Appendix 9.3

GEO-INEGRITY PHASE II GEO-ENVIRONMENTAL SITE INVESTIGATION SEPTEMBER 2023

FINAL

London Borough of Hillingdon

Phase II

Geotechnical and Geo-Environmental Report

(First Phase of Intrusive Investigation

Covering Accessible Areas of the Peninsula)

Hillingdon Water Sports Facility and Activity Centre (HWSFAC)

Broadwater Lake

Moorhall Road

Harefield

UB9 6PE

Report No: 23-09-03B

September 2023

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Issue No Date	Status	Prepared by	Checked by
1 September 2023	Draft Report	Lee Ashworth B.Sc. M.Sc. F.G.S Engineering Geologist SIGNATURE 	Murray Bateman, M.Sc. DIC C.Geol Pg. Cert. Director SIGNATURE 
1 September 2023	Final Report	Lee Ashworth B.Sc. M.Sc. F.G.S Engineering Geologist SIGNATURE 	Murray Bateman, M.Sc. DIC C.Geol Pg. Cert. Director SIGNATURE 

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Executive Summary	
Site Location	Land adjacent to Broadwater Lake, Moorhall Road, Harefield, UB9, 6PE
OS Grid Reference	TQ 04741 89189
Development Proposals	Redevelopment of the site to create the Hillingdon Watersports Facility and Activity Centre including demolition of existing Broadwater Lake Sailing Club (BSC) clubhouse at the north of the lake and erection of a building to be occupied by HOAC and BSC including changing facilities, meeting rooms, storage, workshop and seasonal worker accommodation (sui generis), seven activity shelters; three pontoons; two concrete slipways; one boat shed; two equipment storage huts (north of lake and at entrance); boat parking and racking areas; camping area; outdoor activity areas; ecological enhancement throughout the site; new pedestrian routes through the peninsula; landscaping including new woodland, dense vegetation screens and boundary treatment; new access and access road; localised dredging and land reclamation; relocation of existing sailing area and creation of floating and fixed islands within the lake; coach drop off and turning area; vehicle parking; cycle parking; and associated works.
Published Geology	The site is likely underlain by thick Made Ground associated with the historic processing of aggregate on site with some concrete obstructions overlying Alluvium, overlying Shepperton Gravel, overlying Upper Chalk. Groundwater is likely to be between 1m to 2m below ground level.
Site History	The previous desk study indicates that the site has been in agricultural usage from at least 1881 until the 1960's when it started to be exploited for its underlying sand and gravel deposits. Processing of this material occurred towards the southeast of the site, accessed from a trackway leading down to Moorhall Road to the site. Extraction continued until the end of the 1990's. Currently the site area is a Nature Reserve and the lake is used by fishing clubs and the Broadwater Sailing Club, there is also one residential house to the very southeast corner of the main site.
Ground Conditions Encountered	Concrete hardstanding was encountered across the majority of the eastern side of the site and part of the proposed activity field at the southern end of the site, associated with the historic gravel extraction activities. The lateral extent of concrete is shown on the hardstanding plan within Appendix A. Made Ground soils were also encountered across the entire site from ground level and underlying the hardstanding down to depths between 1.00m and 2.00m bgl, however some areas encountered locally deeper Made Ground including BH3 and BH4 down to depths of 2.45m and 3.45m bgl which were located along the eastern side of the site. Reworked soils were located locally along the northern boundary becoming thicker westwards. These reworked natural gravels were encountered down to depths ranging between 2.45m and 3.25m bgl interpreted to reflect the infilling processes which was noted on the historical OS maps from 2001. The first natural soil encountered is a consistent layer of Alluvium which is present across the entire site. Alluvium was encountered down to depths ranging between 1.30m and 4.50m bgl. This was underlain by a consistent medium dense to dense granular layer of superficial gravel known as the Shepperton Gravel Member down to depths ranging between 6.10m and 8.00m bgl. The superficial gravels were underlain by structureless chalk comprising layers of gravelly silt (Grade Dm) and silty gravel (Grade Dc) down to the base of the exploratory holes in excess of 15.00m bgl.
Groundwater Encountered	Groundwater was encountered as water strikes ranging between 1.00m and 4.90m bgl and standing levels between 1.20m and 4.60m bgl within the Made Ground, Alluvium and Shepperton Gravel Member soils across the entire site. Subsequent groundwater monitoring recorded standing water levels between 0.75m and 2.39m bgl. It is considered the groundwater is in continuity with Broadwater Lake.

