Report No. 30156/1A
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SUPPLEMENTARY GEOENVIRONMENTAL APPRAISAL of land at BURLOW ROAD, HARPUR HILL, BUXTON (NORTHERN SITE – 'SITE A')

Prepared for

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SITE A, BURLOW ROAD, HARPUR HILL, BUXTON
SUMMARY OF GEOENVIRONMENTAL ISSUES

The site is located to the northeast of Burlow Road and northwest of Heathfield Nook Road, in the village of Harpur Hill, approximately 3km south of Buxton (OS Grid Ref:407040E, 370850N). The site occupies an area of 6.17 hectares (16.25 acres), which rises from southeast to northwest on shallow gradients, becoming steeper in the northwest. The site is currently in agricultural use as grazing pasture / grass crop.

The site has remained in agricultural use since prior to earliest available maps dating from 1879. However, limestone quarrying to the northeast of the site had expanded and encroached approximately 25m into the northeast of the site, by 1938, with evidence of soils also being stockpiled within the east of the site. The former quarry has since been infilled with what is understood to be inert soils, and restored to agricultural use, with the remaining restoration continuing under appropriate planning permission.

ALM were commissioned by Barratt Homes Manchester to provide a supplementary geoenvironmental appraisal of the site. It is understood that the site is to be redeveloped with 152No. 2-3 storey domestic dwellings, associated gardens, a 'Community Building', public open space, and adoptable roads and sewers, as shown on Barratt Homes Manchester 'Sketch Layout' plan (un-numbered). ALM's investigation included a review of a number of previous phases of desk study and ground investigation, and a supplementary ground investigation comprising 54No. trial pits and 7No. windowless sample boreholes, and a programme of gas/groundwater monitoring.

A summary of salient geoenvironmental issues is provided in the Table below.

Issue	Remarks
Made Ground	Organic sandy clays with gravel and cobbles of limestone, concrete, brick, slate and occasional pieces of wood and ceramic to a depth in excess of 7.2m within the former quarry. Reworked topsoil and clays (<1m) above the quarry infill and relic topsoil in vicinity of former quarry Ash/clinker (<0.8m) made ground in an isolated area in the east of the site. Cohesive made ground with gravel and cobbles of limestone, concrete, brick and pieces of rope and glass recorded to a depth in excess of 2.3m in localised area of historic subsidence.
Natural Ground	Clayey topsoil overlying orange brown clays to average depths <1.1m, overlying limestone bedrock beneath much of the site, and Miller's Dale Lava strata beneath the northwest. Possible palaeo-karst features underlying Miller's Dale Lava strata in the northwest.
Contamination	Asbestos, benzo(a)pyrene and SVOC's in quarry infill. Metals, water sol.sulphate and PAH's in ash clinker made ground. Hotspot of nickel contamination in natural clay in the northwest.
Hazardous Gas	Full Radon Protective Measures required for new buildings. Elevated concentrations of methane and carbon dioxide recorded in quarry infill. No significant concentrations of gas recorded generally elsewhere across the site.
Mining & Quarrying	Not in a coal mining area. Limestone quarrying is prominent in the local area with the nearest quarrying occurring immediately to the northeast of the site, extending approx.25m into the site.
Preparatory Works	Stripping of topsoil, excavation and disposal or relocation of made ground, cut/fill earthworks (including significant breaking out of limestone bedrock), preparation of sub-grade to raft foundations, provision of sufficient depth of clean soil cover above contaminated soils in gardens.
Foundations	Depending on finished ground levels, strip/trench fill foundations likely to be possible across much of the site, with piled foundations preferred where site levels are raised resulting in >2m depth to competent strata. Raft foundations recommended above Millers Dale Lava strata in the northwest.
Groundwater & Excavations	No groundwater encountered in near surface soils during all phases of ground investigation. Excavation within the limestone bedrock will be difficult, and relatively easy in the Miller's Dale Lava
Flooding & Drainage	Not in an Environment Agency Indicative Flood Zone. Soak-away drainage considered feasible for surface water drainage.
Highways	In-situ natural clays likely to offer a CBR of 3%, although re-compacted clays likely to offer a CBR of <1%. Re-compacted Millers Dale Lava strata likely to offer a CBR of approximately 5%.

This brief summary should not be assumed to represent a complete account of all the potential geo-environmental issues that may exist at the site. As such it is strongly recommended that the report be read in its entirety.

Significant developer abnormals relating to geoenvironmental issues at the site are:

- Excavations within strong limestone bedrock for site regrade and foundation excavations.
- Preparation of the sub-grade to recommended raft foundations.
- Diversion of existing live services.

Some further work is required, most notably:

- Plot specific foundation appraisal once development layout and development levels finalised.

This brief summary should not be assumed to represent a complete account of all the potential geo-environmental issues that may exist at the site. As such it is strongly recommended that the report be read in its entirety.

TABLE OF CONTENTS

APPENDICES

Appendix A - General Notes

01	Environmental Setting
02	Ground Investigation Fieldwork
03	Geotechnical Testing
04	Contamination Laboratory Analysis & Interpretation (including WAC)
05	Hazardous Gas
06	Soakaways

Appendix B – Drawings

Drawing No.	Title
30156/A/1	Site Location Plan
Un-numbered	Sketch Layout (Barratt Homes Manchester)
BUX/ED/04	Cut and Fill Analysis (Barratt Homes Manchester)
30156/A/2	Existing Site Features & Topographical Survey
30156/A/3	Photograph Location Plan
30156/A/4	Historical Site Features Plan
30156/A/5	Conceptual Site Model
30156/A/6	Exploratory Hole Location Plan
30156/A/7	Depth/Level of Rockhead
30156/A/8	Excavatability Assessment Chart
Figure 2	Geophysical Survey (Bentham Geoconsult Ltd – 2015)

Appendix C – Commission

Appendix D – Photographic Survey

Appendix E – Historical Ordnance Survey Maps

Appendix F – *Envirocheck* Report

Appendix G – Exploratory Hole Records – GRM (2013 & 2015) Investigation (WS01-05) & (WS06-WS13, TP01-TP30)

Appendix H – Exploratory Hole Records – ALM (2017) Investigation (TPA101-TPA135, TPA201-209, TPA301-305, WSA101-107 & SAA1-SAA2)

Appendix I – Chemical Test Results

Appendix I(1)	GRM (2015) Investigation
Appendix I(2)	ALM (2017) Investigation

Appendix J – Geotechnical Test Results

Appendix J(1)	GRM (2015) Investigation
Appendix J(2)	ALM (2017) Investigation
Appendix J(3)	In-Situ Soakaway Tests ALM 2017 Investigation

Appendix K – Gas and Groundwater Monitoring Results

Appendix K(1)	GRM (2013 & 2015) Investigations
Appendix K(2)	ALM (2017) Investigation

FOREWORD

This report has been prepared for the sole internal use and reliance of the Client named on page 1. This report shall not be relied upon or transferred to any other parties without the express written authorisation of ALM Consult Ltd (ALM); such authorisation not to be unreasonably withheld. If any unauthorised third party comes into possession of this report, they rely on it at their peril and the authors owe them no duty of care and skill.

The report presents observations and factual data obtained during our site investigation, and provides an assessment of geoenvironmental issues with respect to information provided by the Client regarding the proposed development. Further advice should be sought from ALM prior to significant revision of the development proposals.

The report should be read in its entirety, including all associated drawings and appendices. ALM cannot be held responsible for any misinterpretations arising from the use of extracts that are taken out of context.

The findings and opinions conveyed in this report (including review of any third party reports) are based on information obtained from a variety of sources as detailed within this report, and which ALM believes are reliable. All reasonable care and skill has been applied in examining the information obtained. Nevertheless, ALM cannot and does not guarantee the authenticity or reliability of the information it has relied upon.

The report represents the findings and opinions of experienced geo-environmental consultants. ALM does not provide legal advice and the advice of lawyers may also be required.

Intrusive investigation can only investigate shallow ground beneath a small proportion of the total site area. It is possible therefore that the intrusive investigation undertaken by ALM, whilst fully appropriate, may not have encountered all significant subsurface conditions. Consequently, no liability can be accepted for conditions not revealed by the exploratory holes. Any opinion expressed as to the possible configuration of strata between or below exploratory holes is for guidance only and no responsibility is accepted as to its accuracy

It should be borne in mind that the timescale over which the investigation was undertaken may not allow the establishment of equilibrium groundwater levels. Particularly relevant in this context is that groundwater levels are susceptible to seasonal and other variations and may be higher during wetter periods than those encountered during this commission.

Where the report refers to the potential presence of invasive weeds such as Japanese Knotweed, or the presence of asbestos containing materials, it should be noted that the observations are for information only and should be verified by a suitably qualified expert.

This report assumes that ground levels will not change significantly from those existing at present and that houses will be of two storey construction. If this is not to be the case, then some modification to this report may be required.

ALM cannot be responsible for the consequences of changing practices, revisions to waste management legislation etc. that may affect the viability of proposed Remediation options.

ALM reserves the right to amend their conclusions and recommendations in the light of further information that may become available.

SUPPLEMENTARY GEOENVIRONMENTAL APPRAISAL of land at BURLOW ROAD, HARPUR HILL, BUXTON (NORTHERN SITE – 'SITE A')

1 INTRODUCTION

1.1 The Commission and Brief

1.1.1 ALM Consult Ltd (ALM), were commissioned by Barratt Homes Manchester to carry out a Supplementary Geoenvironmental Appraisal of land to the northeast of Burlow Road, Harpur Hill, Buxton, in the context of the proposed development of the site for low rise residential housing.

1.1.2 The site is referred to as the 'Northern Site, or 'Site A', which is an irregular shaped parcel of land covering and area of approximately 6.17 hectares, located immediately to the northeast of Burlow Road and northwest of Heathfield Nook Road.

1.1.3 Land immediately to the south of Burlow Road, referred to as the Southern Site, or 'Site B', is also being investigated by ALM on behalf of Barratt Homes Manchester, at the same time as this study. However, the findings of that study are reported separately.

1.1.4 Correspondence regarding ALM's appointment, including the brief for this investigation, is included in Appendix C. The agreed scope of works included:

- A review of third party reports and other information.
- A site walkover and inspection.
- Confirm the site's land use history and environmental setting.
- An intrusive ground investigation comprising 54No. Trial Pits, 7No. Windowless Sample Boreholes, and 2No. in-situ soakaway tests.
- An assessment of the geotechnical properties of the near surface deposits to enable provision of foundation and highway recommendations.
- A qualitative assessment of contamination risks, with respect to potential receptors
- The provision of recommendations with respect to site preparatory and remediation works.

1.1.5 The 'Northern' site (Site A) has been the subject of a 'Preliminary Geoenvironmental Assessment/'Phase 1' Desk Study' was undertaken by GRM Development Solutions (GRM) in 2013, followed by a 'Mineral Desk Study' undertaken by Wardell Armstrong in 2014, a Phase II Ground Investigation undertaken by GRM in 2013 and 2015, and a 'Geophysical Survey' undertaken by Bentham Geoconsulting in 2015, all on behalf of Harpur Homes Ltd. The findings of the previous desk study and ground investigation works are presented in the following reports:

- GRM Development Solutions Limited. "Land off Burlow Road, Harpur Hill, Buxton. Site Appraisal for Harpur Homes". Report No. GRM/P6222/DS.2A, August 2013.
- Wardell Armstrong LLP. "Mineral Desk Study at Buxton". Report No.ST14225/01, dated July 2014.
- GRM Development Solutions. *"Land off Burlow Road, Harpur Hill, Buxton. Site Appraisal for Harpur Homes"*. Report No. GRM/P6222/COMB.1A, dated August 2014.

- GRM Development Solutions Limited. "Burlow Road, Harpur Hill, Buxton. Phase II Site Appraisal for Harpur Homes". Report No. GRM/P6222/F.1, April 2015.
- Bentham Geoconsulting Limited. "Geophysical Survey to Attempt to Indicate Potential Limestone Dissolution" Report No. BGC715a, April 2015.

1.1.6 The findings of the GRM Desk Study, Wardell Armstrong Mineral Desk Study, and Bentham Geoconsulting Geophysical Survey, have been reviewed as part of this present study, and are discussed within Sections 3, 4 and 5 of this present report.

1.1.7 The ground investigation works undertaken by GRM in 2013 comprised the drilling of 5No. window sample boreholes, all of which were installed with gas/groundwater monitoring pipe and monitored on four weekly occasions. The GRM ground investigation work undertaken in 2015 comprised the excavation of 30No. trial pits and the drilling of 13No. window sample boreholes, with associated chemical and geotechnical laboratory testing and programme of ground gas monitoring. A summary of the findings of the previous ground investigation works is presented in Section 5 of this present report.

1.1.8 The primary aims of this 'supplementary' phase of investigation were to review the findings of the previous Desk Study and Ground Investigation works and to carry out further investigation works, principally in order to:

- Confirm ground conditions beneath the site to provide further recommendations with respect to foundations for proposed structures.
- Confirm the location of 'Quarry High Walls' inferred to the present within the northeast of the site on historical plans.
- Inspect possible locations of potential dissolution features identified by previous ground investigation and geophysical surveys in the northwest of the site.
- Undertake additional sampling and chemical and geotechnical analysis of topsoil materials and natural strata to further assess their potential for re-use within the proposed development.
- Undertake an assessment of the depth of rock strata to assist in the formulation of a site regrading scheme and to further assess the 'excavatability' of the rock strata with respect to the site regrade works and proposed foundation/service trenches.
- Undertake in-situ soakaway tests in the vicinity of proposed surface water drainage ponds.

1.1.9 The above 'supplementary' investigation works have therefore been designed to supplement, and be consolidated with, the findings of the previous investigations to confirm and identify salient geoenvironmental issues affecting the site to enable the client to obtain budget costs for the necessary site preparatory and remediation works.

1.2 The Proposed Development

1.2.1 Consideration is being given to the development of the site with 152No. 2-3 storey domestic dwellings, associated gardens, a 'Community Building', public open space, and adoptable roads and sewers.

1.2.2 A Barratt Homes Manchester 'Sketch Layout' plan (un-numbered) showing the proposed development, is presented in Appendix B.

1.3 Report Format and Limitations

1.3.1 All standard definitions, procedures and guidance are contained within Appendix A, which includes background, generic information on:

- Assessment of the site's environmental setting
- Ground investigation fieldwork (including techniques, in-situ testing and sampling)
- Geotechnical Testing
- Contamination Testing (including current guidance, notes about organics analyses, and WAC)
- Hazardous Gas (including potential sources and notes about current guidance)
- Soakaways

1.3.2 General notes and limitations relevant to all ALM geoenvironmental investigations are described in the Foreword and should be read in conjunction with this report. The text of the report draws specific attention to any modification to these procedures and to any other special techniques employed.

2 SITE DESCRIPTION

2.1 General

2.1.1 The site location is shown on Drawing No. 30156/A/1 in Appendix B to this report. Site details are summarised in Table 1 below.

Table 1
General Site Details

Detail	Remarks
Location	3 km south of Buxton town centre
NGR	SK 070 708 (OS Grid Reference Centre = 407040E, 370850N)
Approximate Area	6.17ha
Known services	An 11kV electricity cable enters the site off Heathfield Nook Road to the southeast and runs along the boundary with the adjacent playing field, before continuing northwest through the north of the site. A 400mm diameter ductile iron water main enters the southeast of the site from Heathfield Nook Road, crosses the southeast corner of the site before running parallel with the electricity cable and exiting the north of the site.

2.2 Site Features ad Surrounding Land

2.2.1 An ALM Engineer completed a walkover survey of the site on the 11th August 2017.

2.2.2 Existing salient site features are depicted on Drawing No. 30156/A/2 in Appendix B. Topographical survey information from a drawing previously been prepared by Survey Systems Limited in July 2013, is included on Drawing No. 30156/A/2.

2.2.3 A selection of photographs taken during the course of the site walkover survey is presented in Appendix D. The location/orientation of the photographs are shown on Drawing No.30156/A/3 in Appendix B.

2.2.4 The site exists as an irregular-shaped parcel of land covering an area of approximately 6.17ha and is located to the northeast of Burlow Road and to the northwest of Heathfield Nook Road in the area of Harpur Hill, Buxton. Access into the site is got via existing gateways off Heathfield Nook Road in the southeast (Photograph No.1), and off Burlow Road in the west (Photograph No.8).

2.2.5 The whole of the study site exists as an area of managed pasture that is currently used for the grazing of cattle and production of grass crop for silage.

2.2.6 A small area of tarmac hardstand enters the southeast of the site, from which a gravel trackway (Photograph No.1) runs up the eastern boundary of the site to the former quarry restoration area, located to the northeast of the site. Photograph No.4 shows the types of material currently being deposited in the quarry restoration area, which appear to be inert soils and gravel/rubble.

2.2.7 No structures are present on site other than dry stone walls which line the northwest, west, and southern boundaries, and extend into the central part of the site.

2.2.8 The northern and northeast boundaries of the site are not marked by any surface features.

2.2.9 Ground levels rise gently from an elevation of 340.5mAOD in the southeast to an elevation of 365mAOD in the northwest across the site, becoming moderately steep in the northwest.

2.2.10 Ground levels are broadly continuous with surrounding land, with the exception of a railway embankment to the southeast, which rise approximately 5m on steep slopes, and in the west where ground levels rise approximately 3-4m on steep slopes within the site, from Burlow Road. The adjacent playing fields to the south are relatively flat, rising from approximately 344mAOD to 348mAOD, with some evidence of original ground levels being cut in the north of the playing fields, to provide a more level surface.

2.2.11 The study site is located on the southern margins of the village of Harpur Hill. Residential houses are present to the north of the site, and to the south beyond Heathfield Nook Road and a playing field. An abattoir and farm buildings are present to the southwest of the site, beyond Burlow Road. Land formerly occupied by the Buxton Sports Centre (University of Derby) is present immediately to the northwest of the site, however, former buildings have been demolished and the site is understood to be under consideration for residential redevelopment.

2.2.12 Land to the north and northwest of the site is in the same agricultural/pasture usage as the study site. Land to the east is occupied by an active mineral railway, which passes the site atop of an embankment, and serves the nearby Hillhead and Buxton Limestone Quarries that are present ca. 1km and 2.6km to the south and southeast of the site respectively.

Table 2
Summary Site Details

Feature	Remarks
Current Access	Off Burlow Road and Heathfield Nook Road.
Topography	Sloping site. Ground levels at ca. 340.5mAOD in the southeast of the site rising to 365mAOD to the northwest with ground level rising more steeply in the northwest.
Approximate areas	100m^2 tarmac. 600m^2 gravel surface. 61,000m^2 grassland.
Nature of boundaries	Northwest, west, south and southwest – dry stone walls. North and northeast – no physical boundary.
Surrounding land uses	North and south – Residential housing. Northeast – Open grassland / pasture and an infilled former quarry (quarry restoration). East – Mineral railway. West – Abattoir and Farm buildings.

2.3 Site Operations

2.3.1 The study site is currently used for the grazing of livestock and the production of a grass crop for silage. The eastern boundary of the site is used for access to an ongoing quarry restoration located immediately to the northeast of the site.

2.4 Japanese Knotweed

2.4.1 During the site walkover, we did not notice the presence of any Japanese Knotweed. However, it should be noted that we are not qualified ecologists and as such cannot guarantee the absence of Knotweed or other invasive vegetation.

3 SITE HISTORY

3.1.1 In order to investigate the development history and previous land uses at the site and immediate surrounding land, site centred extracts from Ordnance Survey (OS) maps dating back to 1879 have been examined. The historical OS map extracts are presented in Appendix E to this report.

3.1.2 Table 3 below provides a summary of the salient points relating to the history of the site with respect to the proposed end use. It is not the intention of this report to describe in detail all the changes that have occurred on or adjacent to the site. Significant former uses/operations are highlighted in bold text for ease of reference.

Table 3
Site History

Date(s)	Site	Surrounding Land
1879/1883	The site is shown to be in agricultural use. Field boundary are shown to have been present aligned NE-SW and NW-SE through the eastern part of the site. A small circular **pond** is shown to be present in western central part of the site.	Burlow Road and Heathfield Nook Road are both shown to have been present at this time. Small **'Old Quarry'** features are shown approximately 80m to the northeast and northwest of the site, and a rock escarpment is indicated immediately to the northwest of the site. Buildings (possible farm buildings) noted as 'Haslin House' are shown approximately 75m to the southwest of the site, and residential dwellings are shown approximately 100m west of the site. A **Railway** connecting a number of **Quarries** and **Lime Works** to the west and south of the site, is shown approximately 150m west of the site. The **Harpur Hill Lime Works** and quarry complex are shown between 250m to 1km west of the site. A 'Roman Road' is shown running NW-SE parallel with Ashbourne Road, approximately 240m to the east.
1899	No significant changes.	The L&NWR Buxton & High Peak **Railway Line** is now shown to pass immediately to the east of the site.
1922/1924	An elongate **earth embankment** is shown to enter the east of the site, which is connected to new/expanded quarrying activity to the northeast (Burlow Works – Lime), by a short rail line.	Quarrying activity is shown between 20m to 150m northeast of the site, with buildings and railway lines associated with the '**Burlow Works (Lime)**' also shown in this area. Land immediately to the south of the site is shown as '**Allotment Gardens'**. Additional residential properties are shown along Burlow Road immediately to the southwest, and approximately 75m west of the site.
1938	**Quarrying** associated with the Burlow Works, has extended into the northeast of the site by approximately 25m. **Earth embankments / spoil heaps**, have expanded to cover central eastern parts of the site. Little change is shown within the site which is still shown to be in agricultural use.	The Burlow Works to the northeast is now noted as 'disused'. Development of **residential houses** is shown approximately 30m east of the site, beyond the railway embankment, and 100m to the south of the site off Burlow Road and the new 'Dolby Lane'.
1955	No significant changes.	**Hillhead Quarry (and tarmacadam works)** is shown 900m to the south of the site.
1967	A small circular pond in the western central part of the site is no longer shown.	Buildings associated with the '**High Peak College of Further Education**' are shown immediately to the northwest of the site. Significant residential development is also shown around the new college, within 500m northwest of the site. An elongate building beyond Burlow Road immediately to the southwest of the site, is now shown as an '**Abattoir**'.

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Date(s)	Site	Surrounding Land
1973 - 1993	The quarry high wall is still shown extending into the east of the site, although the former quarry appears to have become **infilled** to some extent. Earth embankments / spoil heaps are no longer shown in the east of the site.	Rail lines associated with the former quarry are no longer shown.
1999	An aerial photograph dated 1999 show the former quarry to be infilled.	No significant changes.
Present	No significant changes.	Buildings associated with the 'High Peak College of Further Education' to the northwest, are no longer shown.

3.1.3 In summary, the vast majority of the site has remained in agricultural use since before the late 19th Century. Quarrying associated with the Burlow Works (Lime) is shown to extend a short distance into the east of the site, between 1938 to 1999, after which, the former quarry is shown as infilled. Spoil (waste spoil / overburden) likely associated with the former quarry, is indicated to have been deposited in the east of the study site from 1922. The former quarry is shown as disused from 1938 onward, with spoil heaps no longer shown within the study site from 1973, and some evidence of infilling of the former quarry apparent on plans dated between 1938 to 1973.

3.1.4 Surrounding land has been dominated by agriculture, interspersed with limestone quarrying and lime works, with associated railway lines. Residential development has been sporadic and gradual since earliest plans dating from 1879, with development concentrated along Burlow Road and Heathfield Road, and later to the northwest of the site.

3.1.5 Drawing No.30156/A/4 in Appendix B presents a summary of significant historical features both within, and in close proximity to the site.

4 ENVIRONMENTAL SETTING

4.1 General

4.1.1 Notes describing how the site's environmental setting has been assessed are included in Appendix A to this report. Information from High Peak Borough Council, Derbyshire County Council, the Environment Agency and the British Geological Survey (in the form of an *'Envirocheck'* report from Landmark Information Group Ltd) are presented in Appendix F. This information summarised below.

4.2 Geology

4.2.1 The British Geological Survey (BGS) map (Sheet 111, 1:50,000 scale) shows that Drift strata are absent within the area of the site.

4.2.2 The BGS Geological Sheet for the area shows that the solid geology underlying the site comprises the Carboniferous Bee Low Limestone Formation. The Bee Low Limestone Formation generally comprises thickly bedded pale grey, pale brownish grey to grey, fine to medium-grained biosparitic limestone. A weathered profile of clay with limestone gravel/cobbles is anticipated to overlie the less weathered limestone strata. Outcrops of the Upper Miller's Dale Lava (a basalt) are shown to the north of the site, whilst outcrops of the Lower Millers Dale Lava are shown across the valley to the south.

4.2.3 Aitkenhead *et. al.* [1] indicate that the stratigraphic thickness of the Bee Low Limestones are generally in excess of 200m in the vicinity of the site and are underlain by the Woo Dale Limestone series comprising dark grey limestone and dolomite horizons.

4.2.4 The presence of limestone strata beneath the site may suggest a potential risk from karstic features such as sinkholes and caves. However, neither the geological information nor the historic mapping indicate the presence of such features on, or in the vicinity of, the site. The BGS consider there to be only a low risk of ground dissolution related stability hazards being present in this area.

BGS Borehole Records

4.2.5 No borehole records held by the BGS are available within the vicinity of the site. However, a log of the nearby Hillhead Quarry (ca. 700m to the south) is available which shows that the Bee Low Limestone extends to a depth of in excess of 133m and locally possesses clay partings.

4.3 Hydrogeology

4.3.1 The Environment Agency classifies the Bee Low Limestone as a Principal Aquifer. The Miller's Dale Lava strata are classified as a Secondary B Aquifer. The Environment Agency's 1:100,000 Groundwater Vulnerability Map (Sheet 17) indicates that the bedrock is overlain by soils of intermediate leaching potential.

4.3.2 The natural aquifer properties of the area are dominated by the following:

- Structure – Flow below the water table is generally along bedding planes particularly in areas of shallow dip.
- Vertical Discontinuities – Groundwater flow along joints, faults and mineral veins. These are likely to be important for the vertical movement of groundwater, but less so for horizontal flows, unless they form a low angle with the hydraulic gradient.

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[1] Aitkenhead, N, Chisholm, J I and Stevenson, I P (1985) *"Geology of the Country Around Buxton, Leek and Bakewell"*. Memoir of the BGS, Sheet 111.

- Lateral Discontinuities – Bedding planes form the main route for lateral flow within the aquifer.
- Lithology – Whilst the above factors are considered important for groundwater movement within the aquifer, intergranular flow also plays a significant part.

4.3.3 Little research has been carried out on the Carboniferous Limestone Aquifer in the Peak District Region due to the unpredictable presence or absence of local fractures. However, in general, transmissivities are generally less than $60m^2$/day (mean approximately $10m^2$/day).

4.3.4 The limestone aquifer is known to contribute significantly to flow within local rivers as both identifiable discrete springs and direct discharge to river channels are common, with the direction of groundwater flow typically orientated towards river valleys. Due to the lack of superficial deposits overlying the limestone, direct recharge of the aquifer is considered to be significant.

4.3.5 The site is indicated to be located within a Groundwater Source Protection Zone (Inner Protection Zone I), which is understood to relate to the potable (bottled) water abstraction held by Buxton Water (Nestle Waters UK Limited) which permits the abstraction of $750m^3$/day of groundwater from multiple points within approximately 3km to the north of the site.

4.3.6 Thermal spring groundwater is also used for supplying baths, hydrotherapy pools and a public fountain. This catchment area is derived from theoretical groundwater flow paths and recharge rates to support the mineral water spring. It is understood that the source of the spring is from deep 'old' water mixing with 'younger' shallow water within shallower limestone aquifers which both outcrop and subcrop the study site.

4.3.7 The nearest permitted groundwater borehole abstraction to the site is located ca. 88m to the southwest of the site which is held by F Redfern & Sons for general washing and process waters in connection with their slaughtering activities at the Haslin Abattoir ($40m^3$/day).

4.3.8 Hockenhull Enterprises (Antigua) Ltd hold a permit for the abstraction of $125m^3$/day of groundwater for 'Water Bottling / General Use / Process Water' ca. 971m to the north of the site.

4.3.9 Seven Trent Water Ltd hold a license to abstract groundwater for potable water supply from an abstraction located approximately 1.9km west of the site.

4.3.10 According to the '*Envirocheck*' Report (Appendix F) the site is located in an area where there is only limited potential for groundwater flooding to occur.

4.3.11 A review of topographic maps and aerial imagery suggests the absence of any water bodies within nearby quarry areas, which would suggest that groundwater is located at considerable depth beneath the site.

4.4 Hydrology

4.4.1 The nearest surface water course is an unnamed tributary of the River Wye which flows in northerly direction ca. 713m to the northwest of the site and which has a confluence with the easterly flowing River Wye approximately 2km to the north of the site. The nearest surface water feature is a small water storage pond located ca. 260m to the west of the site which is understood to be used for livestock watering.

4.4.2 The Environment Agency website indicates that the site is not located within a river floodplain that would be prone to 1:100 and 1:1000 year flood events. However, the south-eastern margins of the site are indicatively shown in Appendix F to be prone to medium (100 year recurrence interval) and low (1000 year recurrence interval) risk of flooding by surface waters.

4.4.3 There are no active discharge consents relating to the study site. The nearest discharge consent relates to a sewerage emergency discharge to underground strata (probably held by Seven Trent Water Ltd), located approximately 211m south of the site (Harpur Hill pumping station).

4.4.4 According to the *Envirocheck* report in Appendix F there have been no recorded pollution incidents to controlled waters with respect to the site.

4.5 Radon

4.5.1 According to Building Research Establishment Report BR 211 (2015), the site is located in an area that would require **Full** Radon gas protection measures for new buildings.

4.6 Coal Mining / Quarrying

4.6.1 The site is not located in an area that has historically been mined for coal.

4.6.2 Historical Ordnance Survey maps (Appendix E) and the *Envirocheck* Report presented in Appendix F indicate the presence of a number of quarries within, and within the vicinity of the site, which have been worked for limestone.

4.6.3 The nearest quarry to the site is the former Burlow Works, which is located immediately to the northeast of the site, and extends approximately 25m into the northwest of the site. A small 'Old Quarry' is first noted approximately 80m to the northeast of the site, on earliest plans dating from 1879. By 1922, the quarry has expanded and is noted as the 'Burlow Works (Lime)', and by 1938, the quarry is noted as disused and covers its maximum extent, extending approximately 25m into the northeast of the site. This former quarry has since been infilled/restored (see Section 4.7 below).

