GROUND INVESTIGATION REPORT

for the site at

LAND TO THE REAR OF NO. 51 GOWER STREET, LONDON WC1E 6HJ

on behalf of

FT ARCHITECTS LIMITED

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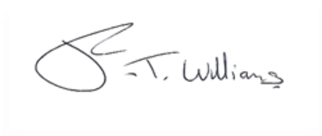
V1.01 April 2015		
	Philip Allvey BSc (Hons) M.Eng Geotechnical Engineer	Francis Williams M.Geol. (Hons) FGS CEnv AGS MSoBRA Director
File Reference: Ground and Water/Project Files/GWPR1183/ Land to the rear of No. 51 Gower Street, London		

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1.0 INTRODUCTION

1.1 General

Ground and Water Limited were instructed by FT Architects Limited, on the 16th February 2015, to undertake a Ground Investigation on land to the rear of No. 51 Gower Street, London WC1E 6HJ. The scope of the investigation was detailed within the Ground and Water Limited fee proposal ref: GWQ2367, dated 13th February 2015.

1.2 Aims of the Investigation

The aim of the investigation was understood to be to supply the client and their designers with information regarding the ground conditions underlying the site to assist them in preparing an appropriate scheme for development.

The investigation was to be undertaken to provide parameters for the design of foundations by means of in-situ and laboratory geotechnical testing undertaken on soil samples recovered from trial holes.

The requirements of the London Borough of Camden, Camden Geological, Hydrogeological and Hydrological Study, Guidance for Subterranean Development (November 2010) was reviewed with respect to this report.

A Desk Study and full scale contamination assessment were not part of the remit of this report.

The techniques adopted for the investigation were chosen considering the anticipated ground conditions and development proposals on-site, and bearing in mind the nature of the site, limitations to site access and other logistical limitations.

1.3 Conditions and Limitations

This report has been prepared based on the terms, conditions and limitations outlined within Appendix A.

2.0 SITE SETTING

2.1 Site Location

From a review of Google/Bing online maps (circa 2013), the site comprised an approximately square shaped plot of land, totalling ~50m^2 in area, located on the north-western side of Chenies Street. The site was located between Ridgmount Gardens and Gower Street in Fitzrovia/Marylebone area of the London Borough of Camden.

The national grid reference for the centre of the site was approximately TQ 29694 81925. A site location plan is given within Figure 1 and a plan showing the site area is given within Figure 2.

2.2 Site Description

The site was occupied by a semi-detached pair of single storey residential garages. A concrete apron was noted to front Chenies Street. Mature trees were noted to the rear of the buildings with residential gardens to the north-east and south-west. Gower Street, located to the north-east of the site, was noted to be at ~26.9m AOD.

2.3 Proposed Development

At the time of reporting, April 2015, the proposed development will comprise the demolition of the existing property and construction of a single storey brick built property with basement. The basement is anticipated to be constructed at 3.0 – 4.0m below existing ground level (bgl). The footprint of the property will cover the entire site area. The basement will be ~8.5m by 6m in area.

The proposed development fell within Geotechnical Design Category 2 in accordance with Eurocode 7. The proposed foundation loads were not known to Ground and Water Limited at the time of reporting but are likely to range from 75 – 150kN/m^2.

The proposed development was understood not to involve any re-profiling of the site and its immediate environs. It is understood that no trees will be removed to facilitate the construction of the basement.

2.4 Geology

The geology map of the British Geological Survey of Great Britain of the South Hampstead area (Sheet No. 256 North London) revealed the site to be situated on the Lynch Hill Gravel Formation, overlying the London Clay Formation. An area of Worked Ground or Made Ground was noted 200m south-west of the site, along Cleveland Street.

Figure 3 of the Camden Geological, Hydrogeological and Hydrological Study showed the same area of Made Ground ~200m south-west of the site.

Lynch Hill Gravel Formation

The rivers of the south-east of England, including the River Thames and its tributaries, have been subject to at least three changes of level since Pleistocene times. One result has been the formation of a complex series of river terrace gravels. These terraces represent ancient floodplain deposits that became isolated as the river cut downwards to lower levels. Deposits generally consist of sand and gravel of flint or chert commonly in a matrix of silt and clay.

London Clay Formation

The London Clay Formation comprises stiff grey fissured clay, weathering to brown near surface. Concretions of argillaceous limestone in nodular form (Claystones) occur throughout the formation.

Crystals of gypsum (Selenite) are often found within the weathered part of the London Clay Formation, and precautions against sulphate attack to concrete are sometimes required.

The lowest part of the formation is a sandy bed with black rounded gravel and occasional layers of sandstone and is known as the Basement Bed.

In the north London area the upper part of the London Clay Formation has been disturbed by glacial and/or periglacial action and may contain pockets of sand and gravel.

A BGS borehole ~200m north of the site revealed 0.60m of Made Ground to overlie sand and gravels, with clay lenses, to ~6.0m bgl. Stiff grey silty clays were then proved to the base of the borehole, a depth of 10.9m bgl.

2.5 Slope Stability and Subterranean Developments

The site was not situated within an area where a natural or man-made slope of greater than 7^{o} was present (Figure 16 Camden Geological, Hydrogeological and Hydrological Study).

Figure 17 of the Camden Geological, Hydrogeological and Hydrological Study indicated the site was not situated within an area prone to landslides.