Contamination	An area of Made Ground impacted by hydrocarbons was encountered at the north of the site, the levels recorded fall below the relevant S4UL for a commercial land-use, however are elevated for a residential land-use. Therefore, remedial measure will be required. An assessment of the risk to controlled waters is described in detail within section 6.4.
Sulphate Attack on Underground Concrete	The following design sulphate class and aggressive chemical environment classification should be applied: Made Ground: DS-1/AC-1 Reworked Ground: DS-2/AC-2 Alluvium: DS-2/AC-2 Shepperton Gravel Member: DS-1/AC-1 Upper Chalk: DS-1/AC-1
Shallow Foundations	Given the poor near surface ground conditions which includes deep Made Ground/Reworked Ground overlying highly compressible alluvial soils with shallow groundwater levels (0.75m bgl) it is considered conventional shallow foundations will not be viable at this site for settlement sensitive buildings. However, advice has been given for raft foundations where settlement is less sensitive.
Pile Foundations	Preliminary working loads for a range of pile sizes, depths are provided for areas and structures within the proposed development. See section 5.3.2 for further details.
Waste Soil Classification	Two sets of Made Ground are considered which are delineated on the Remedial Plan in Appendix A. Impacted Made Ground (Hydrocarbons): 17 05 04 Stable Non-Reactive Hazardous Waste in a Non-hazardous Landfill General Made Ground/Reworked Ground: 17 05 04 Inert Natural Soil: Inert
Recommendations	We recommend a watching brief should be undertaken during the construction phase, and if during development any previously undiscovered contamination (including visual or olfactory evidence) is found then site management should be immediately informed and inspection by a suitably qualified person should be undertaken. Barrier pipe will be required at this site due to elevated levels of hydrocarbons, SVOC's and VOC's within the Made Ground soils. This first phase of intrusive investigation was undertaken solely on the accessible areas of the peninsula. The data collected to date is sufficient to support the conclusions of this report. The surrounding area of the site mainly covered by the lake and islands is not covered by this investigation and it is anticipated further investigation will be required prior to construction works commencing. Given the development proposals have changed this has altered the location of the proposed buildings. It is considered further investigation including boreholes will be required prior to the development works immediately north of the peninsula where it is proposed to extend the peninsula and construct commercial structures. This ground investigation has identified a single hotspot of contamination associated with elevated levels of hydrocarbons identified within two exploratory holes surrounding a concrete bund situated at the north of the peninsula. It is considered remedial measures will be required to protect against the end users of the site which overall is deemed to be commercial with minor residential land-use associated with camping areas. It may be requested to undertake additional testing in areas across the peninsula and the wider site area which were previously inaccessible during this intrusive investigation. It is understood additional intrusive investigations are being undertaken by HydroGeo associated with sampling the lake bed covering the area surrounding the peninsula. A preliminary assessment of the gas regime was undertaken at the site which identified low gas levels indicating a CS1 site, however it may be requested to undertake additional monitoring visits within the standpipes previously installed and/or installation of additional standpipes in the wider site area. The on-site historic landfill recorded in the previous desk study was not found to extend onto the peninsula. Further investigation could be undertaken prior to the development phase to assess the ground conditions below the lake immediately east of the peninsula.

This executive summary must be read in conjunction with the full report text

FACTUAL

1.1 INTRODUCTION

Geo-Integrity Ltd were commissioned by Mace Group via Purchase Order (No. MLIMPD0028877) on the 5th of September to update the existing Phase II Factual and Interpretative Geotechnical and Geo-Environmental Report (23-01-09) for the proposed Hillingdon Water Sports Facility and Activity Centre (HWSFAC), Broadwater Lake, Moorhall Road, Harefield, UB9 6PE in order to inform the design and construction of the proposed development. This updated report has been given a new reference number 23-03-09B. The development proposal has changed and therefore the ground investigation previously undertaken (ref.23-01-09) does not accurately reflect the updated development proposal.

This report describes desk-based searches of geological, environmental and historical information, a summary of the previous Phase I Desk Study (ref. 22-10-12), the fieldwork and laboratory testing undertaken and provides an interpretative section of the geotechnical and geo-environmental data from this investigation to inform the proposed development.

