see Section 2.8.2.2.	See Section 2.8.2.2.
2	IPPC Authorisations	None identified.	None recorded within 500m of the site.
2	Discharge Consents	None identified.	None recorded within 250m of the site.
2	List 1 and 2 Dangerous Substances Sites	None identified.	None recorded within 500m of the site.
2	Radioactive Substance Sites	None identified.	None recorded within 250m of the site.
2	Enforcements	None identified.	None recorded within 500m of the site.
2	Pollution Incidents	Three List 2 incidents recorded on site, see Section 2.8.2.3.	A single incident within 250m.

Cont.

Table 2: Summary of Environmental Data (Cont.)

	Item	On the Site	In the Immediate Vicinity
2	Contaminated Land under Part 2A EPA 1990.	None identified.	None recorded within 500m of the site.
3	Waste Management Facilities	Scrap yard on site. See Section 2.8.2.4.	No others recorded within 500m of the site.
4	Current Industrial/ Commercial Sites	Scrap yard on site	See Section 2.8.2.5.

Notes on Table 2:
1. Numbers on left refer to relevant Sections in environmental data report (Appendix B).
2. Sensitive land uses include Sites of Special Scientific Interest, Nature Reserves, National Parks, Special Areas of Conservation, Special Protection Areas, Ramsar sites, World Heritage sites and Ancient Woodland.
3. Nitrate vulnerable areas relate to the agricultural use of fertilizers and are not considered further in this assessment.

2.8.2 Further Discussion on Salient Environmental Features

2.8.2.1 Potentially Contaminated Land

The environmental data report has listed the following potentially contaminative uses on or around the site:

- railway sidings;
- iron and steel works;
- unspecified ground workings;
- refuse heap;
- disused quarry; and
- joinery works.

With the exception of the ground workings, the refuse heap and railway sidings, the historical maps suggest that the above were located on adjacent land.

Information from Rhondda Cynon Taf Council did not indicate any potentially contaminative uses other than those identified in the environmental data report. As discussed in previous sections, in addition to the above past uses, the site has recently been occupied by a scrap yard – see Section 2.8.2.4.

2.8.2.2 Potentially Infilled Land

The environmental report lists the refuse heap, unspecified worked ground and disused quarry as potentially infilled land at the site. Further potentially infilled land has been identified within 250m of the site, including ponds, ground workings, a heap, pits, shafts and quarries.

2.8.2.3 Pollution Incidents

Three pollution incidents are recorded to have occurred at the site, all on 7th July 2004. The incidents reportedly involved construction and demolition wastes and household wastes, and impacted on water (minor), land (significant) and air (no impact). No further details are provided. A further incident occurred 170m north-east of the site, but this is unlikely to have impacted the site.

2.8.2.4 Waste Management Facilities

As discussed in previous sections, Gene Metals was a recent scrap yard and the details within the environmental data report suggest it was first registered in 1989, then as a metal recycling site (mixed MRS's) in March 1996, with an annual tonnage of waste of 4,000 tonnes. An existing sign above the entrance of Building A indicates that Gene Metals was operated under waste management license no. SY/03/94 issued by Taff Ely Borough Council, however, although the Local Authority identified the scrap yard in their response (Appendix E, Record 11), they did not provide any further information.

The surrender of this waste license prior to development is outside the scope of this assessment.

The environmental data report provides no further information on the tip shown on historical maps in the 1970s within the quarry to the south of the site (see Section 2.3.1). The Local Authority recorded this feature in their response (see Appendix E, Record 10), but provided no further information.

2.8.2.5 Current Industrial/Commercial Sites

The former scrap yard is no longer operating and the site is now generally disused. However, an unknown person appears to be partly operating a skip business from the site. No further significant commercial/industrial sites have been identified in the vicinity.

2.8.3 On-Site Bulk Liquid Storage

No evidence of current bulk liquid storage was identified on site. The Local Authority Petroleum Officer information (Appendix F) indicates no records of known tanks on site.

During the field reconnaissance visit, a brick and concrete bund and metal supports for a former, now removed above ground tank were identified directly in front of Building B (Plate 14). We have no confirmation of the liquids stored in the tank, but they may have been fuels. No significant surface staining was observed within, or around, the bund, suggesting limited or no spillages.

2.8.4 On-Site Bulk Materials and Waste Storage

Numerous skips are currently being stored in Zone A, along the south-eastern boundary of the site. The majority were empty, however, some were full of building waste including furniture, plaster board, bricks, concrete, soil and plastic. From a visual assessment of the contents, it appears that these skips contain recent waste materials, i.e. not relating to the former scrap yard use. The identity of the operator maintaining these skips is not known.

2.9 Preliminary Geotechnical Risk Register

2.9.1 Summary of Potential Geotechnical and Geomorphological Hazards

The potential for various geotechnical and geomorphological hazards at the site is provided in the environmental data report (Appendix C).

The potential hazards, as reported in this data report, are listed in Table 3 below, along with any salient further information on the potential hazard identified by ESP as part of this assessment. Where a potential hazard has been identified, it is discussed further in subsequent sections.

Table 3: Preliminary Geotechnical and Geo-environmental Risk Register

Ground Stability Hazard	Potential[1]	ESP Comment
Coal Mining	-	See Section 2.9.2.
Mining (non-coal)	-	Old quarry immediately to the south of the site. See Section 2.9.3.
Shrinking or Swelling Clays	Negligible	See Section 2.9.4.
Landslides or unstable ground	Very Low	See Section 2.9.5.
Ground Dissolution (Soluble Rocks)	Negligible	No further information identified to contradict data report.
Compressible Ground	Negligible	No further information identified to contradict data report.
Collapsible Ground	Very Low	No further information identified to contradict data report.
Running Sand	Negligible	No further information identified to contradict data report.
Radon	-	See Section 2.9.6.
Volumetrically Unstable Slag	Not reported.	See Section 2.9.7.
Sulphate/Pyritic Ground	Not reported.	See Section 2.9.8.
Unexploded Ordnance	Not reported.	See Section 2.9.9.

Notes on Table 3:
1. Potential as reported in environmental data report (Appendix C).
2. Salient hazards discussed in following sections.
3. An updated Geotechnical Risk Register, following intrusive investigation of salient hazards, is presented as Table 12 in Section 8.4.1.

2.9.2 Past Coal Mining

As discussed in Section 2.5, the site is underlain by Coal Measures bedrock, which contains several seams of coal (and bands of ironstone). Reference to the website of the Coal Authority (August, 2016) indicates that it is not located within a 'High Risk Development Area', nor is it located within an area of known past or probable past shallow underground coal workings. Nonetheless, a mining report has been obtained from the Coal Authority and is presented in Appendix D.

The mining report indicates that, based on the records held by the Coal Authority:

- The property is not within the zone of likely physical influence on the surface from past underground workings;
- The property is not in an area for which a license has been granted to remove or otherwise work coal using underground methods. However, reserves of coal exist which could be worked at some time in the future;
- There are no known mine entries within, or within 20m of, the boundary of the property;
- The Authority has not received any damage notice or claim for the property or any property within 50m.

Based on the available information, we consider that the mining subsidence risk at the site is low.

2.9.3 Past Mining (non-coal)

A former quarry (now gardens to the rear of houses on Birchley Close) is located immediately to the south of the site. It is likely that the quarry was operated to win sandstone for local building materials.

2.9.4 Shrinkable and Swelling Soils

The preliminary phase of investigation at the site (see Sections 2.2 and 5.1) identified fine-grained glacial soils at the site, although no testing of plasticity was undertaken. Given our local experience, glacial soils are commonly of low or moderate plasticity, and we consider that the shrinkable and swelling soils hazard reported in the environmental data report (Table 3, negligible) should be advanced to low or **moderate**, and subject to further testing.

2.9.5 Landslips and Site Instability

Reference to the South Wales Landslip Survey (Conway et al, 1980) indicates no post-glacial landslips within the vicinity of the site.

The south-eastern boundary of the site is formed by the crest of a steep, former quarry face, aligned around north-east to south-west. As discussed in Section 5.1, the published geological map identified the face to comprise massive sandstone dipping at around 18° to the south, i.e. out of the face.

A full visual inspection of the quarry face was not feasible due to access restrictions and the presence of dense vegetation, however, from the available information, the quarry face beneath the site appears to be sub-vertical and around 10 to 15m in height. Historical maps show a disused ‘tip’ at the toe of the face, the materials within which may be acting as a buttress to the face, improving stability, but this has not yet been confirmed. The potential for instability within the quarry face itself will depend on the distribution and angle of discontinuities such as the bedding (which reportedly dips out of the face) and the various joint sets.

In addition, historical map evidence suggests that the slopes to the north of the access track appear to comprise the former slag tip of the Forest Iron and Steel Works, and small exposures within the otherwise heavily vegetated slopes seem to confirm this.

Given the currently available information, we consider that the instability hazard on the south-western boundary (above the quarry face) and to the north of the access road should be advanced from that reported in the environmental data report (Table 3, very low) to potential **high**.

2.9.6 Radon Hazard

Radon is a colourless, odourless, radioactive gas, which can pose a risk to human health. It originates in the bedrock beneath the site, where uranium and radium rich minerals are naturally present, and can move through fractures in the bedrock, and overlying superficial deposits, to collect in spaces within/beneath structures.

The environmental data report (Appendix B) indicates that the site does not lie in a radon affected area as defined by the Health Protection Agency. The environmental data report indicates that the Health Protection Agency reports that the site does not lie within a radon affected area, with less than 1% of properties above the action level.

Reference to BRE 211 (Scivyer, 2007) indicates that the site lies in a 1km square where no radon protection measures are required for new buildings (domestic or non-domestic).

Given the currently available information, the radon hazard is considered low.

2.9.7 Volumetrically Unstable Slag Materials

The environmental data report does not consider the potential risk from expansive slag. The preliminary investigation at the site (see Section 5.1) identified slag materials to be present within the Made Ground and fragments of suspected slag materials were visually observed in the site surface soils. In addition, suspected slag materials were also identified in the localised exposures within the steep slopes to the north of the access road.

There are a number of types of slag found on brownfield sites across the UK, some of which are volumetrically stable, but some can be extremely unstable when hydrated and can lead to significant heave. Given the currently available information, the presence of slag within the shallow Made Ground cannot be discounted across the site and within the slopes above the access road, and the unstable slag hazard is considered **high.**

2.9.8 Pyritic Ground

The environmental data report does not consider the potential risk from sulphate rich or pyritic ground. The bedrock underlying the site is not anticipated to contain elevated levels of pyrite, which could oxidise to sulphates. However, depending upon the origin of the glacial deposits, and in all likelihood, the Made Ground anticipated beneath the site may also contain elevated levels of pyrite.

Given the above, we consider that the potential for sulphate/pyrite attack on buried concrete would be low to **moderate.**

2.9.9 Buried Unexploded Ordnance (UXO)

The environmental data report does not consider the potential risk from unexploded ordnance at the site.

Reference to UXO risk maps available on-line (Zetica, 2016) suggests that the site is located within a **low** risk region with regards to the risk from buried unexploded ordnance.

3.0 PRELIMINARY GEO-ENVIRONMENTAL RISK ASSESSMENT

3.1 Phase One Conceptual Site Model

3.1.1 Background

The Phase One Conceptual Site Model lists the potential sources of geo-environmental risk, the receptors at risk and the pathways between the two. These are discussed in the following sections.

3.1.2 Potential Sources of Contamination

The site history has indicated that it has been recently operated as a scrap metal and recycling yard, which is a potentially contaminative use. From the available information, we consider that the following features identified on site could prove sources of diffuse and point source contamination that could impact on the development, environment or site users:

- Made Ground – general diffuse contamination and areas of buried material;
- Former above fuel tanks – point source;
- Railway sidings – general diffuse contamination; and
- Skips containing building rubble – may contain asbestos containing materials (ACM), point source.

The potential contaminants associated with the above potential sources have been identified from various guidelines published by DEFRA, the Environment Agency and others. The particular guidance referenced includes the 'industry profiles' for railway land and metal recycling sites (DoE, 1995). Based on the guidance in these reports and our experience, we consider that the following contaminants could be present on the site:

- heavy metals and semi-metals (arsenic, barium, beryllium, boron, cadmium, chromium, copper, lead, mercury, nickel, selenium, vanadium, zinc);
- cyanide, sulphate, sulphide;
- polyaromatic hydrocarbon (PAH) compounds;
- petroleum hydrocarbons;
- phenols;
- polychlorinated biphenyls (PCBs);
- chlorinated solvents (volatile organic compounds);
- semi-volatile organic compounds; and
- asbestos.

No evidence has been identified from the desk study to suggest that radioactive substances may be present on the site. The potential presence of radon in discussed in Section 3.1.4.

3.1.3 Potential Sources of Hazardous Ground Gas

Based on the available information, the following potential sources of hazardous ground gas have been identified on, or in close vicinity of, the site:

- General Made Ground – organic and other materials could generate combustible and noxious gases;

- The historical tip (1970s) within the former quarry immediately below the south-eastern boundary of the site – it is not known if this was a colliery spoil tip, or a municipal or inert landfill;
- General worked ground and (probable colliery or ironworks) tips within 250m of the site;
- Petroleum hydrocarbons spilt within Made Ground – unweathered hydrocarbons can generate hazardous volatile organic vapours and as they degrade, the hydrocarbons can generate combustible and noxious gases;
- Chlorinated solvents spilt during the former use as a scrap yard - unweathered solvents can generate hazardous volatile organic vapours, whilst combustible and noxious gases can be generated as they degrade.

Based on the guidelines presented by O'Riordan and Milloy (1995) and revised by Wilson et al (2009), the historical tip to the south-east of the site could be of moderate to high gas generation potential, if it were municipal waste, or low gas generation potential if it were inert waste. This 'tip' appears to now be within the garden of a domestic property on Birchley Close, so it may have been removed in the recent past – however, we have no confirmation of this.

The Made Ground materials across the site, including those impacted by hydrocarbons or solvents are anticipated to be of low gas generation potential.

3.1.4 Potential Sources of Radon

As discussed in Section 2.9.6, the radon hazard is reported to be low.

3.1.5 Potential Receptors

As discussed in Section 1.1, the proposed site development will comprise residential properties with private gardens, landscaping and vehicle parking areas.

A stream (classed as a tertiary river) is partly culverted through the west of the site, which appears to be a tributary of the River Taff, a primary river, some 500m east of the site. The Coal Measures bedrock beneath the site is classified as a Secondary A Aquifer.

Given the above, we consider that the most vulnerable receptors with regards to any contamination or hazardous ground gas present are likely to be as follows.

- Future residents, the critical receptors being young children playing in private garden areas;
- Construction and maintenance workers;
- Buried concrete (foundations, drainage etc.);
- The water quality in the River Taff; and
- The groundwater within the Brithdir Beds beneath the site (classified as a Secondary A Aquifer).

3.1.6 Potential Migration Pathways

Based on the Conceptual Site Model discussed in the previous sections, the following are considered the most likely migration pathways with regard to any contamination or hazardous ground gas present beneath the site.

Site Users:

- Ingestion of soils and inhalation of dust in garden areas;
- Ingestion of soils and inhalation of dust in landscaping areas;
- Ingestion of edible plants and dust associated with such plants;
- Dermal contact with contaminated soils;
- Exposure to asbestos containing materials within the shallow soils;
- Potential explosive risk from flammable ground gas/vapours from on-site sources;
- Potential risk from toxic ground gas/vapours from on-site sources; and
- Potential exposure to flammable or toxic ground gas/vapours originating from off-site sources (particularly the tip materials to the south, if present).

Construction and Maintenance Workers:

- Exposure to asbestos containing materials within the existing buildings;
- Exposure to asbestos containing materials within the shallow soils;
- Ingestion of soils and inhalation of dust across site;
- Dermal contact with contaminated soils;
- Potential explosive risk from flammable or toxic ground gas/vapours from on-site sources; and
- Potential explosive risk from flammable or toxic ground gas/vapours from off-site sources (particularly the tip materials to the south, if present).

Groundwater:

- Leaching of mobile contaminants into the water-bearing strata within the bedrock.

Surface Water/River Taff:

- Leaching of mobile contaminants to the groundwater beneath the site, and then on to nearby surface water courses (e.g. the stream in the west of the site); and
- Surface run-off of contaminated leachate to the stream in the west of the site.

Buildings:

- Sulphate attack on buried concrete (foundations, drainage etc.);
- Potential explosive risk from flammable ground gas/vapours from on-site sources; and
- Potential explosive risk from flammable ground gas/vapours from off-site sources.

3.2 Preliminary Risk Evaluation & Plausible Pollutant Linkages

The land use history of the site and surrounding area, as established from the desk study and walkover, has identified a number of potential contamination linkages due to ground conditions or former operations either on, adjacent to, or in the vicinity of the site. Note that these potential linkages will need to be later assessed and re-established using actual site data obtained from an exploratory investigation.

It should also be appreciated in assessing plausible pollution linkages that the ground levels across the site will change as development platforms are constructed. In particular, in Zone A (south-eastern area) development ground levels will be up to 3m above existing levels, whilst in parts of Zone C (western area) ground levels will be lower than at present.

3.2.1 Introduction to Risk Evaluation Methodology

The methodology set out in CIRIA C552 (2001), *Contaminated Land Risk Assessment – A Guide to Good Practice*, has been used to assess whether or not risks are acceptable, and to determine the need for collating further information or remedial action.

Whilst at a later stage, this methodology may be informed by quantitative data (such as laboratory test results) the assessment is a qualitative method of interpreting findings to date and evaluating risk. The methodology requires the classification of:

- The magnitude of the potential consequence (severity) of risk occurring (Table A1 in Appendix A):
- The magnitude of the probability (likelihood) of risk occurring (Table A2 in Appendix A).

The classifications defined above are then compared to indicate the risk presented by each pollutant linkage, allowing evaluation of a risk category (Tables A3 and A4 in Appendix A). These tables have been revised slightly from those presented in CIRIA C552, to allow for the circumstances where no plausible linkage has been identified and, therefore, no risk would exist.

The methodology described above has been used to establish Plausible Pollutant Linkages (PPL) based on the Conceptual Site Model generated for the site and proposed development, and to evaluate the risks posed by those linkages, using information known about the site, at this desk study stage. This is presented as Table 4 in Section 3.2.2 below.

3.2.2 Tabulated Preliminary Risk Evaluation & Plausible Pollutant Linkages

Table 4: Preliminary Risk Evaluation & Plausible Pollutant Linkages (PPL).