Figure 18 of the Camden Geological, Hydrogeological and Hydrological Study indicated that no major subterranean infrastructure (including existing and proposed tunnels) was noted within close proximity to the site. The map showed that the Northern Underground Line was present ~200m south-west of the site. The Made Ground noted ~200m south-west in the previous section of this report is likely to be associated with Goodge Street station.

2.6 Hydrogeology and Hydrology

A study of the aquifer maps on the Environment Agency website, and Figure 8 of the Camden Geological, Hydrogeological and Hydrological Study, revealed the site to be located within a **Secondary A Aquifer** comprising the superficial drift deposits of the Lynch Hill Gravels. The underlying London Clay Formation was described as **Unproductive Strata**.

Secondary aquifers include a wide range of drift and bedrock deposits with an equally wide range of water permeability and storage capacities. Secondary A Aquifers are 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.

Unproductive strata are rock layers with low permeability that have negligible significance for water supply or river base flow. These were formerly classified as non-aquifers.

Superficial (Drift) deposits are permeable unconsolidated (loose) deposits, for example, sands and gravels. The bedrock is described as solid permeable formations e.g. sandstone, chalk and limestone.

Examination of the Environment Agency records showed that the site did not fall within a Groundwater Source Protection Zone as classified in the Policy and Practice for the Protection of Groundwater.

No surface water feature was noted in close proximity to the site in accordance with Figure 12 of the Camden Geological, Hydrogeological and Hydrological Study. Figure 11 revealed the site was located to the west of where an easterly flowing tributary of the “Lost” River Fleet was present.

Figure 14 of the Camden Geological, Hydrogeological and Hydrological Study revealed the site was not located within the catchment of Hampstead Ponds.

From analysis of hydrogeological and topographical maps groundwater was anticipated to be encountered at moderate to deep depth (4-6m below existing ground level (bgl)) and it was considered that the groundwater was flowing in a south-easterly direction in accordance with the local topography.

Examination of the Environment Agency records showed that the site was not situated within a floodplain or flood warning area. Figure 15 the Camden Geological, Hydrogeological and Hydrological Study revealed that there was no evidence of surface water flooding on the site.

2.7 Radon

BRE 211 (2007) Map 5 of London, Sussex and west Kent revealed the site **was not** located within an area where mandatory protection measures against the ingress of Radon were required. The site **was not** located within an area where a risk assessment was required.

3.0 FIELDWORK

3.1 Scope of Works

Fieldwork was undertaken on the 3rd March 2015 and comprised the drilling of one Premier Windowless Sampler Borehole (BH1) to a depth of 10.45m bgl and the hand excavation of one trial pit foundation exposures (TP/FE1). At the time of the investigation it was not possible to access the proposed TP/FE2 location. Standard Penetration Testing (SPT's) was undertaken at 1.00m intervals in the borehole.

The approximate locations of the trial holes can be seen within Figure 5.

Prior to commencing the ground investigation, a walkover survey was carried out to identify the presence of underground services and drainage. Where underground services/drainage were suspected and/or positively identified, exploratory positions were relocated away from these areas.

Upon completion of the site works, the trial holes were backfilled and made good/reinstated in relation to the surrounding area.

3.2 Sampling Procedures

Small disturbed samples were recovered from the trial holes at the depths shown on the trial hole records. Soil samples were generally retrieved from each change of strata and/or at specific areas of concern. Samples were also taken at approximately 0.5m intervals during broad homogenous soil horizons.

A selection of samples were despatched for geotechnical testing purposes.

4.0 ENCOUNTERED GROUND CONDITIONS

4.1 Soil Conditions

All exploratory holes were logged by David McMillan of Ground and Water Limited generally in accordance with BS EN 14688 'Geotechnical Investigation and Testing – Identification and Classification of Soil'.

The ground conditions encountered within the trial holes constructed on the site generally conformed to that anticipated from examination of the geology map. A capping of Made Ground was noted to overlie the Lynch Hill Gravel Formation, which was underlain by the London Clay Formation.

The ground conditions encountered during the investigation are described in this section. For more complete information about the Made Ground, Lynch Hill Gravel Formation and the London Clay Formation at particular points, reference must be made to the individual trial hole logs within Appendix B.

The trial hole location plan can be viewed in Figure 5.

For the purposes of discussion the succession of conditions encountered in the trial holes in descending order can be summarised as follows:

Made Ground
Lynch Hill Gravel Formation
London Clay Formation

Made Ground
Made Ground was encountered beneath a 0.15m concrete slab and 0.15m thick crushed brick sub-base in BH1 and from ground level in TP/FE1. The base of the Made Ground was not proved in TP/FE1, which was constructed to 1.50m bgl, but was proved to 4.40m bgl in BH1. The Made Ground generally comprised a dark brown gravelly sand to sandy very gravelly clay. The sand was fine to coarse grained and the gravel was occasional to abundant, fine to coarse, sub-rounded to sub-angular, flint, brick, concrete and clinker.

Lynch Hill Gravel Formation
Soils of the Lynch Hill Gravel Formation were encountered beneath the Made Ground to a maximum depth of 7.60m bgl. An initial layer of cohesive deposits were encountered between 4.40m - 5.50m bgl and comprised a orange brown, brown and red slightly sandy to sandy, locally gravelly silty clay. The sand was fine to coarse grained and the gravel was absent to rare, fine, sub-angular to angular flint.