This report should be read in conjunction with the previous Phase I Desk Study Report undertaken by Geo-Integrity Ltd., ref. 22-10-12, dated November 2022.

This ground investigation covers the accessible areas of the peninsula only. It is understood subsequent phases of investigation will be undertaken within the wider site area to aid the proposed development.

This report supersedes the previous Phase II Ground Investigation Report (Ref. 23-01-19) undertaken by Geo-Integrity Ltd. This updated report makes aware further investigation covering the entire site boundary will be undertaken. In addition, amendments to the development proposal have changed the land-use scenario to commercial with some areas of residential therefore the human health risk assessment has been updated and recommendations for further work.

The site is located at National Grid Reference TQ 04741 89189.

The report is likely to be reviewed by Hillingdon Council with reference to the NPPF. The NPPF states that a site must be “suitable for its proposed use taking account of ground conditions and any risks arising from land instability and contamination. This includes risks arising from natural hazards or former activities such as mining”.

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Once the development is completed, and as a minimum, land must not be capable of being determined as 'contaminated land' under the terms of Part IIA of the Environmental Protection Act 1990. However, it also states that "Where a site is affected by contamination or land stability issues, responsibility for securing a safe development rests with the developer and/or landowner."

As such the previous Phase I Desk Study Report (ref. 22-10-12) was the first stage in investigating whether the site is likely to be considered "contaminated", in accordance with clause 183 and 184 of the NPPF.

The objectives of this Phase II Geotechnical and Geo-Environmental Interpretive Report are:-

- To briefly summarise the findings of the previous investigation including historical, geological and environmental information
- To briefly summarise the site development proposals and site setting
- To describe and report the fieldwork undertaken at the site
- To describe and report the geotechnical and chemical laboratory work undertaken on selected samples
- To provide an interpretation of the results of this investigation with regards to the geotechnical properties, and geo-environmental and waste disposal implications for the proposed development

The investigation was performed in accordance with the general requirements of BS 5930:2015, BS EN 1997-2 (2007), BS EN ISO 22475-1 (2006) and other relevant related standards identified below. The fieldwork took place across ten days between the 15th and 28th of February 2023.

1.2 SOURCES OF INFORMATION

The following sources of information have been used to compile this report:-

- Phase I Desk Study Report undertaken by Geo-Integrity Ltd., ref. 22-10-12, dated November 2022
- The British Geological Survey (BGS) and Environment Agency (EA) websites
- A site reconnaissance visit undertaken on the 20th of December 2022
- Information from various internet sites on site history and environmental setting

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1.3 DEVELOPMENT PROPOSALS

The proposed development involves the redevelopment of the site to create the Hillingdon Watersports Facility and Activity Centre including demolition of existing Broadwater Lake Sailing Club (BSC) clubhouse at the north of the lake and erection of a building to be occupied by HOAC and BSC including changing facilities, meeting rooms, storage, workshop and seasonal worker accommodation (sui generis), seven activity shelters; three pontoons; two concrete slipways; one boat shed; two equipment storage huts (north of lake and at entrance); boat parking and racking areas; camping area; outdoor activity areas; ecological enhancement throughout the site; new pedestrian routes through the peninsula; landscaping including new woodland, dense vegetation screens and boundary treatment; new access and access road; localised dredging and land reclamation; relocation of existing sailing area and creation of floating and fixed islands within the lake; coach drop off and turning area; vehicle parking; cycle parking; and associated works.

2 PREVIOUS INVESTIGATION

2.1 PHASE I DESKSTUDY (REF. 22-10-12)

2.1.1 Geotechnical Summary

The previous desk study undertaken by Geo-Integrity Ltd identified the site is likely underlain by thick Made Ground associated with the historic processing of aggregate on site with some concrete obstructions overlying Alluvium, overlying Shepperton Gravel with Chalk strata at approximately 6m below ground level. Groundwater is likely to be between 1m to 2m below ground level.

Given the site is underlain by chalk, which is highly susceptible to dissolution, a natural cavities risk assessment was undertaken by the previous desk study. The score for the site was 28, which means there is predicted to be no anticipated subsidence hazard risk of natural cavities beneath the site (0% occurrence).