4.6.4 Other small quarries are located sporadically around the local area, within 1km of the site, however, large scale quarrying activity has historically taken place at Harpur Hill ca. 250m to the west of the site and historical and current quarrying activity takes place at Hillhead Quarry ca. 1km to the south.

4.7 Landfills

4.7.1 The *Envirocheck* report presented in Appendix F, indicates the presence of a former landfill, which is noted to cover the whole of the east of the site and extend approximately 300m to the northeast. This historical landfill site (known as the 'Burlow Works') located off Heathfield Nook Road, first received wastes in 1970 that were used to restore a former limestone quarry and associated lime works. The site was operated by Mr W H Wright of Haslin House Farm, Harpur Hill.

4.7.2 No details of the types of wastes deposited within the former landfill are presented on the Environment Agency website or contained within the *Envirocheck* report. However, the present owner of the study site, Mr William Wright (the son of the former landfill operator), has verbally indicated that only inert wastes were deposited into a quarry void which was in the order of 10-12m deep. These materials have largely comprised clay soils and, in more recent years, comprised ca. 100,000 tonnes of crushed basalt derived from the construction of a nearby Morrison's supermarket. The former landfill has since substantially been restored to agricultural (pasture) land. However, Mr Wright has received approvals to grant extension to the original planning permission to complete the restoration of the Burlow Works site by means of imported soils and these works are currently ongoing (Derbyshire County Council Planning Permission No. CW1/0105/176).

4.7.3 Five other areas of 'potentially infilled land' are indicatively shown in the *Envirocheck* report presented in Appendix F, within 1km of the site, in connection with former areas of quarrying activity, although no details are known as to the nature (if any) of any fill materials. The nearest of these areas of potentially infilled land is located approximately 150m west of the site.

4.8 Other Issues

4.8.1 The study site is not located within the Peak District National Park, the boundary of which is present ca. 350m to the east.

4.8.2 There are no pollution incidents to controlled waters recorded at the site.

4.8.3 F Redfern and Sons Ltd operate an abattoir 36m to the west of the study site. The Haslin Abattoir is operated under an Integrated Pollution Prevention and Control Permit for 6.8 A(1) (B) activities involving the slaughter of animals >50t/day.

4.8.4 R Mycock and Sons Ltd located 101m to the southwest of the site hold a Local Authority Pollution Prevention and Control Permit for the 'blending, packing, loading and use of bulk cement'.

4.8.5 There are two active Integrated Pollution Prevention and Control (IPPC) permits held at locations within 1km of the site. One relates to the production of Organic Chemicals / Surface Active Agents (Detergents) and is located approximately 645m north of the site. The second relates to processes undertaken for producing/refining metals, and is located approximately 765m north of the site.

4.8.6 A Control of Major Accident Hazards (COMAH) site is located 840m to the west of the site. This site is operated by Christian Salveson Plc at the Buxton Industrial Park, Harpur Hill and is a 'Lower Tier' COMAH registration.

4.8.7 There are no reported fuel storage sites within 500m of the site.

5 PREVIOUS INVESTIGATION FINDINGS

5.1 General

5.1.1 As noted in Section 1.1.5, the site has been the subject of a number of previous geoenvironmental assessments/ground investigations between 2013 and 2015. The findings of the previous ground investigation are presented in the following report:

- GRM Development Solutions Limited. "Land off Burlow Road, Harpur Hill, Buxton. Site Appraisal for Harpur Homes". Report No. GRM/P6222/DS.2A, August 2013.
- Wardell Armstrong LLP. "Mineral Desk Study at Buxton". Report No.ST14225/01, dated July 2014.
- GRM Development Solutions. *"Land off Burlow Road, Harpur Hill, Buxton. Site Appraisal for Harpur Homes"*. Report No. GRM/P6222/COMB.1A, dated August 2014.
- GRM Development Solutions Limited. "Burlow Road, Harpur Hill, Buxton. Phase II Site Appraisal for Harpur Homes". Report No. GRM/P6222/F.1, April 2015.
- Bentham Geoconsulting Limited. "Geophysical Survey to Attempt to Indicate Potential Limestone Dissolution" Report No. BGC715a, April 2015.

5.1.2 Information relating to the historical development of the site and the site's environmental setting, has been reviewed and presented in Sections 3 and Section 4 above.

5.1.3 The following sub-sections present a summary of the previous investigation findings.

5.2 Mineral Desk Study (Wardell Armstrong – 2014)

5.2.1 The Mineral Desk Study undertaken by Wardell Armstrong LLP in 2014, on behalf of Harpur Homes Ltd, whom were seeking planning permission for the residential development of the site. The study was commissioned to address a consultation response from Derbyshire County Council to High Peak Council regarding the viability and practicality of mineral abstraction from the site prior to any development taking place.

5.2.2 The study concluded that mineral abstraction prior to development of the site would not be practical or environmentally acceptable due to the nearby presence of existing residential development, and the location of the site within a Groundwater Source Protection Zone 1.

5.3 GRM Ground Investigation (2013 & 2015)

5.3.1 Fieldwork supervised by GRM in 2013 and 2015, comprised the exploratory holes listed below in Table 4.

Table 4
Scope of Ground Investigation Works
Undertaken by GRM Development Solutions (2013-2015)

Technique	Exploratory holes	Final depth(s)	Remarks
Window Sample Boreholes (2013)	WS01 – WS05	0.5m – 4.0m	Gas/groundwater monitoring pipe installed in WS01 – WS05.
Trial pitting (machine dug) (2015)	TP01 – TP30	0.55 – 3.2m	Hand Vane (shear) tests conducted in cohesive strata.
Window Sample Boreholes (2015)	WS06 – WS13	1.2m – 3.0m	Gas/groundwater monitoring pipe installed in all 8No. boreholes.

5.3.2 The exploratory hole logs relating to the GRM investigations are presented in Appendix G to this Report.

5.3.3 The locations of the exploratory holes established during the GRM investigations are included on Drawing No. 30156/A/5 presented in Appendix B.

Ground Conditions

5.3.4 Made ground deposits were not observed to be widespread during the GRM investigation, and were only encountered in the southeast of the site, within and adjacent to the former quarry area (WS01, WS03, WS04, TP23, TP24 and TP30), and in a single isolated area in the northwest of the site (TP28).

5.3.5 WS01, WS03 and TP25A were positioned within the former quarry, with WS01 located at the northern end of the former quarry, well outside the study site, and TP25A also located outside the study site. WS01 only penetrated to a depth of 1.0m, encountering reworked orange brown clay strata with limestone gravel. However, WS03 penetrated to a depth of 4.0m and encountered reworked orange brown clays with limestone gravel, becoming grey brown with brick/slate below 0.55m, and containing organic material below 1.05m, before encountering a 150mm thick peat horizon at 1.9m. Soft grey brown clays with pocket of peat continued to a depth in excess of 4.0m within WS03. Brown mottled grey clayey sands with ash/clinker, brick, concrete, wood, plastic and rubber, were reported to a depth in excess of 1.55m in TP25A.

5.3.6 WS04, TP24 and TP30 all encountered reworked topsoil over reworked clays to a maximum depth of 0.5m, overlying natural strata, in the southeast of the site.

5.3.7 Ash/clinker made ground was encountered to a depth of 0.8m in TP23, and cohesive made ground containing brick, concrete, slate, glass and rope, were encountered to a depth of 2.3m in TP28, in two isolated pockets of made ground. The GRM report suggested that materials in TP23 may have arisen from stockpiles of soils destined for infilling the quarry, whilst anecdotal evidence from the farmer, reported in the GRM report, indicated that soils were historically used to fill a potential sink hole in the vicinity of TP28.

5.3.8 Natural strata were encountered in all exploratory holes across the study site, with the exception of WS01, WS03 and TP25A, located in the former quarry, and TP28 (>2.3m).

5.3.9 Natural sandy, silty clayey TOPSOIL was encountered across the site to depths ranging between 0.05m to 0.45m, but generally between 0.2m to 0.3m thick.

5.3.10 The natural topsoil was reported to be underlain by weathered Bee Low Limestone strata noted as 'Head', or weathered Miller's Dale Lava Member, across the majority of the site, that were reported to consistently comprise orange brown, slightly sandy, silty to very silty CLAY with occasional, angular to sub-angular, fine to coarse gravel of limestone or volcanic tuff/basalt, depending on the parent rock. Occasional cobbles and boulders of limestone or volcanic tuff/basalt were also present. The shear strength of the weathered Bee Low Limestone/Miller's Dale Lava Member were recorded to be typically firm, but locally firm to stiff, or soft to firm.

5.3.11 Less weathered (intact) Bee Low Limestone strata were typically encountered at depths ranging between 0.3m to 2.55m, but more commonly 0.8m to 1.2m, and were recovered as strong to very strong, grey, thinly to medium bedded, fine-grained LIMESTONE. Slightly weathering along sub-horizontal bedding was noted with fractures often containing gravelly clay infill. GRM reported that the Bee Low Limestone was excavated as gravel, cobbles and boulders.

5.3.12 Less weathered rocks of the Miller's Dale Lava Member were recorded beneath the northwest of the site, at depths between 1.35m to 2.7m, and were generally recovered as moderately weak, brown mottled black, grey and/or purple, fractured volcanic tuff or amygdaloidal basalt.

5.3.13 No groundwater was recorded during the GRM ground investigations.

Possible Karst Features

5.3.14 Previous GRM studies have highlighted the possibility that the site may be underlain by Karst weathering features due to the possible dissolution of the Bee Low Limestone beneath the site. TP22 and TP28 of the GRM ground investigation of 2015, are suggested to have encountered evidence of potential Karst features.

5.3.15 TP22 located beyond the northern boundary of the site, is reported to have encountered collapse of clay strata into a void once the excavation reached a depth of 1.3m. Excavation in clay strata continued to a depth of 3.5m in an area where bedrock was generally encountered within 2m of the surface of the site.

5.3.16 TP28 was excavated in the northwest of the site, in an area indicated by the farmer to require periodic infill of a depression. Here, cohesive made ground with concrete, brick, slate, glass and rope, was encountered to a depth of 2.3m. A number of shallow depressions were also noted in the vicinity of TP28, which could indicate the presence of other similar features.

5.3.17 It is noted in the GRM Report No. GRM/P6222/F.1, that the possible Karst features were present along the boundary between the Miller's Dale Lava Formation and the underlying Bee Low Limestone, which suggest that these features are ancient 'palaeo-karst', which formed when the limestone was exposed, prior to the eruption of lavas over them. Reference to: 'Palaeokarst: A systematic and regional review', Pavel Bosal et al eds., 1989, Elsevier, made in the GRM Report, indicates that at some locations in the Peak District these features in the upper surface of the limestone were up to 30cm in diameter and 1m deep; however, "in a few localities there are pits up to 10m wide and deep, full of collapsed lava and limestone boulders".

5.3.18 The GRM Report considers that the area most at risk from palaeo-karst features is the area underlain by Miller's Dale Lava Member strata, along the boundary with underlying limestone. GRM recommend further investigation of this area of the site, probably comprising geophysical survey and intrusive ground investigation.

Soil Contamination

5.3.19 Visual evidence of contamination is reported in the GRM investigation as ash/clinker deposits in TP23 and TP25 (A&B). TP25A & TP25B are located outside the present study site.

5.3.20 A total of eight soil samples were submitted for laboratory chemical analysis as part of the GRM investigation of 2015.

5.3.21 Five samples of topsoil were tested for a range of chemical determinands including; toxic metals, speciated PAH, phenol, cyanide, sulphate and asbestos. Three samples of topsoil were submitted for analysis for pesticides. None of the samples of topsoil tested exhibited any elevated concentrations of contaminants above GRM's Tier 1 Assessment Criteria (TAC's).

5.3.22 One sample of 'Head' (completely weathered Bee Low Limestone) was tested for a range of chemical determinands including; toxic metals, speciated PAH, phenol, cyanide, sulphate and asbestos. The sample tested did not record any elevated concentrations of contaminants above GRM's Tier 1 Assessment Criteria (TAC's).

5.3.23 Two samples of made ground containing ash/clinker soils (TP23 @ 0.4m and TP25A @ 0.7m), were tested for a range of chemical determinands including; toxic metals, speciated PAH, phenol, cyanide, sulphate and asbestos. The sample of made ground from TP23 recorded elevated concentrations of arsenic, lead, benzo(a)pyrene and naphthalene above the GRM TAC's.

5.3.24 Further discussion with respect to the significance of these chemical test results is presented in Sections 9 & 10 of this report.

5.3.25 Groundwater was not encountered and, therefore, not tested for chemical contaminants as part of the GRM investigation.

Ground Gas

5.3.26 The GRM investigation of 2013 comprised the drilling of 5No. window sample boreholes, in and around the former quarry area within and outside the northeast of the site. Four of the window sample boreholes were installed with combined gas/groundwater monitoring pipe, and monitored on four weekly occasions in August 2013.

5.3.27 The GRM investigation of 2015 comprised the drilling of 8No. window sample boreholes across the site, all of which were installed with gas/groundwater monitoring pipe and monitored on two occasions over a two week period in March and April 2015.

5.3.28 Methane was recorded in WS03 during three of four monitoring visits, with a maximum recorded concentration of 1.4%.

5.3.29 Carbon dioxide was detected at concentrations typically less than 2% have been reported in monitoring wells across the site. However, concentrations in excess of 5% were reported in WS03 and WS04 on three occasions, with a maximum concentration of 15.0% recorded in WS03.

5.3.30 A single elevated gas flow rate of 27.9ltr/hr was reported in WS03 on one occasion. No other gas flows were reported.

5.3.31 In accordance with CIRIA C665, GRM calculated a worst case gas regime of Characteristic Situation 2 / AMBER 1 for methane, and Characteristic Situation 4 / RED for carbon dioxide. However, these worst case values were based on gas readings within the quarry and a single anomalous gas flow rate of 27.9ltr/hr, which GRM considered not to be typical or reasonable.

5.3.32 Discounting the anomalous gas flow rate and adopting a default flow rate of 0.1ltr/hr, GRM calculated a Characteristic Situation 2 / AMBER 1 gas regime for methane, and a Characteristic Situation 2 / AMBER 2 gas regime for carbon dioxide, with the latter considered suitable for proposed new low-rise housing at the site with respect to the ground gases detected and in view of the fact that the site is located in an area where full radon gas protection measures would be required for new buildings.

Geotechnical Testing and Assessment

5.3.33 Geotechnical testing undertaken by GRM comprised 7No. samples for Atterberg limit determination as well as pH and sulphate tests.

5.3.34 The weathered limestone strata (Head) was assessed to possess medium to high shrinkability potential.

5.3.35 Based on the recorded water soluble sulphate and pH levels in the soils below the site and assuming mobile groundwater conditions, in accordance with requirements of BRE Special Digest 1 (2005), 'Concrete in Aggressive Ground', GRM recommended that the Design Sulphate Class for buried concrete at the site should be assumed as DS-1 and the ACEC Class as AC-1.

5.3.36 Further discussion with respect to the significance of these test results is presented in Section 12 of this report.

5.3.37 With respect to proposed foundations, GRM concluded that the natural cohesive soils encountered (weathered Bee Low Limestone), overlying the rock strata, were generally unsuitable as a potential founding strata in their current condition. It was recommended that foundations throughout the site found directly onto the underlying Bee Low Limestone or Millers Dale Lava Member strata, which should possess nett allowable bearing pressure of in excess of 300kN/m^2 for conventional strip or trench footings.

In-Situ Soak-away Tests

5.3.38 In-situ soakaway tests undertaken in accordance with BRE Digest 365, were performed by GRM at six locations in selected Trial Pits, with two soak-away tests being performed in each rest pit. The soil infiltration rates calculated by GRM were as follows (see Table 5).

Table 5
Results of In Situ Soak-away Tests
Undertaken by GRM Development Solutions (2015)

Test Location	Test No.	Test Strata	Soil Infiltration Rate (m/sec)
TP02	1	0.8m/Limestone	2.1×10^{-4}
	2		1.5×10^{-4}
	3		6.7×10^{-4}
TP06	1	1.45m/Limestone	1.2×10^{-3}
	2		1.4×10^{-3}
	3		1.9×10^{-3}
TP10	1	2.55m/Limestone	7.6×10^{-4}
	2		5.6×10^{-4}
	3		6.3×10^{-4}
TP15	1	1.1m/Limestone	1.2×10^{-3}
	2		1.7×10^{-3}
	3		2.7×10^{-3}
TP19	1	0.8m/Limestone	7.1×10^{-4}
	2		1.2×10^{-4}
	3		1.2×10^{-4}
TP23	1	1.1m/Limestone	1.7×10^{-3}
	2		1.7×10^{-3}
	3		1.7×10^{-3}

5.3.39 GRM concluded that the Bee Low Limestone is potentially suitable for the disposal of surface water using soak-away drainage system, with fast infiltration rates driven by fracture flow evident within the limestone.

5.4 Geophysical Survey (Bentham Geoconsulting Ltd – 2015)

5.4.1 Bentham Geoconsulting Ltd were commissioned by GRM in April 2015, to undertake a geophysical survey in an attempt to locate sub-surface dissolution features beneath the northwest of the site.

5.4.2 The electromagnetic conductivity survey identified a moderately abrupt boundary between higher and lower conductivity ranges, running approximately NE-SW in the northwest of the site, which was interpreted to represent the boundary between the Bee Low Limestone Formation and the overlying Upper/Lower Miller's Dale Lava Member.

5.4.3 The potential lava/limestone boundary was not linear, but was interrupted by a series of 'low conductivity embayments'. It was noted that TP28 lay within one of these low conductivity embayments, and suggested that the embayments may represent areas where there is greater potential for dissolution activity. The embayments were highlighted as circles on Figure 2 of the Bentham Geoconsulting Report No. BGC715a, which also depict an area where surface depressions are visible.

5.4.4 Figure 2 from the Bentham Geoconsulting Report No. BGC715a, is represented in Appendix B for reference.

5.4.5 Further physical investigation of the areas highlighted on Figure 2, was recommended in the Bentham Geoconsulting Report No. BGC715a.

5.5 Comments on Previous Investigation Works and Recommendations

5.5.1 The overall scope of the 2013/2015 GRM ground investigations is considered suitable given the nature of the study site and the 'exploratory' nature of the investigation required to be carried out at that time. However, ALM consider that the following additional works will be required to be carried out to expand upon the findings of the GRM investigation:

- Undertake additional trial pitting across the proposed development area to confirm ground conditions and, in particular, the depth to competent rock head to inform potential foundation zoning.
- Undertake additional chemical testing on topsoil and natural strata to further assess the suitability of these materials for reuse on, or off site.
- Confirm the location of 'Quarry High Walls' inferred to the present within the northeast of the site on historical plans.
- Inspect possible locations of potential dissolution features identified by previous ground investigation and geophysical surveys in the northwest of the site.
- It is anticipated that given the existing topography of the site, regrading of site levels will be required prior to development. As such, the trial pits should also seek to ascertain the 'excavatability' of the upper solid strata and to obtain representative samples of the weathered (soil) horizons to ascertain their suitability for compaction/re-engineering beneath roads and house plots.
- Undertake additional in-situ soakaway tests in the area of the proposed surface water drainage ponds (shown on the un-numbered Barratt Homes 'Sketch Layout' Plan in Appendix B) to further determine the soil infiltration rate of the natural weathered and partially weathered limestone at this location to enable an appropriate SUDS drainage strategy to be designed. The existing soakaway tests performed by GRM suggests that the soil infiltration within the in-situ limestone rock is high and that soakaways would, at this stage, be considered viable, however, the infiltration rate at a particular location will primarily be controlled by the degree of fracturing in the limestone.

5.5.2 With respect to gas monitoring, the gas monitoring information provided for the site includes four visits to monitoring wells installed within and around the former infilled quarry feature in the northeast of the site (GRM, 2013), and two of six monitoring visits to monitoring wells installed in boreholes across the site (GRM, 2015).

5.5.3 The existing monitoring confirms expectations of the gas regime across the site, where elevated concentrations of methane and carbon dioxide have been encountered within the former quarry infill, but absent from monitoring wells located generally across the site, where no source of ground gas is evident. However, further installation of monitoring wells both within and in the immediate vicinity of the identified gas source (former infilled quarry) in the northeast of the site is recommended.

6 SUPPLEMENTARY GROUND INVESTIGATION DESIGN

6.1 Anticipated Ground Conditions & Potential Issues

6.1.1 Based on the data reviewed in Sections 3, 4 and 5, anticipated ground conditions are expected to comprise:-

Table 6
Anticipated Ground Conditions

Anticipated Condition	Remarks
Made Ground	Deep made ground (circa 12m) within the former infilled quarry, possibly comprising clays with limestone, concrete, brick, clinker, glass, wood, plastic and organic deposits. Shallow made ground comprising reworked topsoil and clays previously identified in the vicinity of the former quarry (possible quarry overburden). Localised shallow made ground comprising ash/clinker in the southeast of the site (TP23). Cohesive made ground used as infill to possible dissolution feature (TP28).
Natural Soils	Natural topsoil anticipated to be present across the site. Drift strata previously observed to be absent at the site. Weathered Limestone or Millers Dale Lava strata (sandy silty clay) anticipated to be present across the whole site.
Bedrock	Bee Low Limestone and Miller's Dale Lava previously observed to be present at shallow (typically 0.8-1.2m) depth.
Mineworkings/ Quarry Workings	The site is not located in an area that has previously been mined for coal. A moderately sized quarry feature was present immediately to the northeast of the site, which is noted on historical plans to have entered a short distance into the northeast of the study site.
Groundwater	Anticipated to be present at considerable depth beneath the site.

6.1.2 Based on the data above and that in Sections 2 and 3, potential ground-related issues associated with this site are likely to include:

Table 7
Anticipated Ground Related Issues

Type of Issue	Specific Issue	Remarks
Potential on-site contamination sources	1. Former infilled quarry. 2. Made Ground. 3. Ground Gas	1. Made ground comprising clay with limestone, concrete, brick, clinker, slate and organic material (circa 12m deep), potentially containing elevated concentrations of metals, PAH, TPH, sulphates, asbestos 2. Located in the vicinity of the former quarry and in isolated areas of the site (TP23 & TP28). 3. Ground gas, typically methane and carbon dioxide, may be being generated in fill materials within the former infilled quarry beneath the northeast of the site.
Potential off-site contamination sources	1. Landfill (Burlow Works Landfill) 2. Abattoir. 3. Ground Gas	1. Located immediately to the northeast, containing generally inert soil/rock wastes. Potential for significant gas generation considered to be low to moderate. 2. Located ca. 50m to the west. Operations controlled by an IPPC permit. Risks associated with any below ground mobile contamination considered to be low. 3. Ground gas, typically methane and carbon dioxide, may be being generated in fill materials within the former infilled quarry to the northeast of the site, which may have the potential to migrate into the study site.

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Type of Issue	Specific Issue	Remarks
Potential geotechnical hazards	1. Infilled pits/quarry workings 2. Dissolution hollows / sink holes 3. Deep Made Ground 4. Shallow rock 5. Sloping ground	1. Former quarry feature noted to extend into the site on historical plans. Quarry has now been infilled, with depths of 12m of fill being reported within the former quarry. Development across former quarry high walls will likely encountered differential settlement. 2. Potential dissolution features recorded in GRM TP22 and TP28. Further dissolution features possibly present along the limestone/lava boundary in the northwest of the site. 3. Present within the former infilled quarry (circa 12m) and possible dissolution feature in TP28, and possibly present within other potential dissolution features. 4. Rockhead identified during the GRM investigation to be present at shallow (ca. 0.8-1.0m) depth. Possible requirement to use hydraulic pointed tools and overbreak in trench excavations within limestone. Possible ripping required if site regrade levels conflict with rockhead. 5. Existing site topography may necessitate site regrading works and/or the use of retaining walls, particularly in the northwest of the site.
Other potential constraints	1. 11kv electricity cable and water main passing from SE-NW through the site.	1. Approximate locations shown on Drawing No. 30156/A/2 in Appendix B. Diversion of water main and electricity cable may be required or development layout may require incorporation of easements.

6.2 Conceptual Site Model

6.2.1 A Conceptual Site Model (CSM) is graphically presented as Drawing No. 30156/A/5 in Appendix B. The CSM has been prepared after consideration of all the data presented in Sections 2 to 6.1 inclusive, of this report. Potential pollutant linkages are shown on the conceptual site model.

6.2.2 The site currently exists as a field used for the grazing of livestock or growing of grass crop for silage. Historical maps indicate that the site has remained in similar agricultural use since the mid 19^{th} Century and the likelihood of any significant contamination arising from such activities is considered to be very low.

6.2.3 Historical maps of the site show that quarrying has taken place in the surrounding area on a small scale prior to the late 19^{th} Century, with quarrying of limestone shown to have expanded to the northwest of the site (Former Burlow Works) by 1922, and some deposition of quarry materials evident on the 1922 map. By 1938, quarrying activity extended a short distance into the northwest of the site. Previous investigations suggest the presence of up to 12m of fill within the former quarry.

6.2.4 Ground investigations undertaken by GRM in 2013 and 2015 also encountered localised made ground in the southeast of the site (TP23) and the northwest of the site (TP28), which are thought to be associated with either stockpiling of quarry infill materials prior to deposition in the former quarry, and infill of a potential sink hole feature, respectively.

6.2.5 Chemical analysis of selected soils during the GRM ground investigation of 2015, suggested the suitability of topsoil and subsoil for re-use within a proposed residential development. However, only a nominal number of samples were scheduled for laboratory chemical analysis. The chemical testing also highlighted elevated concentrations of arsenic, lead, benzo(a)pyrene and naphthalene in ash/clinker made ground encountered in TP23. An elevated concentration of benzo(a)pyrene was recorded in one sample of quarry infill (TP25A).

6.2.6 The development proposals comprise residential properties with areas of hard standing (e.g. car parking), domestic gardens and areas of soft landscaping/public open space. The primary human health receptors are end users of the completed development and construction workers. The primary pathways of concern include dermal contact with contaminated soil and soil dust, the ingestion of contaminated soil and soil dust, ingestion of home grown produce that have taken up the contamination, indoor and outdoor inhalation of ground gas and soil vapours, and migration of contamination into water supply pipes.

6.2.7 For controlled waters, the primary receptor for the site is the underlying Principal Aquifer (Bee Low Limestone Formation). The primary pathways of concern are leaching of contaminants and vertical migration to the groundwater. Although groundwater is anticipated to be present at significant depth, the presence of fractures within the shallow rock could lead to relatively rapid transmission of mobile and leachable contaminants within the subsurface.

6.2.8 For construction materials, the primary receptors are water pipes and buried concrete. The primary pathways of concern are the migration of contamination leading to degradation of pipe materials and sulphate and/or acid attack on buried concrete.

6.3 Ground Investigation Design & Strategy

6.3.1 The Conceptual Site Model has been used as a basis for design of an appropriate ground investigation, the scope of which is summarised below.

Table 8
Proposed Supplementary Ground Investigation Strategy

Exploratory Holes	Purpose
Trial Pits (Machine Excavated)	To determine and confirm the general nature of soils underlying the site, including the: • Nature, distribution and thickness of made ground • Nature, degree and extent of contamination • Proportion of any undesirable elements e.g. biodegradable matter, foundations etc. • Suitability of the ground for founding structures and highways • The depth to and nature of rockhead
Trial Pits (Machine Excavated)	• To determine the location of former quarry 'high walls' in order to assist with any necessary adjustments to the development layout. • To investigate potential dissolution features highlighted by the Bentham Geoconsulting Ltd Report No.BGC715a, and encountered in TP22 and TP28 of the GRM ground investigation of 2015.
Trial Pits (Machine Excavated	To enable the performing of in situ soakaway tests within the area of a proposed surface water drainage pond/soakaway chamber to determine/confirm whether soakaways could be utilised for surface water drainage at this location.
Windowless Sample Boreholes	To allow the installation of combined gas/goundwater monitoring wells within and in the immediate vicinity of the former quarry, where it enters the northeast of the site.

6.3.2 Proposed exploratory hole locations will be selected to provide a representative view of the strata beneath the site to expand upon, and supplement the findings of, the previous GRM investigations. A nominal 50m grid spacing is proposed. Additional exploratory locations would be scheduled by the site engineer in light of the ground conditions actually encountered.

6.3.3 Selected trial pits will be specifically designed to target former historical site features that have been identified in Sections 3 and 6.1 above, particularly the possible locations of the former quarry 'high wall'.

6.3.4 An assessment of potential contaminants associated with the former uses has been undertaken and with reference to the previous GRM ground investigation findings. As a consequence of this assessment, anticipated potential contaminants, within soil include:

- pH, metals (As, Cd, Cr, Pb, Hg, Se, Cu, Ni and Zn).
- Leachable metals (selected samples).
- 2:1 water soluble sulphate, total sulphate (selected samples).
- Asbestos screen (selected samples).
- Total Organic Carbon/Soil Organic Matter (selected samples, particularly topsoil materials to enable assessment of the significance of PAH/TPH determinands)
- Speciated PAH.
- Speciated TPH and BTEX (selected samples) – these will be required by Severn Trent Water Ltd to enable pipeline risk assessments to be subsequently prepared.
- Speciated SVOC and VOCs (selected samples) – these will be required by Severn Trent Water to enable pipeline risk assessments to be subsequently prepared

6.3.5 The site is located in an area where full radon gas protection measures will be required for new buildings. However, the former infilled quarry is regarded as a potential source of ground gas, which should be characterised by the installation of gas monitoring wells and a programme of gas monitoring. Gas monitoring wells will be installed both within the former infilled quarry and immediately adjacent to the former quarry, in order to quantify any concentrations of ground gas, and gas flow, and determine the potential for any gas migration.

6.3.6 The potential gas risk from the former infilled quarry is initially considered Low. Therefore, the programme of gas monitoring is initially deigned to comprise 6No. monitoring visits over a three month period, in accordance with CIRIA C665, in order to supplement existing gas monitoring data.