This was underlain by the more granular deposits to a depth of 7.60m. These deposits comprised a yellow brown gravelly sand grading into an orange brown sandy gravel below 6.40m bgl. The sand was fine to coarse grained and the gravel was occasional to abundant, fine to coarse, sub-rounded to angular flint.

London Clay Formation
Soils of the London Clay Formation, comprising an initially orange brown silty clay but becoming dark grey silty with depth, were encountered for the remaining depth of BH1, to a depth of 10.00m bgl.

4.2 Foundation Exposures

A description of the foundation layout and ground conditions encountered within the hand dug trial pit/foundation exposure are given within this section of the report.

TP1

Trial pit foundation exposure TP/FE1 was hand excavated from ground level at the south-west corner of the site, adjacent to the boundary wall with Ridgmount Gardens. The exact location of the trial hole can be seen in Figure 5 with a section drawing of the foundation encountered in Figure 6.

The foundation exposure was measured from ground level.

The foundation layout encountered consisted of a brick wall to a depth of 1.05m bgl underlain by a brick step, 0.04m in width and 0.05m in height, to a depth of 1.10m bgl. A second brick step was noted, to a depth of 1.15m, followed by a final step to a depth of 1.30m bgl. The brick foundations were underlain by Made Ground comprising a dark brown slightly clayey gravelly sand. The ground conditions encountered directly surrounding the foundation are shown in Figure 6.

4.3 Roots Encountered

No roots were noted during construction of BH1 or TP1.

It must be noted that the chance of determining actual depth of root penetration through a narrow diameter borehole is low. Roots may be found to greater depths at other locations on the site, particularly close to trees and/or trees that have been removed both within the site and its close environs.

4.4 Groundwater Conditions

A groundwater strike was noted at 6.40m bgl in BH1.

Changes in groundwater level occur for a number of reasons including seasonal effects and variations in drainage. Exact groundwater levels may only be determined through long term measurements from monitoring wells installed on-site. The investigation was undertaken in March 2015, when groundwater levels are close to their annual maximum (highest elevation).

Isolated pockets of groundwater may be perched within any Made Ground found at other locations around the site.

4.5 Obstructions

No artificial or natural sub-surface obstructions were noted during construction of the trial holes.

5.0 INSITU AND LABORATORY GEOTECHNICAL TESTING

5.1 In-Situ Geotechnical Testing

Standard Penetration Testing was undertaken within BH1 at 1.00m intervals during the investigation. The results of the SPT's have not been amended to take into account hammer efficiency, rod length and overburden pressure in accordance with Eurocode 7.

The test results are presented on the borehole logs within Appendix B.

Windowless Sampler Boreholes provide samples of the ground for assessment but they do not give any engineering data. The standard penetration test (SPT) is an in-situ dynamic penetration test designed to provide information on the geotechnical engineering properties of soil. The test uses a thick-walled sample tube, with an outside diameter of 50 mm and an inside diameter of 35 mm, and a length of around 650mm. This is driven into the ground at the bottom of a borehole by blows from a slide hammer with a weight of 63.5 kg falling through a distance of 760 mm. The sample tube is driven 150 mm into the ground and then the number of blows needed for the tube to penetrate each 150 mm up to a depth of 450 mm is recorded. The sum of the number of blows is termed the "standard penetration resistance" or the "N-value".

The granular soils of the Lynch Hill Gravels were classified based on the table below.

Correlation between normalised SPT blow counts $(N_1)_{60}$	
Classification	**SPT “N” Blow Counts**
Extremely Dense	>58
Very Dense	42 – 58
Dense	25 – 42
Medium	8 – 25
Loose	3 – 8
Very Loose	0 – 3

The cohesive soils of the Lynch Hill Gravel Formation and London Clay Formation were classified based on the table below.

Undrained Shear Strength from Field Inspection/SPT results Cohesive Soils (EN ISO 14688-2:2004 & Stroud (1974))		
Classification	**Undrained Shear Strength (kPa)**	**Field Indications**
Extremely High	>300	-
Very High	150 – 300	Brittle or very tough
High	75 – 150	Cannot be moulded in the fingers
Medium	40 – 75	Can be moulded in the fingers by strong pressure
Low	20 – 40	Easily moulded in the fingers
Very Low	10 – 20	Exudes between fingers when squeezed in the fist
Extremely Low	<10	-

An interpretation of the in-situ geotechnical testing results is given in the table below.

Interpretation of In-situ Geotechnical Testing Results					
Strata	SPT "N" Blow Counts	Undrained Shear Strength kPa (based on Stroud, 1974)	Soil Type		Trial Hole/s
			Cohesive	Granular	
Made Ground	4 – 8	20 - 40	Very low – Low/Medium	-	BH1 (GL – 4.40m bgl)
Cohesive Lynch Hill Gravels	13	65	Medium		BH1 (4.40 – 5.50m bgl)
Granular Lynch Hill Gravels	37 – 57	-	-	Dense – Dense/V Dense	BH1 (5.50 – 7.60m bgl)
London Clay Formation	14 – 26	70 – 130	Medium – High	-	BH1 (7.60 – 10.0m bgl)

It must be noted that field measurements of undrained shear strength are dependent on a number of variables including disturbance of sample, method of investigation and also the size of specimen or test zone etc.

The test results are presented on the trial hole logs within Appendix B.