From the historic OS maps the site was once mainly open agricultural land with a network of ditches named Harefield Moor, presumably due to the damp nature of the ground. It is noted the site remains undeveloped for some time however by 1960 it can be seen gravel extraction has begun north and south of the site with Harefield Pit and Troy Mill Gravel Pit both having been extracted and shown as lakes. By 1968 it shows the gravel extraction from the main site area had started with the central and western areas having been extracted. It is not until the plan of 2001 that the site boundaries as seen during the walkover are the same, and this involves a large

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amount of refilling to the west of the land promontory on the site (therefore this is not original land). No significant changes are recorded after this time.

Given the findings of the previous desk study the ground conditions are likely to comprise of deep Made Ground soils (more so on the western half of the site where the refilling has taken place), overlying Alluvium, overlying Shepperton Gravel Member, overlying Upper Chalk.

A desk study of the deeper ground conditions indicates the site will likely be underlain by Upper Chalk which comprises of:

- Seaford and Newhaven Chalk Formations (Undifferentiated) down to a depth of 50-60m bgl. Described as soft chalk with sporadic nodular flint beds
- Lewes Nodular Chalk down to a depth of 80-90m bgl. Described as hard white/yellow chalk with sporadic flints and thin marls

This is underlain by the Middle Chalk which comprises of:

- New Pit Chalk down to a depth of 125-135m bgl. Described as soft which chalk with thin marls and sporadic flints.
- Holywell Nodular Chalk down to a depth of 140m to 150m bgl. Described as hard white to pale grey chalk

This is underlain by the Lower Chalk which comprises of:

- Grey Chalk Subgroup down to a depth of 210-220m bgl. Described as grey chalk with interbedded limestone and marl beds

2.1.2 Geo-Environmental Summary

The previous desk study indicates that the site has been in agricultural usage from at least 1881 until the 1960's when it started to be exploited for its underlying sand and gravel deposits. Processing of this material occurred towards the southeast of the site, accessed from a trackway leading down to Moorhall Road to the site. Extraction continued until the end of the 1990's. Currently the site area is a Nature Reserve and the lake is used by fishing clubs and the Broadwater Sailing Club, there is also one residential house to the very southeast corner of the main site.

Given the proposed development of the site as a commercial end usage, it is considered that there is a low to moderate risk to end users. However, the risk of encountered localised pockets of

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contamination is considered to be moderate to high. There is also a perceived moderate risk of encountered contamination sources that may be affecting the Principal groundwater Aquifer beneath the site and as the site is in a Source Protection Zone, this would need to be dealt with as part of the development.

The surrounding uses of the site generally poses no risk of contamination, however, there is a large old landfill site to the east of the site that is undoubtedly a large source of landfill gases.

The majority of the rest of the land use on the site is a nature reserve and as such no potentially contaminative land uses have been identified.

As such the main potential sources of contamination which will be investigated as part of this Phase II investigation include:

- Historic hydrocarbons within the ground from human history in the area of aggregate processing
- Historic asbestos within any made ground from human history in the area of aggregate processing
- Historic metals and PAH's within any made ground from human history in the area of aggregate processing
- Ground gas from on and off-site landfills
- PCB from electricity sub-station

2.2 SITE WALKOVER

A site walkover was undertaken as part of this phase II ground investigation on the 20th of December 2022 with Richard Weston of Hillingdon Council (Client) and Stephanie Harper of Greengage Environmental Ltd. (Ecologist).

The site walkover survey was undertaken to agree the locations of the exploratory holes given the site is a site of special scientific interest (SSSI) and the risk of quicksand arising from the historic processing of aggregate. In addition, it was also agreed which areas required clearing of invasive species such as buddleia to enable access for the drilling rigs and excavator to complete the exploratory holes. The walkover plan showing the agreed areas of investigation is shown in Appendix A (the plan shows the previous development proposal).

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3 PHASE II INTRUSIVE INVESTIGATION

3.1 SITE WORK AND SAMPLING STRATEGY

The fieldwork was undertaken in accordance with BS 5930:2015, BS EN 1997-2 (2007) and BS EN ISO 22475-1 (2006), with the exploratory locations being selected by Geo-Integrity Ltd and agreed by Richard Weston of Hillingdon Council and Stephanie Harper of Greengage Environmental Ltd. (Ecologist). The exploratory hole locations can be seen in the Appendices.