7 FIELDWORK

7.1 Objectives

7.1.1 The original investigation strategy is outlined in Section 6.3 above.

7.2 Exploratory Hole Location Constraints

7.2.1 An 11kV electricity cable and a water main enter the southeast of the site and run NW-SE along the boundary with adjacent playing fields, before crossing the north of the site and exiting the northern boundary. The locations of the electricity and water mains are indicatively shown on Drawing No. 30156/A/2 in Appendix B. The presence of these underground utilities prevent the excavation of exploratory holes in these locations.

7.3 Scope of Works

7.3.1 Fieldwork was supervised by ALM between 29th-31st August 2017 and comprised the exploratory holes listed below.

Table 9
Scope of Ground Investigation Works

Technique	Exploratory Holes Nos.	Final depth(s)	Remarks
Trial pitting (machine dug)	TPA101 – TPA135	0.5m – 2.8m	Vane tests in cohesive soils.
Trial pitting (machine dug)	TPA201 – TPA209 (including TPA202A, TPA203A, and TP204A)	1.2m – 2.6m	Excavated to target possible dissolution features.
Trial pitting (machine dug)	TPA301 – TPA305	1.6m – 2.8m	Excavated to target former Quarry 'high walls'.
Windowless Sample Boreholes	WSA101 – WSA107	0.8m – 7.2m	Drilled within and around the former infilled Quarry.
Soakaway Tests	SAA1 and SAA2	1.5m – 1.6m	Soakaway tests carried out in accordance with BRE Digest 365 in the location of a proposed attenuation pond/soakaway chamber

7.3.2 Notes describing ground investigation techniques, in-situ testing and sampling are included in Appendix A to this report.

7.3.3 Exploratory hole logs are presented in Appendix H to this Report. These logs include details of the:

- Samples taken
- Descriptions of the soil strata, and any groundwater encountered.
- Results of the in-situ testing

7.3.4 The locations of the exploratory holes were set out by ALM and their respective OS coordinates established by means of a hand held GPS devise. The exploratory hole locations are shown on Drawing No. 30156/A/6 in Appendix B.

8 GROUND CONDITIONS

8.1 General

8.1.1 A complete record of strata encountered beneath the proposed development site is given on the various exploratory hole records, presented in Appendix H. However, a summary of the ground conditions encountered in the ALM exploratory holes is provided below.

8.2 Made Ground

8.2.1 Made ground was encountered in all five trial pits (TPA301 – TPA305) excavated within and around the edges of the former infilled quarry feature in the northeast of the site. Made ground was also encountered in TPA106, WSA101, WSA102, WSA104, WSA105 and WSA106, also excavated/drilled in this area of the site.

8.2.2 Made ground encountered in all six trial pit locations comprised reworked topsoil to depths between 0.1m to 0.15m, overlying reworked orange brown clays with occasional gravel and cobbles of limestone, to depths between 0.45m to 1.2m. Made ground encountered in TPA106 comprised reworked topsoil overlying reworked clays, to a depth of 0.6m. The made ground in TPA106 was found to overlay a horizon of relic topsoil. The reworked topsoil and clays are interpreted as replaced overburden from the former quarry, which has been replaced as part of the subsequent restoration of the quarry.

8.2.3 Dark grey organic sandy silty clay with much gravel and cobbles of limestone and brick, and occasional piece of wood and/or ceramic, was encountered beneath reworked topsoil and clays in all five trial pits (TPA301 – TPA305), and in two window sample boreholes (WSA101 & WSA102) located within and on the margins of the former quarry feature. These strata were encountered to a maximum depth in excess of 7.2m (WSA101) and are interpreted as quarry infill.

8.3 Obstructions

8.3.1 No relict foundations, floor slabs or other obstructions were encountered during the ALM ground investigation.

8.4 Natural Ground

8.4.1 Natural strata were encountered in the all of the ALM exploratory holes, with the exception of WSA101 and TPA305, which were terminated within quarry fill. Ground conditions were observed to be relatively uniform across the site and the strata observed comprised the following.

Topsoil

8.4.2 The natural topsoil typically comprised a dark brown clayey topsoil with rootlets. The natural topsoil was encountered to depths between 0.2m to 0.4m, but generally to a depth of 0.3m. Topsoil was generally slightly thinner on slopes in the northwest of the site, typically 0.2m thick.

Completely Weathered Bee Low Limestone & Millers Dale Lava

8.4.3 The majority of the trial pits encountered Completely Weathered Bee Low Limestone strata, which was present beneath topsoil across most of the site, with the exception of the northwest of the site, which was generally underlain by Completely Weathered Miller's Dale Lava Member strata.

8.4.4 Within the context of this report, 'Completely Weathered' strata are defined as:

> Rock has completely changed to a soil in which the original rock fabric is completely destroyed, or the original rock fabric may still be locally preserved and may contain lithorelicts.

8.4.5 Completely Weathered Bee Low Limestone was observed directly beneath the natural topsoil and typically comprised a soft, becoming firm, (friable) slightly sandy very silty CLAY with rare fine to coarse gravel of limestone.

8.4.6 The Completely Weathered Millers Dale Lava strata was observed to be similar to the Completely Weathered Bee Low Limestone, with the only noticeable difference being the inclusion of volcanic tuff / basalt lithorelics instead of limestone lithorelics.

8.4.7 The Completely Weathered Bee Low Limestone materials were recorded to depths between 0.4m-1.7mbgl (average 0.91mbgl), whilst the Completely Weathered Millers Dale Lava strata were recorded to depths between 0.0m to 2.8m (average 1.07m).

8.4.8 The undrained shear strength of this stratum was ascertained by means on a hand vane – the test results are presented on the respective trial pit logs in Appendix H. Hand vane tests were problematic due to the friable nature of the materials but gave undrained shear strength values ranging between 39kN/m^2 and 71kN/m^2 (56.6kN/m^2 average) in the Completely Weathered Bee Low Limestone, and values ranging between 44kN/m^2 and 158kN/m^2 (78kN/m^2 average) in the Completely Weathered Miller's Dale Lava.

8.4.9 Two shear values of 125kN/m^2 and 136kN/m^2 were obtained from a stiff yellow clay encountered just above Weathered Bee Low Limestone in TPA108 and TPA109 respectively. These two readings were not considered representative of the Completely Weathered Strata.

Moderately Weathered Bee Low Limestone

8.4.10 Moderately Weathered Bee Low Limestone Strata were present beneath most of the site, with the exception of the northwest of the site, which was generally underlain by Weathered Miller's Dale Lava Member strata.

8.4.11 Within the context of this report, 'Moderately Weathered' strata are defined as:

> Rock is discoloured; original rock fabric is preserved but discontinuities may be open and have discoloured surfaces with alteration penetrating inwards.

8.4.12 Moderately Weathered Bee Low Limestone Strata comprised strong to very strong pale grey fine grained thinly to medium bedded LIMESTONE. The sub-horizontal bedding surfaces were observed to be weathered and discontinuities were observed to be filled with soft brown clay.

8.4.13 This stratum was very hard to excavate and trial pits were required to terminate at the stratum surface that was recovered as angular cobbles and boulders (see Section 8.5).

8.4.14 The depth to the top of the Moderately Weathered Bee Low Limestone ranged between 0.4mbegl to 1.70mbegl, but was typically encountered at depths ranging between 0.8-1.2mbegl (average 0.91m).

Moderately Weathered Millers Dale Lava

8.4.15 Moderately Weathered Miller's Dale Lava Member strata were present beneath the northwest of the site, and typically comprised moderately weak purple brown mottled grey very sandy gravelly cobbley clay, with gravel and cobbles of volcanic tuff.

8.4.16 The Moderately Weathered Miller's Dale Lava Member strata was generally easy to excavate, with the rock degrading to angular gravel and cobbles along horizontal and vertical fractures.

8.4.17 The depth to the top of the Moderately Weathered Miller's Dale Lava strata ranged between 0.2mbegl to 2.80mbegl, but was typically encountered at depths ranging between 0.9-1.5mbegl (average 1.07m).

8.4.18 Drawing No. 30156/A/7 in Appendix B presents a summary of the depth/level to the Moderately Weathered Limestone and Lava rockhead encountered in both the GRM and ALM exploratory holes.

8.5 Excavatability of Solid Strata

8.5.1 All of the trial pits were excavated using a JCB 3CX excavator using a 600mm wide toothed bucket.

8.5.2 The Completely Weathered Bee Low Limestone and Completely Weathered Millers Dale Lava strata were excavated as a residual soil (slightly sandy very silty clay) and were easily excavated.

8.5.3 The change from Completely to Moderately Weathered Bee Low Limestone was noted to be very abrupt, with the Moderately Weathered Limestone strata (in-situ rock) proving very difficult to excavate. The trial pits were forced to be terminated ca. 0.2-0.5m into this stratum with the rock being excavated as angular cobbles and boulders. The degree to which the rock was able to be excavated was generally dependent on the presence of rock discontinuities aligned transverse to the direction of dig.

8.5.4 The change from Completely to Moderately Weathered Millers Dale Lava strata was noted to be less marked, with the rock strata being fairly easy to excavate.

8.5.5 Drawing No. 30156/A/8 in Appendix B presents a plot of the estimated compressive strength of the encountered moderately weathered limestone strata against the stratum discontinuity spacing to provide a general assessment of the 'excavatability' of the encountered rock strata based on the assessment method presented by Pettifer and Fookes (1994)[2].

8.5.6 The limestone was noted to be strong to very strong and was typically thinly to medium bedded. Excavation of the limestone would be expected to be problematic and would be categorised as 'hard-extremely hard ripping/hydraulic breaking'. As such, the use of pointed hydraulic breaker tools will be required to excavate into the limestone in trench excavations and ripping and breaking will be required in more open excavations.

8.5.7 The Miller's Dale Lava strata was generally noted as moderately weak and typically thinly bedded. Excavation of the Miller's Dale Lava is expected to be relatively easy, with the bedrock likely to be excavatable with a moderate sized backhoe excavator with toothed bucket.

8.6 Visual & Olfactory Evidence of Organic Contamination

8.6.1 None of the exploratory holes encountered any visual or olfactory evidence of any hydrocarbon (petroleum/solvent etc.) contamination.

8.7 Groundwater

8.7.1 No groundwater seepages were encountered in any of the exploratory holes.

8.8 Stability

8.8.1 The stability of trial pit excavations within was observed to be generally good. However, there was a tendency for cobbles and boulders loosened by excavation activity within the Moderately Weathered Bee Low Limestone to fall into the pits.

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[2] Pettifer G.S and P.G Fookes (1994) "A Revision of the Graphical Method for Assessing the Excavatability of Rock". Quat. Journal of Engineering Geology. 24. 145-164

9 CONTAMINATION (ANALYSIS)

9.1 General

9.1.1 Notes outlining current guidance with respect to the interpretation of analytical data are included in Appendix A to this report.

9.1.2 The study site has been, and has remained, agricultural use since the mid 19^{th} Century, with an adjacent limestone quarry extending a short distance (25m) into the site from prior to 1922 prior to becoming infilled after 1938.

9.1.3 A number of phases of ground investigation have encountered fill materials within the infilled quarry feature to depths in excess of 7.2m, which typically comprise grey organic clays with concrete, brick and limestone, with occasional pieces of wood and ceramic. Reworked topsoil and clay have also been identified in the southeast of the site, which are likely to represent stockpiled overburden from the former quarry, which have been re-profiled as part of restoration works. Localised areas of made ground have also been encountered in the southeast of the site, and as infill to a potential dissolution feature in the north west of the site.

9.1.4 The identified made ground have the potential to be contaminated. An assessment of potential contaminants and contamination sources associated with the former use of the site has been undertaken; see Sections 6.2 and 6.3 above.

9.2 Testing Scheduled

9.2.1 Based on the above assessment, an ALM Engineer submitted a test schedule (summarised in Table 10 below) to a UKAS accredited laboratory (Exova Jones Environmental, Deeside).

Table 10
Summary of Chemical Tests Scheduled

Type of Sample	No. of Samples	Determinands
Made Ground (Quarry Fill, Reworked Topsoil and Clay)	10	pH and total metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, zinc and water soluble boron)
	10	Speciated PAH
	10	Total organic carbon
	10	Asbestos (screen)
	3	Speciated TPH+BTEX
	3	Speciated VOC + SVOC (incl. PAH)
	5	Total and Water Soluble Sulphate
	6	Leachable pH and metals (arsenic, boron, cadmium, chromium, copper, lead, mercury, nickel, selenium and zinc)
Natural Topsoil	12	pH and total metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, zinc and water soluble boron)
	12	Speciated PAH
	6	Total organic carbon
	2	Asbestos (screen)
	1	Total and Water Soluble Sulphate

Continued….

…. Table 10 Continued

Type of Sample	No. of Samples	Determinands
Natural Strata (Completely Weathered Bee Low Limestone)	6	pH and total metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, zinc and water soluble boron)
	6	Speciated PAH & TOC
	8	Total and Water Soluble Sulphate
	2	Speciated VOC & SVOC (incl PAH)
	2	Speciated TPH+BTEX

9.2.2 Notes describing the various organics analyses are included in Appendix A to this report.

9.3 Laboratory Chemical Analysis Results

9.3.1 The soil contamination test results are summarised in Tables 11, 12 and 13 below.

9.3.2 It should be noted that the results of chemical tests previously obtained as part of the GRM 2015 investigation are included in Tables 11, 12 and 13.

9.3.3 Laboratory test certificates as received from the laboratory(ies) are presented in Appendices I(1) and I(2) to this report.

Soil Contamination Results

9.3.4 The samples are classified by comparison of parameters concentrations with the relevant current UK guidance threshold value for an end use including domestic gardens and any area where plants are to be grown.

9.3.5 Samples have initially been compared with available LQM/CIEH 'Suitable for Use Levels (S4UL's), for residential development with home grown produce, with the exception of boron, copper and zinc, which have been assessed with regard to phytotoxic concentrations, as outlined in BS3882:2007 & BS8601:2013 (copper, nickel and zinc) and ICRCL Guidance Note 59/83 (boron). The phytotoxic values for boron, copper and zinc are lower than their respective S4UL's.

9.3.6 Were no S4UL is available, consideration has been given to the most appropriate available guidance threshold.

Table 11 - Summary of Degree of Ground Contamination (Inorganics) at Site A, Burlow Road, Buxton.

Hole ID	Depth (m)	Material	Concentrations in mg/kg unless otherwise stated. Results are quoted to 1 decimal place if <10, and whole numbers if >10. Trigger Level Concentrations are Shown in Brackets and assume a **residential with gardens** end-use.											
			pH#	As (37)~	Cd (11)~	Cr (910)~	Pb (200)^	Hg (40)~	Se (250)~	B (3)*	Cu (200)♣ x	Ni (130)~	Zn (300)♣ x	Sol SO_4 (0.5 g/l) ◊
TPA-106	0.05	MG: Topsoil	7.56	8.2	3.2	87.6	38	<0.1	1	1.1	32	49.9	154	
TPA-305	0.05	MG: Topsoil	7.21	7.9	3.2	83.9	44	<0.1	2	1.4	33	47.4	155	
WSA-101	0.15	MG: Topsoil	7.96	7.8	3.3	80.3	37	<0.1	<1	0.6	25	43.2	128	
WSA-105	0.2	MG: Topsoil	7.71	16.7	2.6	93.3	102	0.2	2	1.4	37	34.6	194	
TPA-106	0.4	MG: Clay	7.93	6.3	0.4	98.3	25	<0.1	<1	0.3	23	45.7	83	
TPA-305	0.4	MG: Clay	8.13	8.5	3.2	91.3	42	<0.1	2	0.8	31	52.3	143	<0.0015
TPA-302	1.0	MG: Quarry	7.52	32.9	0.5	47.7	101	<0.1	5	1.3	96	19.1	51	0.0955
TPA-305	1.1	MG: Quarry	7.55	28.0	1.6	38.0	145	<0.1	3	1.3	108	40.5	163	0.1427
WSA-102	0.6	MG: Quarry	8.06	8.5	2.3	68.7	38	<0.1	1	0.4	27	52.1	120	0.0159
WSA-102	2.0	MG: Quarry	7.91	19.2	0.5	61.9	64	<0.1	<8	0.9	25	14.8	70	0.1063
TP25A	0.7	MG: Quarry	12.5	<10	3.2	23.7	129	<2.5	<8		41.6	33.6	178	0.250
TP23	0.4	MG: Ash/clinker	11.4	**103**	4.4	49.8	**525**	5.4	<8		**493**	77.6	159	**0.580**

Key		**Source of Guidance Trigger Level**	
bold	Parameter found to be in excess of trigger concentration	$	DEFRA and the EA Contaminated Land Exposure Assessment (CLEA)
	Parameter not tested for	~	LQM/CIEH Suitable for Use Level (S4UL) for residential with home grown produce
#	All pH results listed to confirm which soil guideline values are to be used in CLEA assessment	◊	BRE Special Digest 1, Concrete in aggressive ground (2005)
♣	Tier 1 Value is pH dependent	*	ICRCL Guidance Note 59/83, Second Edition (1987) – (Boron Phytotoxic only)
^	Provisional Category 4 Screening Value (Residential with consumption of home grown produce)	x	Based on phytotoxic risks as plants are the more sensitive receptor (Cu and Zn are pH dependent) - BS3882:2007 & BS8601:2013

Table 11 (cont.) - Summary of Degree of Ground Contamination (Inorganics) at Site A, Burlow Road, Buxton

Hole ID	Depth (m)	Material	Concentrations in mg/kg unless otherwise stated. Results are quoted to 1 decimal place if <10, and whole numbers if >10. Trigger Level Concentrations are Shown in Brackets and assume a **residential with gardens** end-use.											
			pH#	As (37)~	Cd (11)~	Cr (910)~	Pb (200)^	Hg (40)~	Se (250)~	B (3)*	Cu (200)♣ x	Ni (130)~	Zn (300)♣ x	Sol SO_4 (0.5 g/l) ◊
TPA-101	0.1	Topsoil	6.88	13.6	1.7	70.7	119	<0.1	2	1.7	36	29.2	178	
TPA-103	0.1	Topsoil	6.68	13.0	2.1	103.1	95	0.1	<1	1.8	32	37.9	159	
TPA-105	0.1	Topsoil	7.78	28.9	1.2	72.8	**207**	<0.1	1	0.8	105	52.0	157	
TPA-108	0.1	Topsoil	6.22	13.7	1.5	74.4	104	<0.1	2	1.0	31	31.5	135	
TPA-110	0.1	Topsoil	6.73	12.2	2.0	72.9	105	<0.1	2	1.0	27	34.8	145	
TPA-112	0.1	Topsoil	6.57	9.8	1.6	73.6	108	<0.1	2	1.1	32	38.7	138	
TPA-117	0.1	Topsoil	6.02	5.2	1.2	111.8	103	<0.1	1	0.8	38	85.6	124	
TPA-120	0.1	Topsoil	5.94	17.2	1.7	77.8	163	<0.1	<1	1.2	36	35.3	172	
TPA-124	0.1	Topsoil	6.01	11.7	1.6	132.1	111	0.2	3	1.3	43	65.9	186	0.0118
TPA-126	0.1	Topsoil	5.95	12.4	1.6	92.9	103	<0.1	2	1.3	39	48.4	170	
TPA-127	0.1	Topsoil	7.30	7.4	2.6	88.1	87	<0.1	1	0.9	43	75.9	197	
TPA-130	0.1	Topsoil	7.80	12.1	3.2	82.4	121	<0.1	2	1.6	35	48.8	200	
TP01	0.15	Topsoil	7.80	11.2	2.6	43.6	80.1	<2.5	<8		30.9	44.2	150	0.028
TP10	0.20	Topsoil	7.30	11.8	1.4	15.9	72.3	<2.5	<8		30.0	13.8	78.4	<0.010
TP13	0.10	Topsoil	7.0	10.2	1.4	21.7	77.7	<2.5	<8		19.2	18.3	95.7	0.024
TP14	0.10	Topsoil	10.5	13.3	1.7	27.4	159	<2.5	<8		28.7	22.6	109	0.053
TP16	0.10	Topsoil	10.8	<10	2.2	112	27	<2.5	<8		48.2	109	83	0.014

Key		Source of Guidance Trigger Level	
bold	Parameter found to be in excess of trigger concentration	$	DEFRA and the EA Contaminated Land Exposure Assessment (CLEA)
	Parameter not tested for	~	LQM/CIEH Suitable for Use Level (S4UL) for residential with home grown produce
#	All pH results listed to confirm which soil guideline values are to be used in CLEA assessment	◊	BRE Special Digest 1, Concrete in aggressive ground (2005)
♣	Tier 1 Value is pH dependent	*	ICRCL Guidance Note 59/83, Second Edition (1987) – (Boron Phytotoxic only)
^	Provisional Category 4 Screening Value (Residential with consumption of home grown produce)	x	Based on phytotoxic risks as plants are the more sensitive receptor (Cu and Zn are pH dependent) - BS3882:2007 & BS8601:2013

Table 11 (cont.) - Summary of Degree of Ground Contamination (Inorganics) at Site A, Burlow Road, Buxton

Hole ID	Depth (m)	Material	Concentrations in mg/kg unless otherwise stated. Results are quoted to 1 decimal place if <10, and whole numbers if >10. Trigger Level Concentrations are Shown in Brackets and assume a **residential with gardens** end-use.											
			pH#	As (37)~	Cd (11)~	Cr (910)~	Pb (200)^	Hg (40)~	Se (250)~	B (3)*	Cu (200)♣ x	Ni (130)~	Zn (300)♣ x	Sol SO_4 (0.5 g/l) ◊
TPA-101	0.5	Clay	7.66	8.3	1.3	58.4	26	<0.1	<1	0.6	22	50.9	198	0.0081
TPA-108	0.5	Clay	6.48	6.0	2.3	64.9	23	<0.1	1	0.3	34	85.4	110	0.0115
TPA-112	0.5	Clay	7.15	3.7	0.9	67.1	27	<0.1	1	0.3	27	76.5	116	0.0084
TPA-120	0.6	Clay	6.97	4.6	1.1	83.7	30	<0.1	<1	0.3	32	92.5	105	0.0118
TPA-125	1.5	Clay												<0.0015
TPA-126	1.5	Clay	6.93	<0.5	0.1	92.7	<5	<0.1	1	0.4	77	**300.4***	41	0.0153
TPA-127	0.6	Clay	7.38	<0.5	3.4	92.0	5	<0.1	<1	0.3	43	108.8	57	0.0063
TPA-127	1.6	Clay												0.0050
TP01	0.6	Clay	10.7											0.026
TP05	0.5	Clay	10.4											0.018
TP13	0.8	Clay	9.0											0.014
TP16	0.7	Clay	6.7											0.032
TP18	0.9	Clay	7.9											0.021
TP20	0.4	Clay	7.3											0.031
TP26	0.3	Clay	12.6	<10	3.3	30.2	21.7	<2.5	<8		21.5	45.6	78.1	0.022

Key	
bold	Parameter found to be in excess of trigger concentration
	Parameter not tested for
#	All pH results listed to confirm which soil guideline values are to be used in CLEA assessment
♣	Tier 1 Value is pH dependent
^	Provisional Category 4 Screening Value (Residential with consumption of home grown produce)

Source of Guidance Trigger Level	
$	DEFRA and the EA Contaminated Land Exposure Assessment (CLEA)
~	LQM/CIEH Suitable for Use Level (S4UL) for residential with home grown produce
◊	BRE Special Digest 1, Concrete in aggressive ground (2005)
*	ICRCL Guidance Note 59/83, Second Edition (1987) – (Boron Phytotoxic only)
x	Based on phytotoxic risks as plants are the more sensitive receptor (Cu and Zn are pH dependent) - BS3882:2007 & BS8601:2013

Table 12 - Summary of Leachable Contamination at Site A, Burlow Road, Buxton

Hole ID	Depth (m)	Material	Concentrations in μg/l unless otherwise stated. Results are quoted to 1 decimal place if <10, and whole numbers if >10. Trigger Level Concentrations are Shown in Brackets										
			pH	As	B	Cd	Cr	Cu	Pb	Hg	Ni	Zn	Se
			(6.5-9.5)*	(10)*	(1000)*	(5)*	(50)*	(2000)*	(10)*	(1)*	(20)*	(5,000)*	(10)*
TPA-106	0.4	MG: Clay	7.74	<2.5	<12	<0.5	<1.5	<7	<5	<1	<2	5	<3
TPA-305	0.4	MG: Clay	8.15	<2.5	<12	<0.5	<1.5	<7	<5	<1	<2	4	<3
TPA-302	1.0	MG: Quarry	7.78	<2.5	27	<0.5	<1.5	13	<5	<1	<2	18	<3
TPA-305	1.1	MG: Quarry	7.86	3.5	26	<0.5	<1.5	<7	<5	<1	<2	4	<3
WSA-102	0.6	MG: Quarry	8.10	<2.5	<12	<0.5	<1.5	<7	<5	<1	<2	4	<3
WSA-102	2.0	MG: Quarry	7.94	3.6	17	<0.5	<1.5	<7	<5	<1	<2	3	<3
TP25A	0.7	MG: Quarry	10.0	<2.5		<2.5	<2.5	3	<1	<1	<2.5	<1	<1
TP23	0.4	MG: Ash/clinker	8.3	<2.5		<2.5	<2.5	9	1	<1	<2.5	<1	<1
TP26	0.3	Clay	8.9	<2.5		<2.5	<2.5	1	<1	<1	<2.5	<1	<1

Hole ID	Depth (m)	Material	Concentrations in μg/l unless otherwise stated. Results are quoted to 1 decimal place if <10, and whole numbers if >10. Trigger Level Concentrations are Shown in Brackets								
			Phenol	Cyanide	Amm. N	Naphthalene	Benzo(a)pyrene				
			(0.5)*	(50)*	(0.5mg/l)*	(PAH = 0.1)*	(0.01)*				
TP23	0.4	MG: Ash/clinker	**2.3**	<0.5	7.2	**0.15**	<0.01				
TP25A	0.7	MG: Quarry	**3.3**	<0.5	1.0	0.04	<0.01				
TP26	0.3	Clay	**3.3**	<0.5	0.2	0.20	<0.01				

Key			
BOLD	Parameter in excess of trigger level concentration	*	UK Drinking Water Standard
		~	Environmental Quality Standard (EQS) for Freshwater

Table 13 - Summary of Degree of Ground Contamination (Organics) at Site A, Burlow Road, Buxton

Hole ID	Depth (m)	Material	Concentrations in mg/kg. Results are quoted to 1 decimal place if <10, and whole numbers if >10. Trigger Level Concentrations are shown in brackets and assume a **residential with gardens** end use											
			SOM	Benzene	Toluene	Ethyl Benzene	Xylenes			PAH		TPH - C_6 to C_{40}		
			%	(0.087) ~	(130) ~	(47) ~	(56) ~			Naphthalene	benzo(a) pyrene	GRO C_6 to C_{10}	DRO C_{10} to C_{21}	LRO C_{21} to C_{40}
										(2.3)~	(2.2)~	(0.087)~◇	(74)~	(1100)~
TPA-106	0.05	MG: Topsoil	3.82							<0.04	<0.04			
TPA-305	0.05	MG: Topsoil	5.66							<0.04	0.06			
WSA-101	0.15	MG: Topsoil	2.08							<0.04	<0.04			
WSA-105	0.2	MG: Topsoil	6.16							<0.04	0.20			
TPA-106	0.4	MG: Clay	1.43							<0.04	<0.04			
TPA-305	0.4	MG: Clay	2.84							<0.04	0.05			
TPA-302	1.0	MG: Quarry	7.74	<0.02	<0.03	<0.03	<0.05			<0.04	<0.04	<0.1	<7	67
TPA-305	1.1	MG: Quarry	NDP	<0.02	<0.03	<0.03	<0.05			<0.04	1.05	<0.1	59	202
WSA-102	0.6	MG: Quarry	1.93	<0.02	<0.03	<0.03	<0.05			<0.04	<0.04	<0.1	<7	<7
WSA-102	2.0	MG: Quarry	2.54							<0.04	0.11			
TP25A	0.7	MG: Quarry	4.5							0.1	**3.1**			
TP23	0.4	MG: Ash/clinker	30.7							**3.6**	**43.9**			

Key		Source of Guidance Trigger Level	
bold	Parameter found to be in excess of trigger concentration	♣	CLEA SGV is dependent on Soil Organic Matter content. The Tier 1 values used here are the most conservative, and in the event of exceedances, reference should be made to TOC analysis.
	Contaminant not tested for	~	LQM/CIEH Suitable for Use Level (S4UL) (assumes 1% SOM). For TPH C6-C40, the lowest value of aromatic or aliphatic has been adopted as the initial screening value.
		#	ALM risk-derived Tier 1 screening values. (Assumes **no soil cover**, see Generic Notes 04 in Appendix A).
*	Estimated from Speciated TPH Analysis Results	◇	Conservative value – assumes all C_6 to C_{10} is benzene

Table 13 (cont.) - Summary of Degree of Ground Contamination (Organics) at Site A, Burlow Road, Buxton

Hole ID	Depth (m)	Material	Concentrations in mg/kg. Results are quoted to 1 decimal place if <10, and whole numbers if >10. Trigger Level Concentrations are shown in brackets and assume a **residential with gardens** end use											
			TOC	Benzene	Toluene	Ethyl Benzene	Xylenes			PAH		TPH - C_6 to C_{40}		
			%	(0.087) ~	(130) ~	(47) ~	(56) ~			Naphthalene	benzo(a) pyrene	GRO C_6 to C_{10}	DRO C_{10} to C_{21}	LRO C_{21} to C_{40}
										(2.3)~	(2.2)~	(0.087)~◇	(74)~	(1100)~
TPA-101	0.1	Topsoil	8.03							<0.04	0.48			
TPA-103	0.1	Topsoil	5.76							<0.04	0.10			
TPA-105	0.1	Topsoil	5.38							0.11	2.13			
TPA-108	0.1	Topsoil	5.74							<0.04	<0.04			
TPA-110	0.1	Topsoil	4.83							<0.04	0.06			
TPA-112	0.1	Topsoil	4.76							<0.04	<0.04			
TPA-117	0.1	Topsoil	3.96							<0.04	0.15			
TPA-120	0.1	Topsoil	8.32							<0.04	0.14			
TPA-124	0.1	Topsoil	7.83							<0.04	0.13			
TPA-126	0.1	Topsoil	5.62							<0.04	0.19			
TPA-127	0.1	Topsoil	2.80							<0.04	0.14			
TPA-130	0.1	Topsoil	6.19							<0.04	0.35			
TP01	0.15	Topsoil	5.7							<0.1	<0.1			
TP10	0.2	Topsoil	7.4							<0.1	0.2			

Key		Source of Guidance Trigger Level	
bold	Parameter found to be in excess of trigger concentration	♣	CLEA SGV is dependent on Soil Organic Matter content. The Tier 1 values used here are the most conservative, and in the event of exceedances, reference should be made to TOC analysis.
	Contaminant not tested for	~	LQM/CIEH Suitable for Use Level (S4UL) (assumes 1% SOM). For TPH C6-C40, the lowest value of aromatic or aliphatic has been adopted as the initial screening value.
		#	ALM risk-derived Tier 1 screening values. (Assumes **no soil cover**, see Generic Notes 04 in Appendix A).
*	Estimated from Speciated TPH Analysis Results	◇	Conservative value – assumes all C_6 to C_{10} is benzene

Table 13 (cont.) - Summary of Degree of Ground Contamination (Organics) at Site A, Burlow Road, Buxton

Concentrations in mg/kg. Results are quoted to 1 decimal place if <10, and whole numbers if >10.
Trigger Level Concentrations are shown in brackets and assume a **residential with gardens** end use

Hole ID	Depth (m)	Material	TOC	Benzene	Toluene	Ethyl Benzene	Xylenes			PAH		TPH - C_6 to C_{40}		
										Naphthalene	benzo(a) pyrene	GRO C_6 to C_{10}	DRO C_{10} to C_{21}	LRO C_{21} to C_{40}
			%	(0.087) ~	(130) ~	(47) ~	(56) ~			(2.3)~	(2.2)~	(0.087)~◇	(74)~	(1100)~
TP13	0.10	Topsoil	5.6							<0.1	<0.1			
TP14	0.10	Topsoil	6.9							<0.1	0.3			
TP16	0.10	Topsoil	2.9							<0.1	<0.1			
TPA-101	0.5	Clay	1.94	<0.02	<0.03	<0.03	<0.05			<0.04	<0.04	<0.1	<7	<7
TPA-108	0.5	Clay	1.46							<0.04	<0.04			
TPA-112	0.5	Clay	1.56							<0.04	<0.04			
TPA-120	0.6	Clay	1.39	<0.02	<0.03	<0.03	<0.05			<0.04	<0.04	<0.1	<7	<7
TPA-126	1.5	Clay	1.29							<0.04	<0.04			
TPA-127	0.6	Clay	1.38							<0.04	<0.04			
TP26	0.3	Clay	<1.7							<0.1	<0.1			

Key		**Source of Guidance Trigger Level**	
bold	Parameter found to be in excess of trigger concentration	♣	CLEA SGV is dependent on Soil Organic Matter content. The Tier 1 values used here are the most conservative, and in the event of exceedances, reference should be made to TOC analysis.
	Contaminant not tested for	~	LQM/CIEH Suitable for Use Level (S4UL) (assumes 1% SOM). For TPH C6-C40, the lowest value of aromatic or aliphatic has been adopted as the initial screening value.
		#	ALM risk-derived Tier 1 screening values. (Assumes **no soil cover**, see Generic Notes 04 in Appendix A).
*	Estimated from Speciated TPH Analysis Results	◇	Conservative value – assumes all C_6 to C_{10} is benzene

Inorganic Determinands

9.3.7 A slightly elevated concentration of lead (207mg/kg) has been recorded in one sample of natural topsoil (TPA-105 @ 0.1m), and an elevated concentration of nickel (300.4mg/kg) has been recorded in one sample of natural clay (TPA-126 @ 1.5m). No other elevated concentrations of inorganic contaminants have been recorded in laboratory testing.