5.2 Laboratory Geotechnical Testing

A programme of geotechnical laboratory testing, scheduled by Ground and Water Limited and carried out by K4 Soils Laboratory and QTS Environmental Limited, was undertaken on sample recovered from the Lynch Hill Gravel Formation and London Clay Formation. The results of the tests are presented in Appendix C.

The test procedures used were generally in accordance with the methods described in BS1377:1990.

Details of the specific tests used in each case are given below:

Standard Methodology for Laboratory Geotechnical Testing		
Test	Standard	Number of Tests
Atterberg Limit Tests	BS1377:1990:Part 2:Clauses 3.2, 4.3 & 5	3
Particle Size Distribution	BS1377:1990:Part 2:Clause 9	2
Swelling Test	BS1377:1990:Part 5:Clause 3 & 4	1
Water Soluble Sulphate & pH	BS1377:1990:Part 3:Clause 5	1
BRE Special Digest 1 (incl. Ph, Electrical Conductivity, Total Sulphate, W/S Sulphate, Total Chlorine, W/S Chlorine, Total Sulphur, Ammonium as NH4, W/S Nitrate, W/S Magnesium)	BRE Special Digest 1 "Concrete in Aggressive Ground (BRE, 2005).	2

5.2.1 Atterberg Limit Tests

A précis of Atterberg Limit Tests undertaken on two samples from the cohesive Lynch Hill Gravel Formation and one sample of the London Clay Formation can be seen tabulated below.

Atterberg Limit Tests Results Summary							
Stratum/Depth	Moisture Content (%)	Passing 425 µm sieve (%)	Modified PI (%)	Soil Class	Consistency Index (Ic)	Volume Change Potential	
						NHBC	BRE
Cohesive Lynch Hill Gravel	22	68 - 100	18.36 – 25.00	CL	Stiff – Very stiff	Low – Medium	Low – Medium
London Clay Formation	28	100	50	CV	Stiff	High	High

NB: NP – Non-plastic
BRE Volume Change Potential refers to BRE Digest 240 (based on Atterberg results)
Soil Classification based on British Soil Classification System.
Consistency Index (Ic) based on BS EN IS0 14688-2:2004.

5.2.2 Comparison of Soil's Moisture Content with Index Properties

5.2.2.1 Liquidity Index Analyses

The results of the Atterberg Limit tests undertaken on two samples of the cohesive Lynch Hill Gravel formation and one sample of the London Clay Formation were analysed to determine the Liquidity Index of the samples. This gives an indication as to whether the samples recovered showed a moisture deficit and their degree of consolidation. The results are tabulated below.

The test results are presented within Appendix C.

Liquidity Index Calculations Summary					
Stratum/Trial Hole/Depth	Moisture Content (%)	Plastic Limit (%)	Modified Plasticity Index (%)	Liquidity Index	Result
Cohesive Lynch Hill Gravel Formation BH1/4.50m bgl (Brown and orangey brown slightly gravelly sandy silty CLAY (Gravel is fine to medium and sub-angular))	22	18	18.4	0.22	Overconsolidated
Cohesive Lynch Hill Gravel Formation BH1/5.00m bgl (Brown SAND with numerous silty clay lumps)	22	18	25.0	0.16	Heavily Overconsolidated.
London Clay Formation BH1/8.00m bgl (Dark grey and orange brown silty CLAY)	28	27	50.0	0.02	Heavily Overconsolidated.

Liquidity Index testing revealed no evidence for moisture deficit within the heavily overconsolidated samples of the London Clay Formation tested.

5.2.2.2 Liquid Limit

A comparison of the soil moisture content and the liquid limit can be seen tabulated below.

Moisture Content vs. Liquid Limit				
Strata/Trial Hole/Depth/Soil Description	**Moisture Content (MC) (%)**	**Liquid Limit (LL) (%)**	**40% Liquid Limit (LL)**	**Result**
Cohesive Lynch Hill Gravel Formation **BH1/4.50m bgl** (Brown and orangey brown slightly gravelly sandy silty CLAY (Gravel is fine to medium and sub-angular))	22	45	18.0	MC > 0.4 x LL (No significant moisture deficit)
Cohesive Lynch Hill Gravel Formation **BH1/5.00m bgl** (Brown SAND with numerous silty clay lumps)	22	43	17.2	MC > 0.4 x LL (No significant moisture deficit)
London Clay Formation **BH1/8.50m bgl** (Dark grey and orange brown silty CLAY)	28	77	30.8	**MC > 0.4 x LL** **(Potential moisture deficit)**

The results in the table above indicated that a potential significant moisture deficit was present within one sample of the London Clay Formation (BH1/ 8.50m bgl). The moisture content values were below 40% of the liquid limit.

The apparent moisture deficit was likely to be a result of the lithology of the soil (heavily overconsolidated soils). No roots were noted therefore the possible affect of moisture demand from nearby trees can be discounted.

5.2.3 Particle Size Distribution (PSD) Test

The results of PSD testing undertaken on two granular samples of the Lynch Hill Formation are tabulated below.

PSD Test Results Summary			
Trial Hole/Depth/Soil Description	**Volume Change Potential Range**		**Passing 63µm sieve Range (%)**
	BRE	**NHBC**	
Granular Lynch Hill Formation **BH1/6.00m bgl** (Yellow brown very sandy GRAVEL (Gravel is fine to coarse and sub-angular to rounded))	No	No	1.5
Granular Lynch Hill Formation **BH1/7.00m bgl** (Brown clayey sandy GRAVEL (Gravel is fine to coarse and angular to rounded)).	No	No	5.5

NB Volume Change Potential refers to BRE Digest 240 (based on Grading test results).
Shrinkability refers to NHBC Standards Chapter 4.2 (based on Grading test results).