The fieldwork was undertaken across ten days between the 15th and 28th of February 2023. The sitework consisted of nine cable percussive boreholes down to 15.00m bgl (BH1-BH9), three machine excavated infiltration pits (SA1 – SA3) using a JCB 3CX, fourteen machine excavated trial pits (TP1 – TP14), and seven plate load (equivalent CBR) tests (CBR1 – CBR7). In addition, monitoring wells were installed within boreholes BH3, BH6 and BH9 to undertake subsequent groundwater and gas monitoring and groundwater sampling. Standpipes were installed within boreholes positioned to target potential sources of gas:

- BH3 was positioned within the boundary of the on-site historic landfill (shown on the exploratory hole and landfill plan in Appendix A) identified from the previous Phase I Desk Study.
- BH6 was located at the north-east corner of the site the closest point on the peninsula to the off-site historic landfill identified from the previous desk study
- BH9 was positioned at the north-west corner of the peninsula where deeper Reworked Ground (>3m thick) was encountered

Disturbed samples were taken at selected depths down to the base of the exploratory holes for subsequent laboratory testing and inspection. On completion, all trial pits were carefully backfilled with arisings in thin layers, ensuring that excavated material was replaced in the same order as it had been removed.

3.2 LIMITATIONS

The limitations of this ground investigation which may warrant further investigation are as follows.

1) The development proposal plans were altered after the intrusive investigation had been completed. Therefore, this investigation does not cover areas of the updated development

proposal which include new pontoons, a camping ground, an extension of land to the north of peninsula and construction of new islands.

2) The ground investigation was undertaken whilst the site was being cleared of vegetation which limited the extent which could be covered.
3) Unsafe ground conditions including sinking sand and soft wet ground were outlined on a topographical survey (shown in Appendix A) further limiting the areas which could be safely investigated.

A plan showing the area investigated during this ground investigation is shown in Appendix A. The red highlighted area shows the area covered by the investigation. The areas highlighted black were not accessible during the ground investigation due to quick sand to the south and soft ground and dense tree coverage at the centre and north of the site. The wider site area was not covered by this investigation. It is understood HydroGeo are undertaking ground investigation covering the surrounding lake bed.

3.3 GROUND CONDITIONS

3.3.1 Summary

The site and laboratory test work revealed that the general succession of strata can be represented by localised hardstanding, overlying Made Ground, overlying localised Reworked Ground, overlying Alluvium, overlying the Shepperton Gravel Member, overlying the Upper Chalk.

Descriptions of the strata encountered are given on the exploratory hole records and are summarised below. Further information is provided on the exploratory hole logs within the Appendices.

3.3.2 Hardstanding

Hardstanding was encountered as concrete within the southern and eastern areas of the site within exploratory holes (BH1, BH3, BH4, BH5, CBR2, CBR3, TP6, TP7, and TP10 – TP12). Concrete was encountered down to depths ranging between 0.05m and 0.70m bgl.

In addition, in trial pits TP6 and TP7 located within the proposed camping area at the southern end of the site encountered very dense weathered concrete down to depths of 0.80m and 1.60m bgl upon which the trial pits refused. The ‘weathered concrete’ is considered to be sourced from the

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refilling process indicated by the desk study information. A plan showing the areas of concrete hardstanding is shown in Appendix A.

3.3.3 Made Ground

Encountered in each of the exploratory holes from depths ranging between ground level and 0.70m bgl down to depths ranging between 0.30m and 3.45m bgl.

The material was generally encountered as loose, orange, brown, silty, sandy gravel, gravel is fine to coarse brick, flint, concrete, ash, slag, slate, and quartz with occasional cobbles and boulder size fragments of concrete.

Localised layers of soft to firm, dark brown, beige, silty, slightly gravelly clay (less than 1m in thickness) were encountered at the north-west and southern areas of the site covered by BH2, TP2, TP8, TP9, TP10 and CBR6.

Distinct hydrocarbon staining and odour was encountered within the Made Ground soils surrounding the historic concrete bund located at the north of the site covered by TP4 and CBR5. Additional trial pits were undertaken around the historic concrete bund which did not encounter hydrocarbon staining and odour these include TP3, TP5, BH7. As such, it is considered the main impact from hydrocarbons is localised to the immediate west side of the historic bund.

3.3.4 Reworked Ground

Encountered locally at the north-west area of the site within exploratory holes BH6 – BH7 underlying the Made Ground soils from depths ranging between 0.30m and 0.45m bgl down to depths ranging between 2.45m and 3.25m bgl. The material was encountered as medium dense to dense, light brown, sandy gravel, gravels being fine to coarse flint and quartz.