9.3.8 One sample of ash/clinker made ground encountered during the GRM ground investigation of 2015 (TP23-0.4m) exhibited elevated concentrations of arsenic (103mg/kg), copper (493mg/kg), lead (525mg/kg) and water soluble sulphate (0.580g/l).

9.3.9 Where appropriate, statistical analysis of the laboratory chemical analysis results has been carried out in general accordance with the methods outlined in "*Guidance on Comparing Soil Contamination Data with a Critical Concentration*" CIEH\CL:AIRE (2008) (see Appendix A, Contamination Testing) and the results are summarised below.

Table 14
Results of Statistical Analysis of Soil Contamination Data

Stratum	US_{95} Values for Contaminants that have yielded one or more Tier 1 exceedances for a given made ground type	
	Lead (200)	Nickel (130)
Topsoil	125.41	n/a
Clay	n/a	99.93 (172.83)

Notes: Values are bolded where the US95 value exceeds the relevant Tier 1 value.
Values in brackets are US95 values inclusive of any outliers.
n/a = none of the samples retrieved from this made ground type yielded a concentration in excess of the relevant Tier 1 value.

9.3.10 This statistical analysis indicates that the upper 95th percentile bound values (US95) for lead in natural topsoil are below the relevant current UK guidance threshold value for residential with gardens end use.

9.3.11 The elevated concentration of nickel (300.4mg/kg) reported in natural clays at a depth of 1.5m in TPA126, has been shown to be a statistical outlier from the data set for natural clays, and can therefore be regarded as a 'hotspot' of nickel contamination.

Asbestos

9.3.12 Chrysotile asbestos fibres are reported to be present within former quarry infill made ground in TPA305 at a depth of 1.1m. The laboratory test sheet reports the level screen to be less than 0.1%.

9.3.13 No asbestos fibres were identified in any other of the 10No. samples of made ground and 2No. samples of topsoil screened as part of the ALM supplementary ground investigation, or in the 2No. samples of made ground, 5No. samples of topsoil and 1No. sample of clay screened as part of the GRM ground investigation of 2015.

Poly Aromatic Hydrocarbons (PAH)

9.3.14 Speciated PAH analysis has confirmed the absence of significant concentrations of PAH's in topsoil made ground, natural topsoil and natural clays beneath this site.

9.3.15 Elevated concentrations of naphthalene (3.6mg/kg) and benzo(a)pyrene (43.9mg/kg) have been reported in one sample of ash/clinker made ground (TP23-0.4m), and benzo(a)pyrene (3.1mg/kg) in one sample of quarry fill (TP25A), from the GRM ground investigation of 2015.

Total Petroleum Hydrocarbons (TPH)

9.3.16 No elevated concentrations of TPH were recorded in any of the three samples of quarry fill and two samples of natural clay strata submitted for speciated TPH analysis.

Volatile & Semi-Volatile Organic Compounds (VOC & SVOC)

9.3.17 No concentrations of VOC's were recorded above their respective limits of detection in the three samples of quarry fill and two samples of natural clay strata submitted for VOC analysis, with the exception of a naphthalene concentration of 0.04mg/kg reported in a sample of quarry fill from TPA305-1.1m.

9.3.18 Concentrations of SVOC's above the limits of detection, including; 2-methylphenol (0.085mg/kg), 2,4-dimethylphenol (0.16mg/kg), 4-methylphenol (0.236mg/kg), phenol (0.155mg/kg), 2-methylnaphthalene (1.451mg/kg), carbazole (0.775mg/kg), and dibenzofuran (1.272mg/kg), were recorded in a sample of quarry fill from TPA305-1.1m. The concentration of dibenzofuran (1.272mg/kg) exceeds the former Contaminated Land Exposure Assessment (CLEA) Soil Guidance Value (SGV) of 8ug/kg for residential development with plant uptake.

9.3.19 No concentrations of SVOC's were recorded above their respective limits of detection in the other two samples of quarry fill and two samples of natural clay strata submitted for SVOC analysis.

Leachables

9.3.20 Of the leachability tests conducted on two samples of reworked clays and five samples of quarry fill, one sample of ash/clinker and one sample of natural clay tested, none had concentrations of leachable inorganic contaminants above the maximum permissible concentrations as defined in the Water Supply (Water Quality) Regulations 1989, as amended in 2000.

9.3.21 However, concentrations of leachable phenol (2.3ug/l) and leachable naphthalene (1.5ug/l) were recorded above the respective assessment criteria (0.5ug/l and 0.1ug/l) in one sample of ash/clinker made ground (TP23-0.4m) from the GRM ground investigation. The leachable phenol in this sample does not correspond to an elevated concentration of total phenol in the same sample, with a total phenol concentration of <1.1mg/kg reported.

9.3.22 Leachable phenol concentrations of 3.3ug/l were also reported in a sample of quarry fill (TP25A-0.7m) and natural clay (TP26-0.3m) in the GRM ground investigation. The leachable phenol in these two samples do not correspond to elevated concentrations of total phenol in the same samples, with a total phenol concentration of <1.2mg/kg and <1.3mg/kg respectively reported.

Calorific Value

9.3.23 The calorific values of 1MJ/kg and <1MJ/kg have been recorded in two samples of quarry fill (TPA301-1.0m and WSA102-0.6m). One sample of natural clay (TPA120-0.6m) also exhibited a calorific value of <1MJ/kg.

9.3.24 Materials whose CV's exceed 10MJ/kg are almost certainly combustible, while those with values below 2MJ/kg are unlikely to burn.

Pesticides

9.3.25 No concentrations of pesticides were reported in any of three samples of topsoil tested as part of the GRM investigation of 2015.

10 CONTAMINATION (QUALITATIVE RISK ASSESSMENT & REMEDIATION)

10.1 Assessment of Contamination Test Results

10.1.1 Notes outlining current guidance with respect to the interpretation of analytical data are included in Appendix A to this report.

10.1.2 Topsoil (natural and reworked), typically 300mm thick, is present across the whole of the site. Testing suggests this material is suitable for re-use in private garden and landscaped areas.

10.1.3 Natural and locally reworked clays are present beneath the vast majority of the site, and can be generally regarded as suitable for re-use as subsoil beneath the proposed development. However, a 'hotspot' of nickel contamination is reported in one sample (TPA126-1.5m) in strata extending from 1.2m to 2.0m below existing ground level. Private gardens in this area of the site are shown to be generally subject to a rise in proposed ground level (see Barratt Homes 'Cut and Fill Analysis' Drawing No.BUX/ED/04 in Appendix B), therefore natural clay containing the nickel hotspot will be isolated beneath roads, buildings and a significant depth of soil cover in this part of the site.

10.1.4 The elevated nickel content recorded in natural strata in TPA126, is considered unusual, however, it would be prudent to conduct further chemical analysis on these strata arising from any reduced level dig in this part of the site, in order to prove the suitability of these strata for re-use as near surface fill beneath private garden areas in other parts of the site.

10.1.5 Asbestos fibres, elevated concentrations of benzo(a)pyrene and SVOC's have been recorded in samples of quarry infill beneath the northeast of the site. The dark grey quarry infill was generally present from depths of 0.45m to 1.2m beneath the existing surface of the site. Proposed ground levels in the area underlain by the footprint of the former quarry are generally the same or slightly raised above proposed garden areas, therefore, these soils should remain isolated beneath a suitable depth of clean soils in private garden areas. Notwithstanding the above, where proposed road footprints cross the area underlain by the former quarry, care should be taken to segregate and isolate any soil arisings, so as not to cross contaminate the surface of the site or any other stockpiled soils.

10.1.6 Elevated concentrations of arsenic, lead, copper, water soluble sulphate, naphthalene, benzo(a)pyrene, leachable naphthalene and leachable phenol, have been recorded in ash/clinker made ground beneath the east of the site (GRM TP23). These soil have only been identified in one location and are likely only be present in an isolated area of the site. These soils are considered unsuitable for retention near surface beneath both buildings (due to the naphthalene content), private garden and landscaped areas, therefore, they should be either excavated and removed from site or relocated beneath a minimum 600mm clean soil cover in private garden areas. Leachable contaminants within these localised soils are only slightly elevated and considered not to present a significant risk to controlled waters.

10.1.7 Leachable phenol concentrations of 3.3ug/l reported in samples of quarry fill (TP25A-0.7m) and natural clay (TP26-0.3m) in the GRM ground investigation, are only slightly elevated, and are not considered to present a significant risk to controlled waters beneath the site. It should be noted that these two sample location also lie outside of the site boundary.

10.2 Environmental Setting & End Use

10.2.1 As discussed in Section 10.1 above, contamination exists in quarry infill and ash/clinker deposits locally present beneath this site, and also in one sample of natural clay. In order to assess the significance of this contamination, consideration must be given to the site's environmental setting and the proposed end use.

10.2.2 The underlying limestone is classified as a Principal Aquifer, whilst volcanic strata in the northwest are classified as a Secondary B Aquifer. The site is located in a Groundwater Source Protection Zone I. The nearest surface watercourse is an un-named tributary of the River Wye, which flows in a northerly direction, approximately 713m to the northwest of the site. Therefore, the site's environmental setting is considered to be of moderate sensitivity.

10.2.3 With respect to human health, the proposed end use (residential) is considered sensitive. Transient risks to construction workers can be addressed by the adoption of appropriate health and safety measures, see Section 14.3.

10.3 Pollutant Linkages

10.3.1 In terms of a proposed redevelopment of this site, plausible pollutant linkages can be summarised as follows.

Sources

10.3.2 Contaminant sources have been summarised in Section 10.1 above.

Pathways

10.3.3 Potential contaminant pathways include:

- ingestion
- dermal contact
- inhalation of contaminated particulates
- surface water run-off, including existing drainage infrastructure
- downward infiltration of leachable/mobile contaminants to groundwater

Receptors

10.3.4 Potential contaminant receptors include:

- the environment – Principal Aquifer
- end users of the site (residents)

10.3.5 It can be concluded that there are plausible pathways between actual contaminant sources and potential receptors. Consequently, some Remediation action will be required, either treatment/removal of the source, or "breakage" of the pathway.

10.4 Potential Remediation Options

General

10.4.1 Approval of the recommendations given below should be sought from the appropriate regulatory authorities prior to commencement of site redevelopment.

Soil Contamination

10.4.2 Quarry fill soils beneath the northeast of the site, contain asbestos fibres and elevated concentrations of benzo(a)pyrene and some SVOC's, and are considered unsuitable for retention near the surface beneath private gardens and landscaped areas. Therefore, where these soils are present beneath proposed private gardens and landscaped areas, a minimum depth of 1m clean soil cover should be present above these strata.

10.4.3 Ash/clinker soils encountered in GRM TP23 in the east of the site, contain elevated concentrations of arsenic, lead, copper, water soluble sulphate, naphthalene, benzo(a)pyrene, leachable naphthalene and leachable phenol. These soils are considered unsuitable for retention near the surface beneath buildings (due to naphthalene content), private gardens and landscaped areas. Therefore, where these soils are present beneath proposed buildings, private gardens and landscaped areas, the soils should be removed or retained beneath a minimum depth of 600mm clean soil cover in private garden and landscaped areas.

10.4.4 The 'hotspot' of nickel recorded in natural Miller's Dale Lava strata from a depth of 1.2m in TPA126, is located beneath an area of proposed roadway and where ground levels in the local area are indicated to be raised. Therefore, they are unlikely to be present near surface in private garden areas. However, it would be prudent to conduct further chemical analysis on any of these strata arising from any reduced level dig in this part of the site, in order to prove the suitability of these strata for re-use as near surface fill beneath private garden areas in other parts of the site.

Waste Classification

10.4.5 Disposal of the made ground off site is not considered appropriate, economically viable, nor in line with current Government philosophy regarding sustainable development. However, some excess arisings may be generated by excavations for foundations, sewers etc. Disposal to landfill may be the most practical solution, if redistribution and retention on site is not feasible.

10.4.6 Notes outlining the interpretation of analytical data with respect to waste classification are included in Appendix A to this report, together with notes about Waste Acceptance Criteria (WAC).

10.4.7 Soil arisings generated by excavations at this site are likely to be classified as follows:

Table 15
Waste Classification

Soil Type	Waste Classification	Remarks
Quarry Fill	Non-hazardous	asbestos (<0.1%), benzo(a)pyrene
Ash & Clinker	Non-hazardous	arsenic, lead, copper, naphthalene and benzo(a)pyrene
Topsoil	Non-hazardous	Due to >3% SOM, but suitable for re-use off site as topsoil
Subsoil	Inert	

10.5 Summary of Potential Pollutant Linkages & Mitigation

10.5.1 In terms of the proposed redevelopment plausible pollutant linkages, and feasible remediation options, can be summarised as follows:

Table 16
Summary of Potential Pollutant Linkages

Receptors	Pathways	Contaminants	Remediation Options
Human Health (Future residents) ◇	Consumption of contaminated vegetables	Asbestos, metals, PAH in the made ground	Retention of made ground beneath a 1m clean soil cover (above quarry fill) or 600mm clean soil cover (above ash/clinker) or removal/disposal off site.
	Ingestion		
	Inhalation (dust and/or vapours)		
	Dermal contact		
	Migration & accumulation of explosive gas	Naturally occurring Radon. Methane and carbon dioxide in the made ground.	Adoption of appropriate Radon protective measures for new buildings.
	Infiltration of water supply pipes	Naphthalene in ash/clinker made ground	Adoption of increased specification of water supply pipe, where coincident with ash/clinker made ground and quarry infill.
Buildings	Migration & accumulation of explosive gas	Methane, Hydrocarbons in the made ground	Adoption of appropriate Radon protective measures for new buildings
	Contact with "aggressive" soil and/or groundwater	Sulphate in the made ground	Adoption of DS-1 / AC-1 classification for sub-surface concrete generally across the site. Adoption of DS-2 / AC-2 classification for subsurface concrete where coincident with ash/clinker made ground.
Plants	Uptake of phytotoxic elements	Cu, Ni, Zn & B in the made ground	Provision of a suitably thick growing medium above ash/clinker made ground.
Groundwater	Migration of leachable components	Leachable phenol and naphthalene in the made ground	Mobile contamination considered minor with no significant risk to controlled waters perceived. Hard development and clean cover above made ground will prevent mobilisation of contaminated soils to surface water run-off.
	Surface water run-off	Asbestos, metals, PAH in the made ground	

◇ transient risks to construction workers will be addressed by the adoption of appropriate health and safety measures in accordance with the Health and Safety at Work Act 1974 and regulations made under the Act including for example the COSHH Regulations.

11 HAZARDOUS GAS

11.1 General

11.1.1 Information from historical OS plans, the Environment Agency and Local Authority indicates that the western part of the site is highlighted as a landfill site. However, previous phases of ground investigation, together with this supplementary phase of ground investigation, have determined that the reference to landfilling at the site is confined to a former quarry located immediately to the northwest of the site (former Burlow Works), which extended a short distance into the northeast of the site (circa 25m), and which has since become infilled with generally cohesive soils with gravel and cobbles of limestone, concrete, brick and slate, and some proportion of organic soils.

11.1.2 The site is neither underlain by shallow mineworkings nor located in an area considered susceptible to mines gas emissions.

11.1.3 However, the site is located in an area, which does require basic radon protection measures. These should comprise a minimum of:

- use of 1200 gauge polyethylene DPM\DPC, with suspended concrete floors or ground bearing floor slabs
- continuous membrane across cavity walls
- cavity tray in external walls
- fully sealed service entries/exits

11.1.4 Consideration of the conceptual site model and potential linkages enabled a preliminary qualitative assessment of risks associated with gas:-

Table 17
Hazardous Gas Conceptual Site Model

Source	Receptors	Hazard	Pathway	Initial Risk
On-site made ground (former Burlow Works)	Human Health	Asphyxiation & explosion.	Vertical migration, ingress & accumulation	**Low**: made ground essentially inert, with some organic matter.
	Buildings	Explosion.		
Off-site landfill (former Burlow Works)	Human Health	Asphyxiation & explosion.	Lateral migration, ingress & accumulation	**Low**: made ground essentially inert, with some organic matter.
	Buildings	Explosion.		
	Buildings	Explosion.		
Radon	Human Health	Carcinogenic risks.	Vertical migration, ingress & accumulation	**Applicable** : Full Radon protection Measures will be required for new developments

11.1.5 The generation potential of the gas source was initially considered to be LOW and this has been confirmed by the monitoring results obtained to date. Consequently, in accordance with CIRIA Report C665, given the proposed residential end use, six visits have been scheduled over a three month period, in order to supplement existing gas monitoring undertaken by GRM.

11.1.6 Given the perceived absence of any gas source from beneath the site other than the infilled former quarry in the northeast, gas monitoring wells have been installed in boreholes within the infilled quarry, and in the area immediately surrounding the former quarry. Details of the installations are given on the exploratory hole logs presented in Appendix H to this the report.

11.2 Scope of Works

11.2.1 To date, the ALM monitoring wells have been monitored on four occasions for groundwater levels and soils-gases.

3.1.1 A standard procedure was followed, in accordance with CIRIA guidance:

- Ambient oxygen concentration
- Atmospheric temperature & pressure
- Methane, oxygen and carbon dioxide concentrations and flow rates using a Gas Data GFM430 gas analyser
- Standing water level using a dipmeter
- Ambient oxygen concentration (check for instrument drift)

11.3 Monitoring Results

11.3.1 The results of the monitoring completed to date are summarised below.

Table 18
Summary of Gas Monitoring Results

Hole ID	Range of Methane Concentrations (% v/v)	Range of Carbon Dioxide Concentrations (% v/v)	Range of Positive Flow Rates (litre/hour)	Gas Screening Value (GSV) (CH4 / CO2) (litre/hour)
WSA101	0.0 – 4.8	3.8 – 8.7	0.0 – 0.0	0.0048 / 0.0087
WSA102	0.0 – 2.7	0.9 – 5.3	0.0 – 0.0	0.0027 / 0.0053
WSA103	0.0 – 0.3	0.8 – 1.9	0.0 – 0.0	0.0003 / 0.0019
WSA104	0.0 – 0.0	2.6 – 4.0	0.0 – 0.0	0.0001 / 0.0040
WSA105	0.0 – 0.0	2.7 – 3.8	0.0 – 0.0	0.0001 / 0.0038
WSA106	0.0 – 1.5	1.9 – 4.5	0.0 – 0.0	0.0015 / 0.0045
WSA107	0.0 – 0.0	2.4 – 2.8	0.0 – 0.0	0.0001 / 0.0028

11.4 Discussion

11.4.1 Elevated concentrations of methane (>1%) and carbon dioxide (>5%) have been recorded in WSA101 and WSA102, which were located within the former infilled quarry and encountered slightly organic made ground to depths of >7.2m and 5.8m respectively.

11.4.2 WSA106, also located within the former infilled quarry, but within shallower less organic fill, also recorded a slightly elevated concentration of methane up to 1.5%.

11.4.3 No other elevated concentrations of methane (>1%) and carbon dioxide (>5%) have recorded within monitoring wells to date.

11.4.4 No gas flow rates were recorded in any of the four visits undertaken by ALM to date.

11.4.5 Calculated worst case Gas Screening Values (GSV's) for WSA101, which exhibited the highest concentrations of ground gas, correspond to a GREEN/Characteristic Situation 1 gas regime (CIRIA C665). However, the gas regime should be upgraded to AMBER 1/Characteristic Situation 2 in light of the exceedances of the typical maximum concentrations (>1% CH_4 and >5% CO_2) for these gas regimes.

11.4.6 A hazardous gas risk assessment incorporating all of the results will be issued on completion of monitoring.

11.4.7 The site is, however, located within an area where full radon gas protection measures will be required to be installed in accordance with Building Research Establishment (BRE) Report BR211 (2015) which would nominally be required to conform to the NHBC classification 'Amber 1'. The full radon protection measures would therefore mitigate any risks associated with the identified gas regime at the site.

11.4.8 Based on the current set of gas monitoring data, the site characterisation noted above, the likely foundation solutions, and with reference to BRE BR 211 (2015) and the gas protection "scoring" system outlined in BS 8485:2015 for various site Characteristic Gas Situations, ALM would recommend that the following protective measures should be incorporated in all new dwellings at the site (see Table 19).

Table 19
Recommendations for Gas Protection Measures
(Low Rise Residential Housing
BS 8485:2015 'TYPE A'
Building in Private Ownership with Small Rooms)

Traffic Light Class (NHBC – 10627_R01, 2007)	Characteristic Situation (Wilson & Card 1999)	Gas "score" req'd by BS 8485	Floor Slab (BS 8485 "score")	Protective Measures: Sub-floor ventilation (BS 8485 "score")	Protective Measures: Membrane Type (BS 8485 "score")
Amber 1	**CS2**	**3.5**	*Select one from:* i. Block & Beam – **(0)**. ii. Cast in-situ ground bearing slab (with only nominal mesh reinforcement) **(0.5)**. iii. Cast in-situ monolithic reinforced ground bearing raft or cast in-situ suspended floor slab with minimal penetrations **(1.0)** or **(1.5)** if well reinforced to control cracking and have minimal penetrations cast in. iv. Basement floor and walls conforming to BS8102:2009, Grade 2 waterproofing **(2.0)** v. Basement floor and walls conforming to BS8102:2009, Grade 32 waterproofing **(2.5)**	*Select one from:* Pressure relief pathway, usually formed of low fines gravel, or with a thin composite blanket or strips, terminating in a gravel trench external to the building **(0.5)**. Passive sub-floor dispersal layer: i. Very Good Performance **(2.5)** e.g. min 100mm Clear Void[4] or polystyrene void former[5] with an equivalent clear void depth of at least 60mm, with 1,500mm^2 side ventilation[6] per 1m run of wall on at least two opposite sides. The venting area through any downstand beam should be 4 to 5 times greater that provided by the side ventilation ii. Good Performance **(1.5)** e.g. 25mm geo-composite blanket[7], with 1,500mm^2 side ventilation per 1m run of wall on at least two opposite sides. or 300mm thick gravel dispersal layer[8 & 9] with 'good performance' (BS 8485)	Waterproof DPM (1200g polyethylene) **(0)** Gas resistant membrane[10 & 11] **(2.0)**

Footnotes:

1. Integral garages with occupied rooms above, or direct access through a doorway from the garage to the house, should be provided with the same protective measures as the rest of the dwelling. Buildings with basement car parks (with ventilation in accordance with Building Regulations) may not require gas resistant membranes.
2. There should be minimum penetration of floor slab by services; any penetrations should be suitably sealed.
3. For radon, CS2 protection is required for 'basic' radon measures (but sub-floor ventilation not essential), and protection as per AMBER 1 for 'full' radon measures (minimum membrane requirement 1200g polyethylene).
4. An open void space provides the most effective gas dispersal layer and is suitable for gas regimes up to and including CS4.
5. The maximum point score of 2.5pts should only be applied to the thicker void formers with an equivalent clear void depth of at least 60mm. For thinner polystyrene void formers a maximum point score should be 2pts unless calculations demonstrate a very good performance.
6. For small to medium width buildings (up to 15m wide) the minimum area of side ventilation for open void space and void formers should be 1,500mm^2 per meter run on at least two opposite sides. For larger buildings, side ventilation should be at least 2,000mm^2 per meter run of wall for gas regimes up to and including CS3, and 4,500mm^2 per meter run of wall for gas regime CS4. If the amount of side ventilation or internal cross openings are less than those recommended for a good performance, then the score should be reduced to 2pts or 1.5pts.
7. The minimum thickness of a geo-composite blanket passive gas dispersal layer should be 25mm. As a guide, a score of 1.5pts can be applied for a 25mm thick geo-composite blanket for a building up to 15m wide, but for larger buildings or thinner blankets, the points score should be reduced to 1pt or 0.5pts. For small to medium buildings, the minimum area of side ventilation should be 1,500mm^2 per meter run of wall on at least two opposite sides, increasing to at least 2,000mm^2 for larger width buildings. Geo-composite blankets are not suitable for CS4 sites unless the width of the building is small (<5-8m). Geo-composite blankets thinner than 25mm should not be specified for CS3 or above.
8. A point score of between 0.5-2.5pts can be achieved for gravel dispersal layer depending on the material used and construction detail. A gravel layer should typically be a minimum of 300mm thick, have high porosity (>40%), and have a minimum particle size of 20mm. The minimum side ventilation should be the same as for geo-composite blankets (see Note 7). Well graded aggregates such as MOT Type 1 and Type 2 are unsuitable.
9. The dispersal characteristics of granular layers can be improved by the introduction of drains, which may typically be either perforated plastic pipe of >75mm diameter, or geo-composite strips greater than 1m wide and 12.5mm thick. Granular layers should be at least 200mm thick and drains should be no further than 3m apart. Side ventilation for granular layers with drains should be provided at no more than 10m centres and have an area equivalent to 1,500mm^2 per meter run on at least two opposite sides. Granular layers with drains are not suitable for CS4 or above.
10. There are a wide variety of gas resistant membranes with different properties and performance characteristics but should comply with all of the requirements of Table 7 of BS5485:2015 and possess an average methane gas transmission rate of <40.0 ml/day/m^2/atm. The choice of membrane should consider factors such as; resistance/permeability to methane and/or carbon dioxide, durability, strength, flexibility for installation, resistance to degradation by other contaminants that may be present (i.e. hydrocarbons). The chosen membrane should be manufactured from virgin polymer and not from re-cycled materials.
11. In all cases a gas membrane should be well installed, with no punctures and with all joints sealed correctly. The membrane should always be lapped and sealed and verified in accordance with CIRIA Report C735 *"Good Practice on the Testing and Verification of Protection Systems for Buildings Against Hazardous Ground Gases"* (2014). The membrane should be continuous across cavity walls, and there should be a cavity tray in external walls. If a membrane is installed that does not meet the requirements of Table 7 of BS5485:2015, then the score is 'zero'.

12 GEOTECHNICAL TESTING

12.1 General

12.1.1 Nine samples of natural soil were delivered to a suitably accredited laboratory with a schedule of geotechnical testing drawn up by ALM.

12.1.2 The geotechnical laboratory test results are presented in Appendix J to this report.

12.2 Atterberg Limits

12.2.1 Results are summarised below.

Table 20
Summary of Atterburg Limit Tests

Soil type	Range of Plasticity Indices* (Average)	Shrinkability
CLAY (Completely weathered Bee Low Limestone)	ALM: 25 – 28.9 GRM: 13 – 30 (Ave = 23.65)	Low to Medium
CLAY (Completed weathered Millers Dale Lava)	ALM: 11.9 – 53.8 GRM: 31 – 47 (Ave = 36.05)	Low to High

* Modified where appropriate in accordance with revised Chapter 4.2 of the NHBC Standards (April 2003).