Volume Change Potential – BRE 240 states that a soil has a volume change potential when the clay fraction exceeds 15%. Only the silt and clay combined fraction are determined by sieving therefore the volume change potential is estimated from the percentage passing the 63µm sieve.

NHBC Standards Chapter 4.2 states that a soil is shrinkable if the percentage of silt and clay passing the 63µm sieve is greater than 35% and the Plasticity Index is greater than 10%.

5.2.4 Swelling Test

A one dimensional Swelling Test was undertaken on a disturbed sample of the cohesive Lynch Hill Gravel Formation obtained from BH1 at a depth of 4.60m bgl.

The results of the test are tabulated below.

One Dimensional Consolidation Test - Swelling									
Stratum/Depth		Height (mm)	Moisture Content (%)	Bulk Density (Mg/m³)	Dry Density (Mg/m³)	Void Ratio	Degree of Saturation (%)	Particle Density (Mg/m³)	Swelling Pressure (kpa)
Cohesive Lynch Hill Gravel BH1/4.60m bgl (Brown/ orange brown slightly gravelly, sandy silty CLAY)	Initial	18.86	20	1.70	1.41	0.89	60.9	2.67	15
	Final	18.92	23	1.73	1.41	0.89	-	-	-

It must be noted that the sample was remoulded and this must be taken into account in final design.

5.2.5 Sulphate and pH Tests

Sulphate and pH tests were undertaken on one sample from the cohesive Lynch Hill Gravel Formation (BH1/5.00m bgl). The sulphate concentration was 0.12g/l with a pH of 7.8.

5.2.6 BRE Special Digest 1

In accordance with BRE Special Digest 1 'Concrete in Aggressive Ground' (BRE, 2005) one sample of Made Ground and one sample of the Lynch Hill Gravel Formation (BH1/2.50m and BH1/5.50m bgl) were scheduled for laboratory analysis to determine parameters for concrete specification.

The results are given within Appendix C and a summary is tabulated below.

Summary of Results of BRE Special Digest Testing			
Determinand	Unit	Minimum	Maximum
pH	-	7.6	7.6
Ammonium as NH_4	mg/kg	<0.5	<0.5
Sulphur	mg/kg	<200	639
Chloride (water soluble)	mg/kg	33	46
Magnesium (water soluble)	g/l	0.0033	0.0063
Nitrate (water soluble)	mg/kg	25	28
Sulphate (water soluble)	g/l	0.09	0.15
Sulphate (total)	mg/kg	<200	1915

6.0 ENGINEERING CONSIDERATIONS

6.1 Soil Characteristics and Geotechnical Parameters

Based on the results of the intrusive investigation and geotechnical laboratory testing the following interpretations have been made with respect to engineering considerations.

- Made Ground was encountered from ground level to a maximum depth of 4.40m bgl in BH1.

  As a result of the inherent variability of Made Ground it is usually unpredictable in terms of bearing capacity and settlement characteristics. Foundations should, therefore, be taken through any Made Ground and either into, or onto a suitable underlying natural stratum of adequate bearing characteristics.

- Soils of the Lynch Hill Gravel Formation were encountered beneath the Made Ground to a maximum depth of 7.60m bgl. An initial layer of cohesive deposits were encountered between 4.40m - 5.50m bgl and comprised a medium undrained shear strength (65kpa) orange brown, brown and red slightly sandy to sandy, locally gravelly silty clay. The sand was fine to coarse grained and the gravel was absent to rare, fine, sub-angular to angular flint.

  This was underlain by the more granular deposits to a depth of 7.60m. These deposits comprised dense to very dense yellow brown gravelly sands grading into an orange brown sandy gravel below 6.40m bgl. The sand was fine to coarse grained and the gravel was occasional to abundant, fine to coarse, sub-rounded to angular flint.

  The cohesive soils of the Lynch Hill Gravel Formation were shown to have a **low to medium** potential for volume change in accordance both BRE240 and NHBC Standards Chapter 4.2. Consistency Index calculations indicated the Cohesive Lynch Hill Gravel Formation to be stiff to very stiff. Liquidity Index testing revealed the soils to be heavily overconsolidated to overconsolidated. Geotechnical analysis revealed no potential significant moisture deficits were present within the samples of the Lynch Hill Gravel Formation tested.

  The granular soils of the Lynch Hill Gravel Formation showed no volume change potential in accordance with BRE240 and NHBC Standards Chapter 4.2.

  The soils of the Lynch Hill Gravel Formation are overconsolidated to heavily overconsolidated cohesive soils, becoming granular with depth, and are therefore likely to be a suitable stratum for the foundations associated with the basement. The settlements induced on loading are likely to be low to moderate.

The final design of foundations will need to take into account the volume change potential of the soil, the depth of root penetration and/or moisture deficit and the likely serviceability and settlement requirements of the proposed structure. These parameters for design are discussed in the next section of this report.

- Soils of the London Clay Formation, comprising an initially orange brown silty clay but becoming dark grey silty with depth, were encountered for the remaining depth of BH1, to a depth of 10.00m bgl.

The cohesive soils of the London Clay Formation comprised medium to high undrained shear strength (70-130kPa) soils with the undrained shear strength increasing with depth.