Source	Pathway	Receptor	Classification of Consequence	Classification of Probability	Risk Category	Further Investigation or Remedial Action to be Taken
Potential contaminants in shallow soils	Direct contact/ inhalation/ ingestion of contaminated soil or dust	Site Users (residents)	Medium – potential for chronic levels.	High likelihood[2]	High Risk	Sampling of near-surface soils to confirm levels of total contamination present.
		Construction/ Maintenance Workers	Medium – potential for chronic levels.	High likelihood[2]	High Risk	
	Leaching of soil contaminants	Impact on groundwater	Medium – site lies on Secondary A Aquifer	Likely[2]	Moderate Risk	Sampling of near-surface soils to confirm levels of leachable contamination present.
		Impact on River Taff	Medium – tertiary river on site	Likely[2]	Moderate Risk	
Asbestos in shallow soils	Ingestion of fibres	Construction/ Maintenance Workers	Medium – potential for chronic levels	High likelihood[3]	High Risk	Sampling of shallow soils for asbestos.
		Site Users (residents)	Medium – potential for chronic levels	High likelihood[3]	High Risk	
Soil sulphate and pyrite	Aggressive groundwater	Buried Concrete	Mild – damage to structures	Low likelihood[4]	Low Risk	Sampling of soils to confirm levels of sulphate, pH.
Hazardous ground gas/vapours from Made Ground and off-site sources	Asphyxiation/poisoning. Injury due to explosion.	Site Users/Visitors.	Severe – acute risk.	Likely[5]	High Risk	Install and monitor gas wells.
		Construction and Maintenance Workers.	Severe – acute risk.		High Risk	
	Damage through explosion.	Building/property	Severe – acute risk.		High Risk	
Radon gas	Migration into Buildings	Site Users (residents)	Medium – potential for chronic levels	Unlikely[6]	Low Risk	No protection measures required.

Notes to Table 4:

1. Methodology and details of risk consequence, probability and category based on CIRIA C552 (2001) and discussed in Section 3.2.1.
2. Made Ground, including former scrap yard materials, identified on site and contamination anticipated. (Section 3.1.2).
3. Given the presence of scrap yard materials, asbestos materials cannot be discounted within the Made Ground soils. Asbestos in buildings and skip materials should also be considered (Section 3.1.2).
4. Made Ground and Glacial Till can potentially contain sulphates/pyrite (Section 2.9.8).
5. Numerous sources of ground gas on and off site, and potential of vapours from petroleum hydrocarbons and solvents. (Section 3.1.3).
6. Radon risk identified in environmental data report (Section 3.1.4).
7. The above risk evaluation is updated following the intrusive investigation and testing in Table 10 in Section 6.2.

4.0 EXPLORATORY INVESTIGATION

4.1 Investigation Points

4.1.1 Introduction

As discussed in Section 2.2, the intrusive investigation at the site was undertaken in two phases.

- **Phase One Investigation:**
  Comprised the excavation of fifteen trial pits (TP1 to TP15) across the site in May 2015, to provide a preliminary indication of the shallow ground conditions and, in particular, the nature of the Made Ground present.
- **Phase Two Investigation:**
  Undertaken in July 2016 and comprised the excavation of fourteen further trial pits (TP101 to TP114) across the site, and slit trenches within the slopes to the north of the access road (ST1 to ST5), the installation of gas and groundwater monitoring wells within windowless sample boreholes (WS1 to WS5), soakaway infiltration testing, a visual inspection of the quarry face immediately to the south-east of the site, and monitoring for gas and volatile compounds during and following the site works.

Both phases of intrusive investigation were undertaken in accordance with BS5930:2015 and BS10175:2013, and were designed to investigate both geo-environmental and geotechnical hazards identified in the desk study (Section 2.0). The exploratory holes were supervised and logged by an engineering geologist in general accordance with BS5930:2015, along with appropriate published weathering schemes.

Descriptions and depths of the strata encountered are presented on the trial pit records presented in Appendices F1 (Phase One) and F2 (Phase Two), the windowless sample borehole records in Appendix G, and the slit trench records in Appendix H. The results of the soakaway infiltration testing are presented in Appendix I, the rock slope stability assessment in Appendix J, and the gas and groundwater monitoring undertaken to date in Appendix K.

The investigation point positions within the main site are shown on Figure 4a, whilst the slit trench positions, along the access road, are shown on Figure 4b. The ground levels indicated on the investigation point records are approximate only and have been interpolated from the topographic survey provided by the Client (dwg. S9351 PR101). The coordinates shown on the investigation point records are for the centre of the site.

4.1.2 Investigation Strategy

The investigation strategy was generally designed in accordance with BS10171:2013, taking into account the additional potential for geotechnical hazards to be present. The desk study and site reconnaissance identified a number of potential contaminant sources/geotechnical hazards at the site including:

- Potential Made Ground across the site including areas of slag and hydrocarbon odours;
- Above-ground (fuel) storage tanks (AST);
- Possible instability within the slopes to the north of the access track;
- Possible instability in a quarry face immediately to the south-east of the site; and
- Potential hazardous gas and vapour sources.

The preliminary Phase One investigation (May 2016) was completed to provide a preliminary overview of the ground conditions across the site, and no further sampling or testing was required by the Client. The Phase Two investigation was designed to further investigate the above potential hazards and allow sampling and analysis of the shallow soils.

The Phase Two investigation point positions were generally located around the site to provide a general overview, however the following investigation point positions were targeted at specific potential hazards:

- TP101 – excavated adjacent to the former above ground tank adjacent to Building B;
- TP109 and TP110 – excavated close to the south-eastern boundary to provide information on the nature of the soils/depth to bedrock within the former quarry face on the south-eastern boundary; and
- ST1 to ST5 – excavated within the slopes to the north of the access track.

4.1.3 Trial Pits

As part of the Phase One investigation, fifteen trial pits (TP1 to TP15) were excavated using a wheeled, backacting, hydraulic excavator (JCB 3CX) on 20th May 2106. The pits were excavated to a maximum depth of 2.5m and most were terminated at shallower depth on sandstone bedrock. The Client was present on site during the excavation of most of these pits.

In the Phase Two investigation fourteen trial pits (TP101 to TP114) were excavated across the site on 21st and 22nd July 2016 using a similar wheeled, backacting hydraulic excavator. These trial pits were excavated to a maximum depth of 4.4m, but again many were terminated on bedrock at shallower depth. Where present, the tarmacadam and concrete surface was broken out prior to the excavation of the pits using a hydraulic breaker.

Disturbed samples were collected from the Phase Two trial pits for laboratory testing. No man entry into the pits was undertaken. On completion, the trial pits were backfilled with arisings in layers compacted with the excavator bucket, but the concrete/tarmacadam surface was not reinstated. The arisings were left slightly proud of the adjacent surface to allow for future settlement. The trial pit records are presented in Appendices F1 (Phase One) and F2 (Phase Two).

4.1.4 Windowless Sampling

5no. windowless sample drillholes (WS1 to WS5) were constructed across the site on 20th July 2016. A hydraulically powered rig was used to drive plastic lined sampling tubes into the ground, with the soil recovered within the tubes, which are then split to allow sampling and logging. Disturbed samples were obtained throughout the boreholes for identification and laboratory testing purposes. The windowless sampling provided generally good recovery to the depth of refusal. At the commencement of each borehole, a service inspection pit excavated by hand to a depth of 1.2m.

Due to the presence of sandstone bedrock, the boreholes penetrated to depths of between 1.3 and 2.3m. The borehole records are presented in Appendix G.

Standard Penetration Tests (SPT) were carried out using a solid cone (due to the gravelly nature of the shallow soils) in the boreholes in accordance with BS EN ISO 22476-3 (2005) and BS5930 (2015) to assess the relative density of the coarse-grained soils encountered in the borehole and to provide an correlated assessment of the likely undrained shear strength of fine-grained soils using relationships published by Stroud (1975). As required in BS5930:2015, the SPT N-values shown on the borehole records are the direct, uncorrected results obtained in the field.

Caution must be applied when using in-situ SPT data collected using a solid cone: Much of the existing correlations using N-values obtained from standard penetration tests rely on the energy imposed on a split-spoon sampler (SPT) and not a solid cone (SPT-C). The solid cone has a greater surface area and, therefore, imparts a lower energy per blow than the split-spoon sampler, and can result in an over-estimation of the true SPT N-value. Based on the relationship of energy inputs at the point of penetration (Thorburn 1986), it can be inferred that the equivalent SPT N-value for a test using a cone (SPT-C) is equal to:

$$\text{SPT N-value} = \frac{\text{SPT-C}}{1.869}$$

The corrected SPT N-values (allowing for the use of a solid cone and the presence of sandy soils) are presented as Table G1 in Appendix G.

On completion, monitoring wells were installed in three of the boreholes as detailed in Section 4.2.1. The remaining boreholes were backfilled with arisings.

4.1.5 Slit Trenches

5no. slit trenches (ST1 to ST5) were excavated to the north of the access road on 22nd July 2016 using a wheeled, backacting, hydraulic excavator. The slit trenches were excavated from the access road and extended between 3.0 and 5.5m into the slopes, as measured from the edge of the track.

Disturbed samples were collected from the slit trenches for laboratory testing. No man entry into the trenches was undertaken. On completion, the slit trenches were backfilled with arisings in layers compacted with the excavator bucket. The arisings were left slightly proud of the adjacent surface to allow for future settlement. The slit trench records are presented in Appendix H.

4.1.6 Soakaway Infiltration Testing

Soakaway infiltration tests were undertaken in general accordance with BRE Digest 365 (2007) in two selected trial pits within the lower lying parts of the site (TP112, near the entrance, and TP113, in the south-west). At each position, the test pit was excavated to a depth which was anticipated to be a possible depth for the soakaway given the ground conditions identified and taking into account any proposed change in ground levels. Clean water was added from a large capacity bowser and the water level monitored as it percolated into the soil.

The infiltration rate was calculated from the time taken for the water to fall between the 75% and 25% full level. Where insufficient time was available for the water level to fall to the 25% full level, but a significant drop in water level was recorded, the infiltration rate can be estimated by extrapolating the test results.

However, where the water level only dropped marginally during the available test period (e.g. not as far as the 75% full level), we consider that there is insufficient data to allow a valid extrapolation with any confidence and no infiltration rate can be estimated. Two fills were completed within TP112 and one fill in TP113.

On completion of the testing in each pit, any remaining water was removed from the test pit and it was backfilled with the excavated arisings.

The results of the infiltration testing, and the calculated infiltration rates, are presented in Appendix I.

4.1.7 Quarry Face Inspection

A visual inspection of the quarry face to the south of the site was undertaken in July 2016. The quarry face appears to be located within private gardens, and access could only be gained (thanks to an accommodating neighbour) to the length of face to the south-east of the telecom mast, i.e. the length of face to the south-west of the site itself - see Figure 4a. However, given the available information, and our local knowledge, we consider that the kinetic geometries of the discontinuities within the length of rock face surveyed are likely to be similar to those within the bedrock immediately below the site itself.

During the inspection, the geometry of the discontinuities within the available face was measured from the adjacent ground level – these included the bedding planes and various joint sets within the rock mass. Multiple measurements were made of available sections of each discontinuity set (in terms of dip angle and direction) and these have been plotted on stereographic projections, from which the kinematic stability of the quarry face (i.e. the potential for major failures within the bedrock) can be assessed. The findings of the inspection and the resulting stereographic plots are presented in Appendix J.

4.1.8 Monitoring for Volatile Hydrocarbons

A photo-ionisation detector (PID) was used during the trial pitting and construction of the boreholes to measure the levels of total volatile hydrocarbons present in the recovered soils. Headspace analyses were also undertaken whereby samples of the soil were collected in sealed plastic bags from the exploratory holes and then left for a period of time (in the sun to allow any volatiles present to escape into the headspace above the soil). The PID was then used to measure the levels of total volatile organic compounds (VOC) within the headspace above the sampled soils.

The results of the headspace testing are included in the trial pit and borehole records in Appendices F2 and G.

4.2 Instrumentation

4.2.1 Gas Well Installations

A 50mm diameter monitoring well was installed in selected boreholes in accordance with BS8576:2013 in order to allow monitoring of hazardous ground gases.

The wells, comprising slotted plastic pipe with a gravel surround (the response zone), bentonite seals above the response zone, and a lockable vandal proof cover, were installed as detailed on the borehole records and summarised in Table 5 below.

Table 5: Gas Well Installations

Well ID	Date of Installation	Response Zone depth	Response Zone Stratum
WS1	20/07/2016	1.0 – 2.0m	Made Ground
WS2	20/07/2016	1.0 – 1.2m	Made Ground
WS4	20/07/2016	1.0 – 2.0m	Made Ground/sandstone bedrock

Notes on Table 5:
1. Details of each monitoring well are presented on the individual borehole records (Appendix G).

4.2.2 Gas Monitoring

Monitoring of the installed gas wells has been undertaken on a 'spot' monitoring basis (periodic visits to monitor gas levels at the time of the visit). CIRIA C665 (Wilson et al, 2007) provides guidance on the number and frequency of monitoring visits required for installed gas wells. These depend on the gas generation potential of the source and the sensitivity of the development to gas risk and are designed as a typical minimum only.

As discussed in Section 3.1.3, the most significant potential source in the vicinity of the site in terms of gas risk, the historical tip to the south of the site, is classified as being of potentially high gas generation potential. The remainder of the anticipated gas sources are of low gas generation potential. The proposed development of housing is classified as of high sensitivity in terms of gas risk. Given that the nature and existence of the historic tip material have not been confirmed (it may have been removed during the construction of the houses), we have based our gas monitoring design on the established gas sources on site. Therefore, based on the guidelines in CIRIA C665, we consider that a minimum of six monitoring visits are required over a two month period. If significant gas levels are identified in this monitoring, the monitoring period would need to be extended.

Due to an instrument malfunction, to date, only two monitoring visits have provided reliable gas monitoring data – four further visits will be undertaken. However, reliable groundwater measurements were possible during the two visits which produced unreliable gas monitoring data, and these have provided valuable information for the assessment. The results of the gas and groundwater monitoring undertaken to date are presented in Appendix K.

During each visit, Gas Data LMSxi G3.18e portable monitoring equipment was used to measures levels of the following ground gases within the airspace in the wells and the flow rates from the wells:

- Methane - total and percentage of Lower Explosive limit (LEL);
- Carbon dioxide;
- Oxygen; and
- Hydrogen sulphide.

The percentage of nitrogen is also calculated by difference. The equipment uses infra-red methane (CH_4) and carbon dioxide (CO_2) detectors, coupled with pressure (barometric and well), temperature and flow sensors. A photo-ionisation detector (PID) was used during the monitoring to measure the levels of volatile organic compounds present in the well.

Following measurement of gas levels and flow rates, the well cap was removed and groundwater levels were measured using a dipmeter from the site surface.

4.3 Sampling Strategy

4.3.1 Soil Sampling

Soil samples were collected from the exploratory holes as discussed in the previous sections. The sampling procedures were selected on the basis of the suitability for the laboratory testing proposed.

A non-targeted, random sampling strategy was generally used to obtain representative information on soil contamination across the site as a whole. However, a number of constraints were imposed on the available sampling locations by existing buildings and therefore a regular grid sampling pattern could not be adopted. Targeted samples were collected from the around the possible identified contamination sources such as the suspected former above ground tank adjacent to Building B (TP101).

Environmental samples (denoted as E on the exploratory holes records) were collected for possible geo-environmental laboratory testing and generally comprised a plastic tub, an amber glass jar and an amber glass vial. The sample containers provided clean by the testing laboratory appropriate for the proposed testing to be scheduled. Immediately after collection the samples were placed in sealed cool boxes with ice packs where they remained during storage and transport to the laboratory.

Samples for logging and geotechnical laboratory testing purposes were collected at regular intervals within the exploratory holes.

4.3.2 Soil Sample Quality

Samples of soil recovered from investigations are classified as Classes 1 to 5 in terms of quality and depend on the investigation and sampling method, the particle size of the strata sampled, and the presence of groundwater. Class 1 and 2 samples are those in which there has been no or only slight disturbance of the soil structure, with moisture contents and void ratios being similar to the in-situ soil. Class 3 and 4 samples contain all the constituents of the in-situ soil in their original proportions, and the soil has retained its original moisture content, but the structure of the soil has been disturbed. In Class 5 samples, the soil structure and original layering cannot be identified and the water content may have changed from that in-situ. The category and class of samples are discussed further in BS EN ISO 22476:2006, EN 1997-2:2007 and BS5930:2015.

In general terms, disturbed samples recovered from trial pits (bulk bags and small tubs) are classed as Class 3 (if dry), Class 4 (fine soil below the water table), or Class 5 (coarse soils from beneath the water table).

The samples recovered within the liner in windowless sampling are generally Class 3 in fine-grained soils with good recovery, becoming Class 2 in favourable circumstances, but Class 3 or 4 in coarse-grained soils. The split spoon sample from a Standard Penetration Test (SPT) is usually considered a Class 5 sample however, it can be deemed Class 4 in homogeneous fine-grained soils. Disturbed sampling (bulk bags and small tubs) from boreholes is considered Class 3 (if dry), Class 4 (fine soil below the water table) or Class 5 (coarse soils from beneath the water table).

4.4 Evidence of Site Hazards Found During Site Works

With regard to potential hazards identified in the desk study and Preliminary Risk Assessment, the following observations were made from the findings of the intrusive investigation.

4.4.1 Site Stability

Trial Pits TP109 and TP110, excavated close to crest of the former quarry face on the south-eastern boundary identified a significant thickness of Made Ground over sandstone bedrock (at 2.2m depth in TP110) and fine-grained glacial soils (at 2.7m in TP109). This suggests that the anticipated former quarry face on the south-eastern boundary comprises soils rather than sandstone bedrock, particularly around TP109. This will have a significant impact on the stability of this slope – this is discussed further in Section 8.2.6.

The slit trenches excavated into the slopes to the north of the access track identified these slopes to comprise predominantly loose cobbles and boulders of angular slag and sandstone, with some cemented slag and man-made materials. The potential instability of these slopes is discussed further in Section 8.3.3.

4.4.2 Site Evidence of Contamination

Made Ground was encountered across the site and contained remnant fragments from the past use of the site as a scrap yard, including car parts such as wheels, tyres and fragments of suspension, wooden timbers, and fragments of ash, slag, coal, clinker, brick, concrete, and metal wiring, pipes and sheets.

Direct visual and olfactory evidence of contamination was identified in several of the trial pits and boreholes. During the Phase One investigation, strong hydrocarbon odours were identified across Zones A, B and C in TP1, TP3, TP9, TP10, TP11, TP12 and TP15.