Note. The term Shrinkability is equivalent to the term Volume Change Potential used in Chapter 4.2.

12.2.2 For the purposes of foundation design, it is recommended that all Completely Weathered Bee Low Limestone be regarded as being of **medium** shrinkability, and all Completely Weathered Millers Dale Lava be regarded as **high** shrinkability.

12.2.3 The above classification is in accordance with the findings of the GRM investigation of 2015.

12.3 Soluble Sulphate and pH

12.3.1 In accordance with BRE Special Digest 1:2005, this site has been classified as generally Greenfield with a mobile groundwater regime.

12.3.2 It is envisaged foundations will generally extend to depths of about 1m through natural strata. No foundations are likely to penetrate the quarry infill. Samples taken from this depth range have been submitted for pH and water-soluble sulphate (2:1 soil/water extract).

12.3.3 The highest water-soluble sulphate concentration and the lowest pH value for each soil type analysed are shown in the Table below.

Table 21
Summary of Sulphate and pH results

Soil type	Lowest pH values	Highest Soluble Sulphate Concentration (g/l)
Quarry Infill	7.52	0.250
MG: Ash/clinker	11.4	0.580
MG: Clay	7.93	<0.0015
Completely Weathered Bee Low Limestone	6.48	0.031
Completely Weathered Miller’s Dale Lava	6.70	0.032

12.3.4 Therefore, in accordance with Tables C1 and C2 of SD1, sub-surface concrete to be in contact with all soils except ash/clinker made ground, should be Design Sulphate Class DS-1, with the site allocated an ACEC Classification of AC-1.

12.3.5 Where sub-surface concrete is to be in contact with ash/clinker made ground, Design Sulphate Class DS-2, with the site allocated an ACEC Classification of AC-2 should be adopted.

12.3.6 The above classifications are in agreement with those determined during the GRM investigation of 2015.

12.4 Compaction Tests

12.4.1 Four samples of the cohesive strata were scheduled for laboratory compaction testing (using a 2.5kg rammer) and particle size distribution analysis to determine their suitability for re-engineering.

12.4.2 Laboratory compaction tests are only appropriate if the material grading demonstrates that:

- At least 70% of the material passes the 20mm sieve and/or
- At least 90% of the material passes the 37.5mm sieve

12.4.3 The results are summarised in the Tables below:

Table 22
Summary of Compaction Tests

Sample location & depth	Material description	% passing 37.5mm sieve	% passing 20mm sieve
TPA106 – 0.5m	MG: CLAY	100	100
TPA111 – 0.5m	Completely Weathered Bee Low Limestone	100	100
TPA125 – 0.6m	Completely Weathered Miller's Dale Lava	61	59
TPA127 – 1.7m	Weathered Miller's Dale Lava	96	82

Sample location & depth	G_s (Mg/m³)	MDD (Mg/m³)	OMC (%)	Allowable mc range for 95% MDD & <5% air voids	In-situ moisture content (%)
TPA106 – 0.5m	2.59	1.54	21	n/a (20.25-24.5 = 90%MDD)	32
TPA111 – 0.5m	2.59	1.57	21	22.5 – 25.75	29
TPA125 – 0.6m	2.63	1.61	23	24.5 – 28.5	20
TPA127 – 1.7m	2.62	1.58	25	22.0 – 28.5	23

12.4.4 In addition, the moisture contents of a further two samples of the completely weathered Bee Low Limestone were determined as 25%, whilst the results of a further three samples of completely weathered Millers Dale Lava were determined as 26%, 30% and 43%.

12.4.5 The test results show that the cohesive made ground does not achieve 95% of optimum compaction and is therefore unsuitable for re-engineering as structural fill. It may however, be used as general fill and achieves upward of 90% compaction, however, its natural moisture content is significantly wet of optimum, and the materials will require drying prior to any compaction.

12.4.6 The completely weathered Bee Low Limestone material is suitable for recompaction. However, it is apparent that the in-situ moisture content of these materials is significantly in excess of the Optimum Moisture Content (OMC) and in excess of the allowable moisture content range that will be required to achieve 95% Maximum Dry Density (MDD) and <5% air voids. On this basis it is considered that the completely weathered Bee Low Limestone is suitable for re-engineering for use beneath highways and hardstanding, subject to drying prior to re-engineering works.

12.4.7 The Completely weathered Millers Dale Lava strata has recorded a significant coarse fraction in the sample from TPA125, which may render the tested soils unsuitable for compaction. However, this does not correspond to field description of the strata, which did not record significant coarse fraction. In any case, gravel and cobbles of the Miller's Dale Lava within clay strata may break down if processed (i.e. if excavated and tracked in by machinery), therefore, field compaction trials for this material are recommended.

12.4.8 The Completely weathered Millers Dale Lava strata is otherwise suitable for compaction testing. However, it is apparent that the in-situ moisture content of the material tested is dry of the range that will be required to achieve 95% Maximum Dry Density (MDD) and <5% air voids. However, three other natural moisture contents recorded in the Completely weathered Millers Dale Lava strata were 26%, 30% and 43%, which demonstrates significant variability of moisture content within the strata. Therefore, given the variable moisture contents and variable degree of weathering apparent within the Completely weathered Millers Dale Lava strata, field compaction trials for this material are recommended, and allowance should be made for possible drying of the strata prior to compaction.

12.4.9 Weathered Millers Dale Lava strata in the sample from TPA127, achieved 95% compaction, with a natural moisture content close to optimum, and is suitable for re-engineering as structural fill.

12.5 Laboratory California Bearing Ratio (CBR) Tests

12.5.1 Two samples were scheduled by ALM for laboratory California Bearing Ratio (CBR) Tests (BS1377:Part 4:Cl7)

12.5.2 Each sample was subjected to re-compaction (using a 2.5kg rammer) at natural (as received) moisture content.

12.5.3 The results of the laboratory CBR tests are summarised in Table 23.

Table 23
Summary of Laboratory CBR Tests

Sample location & depth	Material description	Bulk Density (Mg/m^3)	Natural Moisture Content (%)	Mean CBR (%)
TPA111 – 0.5m	Completely Weathered Bee Low Limestone	1.89	28	0.7
TPA127 – 1.7m	Completely Weathered Miller's Dale Lava	1.95	26	5.2

12.5.4 The test results indicate a design CBR of 0.7% following re-compaction of the natural Completely Weathered Limestone materials, and 5.2% following re-compaction of the natural Weathered Millers Dale Lava materials.

12.6 Soakaway Tests

12.6.1 General notes about soakaways, including their location, design, and ALM's test methodology are presented in Appendix A.

12.6.2 Two soakaway tests were carried out in accordance with BRE Digest 365 "Soakaway Design" within Test Pit Nos. SAA1 and SAA2. The locations of the soak-away tests were designed to test the infiltration of the strata in the area of a proposed drainage pond/soakaway as shown on Barratt Homes Manchester 'Sketch Layout' (un-numbered) presented in Appendix B (test locations are shown on Drawing No. 30156/A/6 presented in Appendix B to this report).

12.6.3 Records of the soakaway tests are presented in Appendix J(3) to this report.

12.6.4 The calculated infiltration rates for each test are summarised in the Table 24 below.

Table 24
Summary of Soakaway Infiltration Rates

Soakaway No.	Stratum	Infiltration Rate
SAA1	Completely and Moderately Weathered Bee Low Limestone	Test 1 – 2.43 x 10^{-4} m/s Test 2 – 3.71 x 10^{-4} m/s
SAA2	Completely and Moderately Weathered Bee Low Limestone	Test 1 – 4.61 x 10^{-4} m/s Test 2 – 5.14 x 10^{-4} m/s

12.6.5 The infiltration rates noted above are broadly comparable to those recorded by GRM in 2015 (see Table 5 on page 16).

12.6.6 Based on the above it is, therefore, considered that soakaways are a practical drainage solution for surface water management at the site within the limestone deposits.

13 GEOTECHNICAL ISSUES

13.1 Conceptual Site Model

Made Ground

13.1.1 Both GRM and ALM ground investigations have identified the presence of only very localised and made ground materials beneath the site.

13.1.2 Made ground was encountered to depths in excess of 7.2m in a former infilled quarry beneath the northeast of the site and generally comprised organic grey sandy clays with gravel and cobbles concrete, limestone, brick and slate, with occasional pieces of wood, ceramic and plastic. The 'high walls' of the former quarry were generally coincident with the outline of the former quarry shown on historical OS maps of the site (see Drawing No.30156/A/4 in Appendix B).

13.1.3 Reworked topsoil and clays were present to generally shallow depth (<1m) immediately above quarry infill soils, and also beneath the area immediately surrounding the former quarry. These materials were interpreted as overburden to the original quarry, which had been removed and stockpiled on the site (see Drawing No.30156/A/4 in Appendix B) and subsequently been used to restore the infilled quarry.

13.1.4 Ash/clinker made ground was recorded to a depth of 0.8m in GRM TP23.

13.1.5 Cohesive made ground with cobbles and boulders of limestone, concrete, brick and slate, with pieces of rope and glass, were recorded to a depth in excess of 2.3m in GRM TP28, which was excavated in a location identified by the farmer of the land to require periodic infill due to surface subsidence.

Natural Strata

13.1.6 Natural clayey topsoil materials are present across the entire development area to an average depth of 0.3m across the vast majority of the site, but slightly thinner (circa 0.2m) on slopes in the northwest of the site.

13.1.7 The topsoil is underlain by a horizon of either completely weathered Bee Low Limestone or completely weathered Miller's Dale Lava strata, which were generally recovered as a friable, soft to firm/firm sandy silty clays with occasional lithorelics. The Completely Weathered Bee Low Limestone materials were recorded to depths between 0.4m-1.7mbgl (average 0.91mbgl), whilst the Completely Weathered Millers Dale Lava strata were recorded to depths between 0.0m to 2.8m (average 1.07m).

13.1.8 Moderately Weathered Bee Low Limestone Strata (rock) was encountered in the majority of exploratory holes, with the exception of the northwest edge of the site, and comprised strong to very strong pale grey fine grained thinly to medium bedded Limestone. The sub-horizontal bedding surfaces were observed to be weathered and discontinuities were observed to be filled with soft brown clay.

13.1.9 Moderately Weathered Miller's Dale Lava Member strata were present beneath the northwest of the site, and typically comprised moderately weak purple brown mottled grey very sandy gravelly cobbley clay, with gravel and cobbles of volcanic tuff and amygdaloidal basalt.

13.1.10 The Moderately Weathered Miller's Dale Lava Member strata was generally easy to excavate, with the rock degrading to angular gravel and cobbles along horizontal and vertical fractures.

13.1.11 A void was reported in GRM TP28 located beyond the northern boundary of the site. The void was encountered by GRM whilst excavating a trial pit (TP22) through completely weathered Miller's Dale Lava strata, which collapsed into a void of unknown size, at a depth of 1.3m. The completely weathered Miller's Dale Lava strata continued to a depth in excess of 3.5m within the trial pit.

13.1.12 Consideration of a photograph of the void in GRM TP22, presented in Appendix M of GRM Report No. GRM/P6222/F.1, suggests the void may have been approximately 0.5m deep.

Groundwater

13.1.13 No groundwater seepages were encountered in any of the GRM and ALM exploratory holes.

13.2 Mining & Quarrying

13.2.1 The site is not in an area that has historically been mined for coal.

13.2.2 Historical Ordnance Survey maps indicate the presence of a number of quarries both within, and within the vicinity of the site, which have been worked for limestone.

13.2.3 The nearest former quarry to the site is the former Burlow Works, which is located immediately to the northeast of the site, and extends approximately 25m into the northwest of the site. This former quarry has since been infilled/restored, a process which is currently ongoing to the northeast of the site.

13.2.4 Other small quarries are located sporadically around the local area, within 1km of the site, with large scale quarrying activity has historically taken place at Harpur Hill ca. 250m to the west of the site and historical and current quarrying activity takes place at Hillhead Quarry ca. 1km to the south.

13.2.5 A mineral desk study undertaken by Wardell Armstrong LLP in 2014, concluded that mineral abstraction prior to development of the site would not be practical or environmentally acceptable due to the nearby presence of existing residential development, and the location of the site within a Groundwater Source Protection Zone 1.

13.3 Site Regrade and/or Ground Improvement

13.3.1 Ground levels across the site generally rise steadily from southeast to northwest, with more marked increases in slope occurring in the northwest. Therefore, it is anticipated that regrading of ground levels will be required in order to provide a workable development platform, with a series of retaining walls also likely to be present across the site.

13.3.2 Barratt Homes Drawing No.BUX/ED/04 gives an analysis of potential cut/fill levels required to achieve desires development levels. The drawing shows cut/fill levels of generally +-1m across much of the eastern half of the site, which provide a series of development plateaux. More significant cut/fill is shown in the western half of the site, with cut/fill levels of +-2m or +-3m common. A maximum cut of 5.06m is shown at the northern boundary of the site.

13.3.3 The Completely Weathered Bee Low Limestone materials will be suitable for re-engineering/compaction, however, existing geotechnical tests suggest that the natural moisture contents of these materials are in excess of the range of moisture contents that would enable 95% of maximum dry density and <5% air voids to be achieved following re-compaction.

13.3.4 The Completely weathered Millers Dale Lava strata will be suitable for re-engineering/compaction, however, geotechnical testing provided variable moisture contents within these strata, which suggest that the natural moisture contents of these materials will be in excess of the range of moisture contents that would enable 95% of maximum dry density and <5% air voids to be achieved following re-compaction.

13.3.5 It is therefore considered that optimum re-engineering of the natural cohesive strata could be problematic during the winter months or during periods of inclement wet weather, and consideration should be given for the drying of the completely weathered strata in windrows or the use of lime stabilisation techniques. If the latter is adopted, field trials will be required to determine the appropriate lime ratio required to achieve optimum (or close to optimum) moisture content.

13.3.6 The near surface soils also have the potential to be disturbed by weathering and site traffic. Precautions should be taken to avoid this, as excessive disturbance may entail more onerous road subbase thickness and increased amounts of off-site disposal etc. The near surface soils may need treatment or reinforcing to allow safe movement of construction plant and labour. An assessment by the contractor should be undertaken once the type of machinery/plant needed to complete the development is known.

13.4 Foundation Recommendations

General

13.4.1 Consideration is being given to the development of the site with 152No. 2-3 storey domestic dwellings, associated gardens, a 'Community Building', public open space, and adoptable roads and sewers. A Barratt Homes Manchester 'Sketch Layout' plan (un-numbered) showing the proposed development, is presented in Appendix B.

13.4.2 Foundation recommendations assume that development will be two-three storey and that line loads will not exceed 60kN/m run. If this is not the case significant alteration to these recommendations will be required.

13.4.3 Foundation recommendations presented below take into consideration the anticipated difference between existing site levels and indicative proposed finished floor levels of the development, as provided by Barratt Homes Manchester. Any modification to the proposed finished floor levels will require amendments to the foundation recommendations provided.

13.4.4 Made ground materials have been observed to be locally present in some parts of the site. Made ground is not considered a suitable foundation material and foundations should therefore be taken through these materials into underlying natural strata of adequate bearing capacity.

13.4.5 The in-situ firm Completely Weathered Bee Low Limestone and Completely Weathered Miller's Dale Lava Member (sandy silty clays) are considered a suitable load bearing stratum.

13.4.6 However, the Completely Weathered Bee Low Limestone and Millers Dale Lava were observed to be friable, generally firm, and locally soft in nature. Therefore, for ease of construction and to reduce the risk of any unacceptable total and/or differential settlement it may be prudent, were possible, to place foundations onto the underlying bedrock.

13.4.7 The Moderately Weathered Limestone (rock) strata were noted to be generally strong to very strong, whereas the Moderately Weathered Millers Dale Lava strata were noted to be generally moderately weak. A nett allowable bearing pressure of in excess of 1,000kN/m^2 for will likely be achievable on the limestone rock, whereas a nett allowable bearing pressure of in excess of 250kN/m^2 will likely be achievable on the Millers Dale Lava strata.

13.4.8 The Completely Weathered strata can be easily excavated using a backhoe excavator. However, the Moderately Weathered Limestone (rock) was very hard to excavate in trial pits, but it should still be possible to excavate the upper horizons of the rock using a backhoe excavator with the assistance of hydraulic pointed tools and will be excavated as hard angular coarse gravel, cobbles and boulders. The Moderately Weathered Miller's Dale Lava strata was relatively easy to excavate using a backhoe excavator, and will be excavated as angular coarse gravel, cobbles and boulders, which will break down further when moved around and/or tracked over.

13.4.9 A suspended floor construction should be used wherever the depth of made ground or infill beneath a plot exceeds 600mm. However, due to the requirement for full radon protection being present, it is recommended that an allowance be made for suspended floors for all house plots with an appropriate ventilated sub-floor void (e.g. "beam-and-block").

13.4.10 Barratt Homes or their groundworker should seek further advice from ALM if unexpected ground conditions are encountered in foundation or sewer excavations, including any conflict between soft ground associated with a backfilled trial pit excavation and the line of a proposed footing.

13.4.11 Sub-surface concrete in contact with made ground and with the natural strata should be Design Sulphate Class DS-1, with the site allocated an ACEC Classification of AC-1. However, sub-surface concrete in contact with ash/clinker made ground (TP23) should be Design Sulphate Class DS-2, with the site allocated an ACEC Classification of AC-2.

13.4.12 No relict floor slabs or foundations are anticipated to be present within the site.

13.4.13 Over-deepened foundations should be stepped in accordance with NHBC Standards, Chapter 4.4.

13.4.14 Foundations will be required to be placed below a line drawn up at 45^0 from the base of any service or similar excavation.

13.4.15 The foundation solution for two or three storey residential properties constructed on this site is discussed below.

Strip/Trench Fill Footings

13.4.16 It is considered that strip footings/deep strip footings will be the most suitable foundation solution for the majority of two or three storey houses proposed to be constructed across the majority of the site. This solution is viable where the depth to competent strata beneath proposed finished floor levels is less than about 2m and firm Completely Weathered or Moderately Weathered Limestone rock are the founding material.

13.4.17 Assuming a strip foundation of 10m length and 0.6m width, founding at 0.90m depth, the Completely Weathered Limestone and Completely Weathered Miller's Dale Lava stratum are generally considered to have a safe bearing capacity of at least 165kN/m^2, where the typical shear strength of the 'firm' clays (50kN/m^2) recorded in hand vanes tests is assumed. With respect to the above foundation geometry and a maximum line load of 60kN/m run, settlements in the order of 4-8mm would be anticipated. This is considered likely to be acceptable, however further advice should be sought from the Structural Engineer responsible for design.

13.4.18 As noted above, due to potential variability of the bearing capacity of the Completely Weathered (clay) strata, it may be prudent that, where possible, all foundations found upon the Moderately Weathered Limestone rock. The rockhead will be expected to contain significant amounts of coarse granular (cobbly/bouldery) weathered rock with some clay infill within discontinuities, therefore reinforcement of footings is recommended as a precaution against differential settlement.

13.4.19 Reinforcement, as a precaution against differential settlement, is recommended only where foundation excavations encounter significant lateral and vertical variations in strata.

13.4.20 Foundations on rock should be placed entirely on rock and not partially on rock and partially on residual soil. This may, depending on surface gradient of the rock strata, necessitate localised over-deepening of foundations and over-break of the rockhead will be anticipated for a number of house plots.

13.4.21 Clay classification tests suggest that the Completely Weathered Bee Low Limestone at the site should be regarded as being of medium shrinkabilty, whereas classification tests suggest that the Completely Weathered Millers Dale Lava strata should be regarded as being of high shrinkabilty. Minimum founding depths of 900mm and 1m respectively, are recommended for buildings where strip footings are proposed to be seated within Completely Weathered Bee Low Limestone or Completely Weathered Millers Dale Lava strata, although strip/trench fill foundations are not recommended above the Millers Dale Lava strata (see below). Alternatively, foundations could be seated on bedrock whichever is the shallower depth.

13.4.22 Foundations should be deepened near trees in accordance with NHBC Standards Chapter 4.2. This may affect a number of properties located in centre of the site.

13.4.23 Founding depths are from original or finished ground level, whichever is the lower, to the underside of the footing.

13.4.24 In order to minimise softening and swelling of the cohesive soils, it is recommended that as soon as formation level is reached, it should be blinded. The blinding should consist of concrete with as low a water:cement ratio as possible.

13.4.25 In addition to the above, Barratt Homes should review proposed plot designs and layouts, since deeper excavations for trench fill are likely to be unstable where the centre-lines of parallel trenches are closer than about 2m (assuming 600mm widths). Barratt Homes should supervise their groundworker to ensure footings are excavated in a controlled and safe manner.

13.4.26 The GRM report of 2015 highlights the occurrence of a void in TP22 and a possible dissolution feature resulting in subsidence in TP28. These features are considered to be a possible consequence of 'paleo-karst' that formed on the exposed surface of the underlying limestone prior to lavas erupting over them. The lava may not have immediately filled the karstic features during eruption, resulting in voids underlying the lava, which, following subsequent weathering of the lavas, are now allowing the weathered lavas to migrate into the voids resulting in localised subsidence. This accounts for the location of these possible dissolution features in the Millers Dale Lava, rather than across the whole site.

13.4.27 No similar features were noted during the ALM ground investigation, which suggests that this process is not widespread, but localised. However, the possibility of voids arising from these processes beneath the northwest of the site, cannot be ignored.

13.4.28 Reference to 'Palaeokarst: A Systematic and Regional Review, PavelBosal et al eds, 1989, Elsevier, made in the GRM report of 2013, suggests that in some locations in the Peak District, karstic features in the upper surface of limestones were up to 30cm in diameter and 1m deep, and up to 10m wide and deep in few locations, filled with collapse lava and limestone boulders.

13.4.29 As a consequence of the possible presence of voids beneath the northwest of the site, we would not recommend adopting conventional strip/trench fill or piled foundations onto the Millers Dale Lava strata. Instead, consideration should be given to raft foundations for plots located above the Millers Dale Lava strata.

Raft Foundations

13.4.30 As discussed above, given the possible presence of voids beneath the northwest of the site, the use of raft foundations is preferred to conventional strip/trench foundations and/or piles foundations in this area.

13.4.31 In areas where raft foundations are proposed, the uppermost 3.0m should be excavated, screened and placed in engineered layers. Excavations below proposed new-build should extend at least 3.0m beyond the footprint of structures. Excavation and screening will enable the inspection of the sub-grade and the removal of any oversize material, which could subsequently be processed (crushed) to a suitable grade for re-use.

13.4.32 Any soft spots or voids in the base of the excavation should be excavated and filled with a suitable material, and proof rolled prior to commencement of re-engineering of the raft.

13.4.33 Given the possible presence of voids beneath the northwest of the site, consideration should be given to the adoption of a geotextile/geogrid at the base of the raft sub-grade construction, to further mitigate against any potential migration of overlying soils into voids.

13.4.34 The suitability of the ground for placement as engineered fill should be confirmed by field trials and laboratory testing. Field trials should be carried out in accordance with ALM's Specification for Engineered Fill. The field trial will enable estimation of tolerable settlement characteristics and an achievable safe bearing capacity, with a view to establishing new dwellings on raft foundations. It will also yield the following information:

- number of passes with the compaction plant (to be used during subsequent earthworks)
- maximum and minimum layer thickness (plant dependent)
- acceptance criteria; minimum dry density and moisture content range

13.4.35 Engineered fill should achieve at least 95% maximum dry density, with air voids comprising less than 5%; as determined by appropriate laboratory compaction tests (refer to Section 4.2 of ALM's Specification for Engineered Fill).

13.4.36 Raft design should be in accordance with NHBC Standards, Chapter 4.5. Granular sub-base product should be placed in accordance with Table 8/1 of the Highways Agency Specification for Highway Works (1998).

13.4.37 NHBC generally recommend that rafts be founded on a minimum 150mm thickness of DoT granular sub-base product. Granular sub-base should extend laterally for at least 0.5m beyond the raft. The base of the granular sub-base must be at least 600mm below original or finished level, whichever is the lower.

13.4.38 Placement of blankets of a granular sub-base, directly on top of engineered fill would normally be acceptable immediately after placement of the final layer of fill. However, if placement is delayed, climatic factors can lead to a deterioration of the near surface fill.

13.4.39 Where the engineered fill is cohesive, rainfall, (softening) or sunshine (desiccation) may cause deterioration. Cohesive fill should therefore be "blinded" with granular sub-base within 48 hours of placement of the final layer of fill. Wherever this is not possible, it is recommended that a minimum 300mm depth of fill is excavated from beneath the plot footprint, prior to placement of the granular sub-base. Furthermore, it may be necessary to remove any desiccated material if the engineered fill is left exposed during a prolonged spell of dry weather.

13.4.40 Where the engineered fill is granular, deterioration may be caused by frost (unless the fill contains less than 10% fines). Granular fill should therefore be "blinded" with granular sub-base prior to frosty weather.

Piled Foundations

13.4.41 Consideration of Barratt Homes Drawing No.BUX/ED/04 'Cut and Fill Analysis', indicates that some areas of the site will be subject to a rise in ground levels of between 2-3m, which will significantly increase the depth from proposed ground levels to competent strata. Where the depth to competent strata is greater than 2.0m, piled foundations may be the most economical foundation for new buildings in those areas.

13.4.42 Piled foundations should extend into the underlying Bee Low Limestone bedrock. The safe working load that may be supported on a pile is dependent on the pile diameter, its founding depth and the method of installation. As piles would be founded in bedrock, they will be essentially end bearing, although there may also be some shaft adhesion in the cohesive strata.

13.4.43 Given the likely placement of significant depths of cohesive made ground beneath parts of the site, it is essential that pile design allows for downdrag (negative skin friction).

13.4.44 Driven piles may lessen the volume of potentially contaminated made ground requiring off-site disposal (cf arisings associated with say trench fill). However, driving can induce some ground vibration. Assessment of any vibration risk to adjacent structures and/or existing site features should be undertaken by pile designer.

13.4.45 For piled foundations suspended floor slabs should be utilised. A pre-cast 'Beam and Block' concrete ground floor construction could be utilised, and suspended across the ring beams. A proprietary driven piling system, incorporating ring beams and pre-cast concrete ground floor construction could be considered for this development.

13.4.46 Ground conditions at this site are considered likely to require provision of a piling mat (working platform) and further advice should be sought from the appointed specialist-piling contractor regarding the proposed plant loadings and resulting pressures. This data, together with a knowledge of the strength and variability of the near-surface ground conditions is required in order that design of a mat can be undertaken in accordance with guidance provided in the 2004 BRE document, "*BR 470: Working platforms for tracked plant*".

13.4.47 The design of working platforms for tracked plant is a geotechnical design process and should be carried out by a competent person. The following parties should have input into the design:

- Permanent works designer, to consider additional uses for platform material as part of the overall development
- Principal contractor, to define any other purposes for which the platform might be used
- Contractor or subcontractor, to specify requirements for the platform, including gradients, ramps and edges

13.4.48 The number of plots affected by piling will depend on final layout proposals, however, considering Barratt Homes Drawing No.BUX/ED/04, it could affect approximately 25% of the total number.

13.4.49 Piles can provide an enhanced pathway for the vertical migration of mobile contaminants. The Environment Agency may therefore object to the adoption of piles as a foundation solution. However, objection is considered unlikely given that, no buildings will be situated within the former backfilled quarry, and the limited nature and extent of the contamination encountered.

13.5 Excavations

13.5.1 Based on the results of the investigations it is unlikely that major groundwater flows will be encountered in shallow excavations. However, shallow excavations terminating within the Completely Weathered Limestone would have a tendency to hold surface waters during periods of rainfall, as such, provision should be made for the dewatering of foundation and service trench excavations. The extent to which dewatering of excavations will be required will, in part, depend on the time of year and preceding and prevailing weather conditions at the time of development works.

13.5.2 Excavations within made ground materials (i.e. regrade infill beneath house plots) would be expected to be unstable and will require shoring, whereas excavations in natural ground should remain stable in the short term but if left open for any significant period of time, may require shoring.

13.5.3 The completely weathered strata be excavated as a residual soil (sandy silty clay).

13.5.4 Excavations within the Moderately Weathered Limestone rock strata will be expected to be difficult. As such, it would be prudent to allow for excavation of hard rock in all excavations, which will require the use of pointed hydraulic breaker tools to excavate the limestone in trench excavations and ripping may be required in more open excavations.

13.5.5 Excavations within the Moderately Weathered Miller's Dale Lava will be relatively easy, with these strata likely to be readily excavated by a typical backhoe excavator.

13.5.6 Drawing No. 30156/A/7 in Appendix B presents the approximate levels of rockhead observed within the site.

13.5.7 Drawing No. 30156/A/8 in Appendix B presents a plot of the estimated compressive strength of the moderately weathered limestone strata, and moderately weathered Miller's Dale Lava, against the stratum discontinuity spacing to provide a general assessment of the 'excavatability'.

13.6 Drainage

13.6.1 The majority of site is underlain at shallow depth (average depth 1mbegl) by Moderately Weathered Bee Low Limestone rock. In-situ soakaway tests performed by GRM as part of their 2015 investigation, and ALM as part of this study, indicate that the in-situ limestone rock possesses an infiltration rate that would make the use of soakaways as part of a sustainable surface water management system feasible. The 'soil infiltration rates' measured at the site by GRM and ALM varied between 1.2×10^{-4} and 2.7×10^{-3} m/s (average soil infiltration rate = 9.46×10^{-4} m/s)

13.6.2 The measured soil infiltration rates were dictated by the presence of fractures within the rock and also the presence of weathered clay infill within rock discontinuities.

13.6.3 It should be noted that the site is located within a Groundwater Source Protection Zone (Inner Protection Zone I) with respect to potable water abstractions and water abstractions for public amenity use which are of major significance in the area. Therefore, consultations should be held with the Environment Agency with respect to confirming their acceptance for the use of soakaway drainage and determining the requirements for any precautions required, such as the use of oil/water interceptors. Oil/water interceptors are likely to be required for soakaways for highway drainage. The highway adopting authority should be consulted at the earliest opportunity regarding the use of soakaways for highway drainage.

13.6.4 All soakaways should be designed in accordance with BRE Digest 365 "Soakaway Design".

13.6.5 It is recommended that Barratt Homes Manchester contact Severn Trent Water Limited with respect to identifying the capacity in existing foul and surface water sewers and in the vicinity of the development area.