Particle size distribution test undertaken on a representative sample recorded the following grain size percentages: Fines:-3%, Sand:- 38%, Gravel:- 59%. These percentages indicate the material is predominantly a gravel with lesser amounts of sand and fines, respectively.

SPT tests undertaken within this material recorded ‘N’ values between 19 and 32 indicating a medium dense to dense granular soil.

3.3.5 Alluvium

Encountered within the majority of the exploratory holes except the shallow ones including the CBR pits and those located at the south-west area of the site. It is considered Alluvium is encountered

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across the entire site at depth, which from this investigation has been proven at depths from 0.60m and 3.45m bgl down to depths ranging between 1.30m and 4.50m bgl. The material was encountered as very soft, dark brown, black, grey, green, highly organic, silty, slightly gravelly clay with peat and plant debris. Gravels were encountered as fine to coarse flint.

Laboratory tests undertaken on representative samples revealed a moisture content range between 66% and 112% and a modified plasticity index range of 11% to 18% which equates to a low shrinkage soil in accordance with NHBC guidelines. The extremely high recorded moisture content indicates the high organic content within this material, as organic matter characteristically enables high water retention. Given the high organic content this material is considered to be highly compressible and unsuitable as a founding stratum due to unacceptable settlements.

SPT tests undertaken within this material recorded ‘N’ values between 3 and 7 indicating very soft cohesive soil.

3.3.6 Shepperton Gravel Member

Encountered only in the majority of the deeper exploratory holes (BH1 – BH9, TP11 – TP14) from depths ranging between 0.50m bgl and 4.50m bgl down to depths ranging between 6.10m and 8.00m bgl. The material was encountered as medium dense to dense, dark grey, orange, brown, sandy gravel, gravels being fine to coarse, sub-angular to sub-rounded flint and quartz. Local layers of loose granular material was also located within BH5

Particle size distribution tests undertaken on representative samples recorded the following grain size percentages: Fines:- 0% - 3%, Sand:- 6% - 38%, Gravel:- 59% - 94%. Cobbles were also recorded within two samples however these were excluded from the total percentage as they are not representative of the material.

SPT tests undertaken within this material recorded ‘N’ values generally between 17 and 50 indicating a medium dense to very dense granular soil. Some lower ‘N’ values were also recorded between 6 and 9 which corresponded to the top of the formation in BH5 and the bottom of the formation within BH2 and BH4. It is considered the lower ‘N’ values likely reflect transitional water softened soils given the lower values are located at the top and base of the formation.

3.3.7 Upper Chalk

Encountered only in the deep cable percussive boreholes (BH1 – BH9) at a depth of 4.50m bgl down to the base of the exploratory holes in excess of 19.95m bgl. The material was encountered

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at depths ranging between 6.10m and 8.00m bgl down to the base of the exploratory holes in excess of 15.00m bgl. The material was encountered as structureless off-white chalk comprising both gravelly silt (Grade Dm) and silty gravel (Grade Dc).

Laboratory tests undertaken on representative samples of the coarse chalk gravel recorded saturated moisture contents between 21% and 27%, intact dry density between 1.57 and 1.73mg/m^3 and intact bulk density between 1.97 and 2.09mg/m^3. This equates to medium to high density chalk in accordance with CIRIA C574.

SPT tests undertaken within this material generally recorded 'N' values between 10 and 35 with values increasing with depth. The only variation was recorded within BH1 which recorded 'N' values of 0 and 4 at depths of 7.00m and 8.50m bgl, respectively. The value of 0 indicates the SPT fell under its own weight and is considered to be a localised zone of weakness at the top of the formation in this area. The 'N' values increased to >10 below 10.00m bgl.

3.3.8 Sulphate and pH Tests

Soluble sulphate and pH tests were carried out on samples of Made Ground recovered from depths ranging between of 0.10m and 1.65m bgl, the Reworked Ground recovered from depths ranging between 0.30m and 1.65m bgl, Alluvium recovered from depths ranging between 1.20m and 3.45m bgl, the Shepperton Gravel Member recovered from depths ranging between 5.00m and 5.45m bgl and the Upper Chalk from depths ranging between 7.00m and 7.45m bgl. In addition, total sulphur and acid soluble sulphate tests were undertaken on Alluvial samples as sulphates may found in locally significant concentrations in Alluvium and Peat.