The direct evidence of contaminants identified within the Phase Two investigation is summarised in Table 6 below.

Table 6: Site Evidence for Contamination (Phase Two Investigation)

Hole ID	Zone	Stratum	Comment on contamination encountered
TP112	A	Made Ground	Unusual odour within shallow Made Ground. No reading on PID. Possible solvent odour.
WS3	B	Made Ground and Diamicton	Odour of petroleum hydrocarbons (possibly diesel) within Made Ground (PID reading 69ppm), and underlying glacial soils (PID reading 40ppm).
TP103	B	Made Ground and Diamicton	Strong hydrocarbon odour within Made Ground and underlying glacial soils of 141ppm and 207ppm respectively.
TP111	B	Made Ground	Strong odour of petroleum hydrocarbons (possibly diesel) within Made Ground and PID reading of 50 to 80ppm.
TP102	C	Made Ground and Bedrock	PID reading of 16ppm within Made Ground and 13ppm within weathered bedrock. No odour identified.
TP104	C	Made Ground	Slight hydrocarbon odour noted with PID readings up to 6ppm between GL and 1.4m.

Table 6: Site Evidence for Contamination (Phase Two Investigation) cont.

Hole ID		Stratum	Comment on contamination encountered
TP114	B	Made Ground and Diamicton	Strong hydrocarbon odour in Made Ground and glacial soils with PID readings up to 6ppm
WS2	C	Made Ground	Strong odour of petroleum hydrocarbons (possibly diesel) between GL and 1.2m. PID reading between 105 and 175ppm.

Notes to Table 6:
GL: ground level.
PID: photo-ionisation detector

4.5 Geotechnical Laboratory Testing

Geotechnical laboratory testing was undertaken on samples from the suitable quality classes recovered from the exploratory holes in order to obtain information on the geotechnical properties on the soils beneath the site.

The following tests were undertaken by a UKAS accredited laboratory on samples selected by ESP in accordance with the methodologies presented in BS1377:1990. The results are presented in Appendix L:

- Natural moisture content;
- Atterberg limits; and
- Particle size analysis.

Selected samples were also analysed for soil sulphate and pH value in accordance with the analytical methods specified in BRE Special Digest 1 (BRE, 2005). Due to the potential presence of pyrite in the soils, these samples were also analysed to determine the levels of total sulphur, acid soluble sulphate in accordance with the analytical methods specified in BRE Special Digest 1 (BRE, 2005). The results of the sulphate testing are included with the geo-environmental test results in Appendix M.

In addition to the above testing, Phase One slag expansion testing has been undertaken on three samples of suspected slag recovered from the exploratory holes within the site (TP104 and TP114) and from the slopes to the west of the access track (ST4). The Phase One testing comprises a mineralogical inspection, by a specialist laboratory (TRS Limited), to identify whether any potentially expansive minerals are present within the slag materials. The specialist report of the Phase One slag expansion testing is presented in Appendix O.

4.6 Geo-environmental Laboratory Testing

Laboratory testing has been undertaken to identify the levels of selected contaminants within samples of soil, and leachate generated from shallow soils across the site.

The geo-environmental analyses were carried out by a UKAS accredited testing laboratory with detection limits being generally compatible with the relevant guideline values adopted in the assessment (see Section 5.4.3).

4.6.1 Soil Samples

To allow an assessment of the potential chronic risks posed to human health, a total of twelve selected samples of the Made Ground have been analysed for the contaminants identified in Section 3.1.2, plus other determinands typically present on brownfield sites in the UK. The general suite of geo-environmental laboratory testing undertaken comprised:

- Arsenic, barium, beryllium, boron, cadmium, total chromium, chromium VI, copper, lead, mercury, nickel, selenium, vanadium, zinc;
- US EPA 16 polyaromatic hydrocarbon (PAH) compounds;
- Total monohydric phenols;
- Total cyanide, asbestos qualitative screen (presence or absence);
- Soil organic content, pH value;
- Petroleum hydrocarbons (CWG ali/aro carbon banded C_5 to C_{35});
- Volatile organic compounds (including chlorinated solvents);
- Semi-volatile organic compounds; and
- Polychlorinated biphenyls (PCBs, Euro 7).

Asbestos was identified in some of the samples analysed and these were subjected to further quantitative testing to determine the quantity of asbestos fibres present by gravimetric quantification. The geo-environmental soil test results are presented in Appendix M.

4.6.2 Leachate Samples

In order to allow an initial assessment of the potential pollution risks to controlled waters, samples of leachate have been generated from eight samples of Made Ground recovered from the exploratory holes. The leachate preparation was carried out in accordance with BS EN 12457, at a 10:1 elluate ratio.

The resulting leachate was analysed for the following determinands:

- Arsenic, barium, beryllium, boron, cadmium, total chromium, copper, iron, lead, mercury, nickel, selenium, vanadium, zinc;
- US EPA 16 polyaromatic hydrocarbon (PAH) compounds;
- Total monohydric phenols;
- Cyanide, soluble sulphate, pH value;
- Petroleum hydrocarbons (CWG ali/aro carbon banded C_5 to C_{35});
- Volatile organic compounds (including chlorinated solvents);
- Semi-volatile organic compounds (SVOCs); and
- Polychlorinated biphenyls (PCBs, Euro 7).

To allow the selection of the appropriate assessment criteria in assessment (see Section 5.6.3), the hardness (concentration of calcium carbonate) of the water within the stream in the west of the site has also been analysed.

The results of the leachate and hardness tests are presented in Appendix N.

5.0 DEVELOPMENT OF THE REVISED CONCEPTUAL MODEL

5.1 Geology

The exploratory holes have identified the site to be generally underlain by Made Ground, over fine-grained Glacial Diamicton and, commonly at relatively shallow depth, Coal Measures sandstone bedrock. The distribution of these strata across the three zones, as identified in both phases of investigation, is discussed in more detail in the following sections. The geological succession identified in the exploratory holes is presented on a Conceptual Ground Model in Figure 5.

5.1.1 Zone A – east of the site

Relevant exploratory holes: TP6, TP7, TP8, TP13, TP14, TP15, TP106, TP107, TP108, TP109, TP110, TP112, TP113, WS4.

Made Ground: encountered across the zone in all exploratory holes to depths of between 0.15 and 2.7m as a variable deposit. A gravelly sand of grey brown and black apparent pfa (sand sized particles of pulverised fuel ash from coal fired power stations) was observed in several pits (TP6, TP7, TP13, TP110 and TP112). The remainder of the Made Ground in Zone A comprised dark grey, grey or black, very clayey, sandy, gravelly cobbles or sandy, cobbly clayey gravel, with much sandstone and many fragments of brick, plastic, glass, pipe, timber, metal, tile and further pockets of pfa sand. Some boulders were also present. Significant quantities of slag were observed in TP14.

The Made Ground was notably deeper in the south-eastern margins in TP109 (2.7m) and TP110 (2.2m) - see Section 4.4.1. An SPT N-value of 4 was recorded in the Made Ground in WS4 indicating a 'very loose' state.

Glacial Diamicton: encountered beneath the Made Ground to depths of between 0.65m and in excess of 4.4m (the base of TP109) generally as a brown mottled grey, very sandy, gravelly clay or silt of soft becoming firm consistency, with occasional cobbles. In TP108, the clay was visually assessed as being desiccated to the full depth, of 0.65m. The stratum comprised a silty, gravelly sand in TP6, TP7 (lower parts), TP8 and TP13, and a sandy gravel in TP14. The glacial soils were absent in WS4, TP106, TP110 and TP113 where the Made Ground lay directly on the underlying weathered bedrock.

Coal Measures bedrock: encountered at the base of all exploratory holes from depths as shallow as 0.3 to 0.7m (TP106, TP108 and TP113 in the west of the zone), but generally between 1.4 and 2.2m as a grey and reddish brown gravel of subangular to angular, medium to coarse grained sandstone blocks, with numerous angular sandstone cobbles and boulders. This is considered to comprise the weathered zone of the Birthdir Sandstone, and penetration was generally limited to 50 to 100mm.

The weathered bedrock in TP113 was excavated to a depth of 700mm using a breaker in order to construct a soakaway test pit, and by around 500mm in Borehole WS4, where an SPT N-value in excess of 50 was recorded. Bedrock was not encountered in TP109.

5.1.2 Zone B – centre of the site

Relevant exploratory holes: *TP1, TP3, TP4, TP5, TP9, TP12, TP101, TP103, TP111, TP114, WS1, WS3.*

Made Ground: encountered in all exploratory holes across the zone generally to depths of between 0.6 and 1.9m as variable deposit, predominantly comprising dark grey and dark brown, very sandy, silty, gravel, with many fragments of man-made materials, including car tyres and other parts, brick, glass, pipe, timber, metal, clinker, slag, tile, plastic sheeting, concrete, timber sleepers and tarmacadam. Cobbles and boulder sized fragments were common. A pfa sand was identified in TP5, TP9 and WS1 in the eastern margins of the zone. An SPT N-value of 2 was measured in Borehole WS1.

Glacial Diamicton: encountered beneath the Made Ground in most exploratory holes as heterogeneous deposit of predominantly light brown, silt, clay, sand and gravel, soft or soft to firm in consistency where fine-grained. Sandstone cobbles were present in areas. The glacial soils were absent in TP111 and extended below the depth of Borehole WS3 (at 1.9m depth). SPT N-values of 28 and in excess of 50 were measured in Boreholes WS1 and WS2.

Coal Measures bedrock: encountered at the base of all exploratory holes apart from TP12 and WS3 (although the lower strata in this borehole may be weathered bedrock), and from depths of between 0.9 and 2.4m as a grey and brown gravel of subangular to angular, medium to coarse grained sandstone blocks, with numerous angular sandstone cobbles and boulders. As in Zone A, this is considered to comprise the weathered zone of the Birthdir Sandstone, and penetration was generally limited to 50 to 100mm.

5.1.3 Zone C – west of the site

Relevant exploratory holes: *TP2, TP10, TP11, TP102, TP104, TP105, WS2, WS5.*

Made Ground: encountered in all exploratory holes except TP105, to depths of between 0.3 and 1.3m predominantly as a very dark brown/black, gravelly, silty, sandy gravel/gravelly sand with fragments of cars (including a whole wheel in TP104), coal, ash, clinker, slag, plastic, brick (including sections of masonry), glass, pipe, timber and metal. Sandstone cobbles were identified in some pits.

Glacial Diamicton: encountered in most exploratory holes beneath the Made Ground predominantly as a light brown/orange brown, gravelly clay or silt of soft consistency. A brown/grey clayey, gravelly sand with some cobbles was identified in TP2 and WS5. The glacial soils were absent in TP105, and in TP102 and WS2 where the Made Ground lay directly above the weathered bedrock.

Coal Measures bedrock: encountered at the base of all exploratory holes from depths as shallow as at ground level (TP105) and less than 0.5m (TP102 and TP2), but generally between 1.2 and 2.0m depth. It predominantly comprised a grey and brown gravel of subangular to angular, medium to coarse grained sandstone blocks, with numerous angular sandstone cobbles and boulders. This is considered to comprise the weathered zone of the Birthdir Sandstone, and penetration was generally limited to 100 to 200mm. Borehole WS5 penetrated the weathered bedrock by some 600mm and recorded SPT N-values of 26 in the upper strata, and in excess of 50 at the base.

5.1.4 Overall Summary

Overall, the Made Ground soils appeared to predominantly comprise materials used to raise lower lying site levels (e.g. the PFA in TP6, TP7, TP9, TP13, TP110 and TP112), as backfill behind retaining walls (e.g. the PFA in TP5 and WS1), or tipped materials containing substantial quantities of probable remnant scrap yard materials such as car parts, scrap metal, glass, tile, timber and brick. Buried car parts were evident across the site. Suspected slag gravel was identified in several pits, commonly as occasional fragments, but as a more substantial proportion of the soils in TP14, TP104 and TP114.

Sandstone bedrock was evident beneath all three zones, from generally at depths of between 1.0 and 2.0m, but much shallower in places, and less than 0.5m in several exploratory holes.

A layer of predominantly fine-grained glacial soils, generally between 0.5 and 1.0m in thickness (but less than 0.5m in places) was identified in most exploratory holes, but this was absent in several holes where the Made Ground lay directly above the weathered bedrock (TP102, TP106, TP110, TP111, TP113, WS2 and WS4).

Laboratory testing within the fine-grained Glacial Diamicton across all three zones indicated liquid limits between 44 and 54%, plasticity indices between 21 and 25%, and natural moisture contents between 21 and 36%. The modified plasticity indices (after the coarse-grained particles have been removed) suggest that the soils are of low to moderate shrinkage and swelling potential and would be generally classified as clays of intermediate to high plasticity (CI and CH).

5.1.5 Access Road

Relevant exploratory holes: ST1, ST2, ST3, ST4 and ST5.

The slit trenches excavated into the slopes to the north of the existing access track (see Appendix H) confirmed that these slopes predominantly comprised blueish grey, sandy, cobbly gravel of slag, and black and dark grey, gravelly, sand with cobbles and boulders and fragments of ash, clinker, metal, bricks and coal. These are considered to represent the former ‘slag tip’ of the Forest Iron and Steel Works and their placement probably dates from the nineteenth century. The materials are likely to have been end-tipped, and during excavation, the trench sides suffered spalling and collapse, confirming their likely ‘loose’ state. Trench ST5 was terminated at a depth of 1.6m within a suspected layer of fused slag.

The base of the tipped materials was identified in Trenches ST3 and ST4, where fine-grained Glacial Diamicton was encountered around 400mm below track level. Sandstone bedrock was identified at the base of Trench ST4.

5.2 Hydrogeology

5.2.1 Groundwater Bodies

Groundwater was not generally encountered within the exploratory holes. However, it was found in occasional exploratory holes as summarised in Table 7 below:

Table 7: Summary of groundwater ingress in the investigation

Hole ID	Zone	Stratum	Comment on groundwater encountered
TP109	A	Diamicton	Soils damp below a depth of 2.7m (top of Diamicton).
TP4	B	Diamicton	Slow inflow at 0.5m.
TP5	B	Diamicton	Slow inflow at 2.2m.
TP102	C	Sandstone bedrock	Slow inflow at 0.6m.
WS2	C	Made Ground	Slow inflow encountered at 0.7m during drilling. Standing water level recorded in well at 0.3m and 0.45m depth during monitoring visits V3 and V4 respectively.
WS5	C	Diamicton	Groundwater measured at a depth of 0.8m, upon completion of borehole. No noticeable strike during drilling.

During subsequent monitoring, apart from Well WS2 (see Table 7 above), the wells installed in the boreholes remained dry.

Given the lack of identified groundwater across the site, we consider that the main groundwater body beneath the site is likely to be within the sandstone bedrock at depth and was not encountered in the investigations. Therefore, the groundwater identified in the exploratory holes is likely to represent localised perched water bodies within the glacial soils. In particular, within Well WS2 no groundwater was identified during the first two monitoring visits, but a standing level of 0.3 and 0.45m was recorded during Visits 3 and 4. This well lies close to the stream in the west of the site and the groundwater may represent a response to raised water levels within the stream following a period of heavy rainfall.

5.3 Site Instability

5.3.1 Global Site Stability

The Preliminary Geotechnical Risk Register (Section 2.9) identified two potential stability hazards, within the slopes to the north of the access road, and within the former quarry face on the south-eastern boundary. The stability of these areas is discussed further in Sections 8.2.6 and 8.3.3.

5.3.2 Excavation Stability for Development

During the excavation of the trial pits, some spalling of the pit walls was experienced, particularly within the coarse-grained Made Ground across the entire site.

5.4 Chronic Risks to Human Health – Generic Assessment of Risks

5.4.1 Assessment Methodology

The long term risks to health have been assessed using methodologies and frameworks determined by the Environment Agency within documents SR2, SR3, SR4 and the CLEA Technical Review published to support the Contaminated Land Exposure Assessment Model (CLEA).

Where applicable, reference has been made to the supporting toxicological reports (TOX Series) and the Soil Guideline Value reports (SGV Series). It is assumed that the reader is familiar with the above documents and it is not intended to repeat these described methodologies in detail, for further information, please refer directly to the specific documents.

In order to provide an initial 'screen' to identify elevated levels of contaminants, a Generic Quantitative Risk Assessment (GQRA) has been undertaken using the most appropriate Generic Assessment Criteria (GAC) determined by assessment of exposure frequency/duration relevant to the critical receptor.

5.4.2 Assessment Criteria

In 2014, DEFRA published the Category 4 Screening Levels (C4SL) for use in Part 2A determinations. The C4SL are designed to be more pragmatic, but still strongly precautionary, assessment criteria compared to the previous assessment criteria (SGV – see below) used to assess chronic human health risks. They are designed for use in deciding whether land is suitable for use and definitely not contaminated, and DEFRA and the Welsh Government have recommended that they be used in assessing human health risks during the planning regime (i.e. as part of standard development investigations). However, the C4SL have been calculated for a limited number of contaminants at this stage, and range of land uses including residential, commercial and public open space, but are based on a 'low level' of risk rather than the 'minimal level' of risk adopted by the Environment Agency in preparing their Soil Guideline Values (SGV). At the time of writing, the use of the C4SL in planning has not yet been accepted by many parties, including some regulators. The C4SL have also only been published for a limited number of contaminants. The C4SL have not been generally adopted in this assessment.

In this assessment, where available, the Soil Guideline Values (SGV) published by the Environment Agency have been adopted as the Generic Assessment Criteria (GAC) in the first instance. However, the SGV are only available for a limited number of contaminants for three proposed land uses (residential, commercial and allotments - not public open space). Where no SGV is available, the Suitable For Use Levels (S4ULs) published in January 2015 by the Chartered Institute of Environmental Health (CIEH) and Land Quality Management (LQM) have been adopted (Nathanail et al, 2015). These assessment criteria adopt updated toxicological data and exposure models, but the same 'minimal level' of risk as the SGV (i.e. unlike the C4SL). The S4ULs have been published for a large number of contaminants typically found on brownfield sites in the UK, and for the same range of land uses as the C4SL, i.e. including public open space scenarios.

For more exotic, predominantly organic, compounds no SGV, S4UL or C4SL assessment criteria have been published. In this instance, GAC published by CL:AIRE and the Environmental Industries Commission (CL:AIRE/EIC, 2010) have been adopted. These GAC have also been developed using the CLEA UK software based on a 'minimal level' of risk and for the same land use scenarios as the SGVs (i.e. not public open space).