13.7 Highways

13.7.1 Where the Completely Weathered Bee Low Limestone and Completely Weathered Miller's Dale Lava (clay) strata are exposed at road formation level and are to be used as road subgrade, these strata should first be proof rolled and any soft spots removed and replaced with suitable engineered fill.

13.7.2 Based on visual inspection of the natural materials and the recorded plasticity indices at the site, published tables (Highways Agency 'Design Manual for Roads and Bridges' – Volume 7, Section 2 – Design Guidance for Road Pavement Foundations Interim Advice Note 73/06, 2009) indicate that the Completely Weathered Limestone and Completely Weathered Miller's Dale Lava strata could be expected to have a CBR value of at least 3%.

13.7.3 Laboratory CBR tests on 2No. remoulded samples indicate a design CBR of 0.7% following re-compaction of the natural Completely Weathered Limestone materials, and 5.2% following re-compaction of the natural Completely Weathered Millers Dale Lava materials. Actual CBR values should be verified prior to or during road/pavement construction.

13.7.4 The un-numbered 'Sketch Layout Plan' for the site indicates a proposed road crossing the area underlain by the former infilled quarry beneath the northeast of the site. Where the proposed roadway crosses the 'high wall' of the former quarry there is significant potential for differential settlement to occur. Therefore, appropriate design measures should be adopted in order to mitigate against potential differential settlements along the proposed road in this part of the site. Such measures may include the inclusion of an appropriate geotextile/geogrid within the road construction.

13.7.5 Road construction in areas underlain by Miller's Dale Lava strata should incorporate a geotextile/geogrid within the construction in order to mitigate against any potential instability associated with the possible presence of voids beneath that part of the site.

13.7.6 The adopting authority should be consulted at the earliest opportunity to confirm any local requirements regarding sub grade requirements. Incorporation of a biaxial geogrid into sub-base layers may allow for reduced capping thickness.

13.8 External Works

13.8.1 Based on cut/fill levels presented on Barratt Homes Drawing No.BUX/ED/04, it is anticipated that retaining wall structures will be required to be constructed at various locations across the site.

13.8.2 As with proposed buildings and roads, the design of retaining wall structures in areas underlain by Miller's Dale Lava strata should incorporate an appropriate design in order to mitigate against any potential instability associated with potential voids beneath that part of the site. It is recommended that a structural engineer be consulted at an early stage with respect to the design of these structures and to identify any preparatory foundation works that will be required to be carried out during site regrading operations.

14 REDEVELOPMENT ISSUES

14.1 General

14.1.1 This report has presented options with respect to foundation solutions, treatment of contamination etc. that are considered technically feasible and in line with current good practice. Consequently, we would expect to obtain regulatory approval for whichever option is adopted, although this cannot be guaranteed. Copies of this report should be forwarded to the relevant regulatory authorities (NHBC & Local Authority) for their comment/approval.

14.2 Enabling / Earth Works Strategy

14.2.1 Redevelopment of this site may be subject to planning conditions relating to remediation and validation. Once a specific, preferred development strategy has been decided, ALM could liaise with local Planning Authority and NHBC and prepare an Enabling Works Strategy document for approval.

14.2.2 The Enabling Works/Remediation Strategy document would include:

- General background information, including site location, site description and a summary of ground investigation data
- An overview of existing constraints on development and the aims of the proposed Remediation works
- Specific details of the anticipated site Remediation/preparatory works
- Details of site supervision and verification
- A summary of implications for redevelopment

14.2.3 The anticipated enabling works are summarised below:

- Identification/fencing of existing trees that are to be retained and protected.
- Identification of the location of existing live services present within the site.
- Clearance of pre-existing vegetation and removal of any unprotected trees.
- General site clearance.
- Strip existing natural and 'reworked' topsoil materials and relocate to stockpiles in accordance with DEFRA '*Construction Code of Practice for the Sustainable Use of Soils on Construction Sites*' (2009) for subsequent reuse in garden and landscaped areas.
- Excavation of ash/clinker made ground noted in GRM Trial Pit TP23, and stockpiling on site prior to disposal off site or relocation beneath roads, hardstand or a minimum 600mm clean soil cover, but not beneath proposed buildings due to slightly elevated naphthalene concentrations.
- Undertake phased regrading of the site to appropriate lines and levels to achieve finalised development levels. Earthworks associated with the regrading operation may require to use of lime stabilisation techniques to permit optimum compaction of the completely weathered limestone strata beneath house plots and/or adoptable roads.
- Preparation of the footprint to any proposed buildings scheduled to adopt raft foundations, and subsequent re-engineering of suitable soils to form the subgrade to the raft.
- The crushing and screening of rock arisings derived from site regrading works and/or foundation excavations, to form a suitable grade of aggregate for re-use within the proposed development.
- Prepare adoptable road footprints using selected granular materials (reengineered to specification).

- Placement of a suitable minimum 600mm soil cover layer (150mm subsoil/450mm topsoil) in proposed garden areas to plots that possess any residual made ground at surface, or 1m of soil cover above quarry fill where these soils remain beneath proposed garden and landscaped areas. Elsewhere, placement of site won subsoil and topsoil materials in garden and landscaped areas
- Supervision of the works by a suitably qualified consultant to include detailed records, testing requirements, where required etc.
- Validation of the site preparatory works in the form of a detailed Completion Statement confirming that the works set out in this document and any subsequent remediation/earthworks strategy, have been completed and that the site is suitable for its intended use.

14.2.4 It is recommended that any earthworks strategy includes a volumetric assessment of the anticipated earthworks and types of materials to be used to create a sustainable development scheme, and a suitable development platform to required finished development levels.

14.2.5 The finalised earthworks strategy would be required to be documented within a detailed 'Materials Management Plan' prepared in accordance with CL:AIRE *'Definition of Waste: Development Industry Code of Practice Version 2'* (March 2011).

14.3 Health & Safety Issues - Construction Workers

14.3.1 Localised made ground materials have been identified within the proposed development boundary, however, some of this made ground (i.e. ash/clinker and quarry infill) contains contaminants at concentrations above the guidance threshold values for an end use that includes domestic gardens. Workers involved in excavations for foundations, drainage, utilities etc. are likely to come into direct contact with the made ground, where present.

14.3.2 Although workers will only be exposed to the contaminated soil for a relatively short time, the contaminants represent a risk, and simple precautionary measures are required, i.e. good personal hygiene and basic personnel protective equipment.

14.3.3 Consequently, during the remediation and construction phases of the site development it will be necessary to protect the health and safety of site personnel. General guidance on these matters is given in the Health and Safety Executive (HSE) document "Protection of Workers and the General Public during the Redevelopment of Contaminated Land". In summary, the following measures are suggested to provide a minimum level of protection:

- All ground workers should be issued with protective clothing, footwear and gloves. Personnel should be instructed in why and how they are to be used.
- Hand-washing and boot-washing facilities.
- Good practices relating to personal hygiene should be adopted on the site.
- The contractor should satisfy the Health & Safety Executive with regard to any other matters concerning the health, safety and welfare of persons on the site.

14.3.4 Access into excavations etc. must be controlled and only undertaken in accordance with the Confined Spaces Regulations 1997. The atmosphere in all trenches should be monitored for oxygen and hazardous gas (methane & carbon dioxide), prior to personnel entering such excavations. Monitoring should continue whilst personnel are working in excavations.

14.3.5 Before site operations are started, the necessary COSHH statements and Health & Safety Plan should be drafted in accordance with the CDM regulations.

14.4 Control of Excavation Arisings

14.4.1 Excavations into ash/clinker made ground and quarry fill materials, are likely to yield contaminated arisings. Localised natural Millers Dale Lava strata in TP126 exhibited slightly elevated concentrations of nickel, and should be subject to further chemical analysis if excavated and/or placed near to the surface of the site.

14.4.2 The groundworker should carefully segregate (and stockpile separately) made ground arisings from arisings of "clean" natural soils, in order that an excessive volume of unsuitable material is not generated.

14.4.3 Made ground arisings that have been shown to contain elevated concentrations of contaminants could be:

- Redistributed beneath areas of hardstanding, where they would be satisfactorily isolated from end users. This option should not be used beneath buildings if the made ground contains volatile compounds, or beneath roads/pavement if the made ground contains asbestos.
- Isolated beneath the 600mm thick clean soil cover layer in garden or landscaped areas, or a 1m thick soil layer where the made ground contains asbestos fibres.
- Exported from site to a suitably licensed landfill facility.

14.5 New Utilities

14.5.1 It is anticipated that new utilities will be lain within natural uncontaminated strata beneath the site. However, where proposed roads pass over the infilled quarry in the northeast of the site, it is recommended that trenches for services including site drainage and water supply should be cut over size in order to allow site workers to conduct any future works in clean materials in that area of the site.

14.5.2 Depending on the depth of placement, an increased specification of water supply pipe may be necessary where the pipe passes through areas underlain by quarry infill or ash/clinker made ground.

14.5.3 It is recommended that all statutory service bodies are consulted at an early stage with respect to the ground conditions within which they will lay services in order to assess at an early stage any potential abnormal costs.

14.5.4 Given the nature of the ground conditions identified, it is not anticipated that Severn Trent Water Limited will require contamination resistant water supply pipework to be used in the proposed development. However, the findings of this ground investigation should be submitted to Severn Trent Water Limited for their review, once development proposals have been finalised.

14.6 Potential Development Constraints

14.6.1 Existing 11kV electricity cables and water main enter the southeast of the site, before passing along the boundary with the adjacent playing field, crossing the north of the site, and exiting at the northern boundary. The approximate alignments of these live services are indicatively shown on Drawing No. 30156/A/2 in Appendix B.

14.6.2 The lines of these live services will have a significant impact on the plot layout at the site. Consultations should be held at an early stage with the relevant utility company, in order to ascertain the potential to re-align these live services, and the associated costs. Alternatively, consultations should seek to ascertain restrictions with respect to development in the vicinity of the live services and the easements required.

14.6.3 The site is underlain by shallow rock, the depth to which is typically 1mbegl, becoming slightly deeper to the northwest (see Drawing No. 30156/A/7 in Appendix B). It is recommended that, where practical, foundations utilise the rock as the founding stratum. Cut/fill levels shown on Barratt Homes Drawing No.BUX/ED/04 are likely to require significant excavations within bedrock to form development platforms, which will be difficult within the Moderately Weathered Bee Low Limestone. The appointed groundworker will therefore be required to utilise rock breaking equipment in the form of hydraulic breakers and rippers during site regrading works and/or during the construction of foundations. Crushing and screening of rock arisings will generate aggregate, which (subject to confirmatory testing) should be suitable for use as unbound pavement materials within the highways.

15 SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

15.1 General

15.1.1 ALM were commissioned to carry out a Supplementary Geoenvironmental Appraisal of land to the northeast of Burlow Road, Harpur Hill, Buxton, in the context of the proposed development of the site for low rise residential housing.

15.1.2 The site is referred to as the 'Northern Site, or 'Site A', which is an irregular shaped parcel of land covering and area of approximately 6.17 hectares, which is located ca.3km to the south of Buxton town centre.

15.1.3 The primary aims of this 'supplementary' phase of investigation were to review the findings of the previous Desk Study and Ground Investigation works, including work undertaken by GRM Development Solutions in 2013 & 2015 and to carry out further investigation works, principally in order to:

- Confirm ground conditions beneath the site to provide further recommendations with respect to foundations for proposed structures.
- Confirm the location of 'Quarry High Walls' inferred to the present within the northeast of the site on historical plans.
- Inspect possible locations of potential dissolution features identified by previous ground investigation and geophysical surveys in the northwest of the site.
- Undertake additional sampling and chemical and geotechnical analysis of topsoil materials and natural strata to further assess their potential for re-use within the proposed development.
- Undertake an assessment of the depth of rock strata to assist in the formulation of a site regrading scheme and to further assess the 'excavatability' of the rock strata with respect to the site regrade works and proposed foundation/service trenches.
- Undertake in-situ soakaway tests in the vicinity of proposed surface water drainage ponds.

15.1.4 The 'supplementary' investigation works have been designed to supplement, and be consolidated with, the findings of the previous investigations, to confirm and identify salient geoenvironmental issues affecting the site to enable the Client to obtain budget costs for the necessary site preparatory and remediation works.

15.1.5 The ALM supplementary ground investigation comprised the excavation of 54No. Trial Pits and 7No. Windowless Sample Boreholes, with in-situ soakaway tests conducted in two of the Trial Pits. Selected soil samples retrieved during the supplementary ground investigation have been subject to appropriate chemical and geotechnical analysis.

15.1.6 Historical maps indicate that the site is predominantly 'Greenfield' in nature and has remained in agricultural use since at least the mid 19th Century. However, a large limestone quarry (former Burlow Works) historically located immediately to the northeast of the site, extended a short distance (circa 25m) into the site during the mid 20th Century, which has since been infilled/restored.

15.1.7 The ground investigations have identified the presence of localised areas of made ground associated with the former infilled quarry in the east and an infilled possible dissolution feature in the northwest of the site. Quarry infill generally comprised organic sandy clays with gravel and cobbles of limestone, concrete, brick and slate, which extended to a depth in excess of 7.2m within the former quarry area. The quarry infill was generally overlain by reworked topsoil and clay that cover the former quarry fill and also locally overly a relic topsoil horizon. Ash/clinker deposits have been locally recorded to shallow depth in the vicinity of the former quarry, and may be associated with stockpiling of fill materials prior to deposition into the former quarry. Cohesive made ground with occasional concrete, brick, rope and glass, has been reported to a depth in excess of 2.3m in a location indicated by the farmer to have required periodic infill due to subsidence, which may relate to a possible dissolution feature.

15.1.8 A general thickness of 0.3m of clayey topsoil is recorded across the whole of the study site, becoming slightly thinner (0.2m) in the northwest. The topsoil overlies orange brown silty clays that are interpreted as completely weathered bedrock, which were recorded to average depths between 0.91m in the southeast to an average depth of 1.07m in the northwest.

15.1.9 The Completely Weathered strata are underlain by either Moderately Weathered Bee Low Limestone Strata, recorded as strong to very strong pale grey fine grained thinly to medium bedded LIMESTONE, or Moderately Weathered Miller's Dale Lava, recorded as moderately weak purple brown mottled grey very sandy gravelly cobbley clay, with gravel and cobbles of volcanic tuff or amygdaloidal basalt. The sub-horizontal bedding surfaces within the upper surfaces of the limestone strata were observed to be weathered and discontinuities were observed to be filled with soft brown clay.

15.1.10 The change from Completely to Moderately Weathered Bee Low Limestone was noted to be very abrupt, with the Moderately Weathered Limestone strata (in-situ rock) proving very difficult to excavate. The trial pits were forced to be terminated ca. 0.2-0.5m into this stratum with the rock being excavated as angular cobbles and boulders. The change from Completely Weathered Moderately Weathered Miller's Dale Lava was less marked, with Moderately Weathered Miller's Dale Lava being relatively easy to excavate.

15.1.11 No groundwater was encountered during either the GRM or ALM investigations.

15.2 Hazardous Gas

15.2.1 The site is located in an area where full radon protective measures are required for new buildings. Not withstanding this, the presence of an infilled former quarry within and immediately to the northeast of the site, required that this potential source of ground gas be characterised by the emplacement of gas/groundwater monitoring wells and a programme of gas monitoring.

15.2.2 Initial gas monitoring undertaken by GRM in 2013 encountered methane concentrations of up to 1.4%, and carbon dioxide concentrations up to 15% during four monitoring visits to five monitoring wells drilled within and immediately surrounding the former quarry area. A single elevated gas flow rate of 27.9ltr/hr was noted in one monitoring well on one occasion, with no other gas flow rates being recorded. A further 8No. monitoring wells drilled across the site as part of the GRM 2015 investigation, did not record any methane concentrations and generally <2% carbon dioxide, with no gas flow rates during two monitoring visits.

15.2.3 GRM discounted the single high gas flow reading as being not typical or reasonable and calculated a Characteristic Situation 2 / AMBER 1 gas regime for methane, and a Characteristic Situation 2 / AMBER 2 gas regime for carbon dioxide, with the latter considered suitable for proposed new low-rise housing at the site with respect to the ground gases detected and in view of the fact that the site is located in an area where full radon gas protection measures would be required for new buildings.

15.2.4 Four gas monitoring visits undertaken to date by ALM, have recorded methane concentrations up to 4.8% and carbon dioxide concentrations up to 8.7%, in WSA101 and WSA102, which were located within the former infilled quarry and encountered slightly organic made ground to depths of >7.2m and 5.8m respectively.

15.2.5 WSA106, also located within the former infilled quarry, but within shallower less organic fill, also recorded a slightly elevated concentration of methane up to 1.5%.

15.2.6 No other elevated concentrations of methane (>1%) and carbon dioxide (>5%) have recorded within the ALM monitoring wells to date.

15.2.7 No gas flow rates were recorded in any of the four visits undertaken by ALM to date.

15.2.8 Calculated worst case Gas Screening Values (GSV's) for WSA101, which exhibited the highest concentrations of ground gas, correspond to a GREEN/Characteristic Situation 1 gas regime (CIRIA C665). However, the gas regime should be upgraded to AMBER 1/Characteristic Situation 2 in light of the exceedances of the typical maximum concentrations (>1% CH4 and >5% CO2) for these gas regimes.

15.2.9 Therefore, the gas exclusion measures adopted for radon protective measures should also satisfy the requirements for an AMBER 1 / Characteristic Situation 2 gas regime.

15.3 Mining and Quarrying

15.3.1 The site is not in an area that has historically been mined for coal.

15.3.2 Historical Ordnance Survey maps indicate the presence of a number of quarries both within, and within the vicinity of the site, which have been worked for limestone, the nearest being the former quarry (Burlow Works), which is located immediately to the northeast of the site, and extends approximately 25m into the northwest of the site. This former quarry has since been infilled/restored, a process which is currently ongoing to the northeast of the site.

15.3.3 Other small quarries are located sporadically around the local area, within 1km of the site, with large scale quarrying activity has historically taken place at Harpur Hill ca. 250m to the west of the site and historical and current quarrying activity takes place at Hillhead Quarry ca. 1km to the south.

15.3.4 A mineral desk study undertaken by Wardell Armstrong LLP in 2014, concluded that mineral abstraction prior to development of the site would not be practical or environmentally acceptable due to the nearby presence of existing residential development, and the location of the site within a Groundwater Source Protection Zone 1.

15.4 Contamination & Remediation

15.4.1 Elevated concentrations of metals, water soluble, naphthalene and benzo(a)pyrene have been recorded in a sample of ash/clinker made ground from beneath the east of the site (GRM TP23). The ash/clinker made ground appears localised and extended to a depth of 0.8m. The ash/clinker made ground in this location is considered unsuitable for retention at the surface in private garden and landscaped areas, and is also considered unsuitable for retention beneath proposed buildings due to elevated naphthalene. Therefore, the ash/clinker should be either excavated and removed/disposed of from site, or relocated beneath roads/pavements or a minimum 600mm clean soil cover in private garden and landscaped areas.

15.4.2 Asbestos fibres, elevated concentrations of benzo(a)pyrene and SVOC's have been recorded in samples of quarry infill beneath the northeast of the site. The quarry fill made ground is therefore considered unsuitable for retention at the surface in private garden and landscaped areas. Where necessary, the quarry fill should be excavated and removed/disposed of from site, or relocated beneath buildings/hardcover or a minimum 1m clean soil cover in private garden and landscaped areas.

15.4.3 Where the quarry fill soils require excavation (i.e. where they are within 1m of the surface beneath garden and landscaped areas or beneath proposed road footprints where they will likely be disturbed by sewer excavations), care should be taken to segregate and isolate any soil arisings, so as not to cross contaminate the surface of the site or any other stockpiled soils.

15.4.4 The elevated nickel content recorded in natural strata in TPA126, is considered unusual, however, it would be prudent to conduct further chemical analysis on these strata arising from any reduced level dig in this part of the site, in order to prove the suitability of these strata for re-use as near surface fill beneath private garden areas in other parts of the site.

15.4.5 It is considered that the natural topsoil subsoil (silty clays) present beneath site are considered suitable for use within the proposed residential development in private garden areas.

15.5 Foundations

15.5.1 A combination of conventional strip/trench fill, piled and raft foundations should be considered for proposed new buildings at the site.

15.5.2 Weathered cohesive strata beneath the site could be considered to provide a suitable founding strata, depending on proposed loadings, with undrained shear strength values ranging between 39kN/m^2 and 71kN/m^2 (56.6kN/m^2 average) in the Completely Weathered Bee Low Limestone, and values ranging between 44kN/m^2 and 158kN/m^2 (78kN/m^2 average) in the Completely Weathered Miller's Dale Lava.

15.5.3 However, it may be preferable to seat foundations on the underlying bedrock, with the Moderately Weathered Bee Low Limestone strata expected to offer a nett allowable bearing pressure of in excess of 1,000kN/m^2 and the Moderately Weathered Millers Dale Lava strata expected to offer a nett allowable bearing pressure of in excess of 250kN/m^2.

15.5.4 Foundations on rock should be placed entirely on rock and not partially on rock and partially on residual soil. This may, depending on surface gradient of the rock strata, necessitate localised over-deepening of foundations and over-break of the rockhead will be anticipated for a number of house plots.

15.5.5 Due to variability in both the completely weathered strata and the moderately weathered strata, reinforcement to all strip/trench fill foundations is recommended.

15.5.6 Due to proposed cut/fill levels being considered across the site, as presented on Barratt Homes Drawing No.BUX/ED/04, increases in ground level across parts of the site may result in piled foundations being the most economical foundation solution for proposed buildings in some parts of the site, notably in the northwest of the site. It is anticipated that piled foundations may be the most economical foundation solution were fill depths exceed 2.0m.

15.5.7 A single void was encountered in one trial pit excavated to the north of the site as part of the GRM ground investigation of 2015. The presence of the void, encountered in an area underlain by the weathered Miller's Dale Lava strata, prompted speculation that the void may be a result of a Palaeo-Karst surface on limestone strata underlying the Miller's Dale Lava strata. Elsewhere, a requirement to periodically infill a surface depression in the northwest of the site, was noted by GRM in their 2015 investigation, and ground investigation identified >2.3m of made ground at this location (GRMTP22). This may have resulted from the migration of weathered Miller's Dale Lava strata into possible underlying palaeo-karst void. No other evidence of voids was encountered in the GRM or ALM ground investigations.

15.5.8 However, the possible presence of voids associated with a palaeo-karst surface beneath the northwest of the site, cannot be discounted. If present beneath the site, the palaeo-karst related voids may be expected to be typically up to 30cm in diameter and 1m deep, although they are known to be up to 10m wide and deep and filled with collapsed lava and limestone boulders (Pavel Bosal et al eds., 1989, Elsevier).

15.5.9 Therefore, ALM consider it prudent to adopt raft foundations for proposed buildings that will overly the Miller's Dale Lava strata in the northwest of the site.

15.6 Flooding

15.6.1 The site is not located within a river floodplain that is prone to 1:100 and 1:1000 year flood events.

15.6.2 However, the south-eastern margins of the site are indicatively shown to be prone to medium (100 year recurrence interval) and low (1000 year recurrence interval) risk of flooding by surface waters.

15.7 Drainage & Highways

15.7.1 The majority of the site is underlain at shallow depth (average depth 1mbegl) by Moderately Weathered Bee Low Limestone rock. In-situ soakaway tests performed by GRM as part of their 2015 investigation, and ALM as part of this investigation, indicate that the in-situ limestone rock possesses an in situ infiltration rate that would make the use of soakaways as part of a sustainable surface water management system feasible.

15.7.2 The site is located within a Groundwater Source Protection Zone (Inner Protection Zone I) with respect to potable water abstractions and water abstractions for public amenity use which are of major significance in the area. Therefore, consultations should be held with the Environment Agency with respect to confirming their acceptance of the use of soakaway drainage. Oil/water interceptors are likely to be required for soakaways for highway drainage. The highway adopting authority should be consulted at the earliest opportunity regarding the use of soakaways for highway drainage.

15.7.3 It is recommended that Barratt Homes Manchester contact Severn Trent Water Limited with respect to identifying the capacity in existing foul and surface water sewers in the vicinity of the development area.

15.7.4 Where the Completely Weathered Limestone (clay) strata are exposed at road formation level and are to be used as road subgrade, these strata should first be proof rolled and any soft spots removed and replaced with suitable engineered fill.

15.7.5 Laboratory determined CBRs on remoulded samples of the Completely Weathered Bee Low Limestone and Moderately Weathered Millers Dale Lava strata, were recorded as 0.7% and 5.2% respectively. Therefore, it is apparent that re-compacted completely weathered strata will offer a less competent sub-grade than re-compacted moderately weathered strata. Actual in-situ CBR values should be verified prior to or during construction.

15.7.6 The adopting authority should be consulted at the earliest opportunity to confirm any local requirements regarding sub grade requirements. Incorporation of a biaxial geogrid into sub-base layers may allow for reduced capping thickness.

15.8 External Works

15.8.1 Based on cut/fill levels presented on Barratt Homes Drawing No.BUX/ED/04, it is anticipated that retaining wall structures will be required to be constructed at various locations across the site.

15.8.2 As with proposed buildings and roads, the design of retaining wall structures in areas underlain by Miller's Dale Lava strata should incorporate an appropriate design in order to mitigate against any potential instability associated with potential voids beneath that part of the site. It is recommended that a structural engineer be consulted at an early stage with respect to the design of these structures and to identify any preparatory foundation works that will be required to be carried out during site regrading operations.

15.9 Further Works

15.9.1 The following further works are recommended to be carried out:

- Consultations should be held at an early stage with Severn Trent Water Limited with respect to ascertaining the potential to re-align existing live services that are present within the eastern and northern parts of the site. Alternatively, consultations should seek to ascertain restrictions with respect to development in the vicinity of the live services and the easements required.
- Once the development layout and preferred development levels are finalised, a plot specific foundation appraisal should be undertaken in order to gauge the most economical foundation solutions for plots across the site, with regard to known ground conditions.
- It is recommended that an 'Enabling Works Strategy' be prepared to include a volumetric assessment of the anticipated earthworks and types of materials to be used to create a sustainable development scheme, and a suitable development platform to required finished development levels.
- The finalised earthworks strategy would be required to be documented within a detailed 'Materials Management Plan' prepared and approved in accordance with CL:AIRE *'Definition of Waste: Development Industry Code of Practice Version 2'* (March 2011).

APPENDIX A

General Notes

Generic Notes – ALM Geoenvironmental Investigations

01 - Environmental Setting

General

Third party information obtained from the British Geological Survey (BGS), the Coal Authority, the Local Authority etc is presented in the Correspondence Appendix of this Geoenvironmental Report.

Geology, Mining & Quarrying

In order to establish the geological setting of a site, ALM refer to BGS maps for the area, and the relevant geological memoir.

Borehole records held within the BGS archive are additionally obtained where such records are available or are considered relevant to the study site. It should be noted that the exact locations of boreholes held within the BGS archive are not always known and the quality of information presented within the borehole records may vary, depending on the age and nature of the borehole record and the reason for why the borehole was drilled.

A coal mining report is obtained from the Coal Authority where the study site is located within a Coal Authority Search Area. Further information is sourced from the Local Authority and by reference to current and historical OS plans.

Landfills

ALM obtain data from the Landmark Information Group/Emapsite, the Environment Agency and the Local Authority with respect to known areas of landfilling within 250m of the proposed development site. Reference is also made to historical OS plans, which are inspected for evidence of backfilled quarries, railway cuttings, colliery spoil tips etc.

Radon

Radon is a colourless, odourless gas, which is radioactive. It is formed in strata that contain uranium and radium (most notably granite), and can move though fissures eventually discharging to atmosphere, or the spaces under and within buildings. Where radon occurs in high concentrations, it can pose a risk to health.

In order to assess potential risks associated with radon gas, ALM refer to BRE Report BR211, 2015: "*Radon: guidance on protective measures for new buildings*".

The level of protection needed is site-specific and is determined by reference to the maps contained in Annex A of BR211. These maps are derived from the Radon Atlas of England and Wales (2007), and indicate the highest radon potential within each 1km grid square.

If the site falls within a light grey square on the relevant map in Annex A then basic radon protection should be installed in new buildings; if the site falls within a dark grey square then full radon protection should be installed. **If the site is in an un-shaded square then no radon protection is needed.**

BR211 provides a preliminary indication of the measures required for a particular site, but it is also often beneficial to request a BR211 Radon Report from the BGS. The Annex A maps indicate the highest geological radon potential within each 1km grid square, but in many cases the radon potential varies considerably within the grid square. The BR211 Radon Report gives definitive guidance on the requirement for radon protective measures, and therefore may allow the adoption of a lower level of protection than that indicated in the Annex A maps.

ALM typically obtains a BR211 Radon Report for all sites that fall within a shaded square on the relevant Annex A map.

When requesting a BR211 Radon Report from the BGS ALM selects the search radius carefully, since too large a search radius may result in the inclusion of areas of higher geological radon potential, and therefore in the recommendation of too high a level of protection.

Further details of the protective measures required, if appropriate, are provided in the Hazardous Gas section of this Geoenvironmental Report.

Hydrogeology

ALM obtain information from the Environment Agency (EA) and the Landmark Information Group/Emapsite with respect to:

- groundwater quality
- recorded pollution incidents
- licensed groundwater abstractions

Reference is also made to the EA document "*Policy and Practice for the Protection of Groundwater*" (V1.1 August 2013) and the relevant Groundwater Vulnerability Map.

Since 1st April 2010 the Environment Agency's *Groundwater Protection Policy* uses aquifer designations that are consistent with the Water Framework Directive and represent a slight modification to those aquifer designations which have been used in the past. These new designations reflect the importance of aquifers in terms of groundwater as a resource (drinking water supply) but also their role in supporting surface water flows and wetland ecosystems.

The aquifer designation data is based on geological mapping provided by the British Geological Survey and will be updated from time to time based on the ongoing programme of improvements to these maps.