The soils of the London Clay Formation were shown to have a **high** potential for volume change in accordance both BRE240 and NHBC Standards Chapter 4.2.

Consistency Index calculations indicated the cohesive London Clay Formation to be stiff. Liquidity Index testing revealed the soils to be heavily overconsolidated. Geotechnical analysis revealed no potential significant moisture deficits were present within the samples of the London Clay Formation tested.

The soils of the London Clay Formation are heavily overconsolidated cohesive soils and because of their depth are likely to be a suitable stratum for piled foundations associated with the basement. The settlements induced on loading are likely to be low to moderate.

The final design of foundations will need to take into account the volume change potential of the soil, the depth of root penetration and/or moisture deficit and the likely serviceability and settlement requirements of the proposed structure. These parameters for design are discussed in the next section of this report.

- A groundwater strike was encountered at 6.40m bgl in BH1.

- No roots were noted in BH1 or TP1.

6.2 Basement Foundations

At the time of reporting, April 2015, the proposed development will comprise the demolition of the existing property and construction of a single storey brick built property with basement. The basement is anticipated to be constructed at 3.0 – 4.0m below existing ground level (bgl). The footprint of the property will cover the entire site area. The basement will be ~8.5m by 6m in area.

The proposed development fell within Geotechnical Design Category 2 in accordance with Eurocode 7. The proposed foundation loads were not known to Ground and Water Limited at the time of reporting but are likely to range from 75 – 150kN/m^2.

The proposed development was understood not to involve any re-profiling of the site and its immediate environs. It is understood that no trees will be removed to facilitate the construction of the basement.

Basement Foundations should be designed in accordance with soils of **medium volume change potential** in accordance with BRE Digest 240 and NHBC Chapter 4.2.

Given the cohesive nature of the shallow deposits foundations must therefore **not** be placed within cohesive root penetrated and/or desiccated soils and the influence of the trees surrounding the site must be taken into account (NHBC Standards Chapter 4.2). It is recommended that foundations are taken at least 300mm into non-root penetrated strata or granular soils of no volume change potential.

Where trees are mentioned in the text this means existing trees, recently removed trees (approximately 15 years to full recovery on cohesive soils) and those planned as part of the site landscaping. Should trees be removed from the footprint of the proposed building then an alternative foundation system, such as piles or isolated pads should be considered.

No roots were noted within BH1 or TP1. Made Ground was noted to 4.40m bgl within BH1 therefore a minimum foundation depth of 4.40m bgl is recommended.

It is considered likely the proposed basement will be constructed with load bearing concrete retaining walls with semi-ground bearing concrete floors. The following bearing capacities could be adopted for 5.0m long by 0.75m and 1.00m wide retaining wall strip footings pads at a depth of 4.40m bgl. The bearing capacities and settlements were determined based on BH1.

Limit State: Bearing Capacities Calculated (Based on BH1)		
Depth (m BGL)	**Foundation System**	**Limit Bearing Capacity (kN/m²)**
4.40m	5.00m by 0.75m Strip	127.79
	5.00m by 1.00m Strip	127.79

Serviceability State: Settlement Parameters Calculated (Based on BH1)			
Depth (m BGL)	**Foundation System**	**Limit Bearing Capacity (kN/m²)**	**Settlement (mm)**
4.40m	5.00m by 0.75m Strip	125	<9
	5.00m by 1.00m Strip	125	<11

It must be noted that a bearing capacity of less than 80kN/m^2 at 4.40m bgl may results in heave of the underlying soils. A swelling pressure of 15kN/m^2 was observed within a disturbed sample of the cohesive Lynch Hill Gravel Formation taken from 4.50m bgl.

It must be mentioned that it was assumed that excavations will be kept dry and either concreted or blinded as soon after excavation as possible. If water were allowed to accumulate on the formation for even a short time not only would an increase in heave occur resulting from the soil increasing in volume by taking up water, but also the shear strength and hence the bearing capacity would also be reduced.

If the construction works take place during the winter months, when the groundwater level is expected to be at its higher elevation, perched water could accumulate thus dewatering could be required to facilitate the construction and prevent the base of the excavation blowing before the slab was cast. The advice of a reputable dewatering contractor, familiar with the type of ground and groundwater conditions encountered on this site, should be sought prior to finalising the design of the excavation for the basement.

The basement must be suitably tanked to prevent ingress of groundwater and also surface water run-off. The basement must also be designed to take into account pressure exerted by the presence of groundwater in and around the basement.

6.3 Piled Foundations

Alternatively, consideration could be given to the construction of a piled foundation design given the depth of Made Ground (4.40m bgl) and bearing capacities achieved.

The construction of a piled foundation is a specialist job, and the advice of a reputable contractor, familiar with the type of ground and groundwater conditions encountered on this site, should be sought prior to finalising the foundation design, as the actual pile working load will depend on the particular type of pile and method of installation adopted.

For the cumulative pile capacity calculations, shaft friction over the desiccated levels should be ignored and piles should not be terminated within desiccated soils where moisture recovery following tree removal could occur.

Indicative limit loads and settlements for a bored pile have been given within the table below and have been based on BH1.

An allowance for negative skin friction to occur within the top 4.0m of the soil has been included within the calculations where it could pass through any Made Ground or root penetrated soils. An adhesion factor of 0.45m has been applied.