At the time of writing there is no published SGV, S4UL or CL:AIRE/EIC assessment criteria for lead. For the purposes of this assessment, and in the absence of any other current authoritative guidance, the Category 4 Screening Level (C4SL) value published by DEFRA has been adopted.

Details of the source of the GAC adopted for each contaminant are presented in Table 8 below.

The proposed development comprises conventional residential properties with private gardens. Therefore, the GAC appropriate for the residential land use with plant uptake have been adopted in this assessment.

The GAC for most organic compounds are dependent on the organic content of the soil. Analysis has shown that the soil organic content in the soils analysed ranged from 1.2% to 9%. Therefore, for the purposes of this assessment, GAC for a soil organic content of 1% has been adopted. This again is considered a conservative approach for the majority of the soils at the site.

5.4.3 Generic Quantitative Risk Assessment

The samples analysed for soil contaminants comprised twelve samples of Made Ground. At this stage, all samples have been considered across the site as one averaging area. If any exceedances are identified, a statistical analysis based on particular averaging areas may be undertaken to further assess the risks. The risks from asbestos are considered further in Section 5.4.4.

The results of the Generic Quantitative Risk Assessment are presented in Table 8 below. At this stage, the following assessment is based on the soils being present at the development site surface. As discussed in Section 1.1, Zone A will involve filling above the existing ground levels and Zone C will involve some cutting. The implications of these works on the risks to future residents are discussed in Section 7.1.

Table 8: Summary of Geo-environmental Soil Results

Determinand	Range Recorded	GAC	Source of GAC	Exceedances
Metals and Semi-metals				
Arsenic	5.6 - **40mg/kg**	32mg/kg	SGV[2]	**1 of 12**
Barium[6]	72 – **1,400mg/kg**	1,300mg/kg	CL:AIRE[4]	**1 of 12**
Beryllium	<0.2 – 1.7mg/kg	1.7mg/kg	S4UL[3]	None of 12
Boron	0.3 - 10mg/kg	290mg/kg	S4UL[3]	None of 12
Cadmium	0.1 – 1.7mg/kg	10mg/kg	SGV[2]	None of 12
Chromium (total)[7]	12 - 120mg/kg	910mg/kg	S4UL[3]	None of 12
Chromium (hexavalent)	<1mg/kg	6.0mg/kg	S4UL[3]	None of 12
Copper	19 - 1000mg/kg	2,400mg/kg	S4UL[3]	None of 12
Lead	28 - **960mg/kg**	200mg/kg	C4SL[5]	**3 of 12**
Mercury[8]	<0.05-0.69mg/kg	170mg/kg	SGV[2]	None of 12
Nickel	17 - **650mg/kg**	130mg/kg	SGV[2]	**2 of 12**
Selenium	<0.5 – 1.1mg/kg	350mg/kg	SGV[2]	None of 12
Vanadium	8 - 45mg/kg	410mg/kg	S4UL[3]	None of 12
Zinc	68 – **5,000mg/kg**	3,700mg/kg	S4UL[3]	**1 of 12**
Polyaromatic Hydrocarbons (PAH)				
Acenaphthene	<0.03 - 11mg/kg	210mg/kg	S4UL[3,9]	None of 12
Acenaphthylene	<0.03 - 1.7mg/kg	170mg/kg		None of 12
Anthracene	<0.03 - 12mg/kg	2,400mg/kg		None of 12
Benzo(a)anthracene	<0.03 - 30mg/kg	7.2mg/kg		2 of 12
Benzo(a)pyrene	<0.03 - 26mg/kg	2.2mg/kg		5 of 12
Benzo(b)fluoranthene	<0.03 - 34mg/kg	2.6mg/kg		5 of 12

Table 8: Summary of Geo-environmental Soil Results (Cont.)

Determinand	Range Recorded	GAC	Source of GAC	Exceedances
Benzo(ghi)perylene	<0.03 - 12mg/kg	320mg/kg		None of 12
Benzo(k)fluoranthene	<0.03 - 12mg/kg	77mg/kg		None of 12
Chrysene	<0.03 - **26mg/kg**	15mg/kg		**1 of 12**
Dibenzo(a,h)anthracene	<0.03 - **3.2mg/kg**	0.24mg/kg		**5 of 12**
Fluoranthene	0.06 - 60mg/kg	280mg/kg	S4UL[3,9]	None of 12
Fluorene	<0.03 - 9.4mg/kg	170mg/kg		None of 12
Indeno(123-cd)pyrene	<0.03 - 12mg/kg	27mg/kg		None of 12
Naphthalene	<0.03 - **5.1mg/kg**	2.3mg/kg		**2 of 12**
Phenanthrene	<0.03 - 32mg/kg	95mg/kg		None of 12
Pyrene	<0.03 - 49mg/kg	620mg/kg		None of 12
BTEX Compounds				
Benzene	<0.01mg/kg	0.087mg/kg		None of 12
Toluene	<0.01 - 0.06mg/kg	130mg/kg	S4UL[3,9]	None of 12
Ethyl benzene	<0.01 - 0.03mg/kg	47mg/kg		None of 12
Xylene[11]	<0.01 - 0.77mg/kg	56mg/kg		None of 12
Aliphatic Petroleum Hydrocarbons (Equivalent Carbon Number)				
Ali EC 5-6	<0.01-mg/kg	42mg/kg		None of 12
Ali EC 6-8	<0.01 - 0.79mg/kg	100mg/kg		None of 12
Ali EC 8-10	<0.01 - **36mg/kg**	27mg/kg		**1 of 12**
Ali EC 10-12	<1.5 - **340mg/kg**	130mg/kg*	S4UL[3,9]	**1 of 12**
Ali EC 12-16	<1.2 – **1,600mg/kg**	1,100mg/kg*		**1 of 12**
Ali EC 16-35	<4.9 - 3,400mg/kg	65,000mg/kg*		None of 12
Aromatic Petroleum Hydrocarbons (Equivalent Carbon Number)				
Aro EC 5-7	<0.01mg/kg	70mg/kg		None of 12
Aro EC 7-8	<0.01 - 0.06mg/kg	130mg/kg		None of 12
Aro EC 8-10	<0.01 - 4.4mg/kg	34mg/kg		None of 12
Aro EC 10-12	<0.9 - **140mg/kg**	74mg/kg	S4UL[3,9]	**1 of 12**
Aro EC 12-16	<0.5 – **1,200mg/kg**	140mg/kg		**1 of 12**
Aro EC 16-21	<0.6 - **1,600mg/kg**	260mg/kg		**2 of 12**
Aro EC 21-35	<1.4 - **2,200mg/kg**	1,100mg/kg		**1 of 12**
Other Organic Compounds				
Phenol	<0.01 - 0.03mg/kg	280mg/kg	S4UL[3,9]	None of 12
1,2–dichloroethane	<0.01mg/kg	0.0071mg/kg	S4UL[3,9]	None of 12
1,1,1-trichlorethane	<0.01mg/kg	8.8mg/kg	S4UL[3,9]	None of 12
1,1,1,2-tetrachloroethane	<0.01mg/kg	1.2mg/kg	S4UL[3,9]	None of 12
Chloroform	<0.01mg/kg	0.91mg/kg	S4UL[3,9]	None of 12
Vinyl Chloride	<0.01mg/kg	0.00064mg/kg	S4UL[3,9]	None of 12
PCBS				
PCB 28 + PCB 31	<0.01 - **5.9mg/kg**	0.008mg/kg		**2 of 12**
PCB 52	<0.01 **- 0.28mg/kg**	0.008mg/kg		**1 of 12**
PCB 101	<0.01 - **0.76mg/kg**	0.008mg/kg		**3 of 12**
PCB 118	<0.01 - **0.48mg/kg**	0.008mg/kg		**2 of 12**
PCB 153	<0.01 - **0.42mg/kg**	0.008mg/kg	SGV[2,9]	**2 of 12**
PCB 138	<0.01 - **0.73mg/kg**	0.008mg/kg		**3 of 12**
PCB 180	<0.01 - **0.18mg/kg**	0.008mg/kg		**4 of 12**
PCB 7 Total	<0.01 - **6.2mg/kg**	0.008mg/kg		**3 of 12**

Table 8: Summary of Geo-environmental Soil Results (Cont.)

Notes to Table 8:

1. Assessment for residential land use with home-grown produce (apart from barium – see Note 6 below).
2. CLR SGV: Soil Guideline Value published by Environment Agency.
3. S4ULs Suitable 4 Use Levels. Copyright Land Quality Management Limited, reproduced with permission; Publication No. S4UL3156. All Rights Reserved.
4. CL:AIRE/EIC GAC published by CL:AIRE and Environment Industries Commission.
5. C4SL: Category 4 Screening Level. No current SGV, S4UL or CLAIRE/EIC assessment criteria for lead. Category 4 Screening Level adopted in assessment.
6. GAC for barium for residential use without plant uptake. No GAC published for plant uptake risk drivers.
7. In the absence of Chromium VI, all chromium present likely to be Chromium III. GAC for Chromium III adopted.
8. GAC for inorganic mercury adopted.
9. GAC for organic compounds based on 1% soil organic content.
10. No assessment criteria available for asbestos.
11. GAC for xylene based on p-xylene (lowest S4UL).
12. ESP - Generic Assessment Criteria generated by ESP using CLEA software.
13. Exceedances highlighted in red and bold.
14. Laboratory results presented in Appendix M. .

* GAC exceeds solubility or vapour saturation limit.

From Table 8, it is clear that a number of contaminants are present within the Made Ground at levels in excess of the Generic Assessment Criteria (GAC). The recorded exceedances by metals, petroleum hydrocarbons and most PAH compounds occurred in one quarter or less of the samples analysed (1 to 3 samples). However, the exceedances by dibenzo[ah]anthracene and several PCB congeners occurred in multiple samples (4 to 5 samples), and some exceedances were considerably above the respective GAC. The distribution of exceedances within the sois across the site are shown on Figure 6, and discussed further in Section 6.1.

5.4.4 Asbestos

A qualitative analysis has identified bundles of chrysotile and amosite asbestos fibres in the Made Ground in the three of the samples analysed (WS2, TP103 and TP114). Further quantitative testing has been undertaken and identified that the levels of this asbestos varies between 0.004% (chrysotile in TP103) and 0.04% (chrysotile in WS2).

5.5 Risk to Controlled Waters - Level One Assessment

5.5.1 Methodology

The potential impact of contamination originating at the site on controlled waters in the area of the site (i.e. groundwater and surface water) has been initially evaluated in line with the Environment Agency guidance (Carey et al, 2006). Levels of leachable contamination within the soil samples recovered at the site have been analysed, which represents a ‘Level One’ risk assessment (Carey et al, 2006).

5.5.2 Assessment Criteria

As for the assessment of human health risks above, the results of the contamination testing have been compared to assessment criteria appropriate to the controlled water receptors in the area.

The Preliminary Risk Assessment (Section 3.0) has identified that the following controlled water receptors are potentially at risk from contamination originating at the site:

- The groundwater within the Coal Measures bedrock which is classified as a Secondary A aquifer, where the groundwater could be abstracted for potable use in the future; and
- The water within the River Taff, located some 500m to the east of the site, but connected by the culvert that crosses the site.

Given the available information, we consider that the most vulnerable receptor with regards to leachable and mobile contamination would be the surface water within the stream in the west of the site which, based on the monitoring in the wells appears to be in hydraulic connection with groundwater in Well WS2 - see Section 5.2. Our assessment has, therefore, concentrated on this receptor. However, for completeness, we have also extended the assessment to include the groundwater beneath the site.

In order to assess the potential impact on the surface water receptors in the area, the levels of contaminants have been compared to the Environmental Quality Standards (EQS) published by the European Union (2008). For the purposes of this assessment, the Annual Average (AA) EQS have been adopted which represent the acceptable levels of a contaminant over an annual period. For some metals (e.g. cadmium, copper and zinc), the EQS are dependent on the hardness of the receptor water body. Analysis has shown the water in the local surface water (sampled on site) to have a hardness of 9mg/l $CaCO_3$. Therefore, EQS values appropriate for this hardness have been adopted where applicable.

In order to assess the potential risk to groundwater beneath the site, the results of the testing have been compared to the Threshold Values (TV) published by the Environment Agency (2010) which consider the potential impact of contaminants within the groundwater on surface waters. Where no TV has been published, the Prescribed Concentration Values (PCV) of the Water Supply (Water Quality) Regulations (WSR, 2010), which relate to the use of groundwater as a potable resource have been tentatively adopted as the assessment criteria. Where no TV or PCV are published for a compound, the World Health Organisation (WHO) guidelines for drinking waters have been adopted.

There are currently no EU or UK guidelines for ethylbenzene and the World Health Organisation criteria (WHO, 2011) has been adopted for this compound. Similarly, with the exception of the BTEX compounds, there are no published assessment criteria for petroleum hydrocarbons within controlled waters. The Environment Agency have previously stipulated an assessment criteria of 10µg/l for all bands of petroleum hydrocarbons, and this has been used tentatively as the assessment criteria. However, it should be appreciated that this only represents a preliminary, broad-brush appraisal of the levels of contamination present and an exceedance does not necessarily define an unacceptable risk.

The actual assessment criteria adopted are shown in the following table, and further details on them can be found in the respective published documents.

Contaminants within controlled waters have been classed as Priority Substances, Priority Harmful Substances, and Non-Priority Substances by the European Union. Priority Harmful Substances are those toxic substances which are persistent and bio-accumulate and whose emissions are to be eliminated or phased out in time. Priority Substances are those toxic substances whose emissions are to be reduced progressively over time. Whilst the Non-Priority Substances comprise the remaining contaminants analysed in this assessment. Some contaminants analysed in this assessment are currently under consideration for inclusion within the Priority Harmful category.

5.5.3 Assessment of Leachate Test Results

The samples selected for leachate testing comprised Made Ground from across the site. The results of the leachate testing and their comparison to the relevant assessment criteria are presented in Table 9 below, based on the surface waters being the most vulnerable receptor.

Table 9: Controlled Waters Risk Assessment - Leachate Results

Compound	Range Recorded	EQS - AA	TV - PCV	Exceedances
Metals and Semi-metals:				
Arsenic[4]	0.29 - 1.4µg/l	50µg/l	51.6µg/l (TV)	None of 8
Boron[4]	<100 - 170µg/l	-	1000µg/l (PCV)	None of 8
Cadmium[1,6]	<0.03 - **0.22µg/l**	<0.08µg/l	0.2µg/l (TV)	**1 of 8 (both EQS & TV)**
Chromium[4,5]	<0.25 - 0.89µg/l	4.7µg/l	5µg/l (TV)	None of 8
Copper[4,6]	0.7 - **2.6µg/l**	1µg/l	10.1µg/l (TV)	**6 of 8 (EQS)** None of 8 (TV)
Lead[2]	<0.09 - 2.4µg/l	7.2µg/l	7.3µg/l (TV)	None of 8
Mercury[1]	<0.01µg/l	0.05µg/l	1µg/l (PCV)	None of 8
Nickel[3]	<0.5 - 4.3µg/l	20µg/l	20.2µg/l (TV)	None of 8
Selenium[4]	0.29 - 0.85µg/l	-	10µg/l (PCV)	None of 8
Zinc[4,6]	2.7 - **30µg/l**	8µg/l	75.8µg/l (TV)	**2 of 8 (EQS)** None of 8 (TV)
Polyaromatic Hydrocarbon Compounds				
Anthracene[1]	<0.01 - **0.36µg/l**	0.1µg/l	0.1µg/l (TV)	**4 of 8 (both EQS & TV)**
Benzo[a]pyrene[1]	**0.02 - 0.56µg/l**	0.05µg/l	0.01µg/l (PCV)	**8 of 8 (both EQS & PCV)**
Sum BbF & BkF [1]	**0.05 - 1.01µg/l**	0.03µg/l	-	**8 of 8 (EQS)**
Sum BghiP & IDP [1]	**0.05 - 0.74µg/l**	0.002µg/l	-	**8 of 8 (EQS)**
Sum BbF, BkF, BghiP & IDP	0.1 - **1.75µg/l**	-	0.1µg/l (PCV)	**7 of 8 (EQS)**
Naphthalene[2]	<0.01 - 0.98µg/l	2.4µg/l	2.4µg/l (TV)	None of 8
Fluoranthene[3]	0.04 - **1.1µg/l**	0.1µg/l	0.1µg/l (TV)	**4 of 8 (both EQS & TV)**
Petroleum Hydrocarbon Compounds				
Benzene[3]	<1.0µg/l	10µg/l	10.1µg/l (TV)	None of 8
Toluene[4]	<1.0µg/l	50µg/l	50.5µg/l (TV)	None of 8
Ethylbenzene[4]	<1.0µg/	-	300µg/l (WHO)	None of 8
Xylene[4]	<1.0µg/l	30µg/l	30.3µg/l (TV)	None of 8
TPH C_5-C_{10} (GRO)[4]	<0.1 - 0.7µg/l	10µg/l (EA)	10µg/l (EA)	None of 8
TPH C_{10}-C_{21} (DRO)[4]	<1 - **32.7µg/l**	10µg/l (EA)	10µg/l (EA)	**1 of 8 (both EQS & TV)**
TPH C_{21}-C_{40} (LORO)[4]	<1 - **51µg/l**	10µg/l (EA)	10µg/l (EA)	**1 of 8 (both EQS & TV)**
Miscellaneous				
Cyanide[4]	<40µg/l	1µg/l	50µg/l (PCV)	None of 8
Phenol[4]	<0.5 - 0.8µg/l	7.7µg/l	15.2µg/l (TV)	None of 8
Chloroform[4]	<1 - **4µg/l**	-	2.5µg/l (TV)	**2 of 8 (TV)**
Bis(2-ethylhexyl)phthalate (DEHP)[2]	<1 - **16µg/l**	1.3µg/l	8µg/l (WHO)	**5 of 8 (EQS) 1 of 8(WHO)**
Bis(2-ethylhexyl)ester[4]	7.4 - 15µg/l	20µg/l	8µg/l (WHO)	None of 8
pH	7.1 – 7.6	-	6.5 – 9.5 (PCV)	None of 8

Table 9: Controlled Waters Risk Assessment - Leachate Results (cont.)