The Solid and any overlying Drift deposits are classified and defined by the Environment Agency as follows:

'Principal Aquifers' (formerly known as Major Aquifers):

"Layers of rock or drift deposits that have high intergranular and/or fracture permeability which can usually provide a high level of water storage. They may support water supply and/or river base flow on a strategic scale. In most cases, principal aquifers are aquifers previously designated as a major aquifer"

‘Secondary Aquifers’ (generally formerly known as Minor Aquifers):

These include wide range of rock layers or drift deposits with an equally wide range of water permeability and storage. Secondary Aquifers are sub-divided into two types:

- **Secondary A**: *“Permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers. These are generally aquifers formerly classified as minor aquifers”.*

- **Secondary B**: *“Predominantly lower permeability layers which may store and yield limited amounts of groundwater due to localised features such as fissures, thin permeable horizons and weathering. These are generally the water-bearing parts of layers formally classifies as non-aquifers”*

- **Secondary Undifferentiated**: *“Layers of rock or drift where it has not been possible to attribute either Secondary A and Secondary B classification. This means that the layer in question has previously been designated as both minor and non-aquifer in different locations due to variable characteristics of the rock or drift type”*

‘Unproductive Strata’ (formerly known as Non-aquifers):

“*These are rock layers or drift deposits with low permeability that have negligible significance for water supply or river base flow”.* NB: Groundwater flow through Unproductive Strata although imperceptible, does take place and needs to be considered in assessing the risk associated with persistent pollutants. Some non-aquifers can yield water in sufficient quantities for domestic use.

Groundwater vulnerability is determined by 4 variables:

1. The presence and nature of overlying soil (the weathered zone affected by living organisms; soil in the UK can extend up to 2m in depth). Physical properties of the soil affect the downward passage of water and it’s ability to attenuate pollutants. The EA make reference to a three-fold classification of soil types:-

   - Soils of **low** leaching potential are defined as *“soils in which the pollutants are unlikely to penetrate the soil layer because either water movement is largely horizontal, or they have the ability to attenuate diffuse pollutants”.*

   - Soils of **intermediate** leaching potential are defined as *“soils which have a moderate ability to attenuate diffuse source pollutants or in which it is possible that some nonadsorbed diffuse source pollutants and liquid discharges could penetrate the soil layer”.*

   - Soils of **high** leaching potential are defined as *“soils with little ability to attenuate diffuse source pollutants and in which non-adsorbed diffuse source pollutants and liquid discharges have the potential to move rapidly to underlying strata or to shallow groundwater”.*

In urban areas and restored mineral workings the soil information is based on fewer observations than elsewhere. A worst-case vulnerability (H) is therefore assumed for these areas and for current mineral workings by the EA. All are given a designation of **HU** unless proved otherwise.

2. The presence and nature of Drift, which often overlies bedrock. Where Drift is of substantial thickness and low permeability, it can provide an effective barrier to surface pollutant migration. Permeable Drift is classified as a Minor Aquifer except where it is in probable hydraulic continuity with a Major Aquifer, where it is regarded as part of the Major Aquifer unless proven otherwise by site investigation.

3. The nature of the geological strata (bedrock). Rocks that contain groundwater in exploitable quantities are called aquifers.

4. The depth of the unsaturated zone; i.e. that part of the aquifer which lies above the water Table The EA have also designated Source Protection Zones, which are based on proximity to a groundwater source (springs, wells and abstraction boreholes). The size of a Source Protection Zone is a function of the aquifer, volume of groundwater abstracted, groundwater flow travel times and the effective rainfall, and may vary from tens to several thousand hectares.

Hydrology

ALM obtains information from the Environment Agency and the Landmark Information Group/Emapsite with respect to:

- surface water quality
- recorded pollution incidents
- licensed abstractions (groundwater & surface waters)
- licensed discharge consents
- site susceptibility to flooding

The EA have set **water quality** targets for all rivers. These targets are known as River Quality Objectives (RQOs). The water quality classification scheme used to set RQO planning targets is known as the River Ecosystem scheme. The scheme comprises five classes (RE1 to RE5) which reflect the chemical quality requirements of communities of plants and animals occurring in our rivers.

General Quality Assessment (GQA) grades reflect actual water quality. They are based on the most recent analytical testing undertaken by the EA. There are six GQA grades (denoted A to F) defined by the concentrations of biochemical oxygen demand, total ammonia and dissolved oxygen.

The susceptibility of a site to **flooding** is assessed by reference to a Flood Map on the Environment Agency's website. These maps provide show natural floodplains - areas potentially at risk of flooding if a river rises above its banks, or high tides and stormy seas cause flooding in coastal areas.

There are two different kinds of area shown on the Flood Map:

1. Dark blue areas could be flooded by the sea by a flood that has a 0.5% (1 in 200) or greater chance of happening each year, or by a river by a flood that has a 1% (1 in 100) or greater chance of happening each year

2. Light blue areas show the additional extent of an extreme flood from rivers or the sea. These outlying areas are likely to be affected by a major flood, with up to a 0.1% (1 in 1000) chance of occurring each year.

These two colours show the extent of the natural floodplain if there were no flood defences or certain other manmade structures and channel improvements.

The maps also show all flood defences built in the last five years to protect against river floods with a 1% (1 in 100) chance of happening each year, or floods from the sea with a 0.5% (1 in 200) chance of happening each year, together with some, but not all, older defences and defences which protect against smaller floods.

The Agency's assessment of the likelihood of flooding from rivers and the sea at any location is based on the presence and effect of all flood defences, predicted flood levels, and ground levels.

It should also be noted that as the floodplain shown is the 1 in 100 year (or 1 in 200 year as appropriate), areas outside this may be flooded by more extreme floods (e.g. the 1 in 1000 year flood). Also, parts of the areas shown at risk of flooding will be flooded by lesser floods (e.g. the 1 in 5 year flood). In some places due to the shape of the river valley, the smaller floods will flood a very similar extent to larger floods but to a lesser depth.

If a site falls within a floodplain, it is recommended that a flood survey be undertaken by a specialist consultant who can advise on appropriate mitigating measures; i.e. raising slab levels, provision of storage etc.

COMAH & Explosive Sites

ALM obtain information from the Landmark Information Group with respect to COMAH or explosive sites within 1km of the proposed development site. ALM's report refers to any that are present, and recommends that the Client seeks further advice from the HSE.

Areas around COMAH sites (chemical plants etc) are zoned with respect to the implementation of emergency plans. The HSE are a statutory consultee to the local planning authority for all COMAH sites. The COMAH site may have to revise it's emergency action plan if development occurs. This might be quite straightforward or could entail significant expenditure. Consequently, the COMAH site may object to a proposed development (although it is the Local Authority who have final say, and they are likely to place more weight on advice from the HSE).

Preliminary Conceptual Ground Model

The site's environmental setting (and proposed end use) is used by ALM to assess the significance of any contamination encountered during the subsequent ground investigation.

Assessment of contaminated land is based on an evaluation of pollutant linkages (source-pathway-receptor). Contaminants within the near surface strata represent a potential source of pollution. The environment (most notably groundwater), site workers and end users are potential targets.

Potential pollutant linkages are shown on a preliminary conceptual site model, presented as a Drawing in an Appendix to this Geoenvironmental Report. The preliminary model is revised in light of data arising from the subsequent ground investigation.

Generic Notes – ALM Geoenvironmental Investigations

02 - Ground Investigation Fieldwork

General

ALM Ground Investigations are undertaken in accordance with current UK guidance including:

- BS5930:2015 "*Code of practice for ground investigation*"
- BS10175:2013 "*Code of practice for the identification of potentially contaminated sites*".
- "*Technical Aspects of Site Investigation*" – EA R&D Technical Report P5-065/TR (2000)
- "*Development of appropriate soil sampling strategies for land contamination*" – EA R&D Technical Report P5-066/TR (2001)
- Contaminated Land Reports 1 to 6, most notably CLR Report No. 4 "*Sampling strategies for contaminated land*"
- "*Guidance on the protection of housing on contaminated land*" – NHBC & EA R&D Publication 66 (2000)
- AGS: 1996 "*Guide to the selection of Geotechnical Soil Laboratory Testing*"
- BS1377:1990 "*British Standard Methods of Test for Soils for Civil Engineering Purposes*"

Exploratory hole logs are presented in Appendices to this Geoenvironmental Report. These logs include details of the:

- Investigation technique adopted .
- Samples taken.
- Descriptions of the strata and any groundwater encountered.
- Results of any in-situ testing.
- Any gas\groundwater monitoring well installed.

Exploratory Hole Locations

Exploratory hole locations are selected by ALM prior to commencement of fieldwork to provide a representative view of the strata beneath the site and to target potential contaminant sources identified during the preliminary investigation (desk study). Additional exploratory locations are often determined by the site engineer in light of the ground conditions actually encountered; this enables better delineation of the depth and lateral extent of organic contamination, poor ground, relict structures etc.

Investigation Techniques

Ground conditions can be investigated by a number of techniques; the procedures used are in general accordance with BS5930:2015 and BS1377:1990. Techniques most commonly used by ALM include:

- Machine excavated trial pits, usually equipped with a backactor and a 0.6m wide bucket.
- Cable percussive (Shell & Auger) boreholes, typically using 150mm diameter tools and casing.

- Window or Windowless Sampling boreholes. Constraints associated with existing buildings, operations and underground service runs can render some sites partly or wholly inaccessible to a mechanical excavator. In such circumstances, window sampling is often the most appropriate technique. A window sampling drilling rig can be manoeuvred in areas of restricted access and results in minimal disturbance of the ground (a 150mm diameter tarmac/concrete core can be lifted and put to one side). However, it should be noted that window sampling allows only a limited inspection of the ground (especially made ground with a significant proportion of coarse material).
- Rotary percussive open-hole probeholes are typically drilled using a tricone rock roller bit with air as the flushing medium. Probeholes are generally lined through made ground with temporary steel casing to prevent hole collapse.

Where installed, gas\groundwater monitoring wells typically comprise a lower slotted section, surrounded by a filter pack of 10 mm non-calcareous gravel and an upper plain section surrounded in part by a bentonite seal and in part by gravel or arisings. The top of the plain pipe is cut off below ground level and the monitoring well protected by a square, stopcock type manhole cover set in concrete, or the plain pipe is cut off just above ground level and the well protected by 100mm diameter steel borehole helmet set in concrete.

Monitoring well details, including the location of the response zone and bentonite seal are presented on the relevant exploratory hole logs.

In-situ Testing

Where relative densities of granular materials given on the trial pit are based on visual inspection only, they do not relate to any specific bearing capacities. However, wherever possible ALM employ a Mackintosh probe to assess relative density. Mackintosh probe results can be related to approximate allowable bearing capacities.

The relative densities of granular materials encountered in cable percussive boreholes and window sample boreholes are based on Standard Penetration Test (SPT) results. SPT's are carried out in boreholes, in accordance with BS 1377:1990,:Part 9 Section 3.3. Where full penetration (600mm) is not possible, N values are calculated by linear extrapolation and are shown on the logs as N* = x.

The strength of cohesive deposits is determined using a hand shear vane.

Shear strength test results reported on trial pit logs are considered to be more reliable than those reported on window sample logs. Significant sample disturbance occurs during window sampling and consequently shear strength results on disturbed window samples are generally lower than results obtained during trial pitting, in-situ or in large excavated blocks.

Sampling

Representative soil/fill samples are taken at regular intervals from the exploratory holes to assist in description of the ground and to allow selected laboratory testing to be performed. The type of sample taken is dependent on the nature of the stratum and the purpose of the analysis.

Where the soils encountered contain a significant proportion of coarse grained material, truly representative samples are not typically obtained - only the finer fraction is placed in sample containers. However, a visual estimate of the amount of coarse material is made on site.

NB: Coarse constituents not sampled are defined as: coarse gravel, cobbles and boulders. (i.e. any 'particles' with an average diameter greater than 20mm).

Occasionally, unrepresentative 'spot' samples are also taken from some exploratory locations for contaminant analysis, typically where unusual, localised pockets of materials are encountered.

Samples of soil for chemical testing are placed into 1 litre plastic tubs prior to delivery to the selected laboratory. Samples of water are taken in one litre, brown glass bottles and stored in cool boxes, at a temperature of <5ºC, until delivery to the selected laboratory. Soil\fill samples for organic analysis are also stored in cool boxes.

Groundwater

Where encountered during fieldwork, groundwater is recorded on the exploratory hole log. If monitoring wells are installed, groundwater levels are also recorded on one or more occasions after completion of the fieldwork.

It should be borne in mind that the rapid excavation rates used during a ground investigation may not allow the establishment of equilibrium water levels. Water levels are likely to fluctuate with season/rainfall and could be substantially higher at wetter times of the year than those found during this investigation.

Long-term monitoring of standpipes or piezometers is always recommended if water levels are likely to have a significant effect on earthworks or foundation design.

Description of Strata

The soils encountered during an ALM ground investigation are described in general accordance with BS 5930. The descriptions and depth of strata encountered are presented on the exploratory hole logs and summarised in the Ground Conditions section within the main body of text.

The materials encountered in trial pits are logged, samples taken, and tests performed on the in-situ materials in the excavation faces, to depths of up to 1.2m; below this depth these operations are conducted at the surface on disturbed samples recovered from the excavation.

Key to Exploratory Hole Logs

Keys to logs are presented in the Appendix(ces) containing the logs. There are two Keys – Symbols & Legends and Terms & Definitions.

Generic Notes – ALM Geoenvironmental Investigations

03 - Geotechnical Laboratory Tests

General

Soil samples are delivered to the laboratory for testing along with a schedule of testing drawn up by ALM. All tests are carried out in accordance with BS 1377:1990.

The test results are presented as received in an Appendix to this Geoenvironmental Report.

The following laboratory tests are routinely carried out on a selection of samples:

- Atterberg limits (Plastic Limit, Liquid Limit, Plasticity Index) & Moisture Content
- Soluble sulphate & pH
- Quick Undrained Triaxial Shear Stength (on undisturbed 100mm diameter samples)

The additional tests are typically only scheduled where significant earthworks regrade is anticipated:

- Particle Size Distribution
- Five Point Compaction
- Particle Density
- California Bearing Ratio (CBR) on either undisturbed or re-compacted disturbed samples

Atterberg Limits & Moisture Content

The Liquid and Plastic Limits of samples of natural in-situ clay are determined using the cone penetrometer method and the rolling thread test. These tests enable determination of an average Plasticity Index (PI) for each "type" of clay, although judgement is applied where variable results are reported.

PI can be related to shrinkability (low, medium or high) and then to minimum founding depth. ALM typically only consider a soil to be shrinkable if the proportion finer than 63μm is >35%.

PI results are compared against guidance given in the NHBC Standards, Chapter 4.2 (revised April 2003), which advocates the use of modified Plasticity Index (I'p), defined as:

I'p = Ip * (%< 425μm/100)
i.e. if PI is 30%, but the soil contains 80% < 425μm, then: I'p = 30 * 80/100 = 24%.

It should be noted that in accordance with the requirements of BS 1377, the % passing the 425μm sieve is routinely reported by testing labs.

ALM apply engineering judgment where PI results are spread over a range of classifications. Consideration is given to:

- the average values for each particular soil type (i.e. differentiate between residual soil and alluvium),
- the number of results in each class and
- the actual values.

Unless the judgment strongly indicates otherwise, ALM typically adopt a conservative approach and recommend assumption of the higher classification.

Soluble Sulphate and pH

Sulphates in soil and groundwater are the chemical agents most likely to attack sub-surface concrete, resulting in expansion and softening of the concrete to a mush. Another common cause of concrete deterioration is groundwater acidity.

The rate of chemical attack depends on the concentration of aggressive ions and their replenishment at the reaction surface. The rate of replenishment is related to the presence and mobility of groundwater.

ALM refer to BRE Special Digest 1 (SD1) "*Concrete in aggressive ground. Part 1: Assessing the aggressive chemical environment*" (2001). SD 1 provides definitions of:

- the nature of the site (greenfield, brownfield or pyritic)
- the groundwater regime (static, mobile or highly mobile)
- the Design Sulphate Class (DC Class) and
- the Aggressive Chemical Environment for Concrete (ACEC Class)

ALM reports clearly state each of the above for the site being considered.

The concentrations of sulphate in aqueous soil/fill extracts are determined in the laboratory using the gravimetric method. The results are expressed in terms of SO_4 for direct comparison with BS 5328:1997. The pH value of each sample was determined by the electrometric method.

SD1 also discusses determination of "representative" sulphate concentration from a number of tests. Essentially if <10 samples of a given soil-type have been tested, the highest measured sulphate concentration should be taken. If >10 samples have been tested, the mean of the highest 20% of the sulphate test results can be taken. With respect to groundwater, the highest sulphate concentration should always be taken.

With respect to pH (soil & groundwater) the value used is the lowest value if <10 samples have been tested and the mean of the lowest 20% if >10 samples have been tested.

Generic Notes – ALM Geoenvironmental Investigations

4A. Contamination Laboratory Analysis & Interpretation (including WAC)

Waste Classification & Waste Acceptance Criteria (WAC)

In the context of waste soils generated by remediation and\or groundworks activities on brownfield sites, the following definitions (from the Landfill Regulations 2002) apply:

- Inert (e.g. uncontaminated 'natural' soil, bricks, concrete, tiles & ceramics).
- Non-Hazardous (e.g. soil excavated from a contaminated site which contains dangerous substances, but at concentrations below prescribed thresholds).
- Hazardous (e.g. soil excavated from a contaminated site which contains dangerous substances at concentrations above prescribed thresholds).

Dangerous substances include compounds containing a variety of determinants commonly found in contaminated soils on brownfield sites, for example arsenic, lead, chromium, benzene etc.

Since 16th July 2005, landfill operators require Waste Acceptance Criteria (WAC) laboratory data, if soil waste is classified as **hazardous**, and such waste must have been subjected to pre-treatment. However, subject to WAC testing it may be possible to classify it as stable, non-reactive hazardous waste, which can be placed within a dedicated cell within the non-hazardous landfill.

ALM typically only include WAC analysis in site investigation proposals and reports, if significant off-site disposal (of soil classified as hazardous waste) is anticipated, for example where redevelopment proposals include basement construction etc.

If off-site disposal of soils classified as hazardous waste were undertaken during redevelopment, then WAC analysis should be scheduled at an early stage in the remediation programme.

However, organic compounds (BTEX, TPH, PAH, asbestos etc) are the most common contaminants that result in soils being classed as hazardous. These contaminants can often be dealt with by alternative technologies (e.g. by bioremediation or stabilisation) and consequently retention on site is often possible.

It should be noted that **non-hazardous** soil waste can go to a non-hazardous landfill facility; no further testing (eg WAC) is required.

Contamination Laboratory Analysis & Interpretation

An assessment of potential contaminants associated with the former usages of the site is undertaken with reference to DEFRA/Environment Agency R&D Publication CLR8 "*Potential contaminants for the assessment of land*" (2002) and the relevant DETR/DoE Industry Profile(s), where published.

<u>Common Inorganic Contaminants</u>

These can include:

- metals, most notably cadmium, copper, chromium, mercury, lead, nickel, and zinc.
- semi-metals, most notably arsenic, selenium, and (water soluble) boron
- non-metals, most notably sulphur
- inorganic anions, most notably cyanides (free & complex), sulphates, sulphides, and nitrates.

With respect to the terminology used by most analytical laboratories:

Total cyanide = Free cyanide + Complex cyanide

Total cyanide (CN) is determined by acid extraction; whereas free cyanide is the water soluble fraction.

Complex cyanide is "bound" in compounds and is hard to breakdown. Laboratory determination of complex CN involves subjecting the sample to uv digestion for determination of both free and total CN.

Thiocyanate (SCN) is a different species combined with sulphur.

Elemental sulphur (S) and free sulphur are the same. Total sulphur is all forms, including that present in sulphates (SO_4), sulphides etc

There are 2 forms of chromium (Cr), chromium VI and chromium III. Chromium VI is the more toxic of these. In soils, total chromium is determined by a strong aqua regia acid digestion. Chromium VI is an empirical method based on a water extract test.

Common Organic Contaminants

Petroleum hydrocarbons are a mixture of hydrocarbons produced from the distillation of crude oil. They include aliphatics (alkanes, alkenes and cycloalkanes), aromatics (single or multi benzene ringed compounds) and hydrocarbon-like compounds containing minor amounts of oxygen, sulphur or nitrogen.

Petroleum hydrocarbons can be grouped based on the carbon number range:-

- GRO – Gasoline Range Organics (typically C_6 to C_{10}). Also commonly referred to as PRO – Petroleum Range Organics
- DRO – Diesel Range Organics (typically C_{10} to C_{28})
- LRO - Lubricating Oil Range Organics (typically C_{28} to C_{40})
- MRO – Mineral Oil Range Organics (typically C_{18} to C_{44})

However, it should be borne in mind that the terms "GRO", "DRO", "LRO" analysis are purely descriptive terms, the exact definition of which varies.

Total Petroleum Hydrocarbons (TPH) is also a poorly defined term; some testing laboratories regard TPH as hydrocarbons ranging from C_5-C_{44}, whereas others define TPH as C_{10}-C_{30}. TPH cannot be assessed as a single "total" value, and reference has been made to the Environment Agency's document P5-080/TR3, "*The UK approach for evaluating human health risks from petroleum hydrocarbons in soils*". This document supports the assumptions and recommendations made by the US Total Petroleum Hydrocarbons Criteria Working Group (TPHCWG). This approach is in line with the TPHCWG documents volumes 1(1), 2(2), 3(3) and 4(4).

The TPHCWG assessed "TPH" into thirteen representative constituent fractions or "Equivalent Carbon (EC) Bandings". EC Bandings are based around Equivalent Carbon numbers and the TPHCWG have derived a series of physiochemical and toxicological parameters for each of the thirteen EC bandings.

The composition of a TPH plume migrating through the ground can vary significantly; this is primarily dictated by the nature of the source (e.g. petrol, diesel, engine oil etc). Furthermore, different hydrocarbons are affected differently by weathering processes, and this can result in further variation in the chemical composition of the TPH.

Gasoline contains light aliphatic hydrocarbons (especially within the C_5 to C_{10} range) that will rapidly evaporate. The aromatic hydrocarbons in gasoline are primarily benzene, toluene, ethylbenzene and xylenes, referred to as BTEX that are relatively volatile and soluble. Small amounts of polyaromatic hydrocarbons (PAHs) such as naphthalene may also be present.

Diesel and light fuel oils have higher molecular weights than gasoline. Consequently, they are less volatile and less water soluble. About 25 to 35% of diesel/light fuel oil is composed of aromatic hydrocarbons. BTEX concentrations are generally low.

Heavy Fuel Oils are typically dark in colour and considerably more viscous than diesel. They contain 15 to 40% aromatic hydrocarbons. Polar nitrogen, sulphur and oxygen-containing compounds (NSO) compounds are also present.

Lubricating Oils are relatively viscous and relatively insoluble in groundwater. They may contain 10 to 30% aromatics, including the heavier PAHs. NSO compounds are also common.

Polycyclic Aromatic Hydrocarbons (PAHs) have more than two fused benzene rings as a structural characteristic. PAH compounds are present in both petrol and diesel, although in significantly lower concentrations than in coal tars and heavier oils. Certain PAH compounds are carcinogenic (e.g. benzo(a)pyrene) and\or more mobile in the environment (e.g. naphthalene). PAH cannot be assessed as a single "total" value, as each individual PAH compound has different toxicity and mobility in the environment. Speciated analysis is required to determine the concentrations of the various compounds, most notably the key PAHs: benzo(a)Pyrene (considered the most toxic of the PAHs); and naphthalene (the most mobile and volatile of the PAHs).

Volatile (& Semi) Organic Compounds (VOCs/SVOCs) include a variety of compounds which have relatively low boiling points. However, VOC's are much more volatile than SVOC's. Examples of VOC's include benzene, chloroform and trichloroethene (e.g. chlorinated solvents); SVOC's include phenol, fluorine and 'lighter' PAHs. Both groups of chemicals are readily absorbed through skin and some, such as benzene, are believed to be linked to tumour growth.

Phenols are compounds that have a hydroxyl group attached to an aromatic ring (i.e. include a benzene ring and an –OH group). Most are colourless solids. A solution of phenol in water is known as carbolic acid, and is a powerful antiseptic. However, phenol vapour is toxic, and skin contact can result in burns.

Polychlorinated Biphenyls (PCBs) were used in pre-1974 transformers as dielectric fluids. PCB's possess increasing toxicity relative to the degree of chlorination, they do not degrade in the environmental and can bio-accumulate. Acute symptoms of PCB poisoning are irritation of the respiratory tract leading to coughing and shortness of breath. Nausea, vomiting and abdominal pain are caused by ingestion of PCB's.

Dioxins and furans (polychlorinated dibenzodioxins and polychlorinated dibenzofurans) are some of the most toxic chemicals known. In the environment, they tend to bio-accumulate in the food chain. Dioxin is a general term that describes a group of hundreds of chemicals that are highly persistent in the environment. The most toxic compound is 2,3,7,8 tetrachlorodibenzo–p-dioxin or TCDD.

Dioxin is formed by burning chlorine-based chemical compounds with hydrocarbons. The major source of dioxin in the environment comes from waste-burning incinerators and also from uncontrolled burning (e.g. bonfires). Dioxin pollution is also affiliated with paper mills which use chlorine bleaching in their process and with the production of Polyvinyl Chloride (PVC) plastics and with the production of certain chlorinated chemicals (like many pesticides).

Methods of Analysis (Organic Compounds)

TPH by GC-FID is an analytical technique which only detects hydrocarbons (aliphatic and aromatic) in the range C_{10} to C_{40} (volatiles, heavy tars, humic material and sulphur are not detected). The laboratory can provide a breakdown of the TPH results into gasoline range organics (**GRO**), diesel range organics (**DRO**) and heavier lubricating oil range organics (**LRO**).

GRO (PRO) by GC-FID analysis detects the more volatile C_6-C_9 hydrocarbons (aliphatic and aromatic), including those organic compounds present in petrol.

Speciated VOC (by GC-MS) analysis quantifies the concentrations of 30 USA-EPA priority compounds. These include chlorinated alkanes and alkenes (in the molecular weight range chloroethane to tetrachloroethane); trimethylbenzenes; dichlorobenzenes; and the 4 BTEX compounds (benzene, ethyl-benzene, toluene & xylene).

Speciated SVOC by (GC-MS) analysis quantifies the concentrations of a variety of organic compounds, including the chlorinated compounds 16 USA-EPA priority PAHs, phenolic compounds, 7 USA EPA priority PCB congeners, herbicides & pesticides.

Note: PAHs are hydrocarbons and consequently (where present) will be picked-up when testing TPH by GC-FID. Naphthalene (the lightest PAH) is also one of the 58 US EPA VOCs.

Speciated TPH by GC-MS provides a "banded" TPH, initially split into aromatic and aliphatic fractions and then further divided into fraction specific carbon bandings based upon behavioural characteristics and includes speciated BTEX compounds.

Note: Risk assessment models require physiochemical properties (solubilities, toxicities etc) of compounds in order to model their behaviour in the environment. These physiochemical properties cannot be derived from a single "TPH", "GRO" or "DRO" value. However, the carbon banded fractions can be used in risk assessment models.

Current UK Guidance

The UK approach to contaminated land is set out in Environment Agency Contaminated Land Report (CLR) No. 11 (2004) "*Model Procedures for the Management of Land Contamination*". The approach is based upon risk assessment, where risk is defined as the combination of the probability of occurrence of a defined hazard and the magnitude of the consequences of the occurrence.

In the context of land contamination, there are three essential elements to any risk: (1) a contaminant source, (2) a receptor (e.g. controlled water or people) and (3) a pathway linking the (1) and (2). Risk can only exist where all three elements combine to create a pollutant linkage. Risk assessment requires the formulation of a conceptual model which supports the identification and assessment of pollutant linkages.

ALM adopts a tiered approach to risk assessment, consistent with UK guidance and best practice. The initial step of such a risk assessment (or **'Tier 1'**) is the comparison of site data with appropriate UK guidance levels, ALM risk-derived screening values, or remedial targets.

Groundwater

Tier 1 **groundwater** risk assessments are undertaken by comparing soil leachate or groundwater concentrations with the appropriate water quality standard. Depending upon the specific characteristics and environmental setting of the site the appropriate standard is likely to be one of the following:

- Water Supply (Water Quality) Regulations 1989
- Environmental Quality Standards (for Freshwater)
- The Surface Waters (Abstraction for Drinking Water) Regulations

Hazardous Gas

Tier 1 risk assessment of **hazardous gas** is undertaken through reference to the following documents:

- Approved Document C, Building Regulations 2000
- Boyle & Witherington (2006) – 'Guidance on evaluation on development proposals on sites where methane and carbon dioxide are present, incorporating "traffic lights"'. Report Ref. 10627-R01-(02), for NHBC
- CIRIA C665 (2007) – 'Assessing risks posed by hazardous ground gases to buildings'
- BS 8485:2015 – 'Code of practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings'.
- BRE Report 211 (2007) – 'Radon: Guidance on protective measures for new buildings', Building Research establishment

Further information with respect to hazardous gas assessments is presented in 'Generic Note No. 5 – Hazardous Gas'.

Soil Contamination – Human Health

In March 2002 DEFRA and the Environment Agency published a series of technical documents (R&D Publications CLR 7, 8, 9 and 10) outlining the UK approach to the assessment of risk to **human health** from land contamination and which replaced previously published guidance. In March 2004 DEFRA and the Environment Agency published a further four documents ('Briefing Notes 1-4') which expanded, or where necessary revised, the original R&D Documents.