The bearing values may be limited by the maximum permissible stress allowable on a concrete pile. To achieve the full bearing value a pile should penetrate the bearing stratum by at least five times the pile diameter.

EC7 – Factor of Safety of 2 – 2.5 on Limit Load.

Bored Pile – Limit Loads and Settlement Parameters (Based on BH1)						
Depth (m bgl)	Diameter (m)	Limit States (kN)			Settlement (Poulos Davis (1968))	
		Tip	Lateral	Total	Load (kN)	Total (Elastic + Rigid) (cm)
9	0.30	28.22	91.12	105.32	105	0.15
	0.45	63.49	138.18	167.88	165	0.27
	0.60	112.87	184.25	237.03	235	0.29

Classic Theory – Factor of Safety of 3 on Limit Load.

Bored Pile – Limit Loads and Settlement Parameters (Based on BH1)						
Depth (m bgl)	Diameter (m)	Limit States (kN)			Settlement (Poulos Davis (1968))	
		Tip	Lateral	Total	Load (kN)	Total (Elastic + Rigid) (cm)
9	0.30	25.90	72.04	82.92	80	0.11
	0.45	52.28	108.06	132.55	130	0.22
	0.60	103.62	144.08	187.61	185	0.23

The bearing values given in the table above are applicable to single piles. Where piles are to be constructed in groups the bearing value of each individual pile should be reduced by a factor of approximately 0.8 and a calculation made to check the factor of safety against block failure.

The piles will need to be designed in accordance with the volume change potential of the soils encountered, depth of desiccation, root penetration, etc. Temporary casing may be required where the upper portion of the pile passes through the Made Ground, particularly where perched water is encountered, to prevent necking of the concrete.

6.4 Basement Excavations & Stability

Shallow excavations in the Made Ground and Lynch Hill Gravel Formation are likely to be marginally stable at best. Long, deep excavations, through both of these strata are likely to become unstable.

The excavation of the basement must not affect the integrity of the adjacent structures beyond the boundaries. The excavation must be supported by suitably designed retaining walls. It is considered unlikely that battering the sides of the excavation, casting the retaining walls and then backfilling to the rear of the walls would be suitable given the close proximity of the party walls.

The retaining walls for the basement will need to be constructed based on an appropriate angle of shear resistance (*Φ'*) for the ground conditions encountered.

Based on the ground conditions encountered within the boreholes the following parameters could be used in the design of retaining walls. These have been designed based on the SPT profile recorded, results of geotechnical classification tests and reference to literature.

Retaining Wall/Basement Design Parameters					
Strata	**Unit Volume Weight (kN/m³)**	**Cohesion Intercept (c') (kPa)**	**Angle of Shearing Resistance (Ø)**	**Ka**	**Kp**
Made Ground	~15	0	12	0.66	1.52

Unsupported earth faces formed during excavation may be liable to collapse without warning and suitable safety precautions should therefore be taken to ensure that such earth faces are adequately supported before excavations are entered by personnel.

Based on the groundwater readings taken during this investigation to date, it was considered unlikely that groundwater would be encountered during basement construction. Perched water may be encountered within the Made Ground, above the cohesive Lynch Hill Gravel Formation, especially after period of prolonged rainfall.

6.5 Hydrogeological Effects

The proposed development is located on **Unproductive Strata** relating to the London Clay revealed the site to be located within a **Secondary A Aquifer** comprising the superficial drift deposits of the Lynch Hill Gravels. The underlying London Clay Formation was described as **Unproductive Strata**.

The ground conditions encountered generally comprised a capping of Made Ground over the cohesive and granular Lynch Hill Gravel Formation deposits and then the cohesive London Clay Formation. Based on a visual appraisal of the soils encountered the permeability of the cohesive Lynch Hill Gravel Formation and London Clay Formation was likely to be very low to negligible permeability. Permeability within the more granular Lynch Hill Gravel Formation deposits was likely to medium to high.

A groundwater strike was noted at 6.40m bgl in BH1.

Based on the above it is considered unlikely that groundwater will be encountered during basement construction. Perched water may be encountered within the Made Ground, above the cohesive Lynch Hill Gravel Formation, especially after period of prolonged rainfall.

In relation to the basement, once constructed, the Made Ground and underlying cohesive Lynch Hill Gravel Formation deposits are unlikely to act as a porous medium for water to migrate, therefore additional drainage should be considered as the deposits will act as a barrier for groundwater migration.

6.6 Sub-Surface Concrete

Sulphate concentrations measured in 2:1 water/soil extracts taken from the Made Ground and Lynch Hill Gravel Formation, from both the geotechnical and chemical laboratory testing, fell into Classes DS-1 of the BRE Special Digest 1, 2005, *'Concrete in Aggressive Ground'.*

Table C1 of the Digest indicated an ACEC (Aggressive Chemical Environment for Concrete) classification of AC-1 for foundations within the Made Ground and Lynch Hill Gravel Formation. For the classification given, the "mobile" and "natural" case was adopted given the Made Ground (permeability likely to exceed 10^{-7} m/sec) and use of the site.

The sulphate concentration in the samples ranged from 90 - 150mg/l with a pH range of 7.6 - 7.8. The total sulphate concentration recorded ranged from <0.02%-0.19%.

Concrete to be placed in contact with soil or groundwater must be designed in accordance with the recommendations of Building Research Establishment Special Digest 1, 2005, *'Concrete in Aggressive Ground'* taking into account the pH of the soils.