Key to Table 9:
EQS-AA – Environmental Quality Standard (surface waters) - Annual Average.
TV – Threshold Value (groundwater)
PCV – Prescribed Concentration Value (drinking water).
WHO – World Health Organisation Value (drinking water)
EA – Environment Agency defined value.
BbF – Benzo[b]fluoranthene
BkF – Benzo[k]fluoranthene
BghiP – benzo[ghi]pyrene
IDP – indeno [123-cd]pyrene

Notes to Table 9:
1. Priority Harmful substance.
2. Priority substance under consideration as Priority Harmful
3. Priority substance
4. Non-priority substance.
5. Assessment Criteria for Chromium VI.
6. EQS dependent on hardness of water in receptor.
7. Test results presented in Appendix N.

The leachate samples were also tested for PCBs, volatile organic and semi-volatile organic compounds. All were identified at levels below their detection limits apart from the volatile organic compound chloroform and the semi-volatile organic compounds bis(2-ethylhexyl)ester and bis(2-ethylhexyl)phthalate (see Table 9 above).

Many of the contaminants analysed were below the assessment criteria, and the leachable levels of cadmium, zinc, petroleum hydrocarbons and chloroform were found to be elevated above the assessment criteria only in limited samples of Made Ground (one or two samples). However, the levels of copper, PAH compounds and bis(2-ethylhexyl)phthalate were elevated in the majority/all the samples analysed. The distribution of exceedances within the leachates generated from the shallow soils across the site are shown on Figure 7, and discussed further in Section 6.1.

5.6 Ground Gas

5.6.1 Degradation of Organic Materials

The likelihood and severity of a gassing event is considered as part of the risk assessment process in accordance with C665 (Wilson et al, 2007).

The Preliminary Risk Assessment (Section 3.1.3) identified several sources of gas within proximity of the site, including worked ground and a tip adjacent to the southern boundary of the site.

Therefore, gas wells have been installed and will be monitored for hazardous gases on six occasions over a twelve week period. The monitoring to date (two sets of reliable data – see Section 4.2.2) has identified no detectable levels of methane, but levels of carbon dioxide within Well WS4 up to 2.2%. No gas flow has been recorded. Levels of volatile organic compounds within the installed wells have varied between 3 and 6ppm.

A full assessment of gas risks will be presented in a gas addendum report on completion of the monitoring.

5.6.2 Volatile Vapours

As summarised in Table 6, measurement by the PID of the headspace above collected samples indicated levels of volatile vapours within the shallow soils up to 207ppm (0.02%). Such volatiles were only recorded in WS3, TP103, TP111 and TP114 in Zone B, and WS2, TP102 and TP104 in Zone C, and were commonly associated with noticeable, strong hydrocarbon odours. The volatiles were recorded within both the Made Ground and, in places, the underlying glacial soils and sandstone bedrock.

It should be appreciated that the measurement of volatile vapours by a PID provides only an indication of whether volatile vapours are likely to be present. Many different volatile organic and petroleum hydrocarbon compounds are detected by the PID, each with their own risk characteristics.

5.6.3 Radon

As discussed in Section 2.9.6, no radon protection is required for the development.

5.7 Sulphate Attack

The assessment of the concrete protection against sulphate attack has been undertaken in accordance with BRE SD1 (2005).

Classification of Site:
Due to the presence of widespread Made Ground across the site, we consider that it should be considered as 'brownfield' in terms of concrete classification.

Groundwater Setting:
Groundwater was encountered as perched water tables in some of the exploratory holes at shallow depths, which is likely to be close to the depth to which buried concrete will be placed. Therefore, groundwater has been considered as mobile in this assessment.

Sulphate Levels:
Laboratory test results indicate the levels of water soluble sulphate (as SO_4) in the Made Ground soils to be between <10 and 110mg/l. As levels of water soluble sulphate are less than 3,000mg/l, there is no need to consider the levels of magnesium present in the soils. Levels of acid soluble sulphate varied between 0.01 and 0.06% and total sulphur between 0.01 and 0.07%. From these results, the calculated levels of total potential sulphate are between 0.03 and 0.21%, and oxidisable sulphides are between 0.02 and 0.18%. As the levels of oxidisable sulphide are well below 0.3%, pyrite is unlikely to be present.

pH values in the Made Ground varied between 7.2 and 11.5, indicating near neutral to alkaline soil conditions to exist. As the pH levels all exceed 5.5, there is no need to further assess the soils for the types of acids present (e.g. hydrochloric and nitric acids).

Laboratory test results indicate the levels of water soluble sulphate (as SO_4) in the Glacial Diamicton soils to be between 19 and 62mg/l. Levels of acid soluble sulphate varied between 0.02 and 0.04% and total sulphur between 0.01 and 0.02%. From these results, the calculated levels of total potential sulphate are between 0.03 and 0.06%, and oxidisable sulphides are between 0.01 and 0.02%. As the levels of oxidisable sulphide are well below 0.3%, pyrite is unlikely to be present. pH values in the Glacial Diamicton varied between 6.5 and 7.5, indicating near neutral to slightly acidic soil conditions to exist.

Foundation Concrete Design:

Using the above results, we consider that the following characteristic values are applicable for the shallow soils at the site (all as SO_4):

Water soluble sulphate	110mg/l;
Total potential sulphate	0.21%; and
pH value	6.5.

6.0 PHASE TWO GEO-ENVIRONMENTAL RISK ASSESSMENT

6.1 Discussion on Occurrence of Contamination and Distribution

The investigations have identified Made Ground of varying thicknesses across the site, containing a significant proportion of man-made materials including several items obviously originating from its former use as a scrap yard. Visual and olfactory evidence of hydrocarbon contamination has also been confirmed by the presence of elevated levels of volatile organic vapours measured using a PID on samples recovered from the trial pits and boreholes.

Laboratory testing has identified levels of a number of determinands above the adopted assessment criteria both within the Made Ground soils and within leachate generated from these soils. From Table 8 in Section 5.4.3, it is clear that a number of contaminants are present within the Made Ground at levels in excess of the Generic Assessment Criteria (GAC) designed to be protective of future residents. The recorded exceedances by metals, petroleum hydrocarbons and most PAH compounds occurred in a limited number of the samples analysed (1 to 3 samples). However, the exceedances by dibenzo[ah]anthracene and several PCB congeners occurred in multiple samples (4 to 5 samples), and some exceedances were considerably above the respective GAC.

Amosite and chrysotile asbestos were identified in three of the samples of Made Ground analysed. However, given the significant proportion of old car parts and other scrap residue within the Made Ground across the site (much of which may have contained asbestos), we cannot discount, and strongly suspect that further so far unidentified asbestos containing materials are likely to be present within the shallow soils.

The distribution of identified exceedances within the soils across the site is shown on Figure 6. Unacceptably elevated levels of contaminants were identified in all exploratory holes analysed apart from TP104 (Zone C), WS4 and TP106 (Zone A), and TP101 and WS1 (Zone B).

Laboratory testing has also identified the leachable levels of cadmium, zinc, petroleum hydrocarbons and chloroform to be elevated above the assessment criteria designed to be protective of controlled waters only in a limited samples of the Made Ground (one or two samples). However, the levels of copper, PAH compounds and bis(2-ethylhexyl)phthalate were elevated in the majority/all the samples analysed.

The distribution of these exceedances within the exploratory holes across the site is shown on Figure 7. Unacceptably elevated levels of leachate contaminants were identified in all exploratory holes analysed.

Many of the contaminants identified as being present within the Made Ground would be associated with the former use of the site as a scrap yard, e.g. petroleum hydrocarbons, asbestos, PAH compounds, metals. In particular, bis(2-ethylhexyl)phthalate (DEHP), which was identified within the leachate, is commonly found as a dielectric fluid in capacitors, and is likely to be present through leaks from capacitors recycled at the site. Chloroform, which was also found in the leachate, is a solvent used commonly as a cleaning agent.

6.2 Revised Risk Evaluation & Relevant Pollutant Linkages

As discussed in detail within Section 3.2.1, the methodology set out in CIRIA C552 (2001) has been used to assess whether or not risks are acceptable, and to determine the need for collating further information or remedial action.

The risks evaluated at the desk study stage of this report (Table 4, Section 3.2.2) have been updated and revised in Table 10 following information learned from the exploratory works and results of monitoring and laboratory testing.

Table 10: Revised Risk Evaluation & Relevant Pollutant Linkages (RPL).

Source	Pathway	Receptor	Classification of Consequence	Classification of Probability	Risk Category	Further Investigation or Remedial Action to be Taken
Potential contaminants in shallow soils	Direct contact/ inhalation/ ingestion of contaminated soil or dust	Site Users (residents)	Medium – potential for chronic levels.	High likelihood[2]	High Risk	See Section 7.3.
		Construction/ Maintenance Workers	Medium – potential for chronic levels.	High likelihood[2]	High Risk	
	Leaching of soil contaminants	Impact on groundwater	Medium – site lies on Secondary A Aquifer	High likelihood[2]	High Risk	See Section 7.4.
		Impact on River Taff	Medium – tertiary river on site	High likelihood[2]	High Risk	
Asbestos in shallow soils	Ingestion of fibres	Construction/ Maintenance Workers	Medium – potential for chronic levels	High likelihood[3]	High Risk	See Section 7.2.
		Site Users (residents)	Medium – potential for chronic levels	High likelihood[3]	High Risk	
Soil sulphate and pyrite	Aggressive groundwater	Buried Concrete	Mild – damage to structures	Unlikely[4]	Very Low Risk	See Section 7.6.2.
Hazardous ground gas/vapours from Made Ground and off-site sources	Asphyxiation/poisoning. Injury due to explosion.	Site Users/Visitors.	Severe – acute risk.	Likely[5]	High Risk	See Section 7.5.
		Construction and Maintenance Workers.	Severe – acute risk.		High Risk	
	Damage through explosion.	Building/property	Severe – acute risk.		High Risk	
Radon gas	Migration into Buildings	Site Users (residents)	Medium – potential for chronic levels	Unlikely[6]	Low Risk	No protection measures required.

Notes to Table 10:

1. This table updates the PRA risk assessment presented in Table 4, following the intrusive investigation. Methodology based on CIRIA C552 (2001) – see Section 3.2.1.
2. Made Ground, including former scrap yard materials has been identified on site and unacceptably elevated levels of soil and leachate contamination are present – see Sections 5.4.3 and 5.5.3).
3. Chrysotile and amosite asbestos materials have been identified and further so far unidentified asbestos materials cannot be discounted – see Section 5.4.4. Asbestos is also anticipated within the existing buildings and skip waste.
4. Low levels of soil sulphate have been identified. Pyrite is not anticipated. (Section 5.7).
5. Gas monitoring to date has identified no elevated levels of methane and low levels of carbon dioxide. Monitoring is progressing. (Section 5.6.1).
6. Radon risk identified in environmental data report (Section 3.1.4).

7.0 REMEDIAL STRATEGY FOR CONTAMINATION RISKS

The following recommendations are based on interpretations made from the site investigation data obtained to-date, and do not form the full Options Appraisal stage of CLR11. If at any stage of the construction works, contamination or a potential for such contamination is identified that is different to that presented within this report, all of the following should be reviewed and the advice of a geo-environmental specialist sought immediately.

7.1 Implications of Development Earthworks

The previous assessment has been based on the levels of contamination present within the near-surface Made Ground and these soils remaining close to the final development surface. However, as discussed in Section 1.1, the existing ground levels are to be altered to create a suitable earthworks platform for the development, as shown in Figures 5 and 8. This will have a significant impact on the risks posed by contaminants within the Made Ground.

The changes in ground level at each investigation point are summarised in Table 11 below.

Table 11: Changes in Ground Levels Across Site

Investigation Point	Zone	Existing Ground Level[1] (m OD)	Proposed Ground Level[2] (m OD)	Approximate Relative Change
TP1	B	102.2	102.1	Approx. at grade
TP2	C	103.0	101.7	1.3m cut
TP3	B	102.3	101.7	0.6m cut
TP4	B	102.5	101.1	1.4m cut
TP5	B	100.7	100.8	Approx. at grade
TP6	A	98.8	101.5	2.7m fill
TP7	A	98.2	100.6	2.4m fill
TP8	A	99.3	101.2	1.9m fill
TP9	B	100.1	101.2	1.1m fill
TP10	C	105.1	105.1	Approx. at grade
TP11	C	105.2	102.3	2.9m cut
TP12	B	101.7	101.4	<0.5m cut
TP13	A	98.7	100.5	1.8m fill
TP14	A	97.9	100.3	2.4m fill
TP15	A	97.9	100.3	2.4m fill
TP101	B	101.1	101.1	Approx. at grade
TP102	C	106.8	106.8	Approx. at grade
TP103	B	102.3	101.7	0.6m cut
TP104	C	104.9	104.9	Approx. at grade
TP105	C	103.2	101.4	1.8m cut
TP106	A	99.2	100.5	1.3m fill
TP107	A	97.3	100.5	3.2m fill
TP108	A	98.3	101.0	2.7m fill
TP109	A	97.8	100.6	2.8m fill
TP110	A	98.4	100.9	2.5m fill
TP111	B	101.4	101.2	Approx. at grade
TP112	A	97.3	100.3	3.0m fill

Table 11: Changes in Ground Levels Across Site (cont.)

Investigation Point	Zone	Existing Ground Level[1] (m OD)	Proposed Ground Level[2] (m OD)	Approximate Relative Change
TP113	A	100.2	101.5	1.3m fill
TP114	B	102.3	102.3	Approx. at grade
WS1	B	100.2	100.6	<0.5m fill
WS2	C	106.1	106.1	Approx. at grade
WS3	B	102.1	101.4	0.7m cut
WS4	A	98.9	98.9	Approx. at grade
WS5	C	103.8	100.5	3.3m cut

Notes to Table 11:
1. Existing ground level interpolated from site survey – approximate only.
2. Proposed ground level estimated from proposed layout (Figure 2) – approximate only.

In general terms, across Zone A, the existing ground levels will be raised by up to 3m by the placement of fill - hence the Made Ground containing the soil contaminants will be covered and, provided this fill is clean and inert and of sufficient thickness (see following sections), it is likely to mitigate much of the risks posed by contaminants within the Made Ground.

In the eastern part of Zone C, the ground levels will be lowered by up to 3m. The thickness of Made Ground identified in this area (TP2, TP10, TP11, TP104, TP105 and WS5) ranged from 0.3 to 1.4m. Therefore, in constructing the development plateau, the majority of the Made Ground (and hence identified contaminated soils) are likely to be removed, and the risks from the contaminants therein mitigated. Where the Made Ground is of greater thickness (e.g. around TP11 and TP104) and/or the depth of cut is less than 1.4m, some remnant Made Ground may remain beneath the development surface. In these instances, it may be prudent to over-excavate the Made Ground (probably generally by less than 500mm) on the basis of the investigation findings to remove any potential contamination source, and bring levels back up to development level with clean, inert fill.

Therefore, based on the above, much of the contamination risk to future site users will be mitigated by the development earthworks, and no further remedial measures are likely to be required in these areas. However, across the remainder of the site a potentially unacceptable risk will remain and additional remedial measures would be required to mitigate contamination risks to future end users in particular. These areas comprise:

1. The western part of Zone A, where the thickness of fill materials used to raise site levels may not be sufficient to fully mitigate the risks from underlying contaminated soils.
2. Zone B, where final ground levels are anticipated to be broadly the same as existing.
3. The western part of Zone C, where no cut is proposed – in this area, Made Ground with unacceptably elevated levels of soil contaminants will remain at the surface (e.g. around WS2).

The following sections consider the requirement and options for remedial measures to mitigate the risks, allowing for the above.

7.2 Asbestos

7.2.1 Risks to Future Site Users

As discussed in Section 5.4.4, chrysotile and amosite asbestos fibres were identified within the Made Ground soils in three pits (WS2, TP103 and TP114), with a total mass of fibres of up to 0.04% of the soil.

In order to help assess the risks of the identified levels of asbestos, the '*Decision Support Tool for the Qualitative Risk Ranking of Work Activities and Receptors Involved in or Exposed to Asbestos in Soil and Construction and Demolition Materials*' published by CL:AIRE (2016) has been used. The model has currently been published as a beta version and is, therefore, not as authoritative as other guidelines for other contaminants. However, it is a useful tool for evaluating the scale of risks posed from the asbestos present.

We have based our assessment on a conventional residential land use (as defined in CLEA), with Made Ground containing the identified levels and form of asbestos being present at the site surface (e.g. across Zone B). The assessment has resulted in a 'combined hazard, exposure and receptor' ranking of 68, which equates to a high risk to future residents.

As discussed in Section 7.1, across Zone A, the external areas of the site will generally be covered by up to 3m of fill materials. Provided that this fill is clean and inert, and exceeds 1m in thickness, we consider that it is likely to be sufficient to mitigate the risk from any asbestos materials within the underlying Made Ground soils – see also Section 7.3.1. Similarly, in the eastern part of Zone C, the lowering of site levels is likely to remove the Made Ground and hence, mitigate the risk to future site users. No further remedial measures are required in these areas, however, in Zone C, a careful inspection should be made once excavation has been completed to ensure that no Made Ground or potential asbestos containing materials remain in the formation.

Across Zone B and the western part of Zone C, where no earthworks are to be undertaken the risk to future site users from asbestos remains. We consider that within these parts of the site, where soft external landscaping is proposed (e.g. gardens, verges, public open space) the Made Ground would need to be removed to a suitable depth and replaced with a cover layer of clean, inert fill. The depth of excavation and thickness of the cover layer would need to be agreed with the Local Authority Contaminated Land Officer, however, we would recommend a minimum thickness of 600mm. The identified thickness of Made Ground across Zone B varies between 100mm and 1.9m, with three investigation positions (TP4, TP101 and TP114) showing 600mm of Made Ground or less. In these areas, the depth of excavation may be limited to the full thickness of the Made Ground - e.g. around TP114, only the 450m of Made Ground should be excavated and replaced with clean fill. Similarly around TP102, in the northern margins of Zone C the depth of excavation may be limited to the identified 350mm of Made Ground. Where permanent hard surfacing is proposed (e.g. beneath houses, roads, pavement etc.), the hard surfacing would break the pollution linkage and, hence, the Made Ground may remain in-situ.

In the western margins of Zone A, the thickness of fill materials placed to raise site levels will be reduced, and may be insufficient to fully mitigate asbestos risks. In this area, we recommend a similar approach to that discussed for Zone B above. Where the thickness of fill material exceeds 600mm, we consider that this is likely to be sufficient to mitigate risks from asbestos and no further remedial measures are likely to be required.

However, where the thickness of fill materials used to raise site levels is less than 600mm, we recommend that the existing Made Ground is excavated to sufficient depth so that the resulting thickness of fill is 600mm or greater. For example, where the thickness of fill is say 400mm, we recommend that the existing Made Ground is excavated by a minimum of 200mm, and replaced with clean inert fill, so that the resulting thickness of fill is 600mm (or more).