Publications CLR 7, 8, 9 and 10 and Briefing Notes 1-4 set out the UK's quantitative modelling approach to contaminated land (the *Contaminated Land Exposure Assessment* (CLEA) model). The CLEA model set out exposure frequency and duration assumptions, together with technical algorisms for the modelling of human health-related risks to contaminated land. The CLEA model lead to the publication of Soil Guidance Values (SGVs) for certain contaminants of concern ('SGV Reports'), based on collated published toxicity data for the contaminant in question ('TOX Reports')

In 2008 R&D Publications CLR 7, 9 and 10 and all corresponding SGV and TOX reports were withdrawn and superseded by new guidance including:

- Guidance on Comparing Soil Contamination Data with a Critical Concentration - CL:AIRE and CIEH, May 2008 (5) (effectively replaced CLR7)
- Evaluation of models for predicting plant uptake of chemicals from soil - Science Report – SC050021/SR (6)
- Human health toxicological assessment of contaminants in soil - Science Report: SC050021/SR2 (7) (effectively replaced CLR9)
- Updated technical background to the CLEA model - Science Report: SC050021/SR3 (8) (effectively replaced CLR10)
- CLEA Software (Version 1.05) Handbook Science report: SC050021/SR4 (9) (replaced pre-existing CLEA software models released prior to 2009)
- Compilation of data for priority organic pollutants for derivation of Soil Guideline Values - Science Report: SC050021/SR7 (10) (presents a technical physiochemical reference for contaminants of concern)

The revised approach set out in the above documents represented current scientific knowledge and thinking; and included the revised Contaminated Land Exposure Model (CLEA version 1.06). The Environment Agency/DEFRA are intending to use this updated approach to regenerate a selection of Soil Guideline Values (SGVs) under Environment Agency Science Report SC050021 for Residential, Allotment and Commercial end use scenarios.

At the time of writing this report, SGV's are only available for a limited number of contaminants, the development of both the CLEA model and additional SGV's is ongoing, albeit probably now on hold in view of more recent guidance published by DEFRA in 2014 (see below). Where published, SGV's can be utilised as 'intervention values' for the purpose of an initial 'Tier 1' assessment.

In 2015 Land Quality Management and the Chartered Institute of Environmental Health (LQM/CIEH) published Tier 1 soil screening thresholds for assessing risks posed to human health from soil contamination [(11)]. These soil screening thresholds are called 'Suitable For Use Levels' or 'S4ULs'. The S4ULs have been published in the absence of any forthcoming additional SGVs published by the Environment Agency/DEFRA.

The S4ULs have been developed using a modified version of the CLEA model for a wider variety of landuses in line with revised human exposure to soil contamination assumptions and landuse classes recommended by DEFRA (2014)[(12)] (also see below) to reduce the over-conservatism that is commonly attributed to SGVs. However, the S4ULs remain based on the principles of 'minimal' or 'tolerable' risk enshrined in Science Report SC050021/SR2[(7)] in that they utilise appropriate Health Criteria Values in their derivation. Thus the S4ULs are essentially equivalent to SGVs for the use of generic risk assessment under both the planning and Part 2A regimes.

The LQM/CIEH (2015)[(11)] publication presents S4ULs for 85 substances including 11 metals, 4 BTEX compounds, 16 TPH fractions, 16 PAH compounds, 8 chloroalkanes/alkene compounds, 2 explosive compounds, 7 pesticide compounds, 6 chlorobenzene compounds and additional isomers, 3 phenol and chlorophenol compounds and other organic compounds.

The development of S4ULs has been carried out under a peer review process and in accordance with prevailing UK government guidelines that in no way undermines the validity of the existing guidance in SC050021/SR2[(7)], SR3[(8)], SR4 or the existing CLEA software[(9)]. As such **ALM chooses to adopt the use of S4ULs with respect to the assessment of soil contamination posed to human health**. The appropriate S4UL for any given chemical determinand used in the Tier 1 screening process is presented in the various summary tables presented in this report for the appropriate landuse being considered.

It should be noted that exceedance of 'Tier 1' S4UL does not necessarily mean that remedial action will be required.

ALM's use of S4ULs as Tier 1 values is, however based on a number of assumptions, most notably:

a. Contamination identified is located in the top 0.5m of soil on site. The CLEA model assumes that all exposure pathways are relevant within 0.6m of ground level.

b. A conservative **Soil Organic Matter** of 1% is initially assumed.
(Note: TOC = SOM x 0.58; and FOC = TOC/100).
Hydrocarbons tend to be "bind" with SOM, and therefore become less mobile. Consequently, Tier 1 values can be revised if the amount of organic matter within the soil exceeds 1%.

c. Some determinands reach **residual saturation** before a vapour risk is predicted to occur. Prior to residual saturation, as the concentration of a contaminant in soil increases, so does the concentration of the same contaminant in the associated vapour phase. However, once saturation is reached, the concentration of contaminant in the vapour phase remains constant (for any given atmospheric conditions – temperature and pressure).

However, ALM recognise that it is unacceptable to leave free product in the ground and therefore arbitrary Tier 1 values have been ascribed to such contaminants. These values have been selected on the basis that they are below the limit of olfactory detection (i.e. at concentrations below Tier 1, odours are not readily identified).

Soil Contamination - Phytotoxity

With respect to the assessment of potential **phytotoxic effects** of contaminants, ALM refer to BS3882:2015 for copper and zinc[(13)]. Nickel is also regarded as a phytotoxin, however, ALM adopts the S4UL for nickel due to its human health effects.

Soil Contamination – Building Fabric and Combustibility

The potential risk to **building materials** is considered through reference to relevant BRE Digests, with particular emphasis on BRE Special Digest 1, 'Concrete in aggressive ground', 2005.

With respect to the interpretation of the **calorific values**, at present there are no accepted methods to assess whether a sample is combustible and under what circumstances it might smoulder. Some guidance is given in ICRCL Note 61/84 "Notes on the fire hazards of contaminated land" which states that:

> "*In general...it seems likely that materials whose CV's exceed 10MJ/kg are almost certainly combustible, while those with values below 2MJ/kg are unlikely to burn".*

Possible Action in Event of Tier 1 Exceedance

Should any of the Tier 1 criteria detailed above be exceeded, then three potential courses of action are available. (The first is only applicable in terms of human health, but the second and third could also be applied to groundwater or hazardous gas).

- Undertake further statistical analysis following the approach set out in CL:AIRE/CIEH 2008[(5)] in order to determine whether contaminant concentrations of contaminants within soil\fill actually present a risk (only applicable to assessing the risk to human health).
- Carry out a more detailed quantitative risk assessment in order to determine whether contamination risks actually exist.
- Based on a qualitative risk assessment, advocate an appropriate level of remediation to "break" the pollutant linkage - for example the removal of the contaminated materials or the provision of a clean cover.

Prior to undertaking any statistical analysis contamination across the entire site needs to be characterised by reference to the Conceptual Site Model. Consequently, ALM gather and analyse sample results by soil/fill type, and/or by former use in a given sub-area of the site, before undertaking statistical analysis; i.e. the statistical data set is associated with the extent of a particular fill type, or an area affected by spillage\leakage.

In terms of brownfield redevelopment, this is considered a more appropriate methodology which provides a more representative sample population for statistical analysis.

Analysis by soil/fill type is appropriate for essentially immobile contaminants associated with a particular fill type, for example arsenic in colliery spoil, metals in ash & clinker, sulphate in plaster-rich demolition rubble etc.

Analysis by former use is appropriate where more mobile contaminants have entered the ground, for example diesel associated with leakage from a former fuel tank, downward migration of leachable metals through granular materials, various soluble contaminants present in a wastewater leaking into the ground via a fractured sewer etc. In these circumstances, it may be appropriate to undertake statistical analysis of sample results from a variety of different soil\fill types. However, consideration would have to be given to factors such as porosity which might influence impregnation of a mobile contaminant into the soil mass; i.e. contamination would normally be more pervasive and significant in granular soils than cohesive soils.

Category 4 Screening Levels (C4SLs)

In March 2014, DEFRA published the findings of a research project relating to the development of 'Category 4 Screening Levels' (C4SLs)[12] for assessing soil contamination with respect to human health risks. The project was carried out within the context of the revised Statutory Guidance to support Part 2A of the Environment Protection Act 1990 that was published in April 2012. The revised Statutory Guidance introduced a new four-category system for classifying land under Part 2A for cases of a Significant Possibility of Significant Harm to human health, where 'Category 1' includes land where the level of risk is clearly unacceptable and 'Category 4' includes land where the level of risk is acceptably low.

An impact assessment that accompanied the revised Part 2A Statutory Guidance identified that the current practice of 'generic' ('Tier 1') screening of soil contamination concentrations against published SGVs or other generic assessment criteria derived from the CLEA model, was too conservative and identified a potential new role for C4SLs in providing a simple test for deciding whether land is suitable for use and definitely not contaminated land.

The C4SLs are proposed to be more pragmatic (whilst still strongly precautionary) compared to the existing 'generic' screening levels (e.g. SGVs). The development of C4SLs used marginally less conservative human exposure assumptions associated with a wider variety of land use classes as well as modified assumptions on levels of tolerable doses. It is intended by DEFRA that the C4SLs will be used as new generic screening criteria, albeit describing a higher level of risk than the currently available SGVs.

Six substances were selected within the C4SL project because of their ubiquity within contaminated land risk assessments and a draft methodology for the derivation of C4SLs was subjected to peer review.

The final C4SLs derived for the 6 initially modelled contaminants of concern are presented in Table 5 below.

Table 5 – Final C4SLs (after DEFRA 2014 [12])

Substance	Residential (with home grown produce)	Residential (without home grown produce)	Allotments	Commercial	Public Open Space (Residential)	Public Open Space (Park)
Arsenic	37	40	49	640	79	168
Benzene	0.87	3.3	0.18	98	140	230
Benzo(a)pyrene	5	5.3	5.7	76	10	21
Cadmium	26	149	4.9	410	220	880
Chromium VI	21	21	170	49	23	250
Lead	200	310	80	2330	630	1300

Note - All C4SLs are expressed as mg/kg

With respect to the applicability of use of the C4SLs, the DEFRA 2014 report states:

> *"The Part 2A Statutory Guidance…(was) developed on the basis that Category 4 Screening Levels could be used under the planning regime… However policy responsibility for the National Planning Policy Framework and associated Planning Practice Guidance falls to the Department for Communities and Local Government"*

"Where a valid SGV exists for a contaminant where a C4SL has been derived, it is anticipated that risk assessors will use the C4SL…In the absence of a suitable C4SL, risk assessors should identify and select appropriate GAC criteria in accordance with established good practice. It is for the Environment Agency to decide whether or not any of the SGVs will be updated in the light of more recent toxicological data or whether any particular SGV should be withdrawn."

Until such time as C4SLs are formally adopted by the Department for Communities and Local Government into the National Planning Policy Framework and associated Planning Practice Guidance, ALM will adopt the use of the published LQM/CIEH S4ULs for 'generic' ('Tier 1') screening of soil contamination concentrations for the assessment of human health, unless otherwise advised by the Local Planning Authority in question that the use of C4SLs is appropriate. This is with the exception of lead, where ALM will adopt the C4SL presented in Table 5 above given that no recognised/published criteria (SGV or S4UL) for lead are available.

References

(1) Total Petroleum Criteria Working Group Series, Volume 1 Analysis of Petroleum Hydrocarbons in Environmental Media, 1998.

(2) Total Petroleum Criteria Working Group Series, Volume 2 Composition of Petroleum Mixtures, 1998.

(3) Total Petroleum Criteria Working Group Series, Volume 3. Selection of Representative TPH Fractions Based on Fate and Transport Considerations, 1997

(4) Total Petroleum Criteria Working Group Series, Volume 4. Development of Fraction Specific Reference Doses (RfDs) and Reference Concentrations (RfCs) for Total Petroleum Hydrocarbons (TPH), 1998.

(5) Guidance on Comparing Soil Contamination Data with a Critical Concentration. CL:AIRE/Chartered Institute of Environmental Health, May 2008

(6) Evaluation of models for predicting plant uptake of chemicals from soil Science Report – SC050021/SR, 2008

(7) Environment Agency Science Report – SR2 Human health toxicological assessment of contaminants in soil, 2008

(8) Environment Agency Science Report - SC050021/SR3 Updated Technical Background to the CLEA Model (as amended 2009)

(9) Environment Agency Science Report - SC050021/SR4 CLEA Software (Version 1.05) Handbook, 2009

(10) Environment Agency Science Report – SR7 Compilation of Data for Priority Organic Pollutants for the Derivation of Soil Guidelines Values, 2008

(11) The LQM/CIEH S4ULs for Human Health Risk Assessment. Land Quality Management/Chartered Institute of Environmental Health. 2015

(12) DEFRA. SP1010: Development of Category 4 Screening Levels for Assessment of Land Affected by Contamination – Policy Companion Document. Department for Environment Food and Rural Affairs. March 2014

(13) BS3882:2015 – Specification for Topsoil. British Standards Institution

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Generic Notes – ALM Geoenvironmental Investigations

05 - Hazardous Gas

General

Hazardous gas is considered to be any mixture of potentially explosive, toxic or asphyxiating gases, most notably methane, carbon dioxide and oxygen (deficiency).

In addition, radon, a naturally occurring radioactive gas is also considered. Further information about radon is included in 'Generic Notes 01 – Environmental Setting' in Appendix A of this report.

An 'initial' assessment of potential risks associated with hazardous gas are based on a review of data obtained from desk study searches, such as a review of historical maps and other historical records (for evidence of backfilled quarries, railway cuttings, colliery spoil tips etc), information held by the Environment Agency and the Local Authority (current and historical landfill sites etc) as well as a review information obtained from the British Geological Survey and the Coal Authority. Such information is used to develop a Preliminary Conceptual Site Model to identify potential on site and off site gas sources and potential gas migration pathways.

Where landfilling of wastes has occurred within 250m of the site boundary, the Local Planning Authority may request a hazardous gas investigation in accordance with the Town and Country Planning General Development Order 1988.

Sources

Potential sources of hazardous gas are:

- Landfill sites
- Made ground, especially where significant depths are present.
- Shallow mineworkings associated with coal extraction.
- Geological strata, including peat, organic silts, coal-bearing strata and limestone (reaction with acidic waters), granite (radon).
- Groundwater can sometimes act as a "carrier" for dissolved hazardous gas.
- Leakages from pipelines or storage tanks
- Sewers, septic tanks and cess pits

Generation

Wherever biodegradable material is deposited, hazardous gas (principally a mixture of methane and carbon dioxide) is likely to be generated by microbial activity. Carbon dioxide is an asphyxiant and is toxic; methane is flammable and a mixture containing between 5% and 15% methane by volume in air can be explosive. Such gas in the ground is unlikely in itself to pose a significant risk, though it may cause vegetative stress to some plants. However, the migration/accumulation of these gases into confined spaces within buildings (e.g. cellars, services, etc) may give rise to significant risk.

The composition, concentration and length of time gas is produced depends on a number of factor including the organic fraction/nature of organic fraction present, the depth of fill materials, the moisture content of the materials, groundwater conditions etc.

Migration

Gas migration from a gas source may occur in several ways. It may migrate through adjacent strata; the distance of migration being dependent on the pressure gradients, volume of gas and permeability of the strata. Where there are faults, cavities and fissures within the strata, gas may move considerable distances. Other migration pathways for gas include man-made features such as mine shafts, roadways and underground services.

Gas migration can be influenced by a number of climatic factors, such as atmospheric pressure variations, water table level variations and the influence of a covering of snow or ice over the surface of the site and surrounding area.

Gas Monitoring Procedure

ALM adopts a gas monitoring procedure in accordance with guidance contained within CIRIA Report C665 (2007) "*Assessing Risks Posed By Hazardous Ground Gases to Buildings*". This procedure involves the measurement, in the following order of:

- Atmospheric temperature, pressure and ambient oxygen concentration on site immediately prior to and on completion of monitoring.
- Gas emission rate.
- Methane, oxygen and carbon dioxide concentrations using an infra-red gas analyser.
- Standing water level using an electronic dipmeter.

In addition, ground conditions at each sampling location are recorded together with prevailing weather conditions and any other observations such as any vandalism.

Where samples of gas are required for laboratory analysis, Gresham Tubes or Tedlar bags are used. Gas concentrations in the well are typically recorded immediately before and after retrieval of a sample.

Site Characterisation - Current Guidance

CIRIA Report 151 (1995)[i] identified that there was inadequate guidance on trigger concentrations for ground gases. CIRIA concluded that the most important aspect of a gas regime below or adjacent to a site was the surface emission rate, i.e. how quickly the gas is coming out of the ground. The lower the surface emission rate, the lower the risk.

CIRIA Report C665 (2007)[ii] advocates two methodologies for characterising sites:

Situation A – All developments except low rise housing. The advocated methodology is that proposed by Wilson & Card, 1999[iii].

Situation B – Low rise housing. An alternative ('traffic light') methodology, derived by Boyle and Witherington, 2006[iv] for the NHBC

Both methodologies refer to 'Gas Screening Values' (GSV) (previously known as limiting borehole gas volume flow).

‘Situation A’ – All developments except low rise housing.

Wilson & Card, (1999)[iii] revised Table 28 of CIRIA Report 149[v] in terms of a Gas Screening Value (GSV) based on the detected gas concentration and gas flow rate (l/hr) in order to achieve a more consistent design of protection measures. This was done to reflect the importance of recognising the gas surface emission rate.

Wilson & Card then developed a method for classifying gassing sites (Table 1 below), which took into account the combined gas concentration and GSV.

Table 1 – Site Classification (Wilson & Card)

Characteristic Situation (Wilson & Card, 1999)	Gas Screening Value, CH4 or CO2 (l/hr)	Additional limiting factors	Typical source of generation
1	<0.07	Methane not to exceed 1%v/v and carbon dioxide not to exceed 5%v/v	Natural soils with high organic content
2	<0.7	Borehole air flow rate not to exceed >70ltr/hr otherwise increase to Characteristic Situation 3	Natural soils with high peat/organic content
3	<3.5		Old landfill, inert waste, flooded mineworkings
4	<15	Quantitative Risk Assessment required to evaluate scope of protection measures	Mineworkings susceptible to flooding, completed landfill, inert waste (WMP 26B criteria)
5	<70		Mineworkings, unflooded, inactive
6	>70		Recent landfill sites

Notes:
Borehole flow rate = volume of gas (regardless of composition) which is escaping from well (l/hr).
Gas Screening Value (litre/hour) = gas concentration (%) / 100 x borehole flow rate (l/hr).
To facilitate design implementation, the limiting values for both methane and carbon dioxide are identical.

‘Situation B’ – Low rise housing.

The NHBC developed a characterisation system similar to that of Wilson & Card above, but specific to low-rise housing development (Boyle and Witherington[iv]) (see Table 2). This approach compares measured gas emission rates with generic risk-based “Traffic Lights”. The Traffic Lights include “Typical Maximum Concentrations” of gas for initial screening, and risk-based Gas Screening Values (GSVs) for consideration of situations where the Typical Maximum Concentrations are exceeded. Calculations are carried out for both methane and carbon dioxide and the worse case adopted in order to establish the appropriate gas protection measures to be adopted within the low rise housing development.

Table 2 - NHBC Traffic light system for 150 mm void (From CIRIA Report C665, Table 8.7)

Traffic light	Methane[1]		Carbon dioxide[1]	
	Typical maximum concentration[5] (% v/v)	Gas screening value (GSV)[2,4,6] (litres per hour	Typical maximum concentration[5] (% v/v)	Gas screening value (GSV)[2,3,4,5] (litres per hour
Green				
	1	**0.16**	5	**0.78**
Amber 1				
	5	**0.63**	10	**1.56**
Amber 2				
	20	**1.56**	30	**3.13**
Red				

Notes:

1. The **worst gas-regime** identified at the site, either methane or carbon dioxide, recorded from monitoring in the worst temporal conditions, will be the decider for which Traffic Light and GSV is allocated.
2. Generic GSVs are based on guidance contained within "The Building Regulations: Approved Document C" (2004) and assume a **sub-floor void** of 150 mm thickness.
3. The **small room** is considered to be a downstairs toilet, with dimensions of 1.50 × 1.50 × 2.50 m, with a soil pipe passing into the sub-floor void.
4. The **GSV**, in litres per hour, is as defined in Wilson and Card (1999) as the borehole flow rate multiplied by the concentration in the air stream of the particular gas being considered.
5. The Typical Maximum Concentrations can be exceeded in certain circumstances should the conceptual site model indicate it is safe to do so. This is where professional **judgment** will be required, based on a thorough understanding of the gas regime identified at the site where monitoring in the worst temporal conditions has occurred.
6. The GSV thresholds should not generally be exceeded without completion of a detailed gas risk assessment taking into account site-specific conditions.

Type And Design Of Gas Protection Measures

BS 8485:2015[vi] gives recommendations on the choice of solutions for the design of integral gas protective measures for new buildings to prevent entry of carbon dioxide and methane to provide a safe internal environment.

BS 8485:2015 utilises 'Characteristic Gas Situations' (CS), as determined by the calculated Gas Screening Value (GSV) as presented in CIRIA Report C665 (Table 1 above). The appropriate CS for the site (or site zone) is used to determine the type and nature of gas protection systems within any given building utilising a **Gas Protection Score** – see Table 3.

Table 3
Gas Protection Score By CS and Type of Building
(Modified from Table 4 of BS 8485:2015)

CS	Minimum Gas Protection Score			
	High Risk		Medium Risk	Low Risk
	Type A Building[1]	Type B Building[2]	Type C Building[3]	Type D Building[4]
1	0	0	0	0
2	3.5	3.5	2.5	1.5
3	4.5	4	3	2.5
4	6.5[A]	5.5[A]	4.5	3.5
5	- [B]	6.5[A]	5.5	4.5
6	- [B]	- [B]	7.5	6.5

Notes:

1	Private ownership with no structural management controls on alterations to the internal structure and use of rooms, the ventilation of rooms or the structural fabric of the building. Some small rooms present. Probably conventional building construction (rather than civil engineering).Examples include private housing and some retail premises.
2	Private or commercial property with central building management control of any alterations to the building or its uses but limited or no central building management control of the maintenance of the building, including the gas protection measures. Multiple occupancy. Small to medium size rooms with passive ventilation of rooms and other internal spaces throughout ground floor and basement areas. May be conventional building or civil engineering construction. Examples include managed apartments, multiple occupancy offices, some retail premises and parts of some public buildings (such as schools, hospitals, leisure centres) and parts of hotels.
3	Commercial building with central building management control of any alterations to the building or its uses and central building management control of the maintenance of the building, including the gas protection measures. Single occupancy of ground floor and basement areas. Small to large size rooms with active ventilation or good passive ventilation of all rooms and other internal spaces throughout ground floor and basement areas. Probably civil engineering construction. Examples include offices, some retail premises, and parts of some public buildings (such as schools, hospitals, leisure centres and parts of hotels).
4	Industrial style building having large volume internal space(s) that are well ventilated. Corporate ownership with building management controls on alterations to the ground floor and basement areas of the building and on maintenance of ground gas protective measures. Probably civil engineering construction. Examples are retail park sales buildings, factory shop floor areas, warehouses. (Small rooms within these style buildings should be separately categorised as Type B or Type C).
A	Residential buildings should not be built on CS4 or higher sites unless the type of construction or site circumstances allow additional levels of protection to be incorporated, e.g. high-performance ventilation or pathway intervention measures, and an associated sustainable system of management of maintenance of the gas control system, e.g. in institutional and/or fully serviced contractual situations.
B	The gas hazard is too high for this empirical method to be used to define the gas protection measures.

Having determined the minimum Gas Protection Score for the building, an element, or combination of elements, of gas protection should be chosen to achieve a combined score achieving the minimum level of recommended gas protection.

The elements of gas protection are essentially categories into three components each providing a corresponding score:

	Score *
1. Structural Barrier (floor slab or basement slab/walls)	0 – 2.5
2. Sub Floor Ventilation Measures	0.5 - 4.0
3. Gas Resistant Membrane	2

* Scores vary depending on relative performance of differing systems or elements, as presented in Tables 5-7 of BS 8485:2015

ALM CONSULT

Site Characterisation Without Gas Monitoring

ALM would always advocate an appropriate programme of gas monitoring, undertaken in general accordance with CIRIA C665 (2007), specific to the nature of development proposed and identified gas sources and pathway. However, in some circumstances, gas monitoring may not be deemed appropriate or warranted, for example where only shallow materials possessing a low degradable content are present on site.

Annex D of BS 8485:2015 provides guidance for an empirical approach to characterizing sites without gas monitoring data where the source(s) of ground gas on the site is made ground with a low degradable organic content.

In this approach the representative gas regime (CS) is assigned based on:

- The conceptual site model, derived by updating the preliminary conceptual site model to take into account geological, hydrogeological and geotechnical data of an adequate ground investigation conducted to inform the design of the development.
- Knowledge of the Total Organic Carbon (TOC) content of potential ground gas generating made ground.
- A detailed examination of the made ground soil material.

This approach should be adopted with caution and should not be applied on its own to assess off-site sources or materials associated with waste disposal, and should only be used to define sites with very low to moderate hazard potential.

Table 4 below presents the limiting factors that are presented in BS 8485:2015 in assigning a Characteristic Gas Situation (CS) without gas monitoring.

Table 4
Limiting Values of Thickness and Organic Content
in Assigning a Characteristic Gas Situation Without Gas Monitoring
(Adapted from Table D.1 BS 8584: 2015)

Thickness of Made Ground	Maximum Total Organic Carbon Content of Made Ground - TOC		Site Characteristic Situation (CS) to be Assumed
	Made Ground in place for <20 years %	Made Ground in place for >20 years %	
Maximum 5m Average <3m	≤ 1.0	≤ 1.0	CS1
Maximum 5m Average <3m	≤ 1.5	≤ 3.0	CS2
Maximum 5m Average <3m	≤ 4.0	≤ 6.0	CS3

Notes:
The above is for guidance only.
Gas monitoring would be required where TOC is greater than 4% (or 6% in old made ground).
ALM would always advocate gas monitoring where made ground is present at the thicknesses presented above.
ALM consider that where <1.0m of made ground is present the CS may be subject to revision due to the reduced potential for ground gas generation.

i CIRIA Report 151 (1995). Interpreting measurements of gas in the ground. Harries CR, Witherington PJ and McEntee JM

ii CIRIA Report C665 (2007), Assessing risks posed by hazardous ground gases to buildings.

iii Wilson SA and Card GB Reliability and Risk in Gas Protection Design. Ground Engineering, 32 **2** February 1999

iv Boyle & Witherington (2006) – Guidance on evaluation on development proposals on sites where methane and carbon dioxide are present, incorporating "traffic lights". Report Ref. 10627-R01-(02), for NHBC

v CIRIA Report 149 (1995). Protecting Development from Methane. Card GB

vi BS 8485:2015 Code of Practice for the Design of Protection Measures for Methane and Carbon Dioxide Ground Gases for New Buildings. British Standard Institution.

Generic Notes – ALM Geoenvironmental Investigations

06 - Soakaways

Background

Soakaways have been the traditional way to dispose of storm water from buildings and paved areas from a public sewer or watercourse. In recent years, soakaways have been used within urban, fully-sewered areas, to limit the impact of discharge of new upstream developments and to avoid costs of sewer up-grading outside of a development.

Soakaways are seen increasingly as a more widely applicable option alongside other means of storm water control and disposal. Soakaways must store the immediate storm water run-off and allow its efficient infiltration into the soil. They must discharge their stored water sufficiently quickly to provide the necessary capacity to receive run-off from a subsequent storm. The time taken for discharge depends upon the soakaway shape and size, and the surrounding soil's infiltration characteristics. Soakaways can be constructed in many different forms and from a range of materials.

BRE Digest 365: 1991 (revised 2007) describes design and construction procedures and explains how to calculate rainfall design values and soil infiltration rates. Further advice is provided in **NHBC Standards Chapter 5.3**.

Soakaways should generally be built on land lower than, or sloping away from, buildings and be sited at least 5m from the foundations of a building.

Made Ground (and ground within 5m of made ground) is not generally regarded as suitable for soakaways, due to potential for inundation settlement and the leaching of contaminants.

It should be noted that due to possible structural instability and modification of Chalk when wetted, CIRIA Report 11 'Foundations in Chalk' states that "Soakaways should be avoided it at all possible but, if unavoidable, should be sited at least 20m away from any structure".

Test Methodology

ALM undertake in situ soakaway tests in general accordance with BRE Digest 365 'Soakaway Design'. The BRE Digest recommends that each soakaway pit is filled and allowed to drain three times to near empty; the three fillings to be on the same or consequent days. However, each test can take several hours to complete and therefore pits are often filled and allowed to drain on one occasion, due to time constraints imposed by the investigation.

Three fillings/drainage cycles are more important where drainage is primarily by fissures, most notably within a rock mass. Initial drainage within the rock mass may be high, as the fissures fill with water, giving the impression (if only one cycle is undertaken), that soakways would be suitable drainage solution. If infiltration though the matrix of the rock is low, the drainage from the test pit becomes slow as the fissures become saturated.

For non-fissile, granular soils, infiltration is via the soil matrix and, consequently, one filling/drainage cycle is generally considered sufficient.

Soakaway pits are typically excavated to a depth of ca. 2.5m using a mechanical excavator equipped with a 0.3-0.5m wide bucket.

The soakaway test pits are rapidly filled with water to the top of the test section. The fall in water level is then monitored at regular intervals.

Infiltration Rates

Infiltration rates for each soakaway test are calculated, where possible, in accordance with BRE Digest 365. This takes into account the time of emptying the soakaway pit between 25% and 75% of the effective depth. The effective depth is calculated from the starting water level to the soakaway pit base. Where the water level does not fall to 25% effective depth, the data may be extrapolated to obtain a representative infiltration rate.

Soakaway Design

Soakaway design is carried out in accordance with BRE Digest 365 using the infiltration rates calculated above; assuming a rainfall ratio of 0.39; and that each soakaway will have the capacity to handle storm water from an impermeable area of $100m^2$.

Two soakaway types can be designed using BRE Digest 365:

- Perforated concrete ring in a square pit with granular backfill (chamber type)
- Trench with granular backfill (trench type)

The design for the perforated ring type soakaway assumes that the chamber comprises a permeable 900mm internal diameter 'hollow' chamber set in a square pit with granular material around the chamber possessing a void space of 30%.

The design for the trench type soakaway assumes that the trench is 600mm wide filled with granular material, possessing a void space of 30%.

It is generally assumed that the soakaways become impracticable on residential developments when:

- The chamber type design requires a square pit with a side length in excess of 1.8m, or an effective depth greater than 1.5m.
- The trench type design requires a length greater than about 10m, or an effective depth greater than 1.5m.

Increasing the soakaway effective depth might be a solution, but consideration should be given to:

- The standing groundwater level.
- The depth to base of permeable strata.
- Cost of excavation.

Soakaway percolation in some rock types is predominantly via the vertical joints within the rock mass. The relatively small-scale soakaway test pits may not intercept such joints and this can result in variable test results. As such, considerable caution should be adopted when assessing in situ soakaway tests within rock strata.