It is prudent to note that pyrite nodules may be present within the London Clay Formation. Pyrite can oxidise to gypsum and this normally only occurs in the upper weathered layer, but excavation allows faster oxidation and water soluble sulphate values can rapidly increase during construction. Therefore rising sulphate values should be taken into account should ferruginous staining/pyrite nodules be encountered within the London Clay Formation.

6.7 Surface Water Disposal

Infiltration tests were beyond the scope of the investigation.

Soakaway construction within the Made Ground and cohesive soils of the Lynch Hill Gravel Formation are unlikely to prove satisfactory due to negligible to low anticipated infiltration rates. Therefore an alternative method of surface water disposal is required.

Soakaways constructed within the deeper more granular Lynch Hill Gravel Deposits may prove more satisfactory for surface water disposal.

Consultation with the Environment Agency must be sought regarding any use that may have an impact on groundwater resources.

The principles of sustainable urban drainage system (SUDS) should be applied to reduce the risk of flooding from surface water ponding and collection associated with the construction of the basement.

6.8 Discovery Strategy

There may be areas of contamination that have not been identified during the course of the intrusive investigation. For example, there may have been underground storage tanks (UST's) not identified during the Ground Investigation for which there is no historical or contemporary evidence.

Such occurrences may be discovered during the demolition and construction phases for the redevelopment of the site.

Groundworkers should be instructed to report to the Site Manager any evidence for such contamination; this may comprise visual indicators, such as fibrous materials within the soil, discolouration, or odours and emission. Upon discovery advice must be taken from a suitably qualified person before proceeding, such that appropriate remedial measures and health and safety protection may be applied.

Should a new source of contamination be suspected or identified then the Local Authority will need to be informed.

6.9 Waste Disposal

The excavation of foundations is likely to produce waste which will require classification and then recycling or removal from site.

Under the Landfill (England and Wales) Regulations 2002 (as amended), prior to disposal all waste must be classified as;

- Inert;
- Non-hazardous, or;
- Hazardous.

The Environment Agency's Hazardous Waste Technical Guidance (WM2) document outlines the methodology for classifying wastes.

Once classified the waste can be removed to the appropriately licensed facilities, with some waste requiring pre-treatments prior to disposal.

INERT waste classification should be undertaken to determine if the proposed waste confirms to INERT or NON-HAZARDOUS Waste Acceptable Criteria (WAC).

6.10 Imported Material

Any soil which is to be imported onto the site must undergo chemical analysis to prove that it is suitable for the purpose for which it is intended.

The Topsoil must be fit for purpose and must either be supplied with traceable chemical laboratory test certificates or be tested, either prior to placing (ideally) or after placing, to ensure that the human receptor cannot come into contact with compounds that could be detrimental to human health.

6.11 Duty of Care

Groundworkers must maintain a good standard of personal hygiene including the wearing of overalls, boots, gloves and eye protectors and the use of dust masks during periods of dry weather.

To prevent exposure to airborne dust by both the general public and construction personnel the site should be kept damp during dry weather and at other times when dust were generated as a result of construction activities.

The site should be securely fenced at all times to prevent unauthorised access. Washing facilities should be provided and eating restricted to mess huts.

APPENDIX A
Conditions and Limitations

The ground is a product of continuing natural and artificial processes. As a result, the ground will exhibit a variety of characteristics that vary from place to place across a site, and also with time. Whilst a ground investigation will mitigate to a greater or lesser degree against the resulting risk from variation, the risks cannot be eliminated.

The investigation, interpretations, and recommendations given in this report were prepared for the sole benefit of the client in accordance with their brief; as such these do not necessarily address all aspects of ground behaviour at the site. No liability is accepted for any reliance placed on it by others unless specifically agreed in writing.

Current regulations and good practice were used in the preparation of this report. An appropriately qualified person must review the recommendations given in this report at the time of preparation of the scheme design to ensure that any recommendations given remain valid in light of changes in regulation and practice, or additional information obtained regarding the site.

This report is based on readily available geological records, the recorded physical investigation, the strata observed in the works, together with the results of completed site and laboratory tests. Whilst skill and care has been taken to interpret these conditions likely between or below investigation points, the possibility of other characteristics not revealed cannot be discounted, for which no liability can be accepted. The impact of our assessment on other aspects of the development required evaluation by other involved parties.

The opinions expressed cannot be absolute due to the limitations of time and resources within the context of the agreed brief and the possibility of unrecorded previous in ground activities. The ground conditions have been samples or monitored in recorded locations and tests for some of the more common chemicals generally expected. Other concentrations of types of chemicals may exist. It was not part of the scope of this report to comment on environment/contaminated land considerations.

The conclusions and recommendations relate to land to the rear of No. 51 Gower Street, London WC1E 6HJ.

Trial hole is a generic term used to describe a method of direct investigation. The term trial pit, borehole or window sampler borehole implies the specific technique used to produce a trial hole.

The depth to roots and/or of desiccation may vary from that found during the investigation. The client is responsible for establishing the depth to roots and/or of desiccation on a plot-by-plot basis prior to the construction of foundations. Where trees are mentioned in the text this means existing trees, recently removed trees (approximately 15 years to full recovery on cohesive soils) and those planned as part of the site landscaping.

APPENDIX B
Fieldwork Logs

APPENDIX C
Geotechnical Laboratory Test Results