As for Zone B, the minimum final thickness of fill materials above the covered Made Ground in Zone A would need to be agreed with the Contaminated Land Officer.

Wherever the risk is to be mitigated by the provision of a clean cover layer (e.g. fill), we recommend that a suitable geotextile should be placed at the base of the cover layer and immediately overlain by a capillary break layer to prevent contaminants being drawn up into the cover system.

7.2.2 Risks to Construction and Maintenance Workers

The existing buildings on site are likely to contain asbestos within their construction. Prior to their demolition, an asbestos survey should be undertaken, and any asbestos materials found removed by a licensed contractor. The survey should also include an inspection of the materials within any skips remaining on site which should also be removed in an appropriate manner.

Workers involved in the construction and site preparation will potentially be exposed to asbestos within the shallow soils during the development works. The results of the investigation, and in particular, the asbestos analyses should be provided to these contractors so that they may undertake their own assessment of risks.

The results of the investigation should also be published within the Health and Safety File and made available to all future maintenance, utilities companies etc., who may be involved in future excavation beneath hard surfacing, e.g. the future installation of cables in the road.

7.3 Other Contaminants

7.3.1 Site End Users

As shown on Figure 6, a number of chemical contaminants are present within the Made Ground across the site at levels in excess of the Generic Assessment Criteria (GAC) designed to be protective of future residents. Therefore, there is a potential risk to health which will require risk mitigation measures.

The proposed earthworks discussed in Section 7.1 will, as for the asbestos risk, have a beneficial effect on the level of risks posed by chemical contaminants within the Made Ground beneath parts of Zones A and C, and will mitigate the contamination risks over these areas – see Section 7.2.1. However, also as for the asbestos risk, a potentially unacceptable risk would remain in the western parts of Zones A and C, and across Zone B.

The proposed remedial measures discussed in Section 7.2.1 for asbestos are also considered suitable for the non-volatile chemical contaminants present within the Made Ground. Therefore, provided the risks from asbestos are mitigated, the risks to future site users from non-volatile contaminants may also be mitigated.

As summarised in Table 6, measurement by the PID of the headspace above collected samples indicated detectable levels of volatile vapours within the shallow soils at some exploratory hole positions across Zones B and C (up to 0.02%). It should be appreciated that the measurement of volatile vapours by a PID provides only an indication of whether volatile vapours are likely to be present. Many different volatile organic and petroleum hydrocarbon compounds are detected by the PID, each with their own risk characteristics. In the laboratory testing (Appendix M), none of the volatile organic compounds, including the BTEX compounds, were detected at levels in excess of the respective Generic Assessment Criteria (GAC). Therefore, based on our current understanding, no risk mitigation is required for these compounds.

7.3.2 New Service Connections

The current water industry guidance for the suitability of pipe materials on potentially contaminated sites (Blackmore et al, 2010) has onerous requirements and it is likely, based on this guidance, that the levels of contaminants on site will prevent the use of plastic pipework. We recommend that enquiries are made to the local water authority to confirm their requirements for underground service materials for this development.

7.3.3 Risk to Construction and Maintenance Workers

Short term (acute) risks to construction and maintenance workers are generally poorly understood within the industry, certainly when compared to the volume of research undertaken on long term risks. However, given the presence of PAH compounds, metals and PCBs within the Made Ground soils, we consider that such workers could be at risk during site development and future maintenance works.

As discussed in Section 7.2.2, the results of the investigation should be provided to these contractors so that they may undertake their own assessment of risks. The results of the investigation should also be published within the Health and Safety File and made available to all future maintenance, utilities companies etc., who may be involved in future excavation beneath hard surfacing, e.g. the future installation of cables in the road.

7.3.4 General Public/Neighbouring Properties

The site lies immediately above houses on Birchley Road whose occupants could be particularly sensitive to any dust created during development, which could include asbestos fibres. We recommend further assessment of potential dust hazards and, as a minimum, strict dust control measures during development.

7.4 Risks to Controlled Waters

The Level One assessment of risks to controlled waters has indicated that the leachable levels of cadmium, copper, zinc, petroleum hydrocarbons, PAH compounds, chloroform and bis(2-ethylhexyl)phthalate within the Made Ground could pose an unacceptable risk to controlled waters in the vicinity of the site.

The investigation has shown that the Made Ground lies directly on the sandstone bedrock (e.g. WS2) or has only a limited thickness of fine-grained glacial soils between them. Therefore, any leachable contaminants within the Made Ground could impact on the quality of the groundwater beneath the site. In addition, evidence from the groundwater monitoring suggests that the perched water within Well WS2 may be in hydraulic connection with the water within the stream which flows through the west of the site. This perched water body was recorded within the Made Ground, so any leachable contaminants therein could also impact on the quality of the water within the stream.

As discussed in Sections 7.1, earthworks to create development levels will involve filling by up to 3m above the Made Ground in the eastern area (Zone A) and removing much of the Made Ground in the eastern part of Zone C. In addition, the Made Ground will also be at least partly removed from areas of soft landscaping within Zone B to mitigate human health risks.

Where Made Ground is removed as part of the development, the risk to controlled waters will be mitigated, and provided the fill materials imported to site are clean and inert, and appropriate surface water drainage is adopted (see Section 8.10), we consider that where the thickness of fill above remnant Made Ground exceeds 1m, the level of infiltration will be reduced significantly and, hence, the leaching of contaminants present will be reduced, and the risks to controlled waters are likely to be reduced to acceptable levels. However, this should be assessed further as part of the remedial strategy (see Section 7.8).

Across Zone B, and in the western parts of Zones A and C, Made Ground could remain and, therefore, the risk to controlled waters would need to be mitigated. In particular, analysis has shown the Made Ground in Well WS2 to contain unacceptably elevated leachable levels of copper and PAH compounds. As discussed above, the perched water within these Made Ground soils is likely to have a deleterious impact on the surface water within the stream in the west of Zone C.

We recommend that once design options have been finalised (including final surface levels), a Level Three assessment of risks to controlled waters is undertaken to assess the potential risks to the stream in the west of the site and the groundwater beneath the site. This would include the construction of deeper groundwater wells (tentatively estimated as possibly around 20m depth) to allow evaluation of the groundwater quality beneath the site and sampling of the stream in the west of Zone C. If the Level Three assessment identifies an unacceptable risk to controlled waters, further areas of Made Ground from across the site may need to be removed.

During demolition of the buildings on site, care should be taken in the removal of the inspection pits, to ensure that no contaminated waters, soils or sludges within their bases are allowed to pollute the underlying soils or groundwater.

7.5 Risks from Ground Gas

7.5.1 Risk to the Development – Degradation of Organic Material

As discussed in Section 4.2.2, the monitoring of ground gas is currently underway and our recommendations will follow in an addendum report.

7.5.2 Risk to the Development – Radon

As discussed in Section 2.9.6, no radon protection is required for the development.

7.5.3 Risk to Construction and Maintenance Workers

Comments on the risk to construction and maintenance workers from hazardous ground gas will be presented in our addendum report. But at this stage, we consider that all excavations should be treated as confined spaces and suitable precautions taken prior to man entry.

7.6 Risks to Property

7.6.1 Spontaneous Combustion

No evidence of combustible materials has been identified in the shallow soils. Therefore, the risk from spontaneous combustion is considered to be low.

7.6.2 Sulphate Attack on Buried Concrete

From Section 5.10, the following characteristic values are applicable for the shallow soils at the site (all as SO_4):

Water soluble sulphate:	110mg/l;
Total potential sulphate:	0.21%; and
pH value:	6.5.

Based on these characteristic values, we consider that the site would be classified as Design Sulphate Class DS-1 and Aggressive Chemical Environment for Concrete Class AC-2z, allowing for mobile groundwater.

7.7 Re-Use of Materials/Disposal of Excess Arisings

7.7.1 Re-Use of Materials

All soils or other materials excavated from any site are generally classified as waste under the Waste Framework Directive (European Union, 2008) and their re-use is controlled by this legislation.

If the soils are to be re-used on site (e.g. within the red-line planning boundary), provided that they are 'uncontaminated' or other naturally occurring deposits and they are certain to be used for the purposes of construction in their natural state on the site from which they are excavated, they may be excluded from waste regulation (CLAIRE, 2011). A Materials Management Plan (MMP) may be required – further guidance can be provided by this office once proposals have been finalised. However, if they are man-made or contaminated materials, their use on the site may be limited.

In order to raise site levels in the east of the site, a considerable quantity of materials are likely to be required. We consider that given the levels of contaminants therein (including asbestos) the Made Ground excavated from the site should not be used within this fill material without further assessment and consideration.

One option for obtaining suitable fill material for the works would be to construct a borrow pit in the more elevated western part of Zone C – see Section 8.2.3 for further discussion on the geotechnical aspects of this. Such excavation would also require the removal of Made Ground outside the otherwise identified excavation area (thus mitigating the health risks in such areas in Zone C). It may also be an option to backfill such a borrow pit with the excavated Made Ground materials from elsewhere on the site, thus reducing the quantity to be removed from site to landfill subject to further assessment.

In order for this option to be applicable, the excavated Made Ground soils would need to be 'suitable for use' – therefore, they cannot be present within 600mm of the final site surface (based on the 600mm cover layer thickness discussed in Section 7.2.1, but to be agreed with the CLO). They would also need to pose an acceptable risk to controlled waters - this would need to be confirmed by the recommended Level Three assessment of risk (Section 7.4). Options to reduce any residual risk to controlled waters could include the chemical stabilisation of the Made Ground soils prior to placement.

If this option is to be adopted, it should be considered in detail (including size and shape of borrow pit) in the remedial strategy (see Section 7.8) and a materials management plan would be required.

7.7.2 Disposal of Materials to Landfill/Re-Use Off Site

If the soils are to be removed from site, they are automatically classified as waste, and they may only be:

1. Disposed at a licensed landfill;
2. Disposed at a licensed, permitted soil treatment centre; or
3. Removed to a Receiver Site for beneficial re-use.

In Scenarios 1 and 2, the materials must be transferred by a licensed waste carrier and the waste producer (the developer) must ensure that the destination landfill or treatment centre is a legitimate operation (e.g. by requesting a copy of the Environmental Permit before releasing the soils). Prior to removal from site, the excavated arisings would need to be classified as either 'hazardous' or 'non-hazardous' waste based on the hazard that they pose– a WM3 assessment (note that this is a different assessment to the risk assessments reported on in earlier sections of this report). This can commonly be undertaken on the results of soils testing undertaken during the investigation, although further sampling and testing may be required. Only once the soils have been classified under the WS3 assessment, would Waste Acceptability Criteria (WAC) testing then be required to determine the type of landfill in which the arisings could be disposed in Scenario 1. Further testing and assessment may also be required by the soil treatment centre in Scenario 2.

In Scenario 3, management of soils could be undertaken via an Environmental Permit or Exemption. However, these can take time and are costly to arrange.

Therefore, in certain circumstances, it is permissible to use the protocols laid down in the CL:AIRE Definition of Waste, Development Industry Code of Practice (DoWCoP, Duckworth, 2011) to classify the arisings and put a management plan in place to control the use. This involves approval of the proposals by a Qualified Person and is generally more efficient (in terms of time and cost) to implement.

Further guidance on the legislative requirements of the re-use/disposal of materials generated by the development can be provided by this office once the development proposals have been finalised.

7.7.3 Imported Materials

Any soils or materials to be imported to site (including Topsoil) should be certified clean and inert, and suitable for use. An appropriate number of samples (depending on the volume of soils imported) should be analysed for an appropriate suite of contaminants, and verification certificates should be provided. Further guidance can be provided by this office if required,

7.8 Remedial Strategy

In accordance with CLR11 (and under a probable planning condition), the risk mitigation strategy should be considered within a detailed remediation strategy and implementation plan, and supervised and validated by a geo-environmental specialist. This would need to consider the specific final site levels relative to existing and the thickness of clean cover layer required for each dwelling/area. The recommended Level Three assessment of risks to controlled waters would also need to be completed so that the extent of excavation of Made Ground may be determined.

On completion, a validation report should be prepared to demonstrate to regulators and insurance providers that the risk has been successfully mitigated.

8.0 GEOTECHNICAL COMMENTS

8.1 Site Preparation

8.1.1 Invasive Plants

No evidence of Japanese Knotweed/Himalayan Balsam etc. was identified on the site during the site works.

8.1.2 Existing Foundations and Services

The site has been previously been developed as a metal recycling yard, but with few buildings evident. The foundations for both Buildings A (Zone A) and B (Zone B) and a suspected second former building in Zone B will need to be removed. Numerous concrete slabs, predominantly in Zones A and B, have also been identified. These sub-structures and any others identified during development should be grubbed up within the zone of influence of the development as part of the site preparation works.

An underground electricity cable crosses the southern part of the site within Zone A, and runs towards the telephone mast near the southern corner of the site. Up to 3m of fill is proposed in this area, so further discussions should be held with the mast owner/operator to identify options (i.e. diverting or filling over the cable).

8.1.3 New Services

For new services, flexible pipework and connections should be provided as a safeguard against potential settlements where filling is proposed. Consideration could be given to increasing the gradients on sewage connections to mitigate against possible settlements.

8.2 Earthworks – Development Site

8.2.1 Proposed Earthworks

In order to produce a development platform at the site, the ground levels in the elevated western area are to be lowered whilst those in the lower-lying eastern area are to be raised by filling. As discussed in Section 1.1, the site levels within Zone A (south-east) are to be raised by up to 3m, and those in the eastern part of Zone C are to be lowered by up to 3m (as indicated on Figure 5). Minimal level changes are proposed in Zone B.

8.2.2 Excavation of Cut – Zone C

The investigation has identified that the sandstone bedrock is present at relatively shallow depth within the area of the proposed ground lowering in the eastern part of Zone C, between ground level (TP105) and 1.9m (TP11). Therefore, in order to construct the development platform up to 3m of sandstone bedrock is likely to be removed.

We consider that the overlying soils are likely to be readily excavated using conventional backacting plant, however, the sandstone bedrock is likely to require large capacity excavators. Excavation over a large area is always easier than within the constraints of a trial pit, and our local experience suggests that much of the bedrock is likely to be excavated by a large capacity excavator, but the use of hydraulic breakers to remove larger rock blocks is likely. Alternative bedrock removal methods such as ripping or blasting may be considered, but may not be practical given the relatively small area of the site (for ripping to be economic) and proximity to nearby properties (which could be impacted by blasting vibration).

Groundwater has been identified at a shallow depth of 0.3m within Well WS2 and, therefore, shallow perched groundwater bodies may be encountered within the cut. Further monitoring is being undertaken to establish the groundwater regime beneath the site but, at this stage, an allowance should be made for the installation of appropriate crest and toe drainage to manage any groundwater encountered in the final development.

The back wall of the cut in Zone C is likely to comprise predominantly sandstone bedrock and no significant stability issues are anticipated. However, prior to completion, the resulting slope should be inspected by a geotechnical specialist and any areas of loose or potentially unstable sandstone removed/stabilised.

8.2.3 Re-use of Excavated Materials from Zone C

As discussed in Section 7.7.1, the excavated Made Ground soils are not suitable for re-use within the fill material in Zone A.

Given the available information, the sandstone bedrock to be excavated from Zone C is likely to prove good quality coarse-grained fill materials for use in Zone A. Prior to use it would need to be reduced in size to suitable dimensions in accordance with the earthworks specification used for the filling. It is possible that simply breaking up large rock blocks with a hydraulic breaker could provide particles of suitable dimensions.

A limited thickness of glacial soils is also likely to be excavated (from between the Made Ground and sandstone bedrock). The investigation has identified these to comprise soft-to-firm, gravelly clays or clayey, gravelly sand. Given their low strength, these soils are unlikely to be suitable for use on their own, but provided they are mixed with the sandstone blocks, in a suitable proportion, we consider that these soils may also be suitable for use as fill materials in Zone A.

Given the quantity of fill which is likely to be required to raise site level across the site, one option to minimise imported fill material could be to excavate a borrow pit into the sandstone bedrock identified at shallow depth in the west of the site. Sandstone could be excavated from this pit, and used as fill material as discussed above.

In order to re-use the excavated materials from Zone C on site, a Materials Management Plan will be required – see Section 7.7.1.

8.2.4 Filling - Zone A

As discussed above, up to 3m of fill materials will be placed to raise site levels in Zone A. It is presumed that the source material for the filling will predominantly be the excavated soil and bedrock from Zone C (but not the Made Ground – see Section 8.2.3). Depending on the respective volumes of cut and fill, imported fill or a borrow pit may be required (se Section 8.2.3).

In order to construct a suitable filled soil mass, the excavated materials should be placed in accordance with the Highways Agency *Specification for Highway Works* (2010), or a similar appropriate earthworks specification. The particle size of the fill material will determine the compaction method, and the layer thickness and number of passes required will also depend on the compaction plant used.

All materials should be excavated and placed as soon as possible to prevent deterioration in material properties due to adverse weather. Compliance testing should be undertaken on the placed fill materials to ensure that their geotechnical properties (in particular, placed strength and compressibility) are appropriate for the proposed development. Once the design is finalised further advice on the nature of these tests and an appropriate frequency of testing can be provided by this office.

8.2.5 Fill Stability - Zone A

The investigation has identified that the soils beneath the proposed fill area in Zone A are variable comprising relatively thick deposits of Made Ground in excess of 1m (e.g. TP107, TP112, TP6, TP109, TP110), or shallow glacial soils within 0.5m of the current site surface (e.g. TP8, TP108). Prior to filling the formation should be inspected and proof rolled, and any softer zones identified and replaced by compacted suitable granular fill.

As discussed in Section 2.9.5, the south-eastern boundary of the site comprises a sub-vertical former quarry face. Investigation on the south-eastern boundary of the site (above the former quarry face) has identified the ground conditions in this area to comprise between 1.75 and 2.7m of Made Ground, generally directly on sandstone bedrock (WS4 and TP110). However, in the north of the area (TP109), a very sandy, very gravelly clay of soft-to-firm consistency (Diamicton) was identified to a depth of 4.4m, with no sandstone present to this depth.

We consider that the Made Ground would not prove a suitable founding stratum for the fill materials on the south-eastern margins of the site, as the additional weight of 3m of fill above it is likely to cause a failure and collapse of the fill materials and underlying Made Ground down into the adjacent residential properties on Birchley Close. In addition, we consider that the soft-to-firm clay underlying the Made Ground in TP109 could form a slip surface which could lead to the sliding of the placed fill, again possibly down into the adjacent property.

Given the above, we recommend that along the south-eastern boundary, the Made Ground and clay soils are completely excavated and replaced with coarse-fill fill materials (such as the sandstone excavated from Zone C) compacted in layers. Care will be required along this margin to ensure that these works do not impact on the adjacent properties beneath the site. The current slope geometry along this margin has not yet been defined by a survey and we recommend that this is undertaken prior to finalising design.

The area over which the Made Ground and Diamicton need be excavated will depend on the final design proposals, the depth to bedrock in the area, and the likely stability of the fill along this edge. Further investigation by trial pitting to confirm the ground model is recommended once the skips currently occupying this area have been removed.

The leading edge of the fill (along the south-eastern boundary) could be stiffened by the incorporation of geogrids to form a reinforced earth embankment.

8.2.6 Zone A – Global Stability

As discussed in Section 2.5.1 and 2.9.5, the published geological map indicates the sandstone bedrock to dip out of the quarry face, i.e. there is a potential for global instability along the south-eastern margins of the site.

The available sandstone quarry face to the south-east of the site has been inspected and the discontinuities within the rock mass logged. The discontinuities have been plotted on stereographic projections to allow an assessment of the stability of the sandstone bedrock within the face – see Appendix J.

Preliminary Rock Face Stability Assessment

In assessing the kinematic stability of the rock face, the geometry of the discontinuities present are considered in relation to the orientation of the quarry face. Where these discontinuities, or the junction of these discontinuities daylight within the face, there is a potential for instability. However, this can be overcome by the resistance created by roughness along the surface of the discontinuities – known as the shear strength. Hoek and Bray (1981) report typical values for the angle of friction (analogous to shear strength across discontinuities) within sandstones to be between 25 and 35°. For the purposes of this assessment, we have assumed a median value of 30°.

The preliminary assessments presented in Appendix J suggest that at the low bedding angle recorded (16°), and an angle of friction of 30°, planar failure (where rock blocks slide out of the face along the bedding) is unlikely to occur. Similarly, significant wedge failure (where rock blocks slide out of the face along intersections of discontinuities) is also unlikely to occur. The assessment has indicated that there is the kinematic potential for high angle (sub-vertical) wedge failures to occur, however, these are likely to be limited to the immediate surface of the quarry face itself and, these should not pose a long term risk. The stereographic assessment has indicated the potential for toppling failure, whereby surface rock blocks on the face could topple over – such failures are unlikely to be initiated by the proposed development at the crest, nor are they likely to impact on the global stability.

Therefore, based on the above, where sandstone bedrock forms the face immediately beneath the proposed development, it is unlikely to suffer global instability. We recommend that once full access is obtained to this area, as part of the further investigation in of the area (see Section 8.2.5), a further geotechnical inspection is made of the slopes beneath the south-eastern margins of the site.

Preliminary Evaluation of Risk Mitigation Measures:

As discussed above, where sandstone bedrock is present within the rock face on the south-eastern boundary, there is unlikely to be a significant risk of global instability which could impact on the proposed development.

However, as discussed in Section 8.2.5, investigation in the south-eastern margins of the site has suggested that the upper part of the face comprises Made Ground and glacial soils, which could be inherently unstable and the development could lead to failure within these soils.

The risk of instability along the south-eastern boundary must be mitigated to prevent both damage to properties within the development, and properties adjacent and below to the south-east.

As discussed in Section 8.2.5, the removal and replacement of the Made Ground and soft to firm, fine-grained glacial soils within the upper layer of the face will assist in improving stability, but may not be sufficient to mitigate the risks fully

The risks of global instability could be reduced by reducing the proposed fill height and hence the imposed loads. However, as discussed in Section 7.2.1, this could have implications in the risk mitigation strategy for soil contaminants. Further measures that could be adopted and would be prudent would include:

- Benching the fill material into the existing slope beneath the south-eastern margins of the development site;
- Extending the use of geo-grids to create a zone of reinforced earth immediately above the sandstone along the south-eastern boundary, behind which the Made Ground may remain; and
- Excavating the upper layers of the sandstone, to reduce the height of the face, and replacing them with reinforced earth.

Following the topographic survey of the face beneath the site and further investigation following the removal of the skips in the south-east of the site, a full assessment of the global stability of this part of the site will be required.

Any assessment of stability in this area should also consider the foundations of the south-eastern block, which is located some 10m from the south-eastern boundary and the crest of the quarry face.

8.2.7 Integrated Approach to Earthworks

As discussed in the above sections and Section 7.2.1 and 7.3.1, the geotechnical and geo-environmental (contamination) aspects of the earthworks are closely linked and, therefore, it is essential that an integrated approach is adopted in the design of the earthworks, by a specialist experience din both geotechnical and geo-environmental design.

Once the earthworks final design has been determined, a Geotechnical Design Report incorporating a risk register would be required.

8.3 Earthworks – Access Road

8.3.1 Proposed Earthworks

The current access track to the site is around 4m in width. We understand that this is to be widened to around 5.5m (with a 1.8m standoff to the east), to create a new access road into the development.

The eastern side of the track comprises a fence and downslope to the adjacent football pitch, so the widening will be achieved by excavation into the vegetated slopes to the west, which are steep in places. Given this, excavation by up to 3 to 4m into these western slopes may be required.

8.3.2 Excavation of Slopes

The investigation has identified the western slopes to comprise a coarse-grained mix of gravel, cobbles and boulders mainly of sandstone and slag.

The wheeled backacting excavator used in the investigation was generally capable of excavating trenches of around 1m width some 3 to 4m into these slopes. However, in places (e.g. ST5) fused slag was encountered, which could not be excavated.

Given the above, we consider that conventional plant is likely to be capable of excavating the slopes for construction, however, fused slag should be expected, which is likely to require a hydraulic breaker to remove.

8.3.3 Stability of Slopes

No topographic survey has been provided for the slopes to the north-west of the proposed access road at this stage, but from site observations, the current slopes within 3 to 4m of the access track (i.e. those to be excavated for the widening of the road) vary in slope angle from very shallow (less than 10°, e.g. ST5) to in excess of 20 to 30° (e.g. ST2, ST3, ST4). The coarse-grained mix of gravel, cobbles and boulders mainly of sandstone and slag within these slopes appears to have been end-tipped forming a slag heap in the late-nineteenth century and is likely to have poor stability, much of which may be provided by the root network of the dense vegetation. During the excavation of the slit trenches, the material was found to unravel and collapse.

Given the above, if left unsupported we consider that the excavations within the materials to widen the road are likely to be unstable even in the short-term. This could lead to further unravelling of the slopes above and, potentially, cause instability in the ground surface of the football pitch and surrounding property above the slopes (further to the north-west).

We consider that the above risk of instability in the long term would be best mitigated by the provision of a retaining wall along the western side of the new access road to support the upper parts of the slope. The slopes should be subjected to further investigation to allow the most economic design of the wall, including an assessment of the current stability properties of the soils within the slopes, the levels of groundwater, and the potential of slag expansion beneath the foundation of and behind the wall – see Section 8.4.3. A topographic survey should also be undertaken across the slopes to the north of the new access road.

During construction of the new wall, the excavation of the slopes should be limited to only short bays to minimise the risk of instability.

The slope down to the football pitch to the south-east of the access road is around 3 to 4m in height (visually estimate only) and relatively steep in places. Along the main length of the proposed access road (ST3 and ST4), the slit trenches excavated into the north-western slopes encountered glacial soils or sandstone at a relatively shallow level beneath the current track. This suggests that the downslope to the football pitch may comprise sandstone bedrock (given the relative thin horizon of glacial soils in the vicinity). However, at the north-eastern end of the proposed road (ST1 and ST2), the slit trenches did not encounter natural soils, and in this area, the downslope to the football pitch may in part comprise tipped slag materials.

We recommend that rotary boreholes are constructed along the proposed access road to investigate further the nature of the soils/bedrock in the downslope to the football pitch and, hence, confirm its likely long term stability.

8.4 Geotechnical Risk Register

8.4.1 Updated Geotechnical Risk Register

The desk study (Section 2.0) identified the following potential geotechnical hazards at the site that needed further consideration:

- Site instability;
- Shrinkage/swelling of fine-grained soils;
- Volumetrically unstable slag; and
- Sulphate/pyrite.

This has been updated in Table 12 below with additional information on these and other potential geotechnical/construction risks identified by the intrusive investigation.

Table 12: Updated Geotechnical Risk Register

Hazard	Risk	Comment
Site Instability	**Very High**	Discussed in detail in Sections 8.2.5 and 8.2.6.
Shrinkage and swelling	**Moderate**	See Section 8.4.2.
Volumetrically Unstable Slag	**Moderate**	See Section 8.4.3.
Sulphate/Pyritic Ground	Low	See Section 7.6.2.

Notes on Table 12:

1. This table updates hazards that Table 3 in Section 2.9.1 identified to be moderate or higher using the results of the intrusive investigation.
2. Further discussion is presented in the following sections.

8.4.2 Shrinkage/Swelling

Laboratory testing within the fine-grained Glacial Diamicton across all three zones indicated the soils are of low to moderate shrinkage and swelling potential.

8.4.3 Volumetrically Unstable Slag Materials

The preliminary investigation at the site identified slag materials to be present within the Made Ground across the development site and within the slopes to the north of the access road. Three samples of suspected slag have been collected from the Made Ground within the development site (from TP114 and TP104) and from the slopes to the north of the access track (ST4) and were sent to a specialist laboratory for analysis. The laboratory report is presented as Appendix O.

A Phase One qualitative petrological examination was undertaken on the three samples which identified the samples recovered from the Made Ground on site to contain a small to negligible amount of blast furnace slag, a larger amount of alumina-silicate firebricks, a very small proportion of cindery and silicic slag, and a small proportion of coke and coal. No basic steel slag or basic refractory products were identified.

The sample analysed from the slopes to the north of the access road was found to contain a medium amount of blast furnace slag, a large amount of alumina-silicate brick, a medium proportion of silicic slag, and small proportions of coke and coal. It should be appreciated that the phase one stage of analysis provides a qualitative assessment only and no measured proportions are assessed.

The blast furnace slag identified particularly in the slopes to the north of the access track showed secondary alteration indicating weathering, which can result in the slag being expansive when hydrated. However, the main slag types associated with volumetric expansion (basic steel slag and basic refractory products) were found to be absent from the samples analysed.

On the basis of the results of the testing, we consider that the potential for expansive slag being present within the development site is low. However, given the variability of the Made Ground identified across the site, the possibility of further slag which may be expansive being present cannot be discounted, and should be considered in the design of foundations and pavements – see Sections 8.5 and 8.8.

Potentially expansive slag materials have been identified in the slopes to the north of the access track and this potential should be considered in the design of the final slopes/retaining structures and pavement.

8.5 Foundation Design and Construction

We understand that the site is being considered for potential development for residential purposes and the comments and recommendations in this report assume that the development will involve the construction of typical two-storey structures of conventional load-bearing brickwork construction.

For the purposes of this assessment, we have considered the site to comprise three general blocks as shown on Figure 2:

- A north-western row – five blocks predominantly constructed within an area of ground lowering;
- A south-eastern block, predominantly constructed in an area where site levels are to be raised;
- A north-eastern block, predominantly constructed in an area where site levels are to be raised.

Given the above variation in existing and proposed ground levels, foundation options will vary across the site.

8.5.1 North-western Row (Zones B and C)

As discussed above, we anticipated that the row of dwellings to the north-west of the access road will substantially be constructed in an area where ground levels are to be lowered by between 0.5 and 2.8m, or in areas of grade, where the sandstone bedrock is present within 1m of the finished site surface. Over much of the area, and based on the levels provided at this stage, the resulting ground surface will comprise the excavated surface of the sandstone bedrock (e.g. TP11, TP2, TP105), or the sandstone bedrock is within 1m of the final site surface (e.g. TP103, TP114).

In these areas, conventional spread foundations would be appropriate for the development, founded within the sandstone bedrock. We recommend that, where present at the surface, foundations are taken a minimum of 500mm into competent sandstone, or 100mm into competent sandstone where present within depths of 1.0 to 1.5m of the final site surface. A presumed bearing value of 200kPa may be adopted for these footings to limit settlements to tolerable limits.

However, in the north-eastern parts of this row (around TP101 and TP5) the final ground levels will be raised by up to 0.5m. Around TP101 (in front of Building B), the sandstone bedrock is anticipated at a depth of around 1m, and so the above foundations would be appropriate. However, in the north-eastern margins, around 2m of fill/Made Ground is anticipated (e.g. TP5), which will be too deep for conventional spread foundations.

In this area, foundations would need to be taken down through the fine-grained glacial soils to either the underlying coarse-grained glacial soils or, preferably (to maintain consistency in founding strata) the sandstone bedrock anticipated from depths of 2.5m below finished ground levels. Options in this area include:

- Deep trench fill foundations – these have the advantage of consistency of foundation type, but are likely to result in deep, potentially unstable excavations, large volumes of concrete, and the generation of a large volume of Made Ground arisings which could be contaminated.
- Mini-piling – this has the advantage of reducing the volume of concrete required, and the amount of potentially contaminated arisings, but is likely to be expensive if it is only used for foundations in this area.
- Pier and beam – probably the optimum foundation solution, whereby a small caisson is constructed on the sandstone bedrock beneath load bearing positions (e.g. the north-eastern corner) and filled with concrete. Ground beams can then be constructed above this to accommodate line loads. Small diameter manhole rings could provide a suitable caisson. This solution has the benefits of being relatively cheap, and limiting excavation and arisings. A presumed bearing value of 200kPa is considered appropriate for pier and beam foundations constructed in the competent sandstone bedrock.

8.5.2 South-eastern Block (Zone A)

We anticipated that the block of dwellings to the south-east of the access road will substantially be constructed in an area where ground levels are to be generally raised by around 2.5 to 3m. The existing ground conditions in the area comprise between 0.6 and 1.6m of Made Ground, commonly over a fine-grained glacial soil of low strength. These soils are not considered suitable as a founding stratum and conventional foundations are unlikely to be suitable for this row.

We consider that for this block, the following foundation options could be considered:

- Mini-piling - piled foundations taken down through the fill, Made Ground and soft glacial soils to the coarse-grained glacial soils or sandstone bedrock at depths of between 2 to 5m below final ground levels. This solution would has the advantage of reducing the volume of concrete required, and the amount of potentially contaminated arisings, but is likely to be relatively expensive.
- Trench fill/Pier and beam – as for the north-western row above, but is likely to be expensive and logistically difficult due to the depth of excavation, and the volume of concrete required and arisings generated.
- Excavate and replace – we consider that this is likely to be the preferred option, due to its technical suitability, but also that it is an extension of the risk mitigation works recommended for the south-eastern margins to overcome potential global instability – see Sections 8.2.5 and 8.2.6. Provided suitable coarse-grained fill is used to replace the excavated Made Ground and soft fine-grained glacial soils, compacted to a suitable specification, we consider that raft or reinforced strip foundations would be suitable for use. The presumed bearing value and potential settlements will depend in the nature and specification of the re-compacted fill, but we would anticipate that a presumed bearing value of 100kPa should be achievable on coarse-grained fill, compacted to a suitable specification.

8.5.3 North-eastern Block (Zone A)

We anticipated that the block of dwellings in the north-east of the site will substantially be constructed in an area where ground levels are to be generally raised by around 1.4 and 2.5m.

The existing ground conditions in this area are highly variable, with sandstone bedrock at shallow depth (0.3m in TP106) in the north-western margins, but at 1.4m depth beneath the south-eastern margins (TP13). Therefore, the sandstone is likely to be present at depths of between 1.7m (northwest) and 4m (south-east).

We consider that in this area, the following foundation options could be adopted:

- Pier and beam – possibly the optimum foundation solution, whereby ground beams are constructed across a series of small caissons (piers) sunk to the bedrock – as discussed above for the north-western row. A presumed bearing value of 200kPa is considered appropriate for pier and beam foundations constructed in the competent sandstone bedrock.
- Excavate and replace – the existing Made Ground could be excavated and replaced with coarse-grained fill, compacted to a suitable specification, with a raft or reinforced strip foundations constructed above – as discussed above for the south-eastern block. The presumed bearing value and potential settlements will depend in the nature and specification of the re-compacted fill, but we would anticipate that a presumed bearing value of 100kPa should be achievable on coarse-grained fill, compacted to a suitable specification.
- Mini-piling - piled foundations as discussed in previous sections may also be a solution for the southern part of the block, but are only likely to be economic if used on the remainder of the development.

8.5.4 General Comments

For all spread foundation options, including pier and beam, the formations should be cleaned, and subsequently inspected by a suitably qualified engineer prior to placing concrete. Should any soft, compressible or otherwise unsuitable materials be encountered they should be removed and replaced by lean mix concrete or suitable compacted granular material. We recommend that a blinding layer of concrete be placed on the formation after excavation and inspection in order to protect the formation against softening and disturbance.

As discussed in Section 8.2.3, the excavated bedrock from Zone C is likely to provide suitable fill materials for use beneath foundations in Zone A, provided that it is treated to be suitable (e.g. any large rock blocks broken down to a suitable size). However, given the volume of fill likely to be required, a borrow pit may be needed to minimise on imported fill material – see Section 8.2.3.

Given the potential foundation solutions discussed above, we do not consider that the potential for shrinkage and swelling within the fine-grained glacial soils is likely to pose a risk to the future development. However, when foundation designs are being finalised, this potential hazard should be considered.

Where the excavate and replace option is to be adopted, the ground improvement should be carried out over an area extending to a minimum of 1.0m outside the footprint of each foundation – although in the vicinity of the south-eastern block, the treatment is likely to extend across the whole area.

Once the Made Ground and fine-grained glacial soils have been excavated, the formation should be proof rolled and inspected by a suitably qualified geotechnical engineer - any soft, compressible or otherwise unsuitable materials encountered should be removed and replaced by lean mix concrete or suitable compacted granular material. Given the potential for site instability, the lower layers of the fill materials should be benched into the existing slope along the south-eastern margins of the site.

As discussed in Section 8.2.7, the geotechnical and geo-environmental (contamination) aspects of the development, including foundation design and construction are closely linked and, therefore, it is essential that an integrated approach is adopted in design by a specialist experienced in both geotechnical and geo-environmental design.

Given the large variation in existing ground levels and conditions across the site, along with the final ground levels, likely foundation solutions and potential instability in the south-eastern margins, we recommend that a Geotechnical Design Report be prepared with specific foundation designs for the individual blocks based on the existing and proposed ground levels and the ground conditions beneath each point. Further 'fill-in' trial pitting may be required once the existing buildings on site are demolished to provide sufficient information to complete this assessment.

The 'Foundation Design' report should be submitted to the building control and insurance provider for approval prior to development.

8.6 Floor Slab Foundations

Given the available information, and subject to the further monitoring identifying no gas risk (see Section 4.2.2), we consider that the use of cast in-situ, ground bearing floor slabs, founded on the sandstone bedrock would be appropriate for much of the north-western block. The formation should be inspected for loose or soft pockets which, if found, should be excavated and replaced with compacted coarse-grained fill or concrete.

However, in the north-eastern part of this block, the thickness of fill and Made Ground is likely to exceed 600mm, and suspended floor slabs are likely to be required.

For the south-eastern and north-eastern blocks, suspended floor slabs are likely to be required. If the excavate and replace option is adopted, the use of cast in-situ ground bearing floor slabs may be acceptable, subject to further assessment and the agreement of the insurance provider.

8.7 Retaining Wall Design

A retaining wall is recommended along the northern side of the proposed access road. Further investigation is recommended to provide geotechnical parameters for its design – see Section 8.3.3.

8.8 Pavement Design

A new access road is to be constructed along the football pitch to the east of the site and through the centre of the site.

8.8.1 Design CBR Value

The proposed access road through the site will run between areas of cut, fill and at grade. Therefore, the ground conditions within the formation of the road will be variable. Generally in areas of cut or at grade, the existing ground comprises coarse-grained Made Ground, which contains fragments of slag. Initial testing has demonstrated that this slag comprises mainly blast furnace slag is not likely to be expansive. However, we recommend that if extensive pockets are encountered within the pavement formation (e.g. around TP14), they are removed and replaced with suitable compacted granular fill material.

Sand sized PFA is anticipated within the formation beneath parts of the proposed road route (e.g. around WS1 and TP9). We do not consider that this material is suitable as a foundation for the road, and where identified it should be excavated and replaced with suitable compacted granular fill material.

Due to the variability of the likely road formation soils, California Bearing Ratio (CBR) tests have not been carried out at the site, but based on experience we consider that a CBR value of 2.5% should be used for preliminary design purposes, for the near surface coarse-grained Made Ground where it is present in the road formation. Actual design values should be determined for designated areas as required.

The CBR value of the placed fill materials will depend on their nature and compaction. However, provided suitable coarse-grained fill (e.g. reworked sandstone bedrock) is compacted to an appropriate specification, we consider that a CBR value of at least 10% should be achievable.

The final sub-grade should be inspected by a qualified engineer, and any soft or loose material removed and replaced as necessary, to ensure that the Design CBR value is achieved. It is further recommended that the sub-grade be proof-rolled with a suitable roller prior to the placement of the sub-base materials. In order to improve the sub-base performance the use of a suitable geo-grid may be considered.

We consider that it would be prudent to re-measure the CBR values of the sub-grade on exposure to confirm that they are equal to or better than the values measured in this investigation (as recommended by the Highways Agency [HA, 2009a]). If the CBR values in the sub-grade are found to be lower than the Design CBR, the subgrade must be improved to achieve the Design CBR or the road pavement foundation redesigned.

8.8.2 Susceptibility to Frost Action

The coarse-grained Made Ground soils anticipated in the formation are considered to be non-frost susceptible.

8.9 Excavation and Dewatering

It is anticipated that excavation throughout most of the site will be within the capabilities of conventional mechanical excavators. As discussed in Section 8.2.2, large capacity excavators and possibly hydraulic breakers would be required to excavate the sandstone bedrock.

For shallow excavations where there is no danger to life, support of excavation sides is unlikely to be necessary. Should any indication of excavation instability be noted at any depth, support should be provided as appropriate.

Based on our understanding of the proposed development, shallow perched groundwater tables may be present within the shallow soils beneath the site.

8.10 Soakaway Drainage

8.10.1 Soakaway Design

Soakaway infiltration tests were undertaken in two test pits excavated across the site (TP112 and TP113). The results of the testing are presented in Appendix K.

During Test SA1 (TP112), the water level fell almost to the 25% fill level, and an infiltration rate can be estimated with some confidence. During the second fill in this pit (SA2), the water level fell close to the 25% fill level, and again an infiltration rate can be estimated with a reasonable degree of confidence. In Test SA3 (TP113), the water level fell to the 25% fill level and an infiltration rate has been calculated. No time was available for a second fill in TP113.

The calculated and estimated infiltration rates are presented in Table 13 below.

Table 13: Summary of soakaway infiltration test results

SA Test	Test Pit	Fill	Test depth	Measured Infiltration Rate[1]	Estimated Infiltration Rate[2]	Infiltration Soils
SA1	TP112	1	1.90m	-	2.1×10^{-5}m/s	Fine Diamicton and Weathered Sandstone
SA2	TP112	2	1.90m	-	1.1×10^{-5}m/s	
SA3	TP113	1	1.40m	2.4×10^{-5}m/s	-	Fine Diamicton and Weathered Sandstone

Notes to Table 13:
1. Testing undertaken in accordance with BRE 365.
2. Infiltration rate estimated from test results.

Given the above results, we consider that a soakaway infiltration rate of 10^{-5}m/s may be used for the weathered sandstone bedrock for preliminary design purposes. The variability of the soils across the site should be appreciated, and we recommend that further infiltration testing be undertaken at the proposed soakaway positions.

8.10.2 Soakaway Location

Care should be taken in the siting of the soakaways, with in particular, soakaways constructed a minimum of 10m away from the crest of slopes/quarry face.

8.10.3 Soakaway Discharge

Provided soakaways are located more than 18m from the nearest surface water course, we understand that a discharge consent will not be required. However, prior to construction, this should be confirmed with Natural Resources Wales.

The infiltration stratum at the site would be the weathered Brithdir Sandstone bedrock, which is classed as a Secondary A aquifer and the groundwater within is vulnerable to pollution. We understand that Natural Resources Wales (NRW) has a general policy that no direct discharge of surface run-off would be accepted in vulnerable groundwater aquifers.

Given the shallow depth of the bedrock at the site, any soakaways would result in the direct discharge of surface water run-off into the aquifer. We recommend that enquiries are made to NRW to identify whether they would allow such discharge at the site. As a minimum, risk mitigation measures such as oil interceptors are likely to be required. The discharge of roof-run-off is normally accepted, provided that it is maintained within a dedicated drainage system.

Care should be taken to ensure that no discharge occurs within Made Ground beneath the site, which has been found to contain unacceptable levels of leachable contaminants. If a borrow pit is excavated to provide fill materials, and then backfilled with excavated Made Ground (see Section 7.7.1), soakaways should not be located in any position which could lead to the infiltration water leaching contaminants from the backfilled pit.

9.0 RECOMMENDED FURTHER WORK

The investigation undertaken at the site has identified several areas where further investigatory or assessment work would be required to either fully determine risks or provide more information such that an appropriate engineering solution could be determined and implemented:

- The outstanding gas monitoring visits should be completed (Section 4.2.2);
- An asbestos survey should be conducted to determine the location of asbestos materials within the existing buildings and the skips along the south-eastern boundary (Section 7.2.2);
- Deeper groundwater monitoring wells should be installed and sampled to allow a Level Three assessment of risks to controlled waters – an anticipated planning condition (see Section 7.4);
- A remedial strategy and options appraisal should be completed in accordance with CLR11 (an anticipated planning condition). A materials management plan will also be required for the earthworks (Sections 7.7.1 and 7.8);
- A waste assessment would be required on materials leaving site and WAC testing undertaken on materials being disposed of at landfill (Section 7.7.2);
- Topographic surveys of the quarry face beneath the site (Section 8.2.5) and the slopes to the west of the new access road (Section 8.3.3);
- Further investigation above the quarry face in the south-east of the site to determine the ground model and further assessment of the stability and risk mitigation options in this area (Section 8.2.5);
- Further investigation in track and slopes above the access road so that a suitable retaining structure can be designed, and to investigate the stability of the downslope to the football pitch (Section 8.3.3);
- Preparation of an integrated Geotechnical Design Report, possibly requiring additional trial pitting (Sections 8.27 and 8.5.4); and
- Given the nature of the site, and the proposed development, it is considered essential that the remedial strategy and geotechnical design should be integrated (see Section 8.2.7); and
- The current environmental permit for the site should be surrendered to the satisfaction of Natural Resources Wales (see Section 1.4).

Further guidance on these elements can be provided by this office in due course.

10.0 REFERENCES

ALLEN D J, BREWERTON L J, COLEBY L M, GIBBS B R, LEWIS M A, MacDONALD A M, WAGSTAFF S J and WILLIAMS A T. 1997. The Physical Properties of Major Aquifers in England & Wales. BGS Technical Report WD/97/34 - EA R&D Publication 8. BGS and Environment Agency.

ASSOCIATION OF GEOTECHNICAL SPECIALISTS (AGS). 2016. Website accessed September 2016.

BLACKMORE K, BRIERE DE L'ISLE B, GARROW D, JONSSON J, NORRIS M, TURRELL J, TREW J and WILCOX S. 2010. Guidance for the Selection of Water Supply Pipes to be Used in Brownfield Sites. UK Water Industry Research Ltd. Report ref. No 10/WM/03/21.

RHONDDA CYNON TAFF COUNCIL. 2016. Contaminated Land Officer. Pers comm. 18th August 2016.

RHONDDA CYNON TAFF COUNCIL. 2016. Mr Gareth Price. Environmental Health Officer. Pers comm. 1 September 2016.

BOYLE R and WITHERINGTON P. 2007. Guidance on the evaluation of development proposals in sites where methane and carbon dioxide are present. NHBC rpt no 4, March 2007. NHBC Amersham.

BRITISH GEOLOGICAL SURVEY (BGS). 2016. Website accessed August and September 2016.

BRITISH STANDARDS INSTITUTION (BSI). 1990. Methods of Test for Soils for Civil Engineering Purposes. BS1377, Parts 1 to 9, HMSO, London.

BRITISH STANDARDS INSTITUTION (BSI). 2002. Geotechnical Investigation and Testing: Identification and Classification of Soil, Part 1. Identification and Description. BS EN ISO 14688-1. HMSO, London.

BRITISH STANDARDS INSTITUTION (BSI). 2003. Geotechnical Investigation and Testing: Identification and Classification of Rock, Part 1. Identification and Description. BS EN ISO 14689-1. HMSO, London.

BRITISH STANDARDS INSTITUTION (BSI). 2004. Geotechnical Investigation and Testing: Identification and Classification of Soil, Part 2. Principles for Classification. BS EN ISO 14688-2. HMSO, London.

BRITISH STANDARDS INSTITUTION (BSI). 2004. Eurocode 7: Geotechnical Design – Part 1: General Rules. BS EN 1997-1:2004, HMSO, London. (including UK National Annex).

BRITISH STANDARDS INSTITUTION (BSI). 2005. Geotechnical Investigation and Testing – Field Testing, Part 3, Standard Penetration Test. BS EN ISO 22476-3:2005. HMSO, London.

BRITISH STANDARDS INSTITUTION (BSI). 2006. Geotechnical Investigation and Testing – Sampling Methods and Groundwater Measurements. Part 1, Technical Principles for Execution. BS EN ISO 22475-1:2006. 2007 reprint. HMSO, London.

BRITISH STANDARDS INSTITUTION (BSI). 2007. Eurocode 7: Geotechnical Design – Part 2: Ground Investigation and Testing. BS EN 1997-2:2007, HMSO, London.

BRITISH STANDARDS INSTITUTION (BSI). 2007. Code of Practice for the Characterisation and Remediation from Ground Gas in Affected Developments. BS8485, HMSO, London.

BRITISH STANDARDS INSTITUTION (BSI). 2011. Investigation of Potentially Contaminated Sites – Code of Practice. BS10175, HMSO, London.

BRITISH STANDARDS INSTITUTION (BSI). 2013. Guidance on Investigations for Ground Gas – Permanent Gases and Volatile Organic Compounds (VOCs). BS8576:2013. HMSO, London.

BRITISH STANDARDS INSTITUTION (BSI). 2015. Code of Practice for Ground Investigation. BS5930:2015. HMSO, London.

BUILDING RESEARCH ESTABLISHMENT (BRE). 2001. Protective Measures for Housing on Gas Contaminated Land. BRE Digest 414. BRE Garston.

BUILDING RESEARCH ESTABLISHMENT (BRE). 2007. Radon: Guidance on Protective Measures for New Dwellings. BR211. BRE, Garston.

BUILDING RESEARCH ESTABLISHMENT (BRE). 2005. Concrete in Aggressive Ground. Third Edition. Special Digest 1 (SD1). BRE, Garston.

BUILDING RESEARCH ESTABLISHMENT (BRE). 2007. Soakaway Design. BRE Digest 365. BRE, Garston.

CAREY M A, FINNAMORE J R, MORREY M J and MARSLAND P A. 2000. Guidance on the Assessment and Monitoring of Natural Attenuation of Contaminants in Groundwater.

CROWHURST D and MANCHESTER S J. 1993. The Measurement of Methane and other Gases from the Ground. *Construction Industry Research and Information Association.* CIRIA Report 131.

CONSTRUCTION INDUSTRY RESEARCH & INFORMATION ASSOCIATION (CIRIA). 1995b. Protecting Development from Methane. CIRIA 149.

CONTAMINATED LAND APPLICATIONS IN REAL ENVIRONMENTS (CL:AIRE) and THE ENVIRONMENTAL INDUSTRIES COMMISSION. 2010. Soil Generic Assessment Criteria for Human Health Risk Assessment.

CONWAY B W, FORSTER A, NORTHMORE K J, and BARCLAY W J. 1980. South Wales Coalfield Landslip Survey. Institute of Geological Sciences, London.

DEPARTMENT FOR ENVIRONMENT, FOOD AND RURAL AFFAIRS (DEFRA) AND THE ENVIRONMENT AGENCY. 2002b. Potential Contaminants for the Assessment of Land. R&D Publication CLR8.

DEPARTMENT FOR ENVIRONMENT, FOOD AND RURAL AFFAIRS (DEFRA) AND THE ENVIRONMENT AGENCY. 2004. The Model Procedures for the Management of Land Contamination. R&D Publication CLR11.

DUCKWORTH G. 2011. The Definition of Waste: Development Industry Code of Practice. CL:AIRE. Version 2.

ENVIRONMENT AGENCY. 2001e. The Environment Agency Code of Practice for the Management, Destruction and Disposal of Japanese Knotweed.

ENVIRONMENT AGENCY. 2008a. Human Health Toxicological Assessment of Contaminants in Soil. Science Report SC050021/SR2.

ENVIRONMENT AGENCY. 2008c. Updated Technical Background to the CLEA Model. SC050021/SR3.

ENVIRONMENT AGENCY. 2008c. CLEA Software Handbook. SC050021/SR4.

ENVIRONMENT AGENCY (EA). 2012. Groundwater Protection: Principles and Practice (GP3). Document ref. LIT 7562, November 2012, Version 1.

HARRIES C R, WITHERINGTON P J and McENTEE J N. 1995. Interpreting Measurements of Gas in the Ground. *Construction Industry Research and Information Association.* CIRIA Report 151.

HEALTH & SAFETY EXECUTIVE. 1991. Protection of Workers and the General Public During the Development of Contaminated Land. HMSO, London.

HOOKER P J and BANNON M P. 1993. Methane: It's Occurrence and Hazards in Construction. *Construction Industry Research and Information Association.* CIRIA Report 130.

INTERDEPARTMENTAL COMMITTEE ON THE REDEVELOPMENT OF CONTAMINATED LAND (ICRCL). 1990. Asbestos on Contaminated Sites. (ICRCL 64/85, 2nd Edition).

JONES H K, MORRIS B L, CHENEY C S, BREWERTON L J, MERRIN P D, LEWIS M A, MacDONALD A M, COLEBY L M, TALBOT J C, McKENZIE A A, BIRD M J, CUNNINGHAM J and ROBINSON V K. 2000. The Physical Properties of Minor Aquifers in England & Wales. BGS Technical Report WD/00/4 - EA R&D Publication 68. BGS and Environment Agency.

NATHANAIL P, JONES A, OGDEN R, and ROBERTSON A. 2014. Asbestos in Soil and Made Ground. A Guide to Understanding and Managing Risks. CIRIA C733.

NATHANAIL P, McCAFFREY C, GILLETT A, OGDEN R and NATHANAIL J. 2015. The LQM/CIEH S4ULs for Human Health Risk Assessment. Land Quality Press, Nottingham.

NORBURY D. 2010. Soil and Rock Description in Engineering Practice. Whittles Publishing.

O'RIORDAN N J and MILLOY C J. 1995. Risk Assessment for Methane and other Gases from the Ground. CIRIA Report 152.

RAYBOULD J G, ROWAN S P and BARRY D L. 1995. Methane Investigation Strategies. *Construction Industry Research and Information Association.* CIRIA Report 150.

RUDLAND D J, LANCEFIELD R M and MAYELL P N. 2001. Contaminated Land Risk Assessment. A Guide to Good Practice. *Construction Industry Research and Information Association.* CIRIA Report C552.

SCIVYER C. 2007. Radon: Guidance on Protective Measures for New Buildings. Building Research Establishment, BRE 211.

STONE K, MURRAY A, COOKE S, FORAN J and GOODERHAM L. 2009. Unexploded Ordnance (UXO). A Guide for the Construction Industry. CIRIA, rpt C681.

TOMLINSON, MJ. 2001. Foundation Design and Construction (7th edition). Prentice Hall.

WELSH DEVELOPMENT AGENCY. 1998. The Eradication of Japanese Knotweed. WDA: Cardiff.

WILSON S, OLIVER S, MALLETT H, HUTCHINGS H and CARD G. 2007. Assessing Risks Posed by Hazardous Ground Gases to Buildings. *Construction Industry Research and Information Association.* CIRIA Report C665.

WILSON S, CARD G and HAINES S. 2009. Ground Gas Handbook. Whittles Publishing.

ZETICA LTD. 2014. Regional Unexploded Bomb Risk Maps – Glamorgan.

EUROPEAN UNION. 2008. Environmental Quality Standards in the Field of Water Policy. Directive 2008/105/EC of the European Parliament and of the Council.

WELSH GOVERNMENT. 2010a. Water Supply (Water Quality) Regulations. Statutory Instrument No. 994 (W.99), 2010.

WELSH GOVERNMENT. 2010b. The River Basin Districts Typology, Standards and Groundwater Threshold Values (Water Framework Directive) (England and Wales) Directions 2010.