These recorded values are shown in the table below:

Parameter	**Range**
Soluble Sulphate (g/l)	<0.010 – 0.52
pH units	8.5 – 9.8
Acid Soluble (Alluvium)	0.044 – 0.097
Total Sulphur (Alluvium)	0.10 – 0.18

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3.3.9 Groundwater

Groundwater was encountered during the intrusive investigation within the majority of the exploratory holes with water strikes ranging between 1.00m and 4.90m bgl and standing levels between 1.20m and 4.60m bgl within the Made Ground, Alluvium and Shepperton Gravel Member soils.

Subsequent groundwater monitoring undertaken between 09/03/2023 and 29/03/2023 within the standpipes installed within BH3, BH6 and BH9 recorded standing water levels between 0.75m and 2.39m bgl.

Spot heights using GPS were taken to provide accurate elevations for the groundwater levels to estimate the general direction of groundwater flow. It is considered the elevation collected for BH9 is inaccurate due to tree canopy cover and therefore has been discarded. The following table presents the groundwater levels recorded for BH3 and BH6.

Borehole	**Groundwater Levels (mOD)**		
	09/03/2023	**15/03/2023**	**29/03/2023**
BH3	38.56	38.65	38.65
BH6	38.67	38.82	38.82

The results indicate groundwater levels are consistently lower within BH3 which is located south of BH6. Therefore, the general direction of groundwater is considered to be to the south which corresponds to the direction of the River Colne.

3.3.10 Infiltration Tests

Infiltration testing was carried out in three locations (SA1 – SA3). The soakaway tests were excavated down to depths ranging between 0.50m to 1.50m bgl within the Made Ground and Alluvium. Given the high water table and general depth to natural soils it was not possible to undertake infiltration testing within the natural soils. Therefore, infiltration tests were undertaken within the near surface Made Ground soils covered by SA2 and SA3 and Alluvium within SA1. Currently rainwater is continuously percolating through the Made Ground soils so the proposed development is unlikely to impact this. However, as part of this investigation leachate tests have also been undertaken on Made Ground soils to assess the risk of conventional soakaways within

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Made Ground to controlled waters given the proximity to Broadwater Lake and the underlying Principle Aquifer. The results of the leachate tests are discussed within section 6.4.

The general methods set out in BRE 365 Digest were followed and the infiltration rates for each BRE 365 test are presented below and the graphs are shown in Appendix B.

Test Location	**Infiltration Rates (m/s)**			
	Test 1	Test 2	Test 3	Average
SA1	No recorded drop in water level over 44 hours	-	-	-
SA2	$2.94x10^{-4}$	$1.99x10^{-4}$	$1.95x10^{-4}$	$2.29x10^{-4}$
SA3	$5.72x10^{-4}$	$1.99x10^{-4}$	$3.53x10^{-4}$	$3.74x10^{-4}$

The results indicate three repeat infiltration tests were completed within the Made Ground soils of SA2 and SA3 as required by the guidance within BRE 365 Digest.

The infiltration test undertaken within the Alluvium (SA1) recorded no drop in water level over a period of 44 hours.

3.3.11 Plate Load (Equivalent CBR) Tests and Laboratory CBR Tests

Seven Plate Load (equivalent CBR) Tests were undertaken at depths ranging between 0.10m and 0.45m bgl. Three plate load tests were undertaken on the concrete including CBR2 – CBR4 at depths ranging between 0.10m and 0.20m bgl and recorded equivalent CBR values between 9.95% and 41.87%.

The remaining four plate load tests were undertaken within the Made Ground soils and recorded equivalent CBR values between 5.24% and 19.47%.

Laboratory CBR tests were undertaken on selected near surface samples including two samples from the Made Ground taken at depths of 0.10m bgl and 0.50m bgl and two samples of the Reworked Ground taken at a consistent depth of 0.50m bgl.

The Made Ground samples recorded CBR values between 0.5% and 22.1% and the Reworked Ground samples recorded CBR values between 35.3% and 73.4%.

3.3.12 Ground Gas

Four gas monitoring visits were undertaken alongside groundwater monitoring within BH3, BH6 and BH9 to confirm the ground gas regime at the site between 09/03/2023 and 29/03/2023. Methane was recorded between below detection limits and 0.6% in all visits with lower explosive limits between 13.6% and 15.7%; carbon dioxide was recorded between 0.1% and 0.8% with oxygen between 0.6% and 19.3%. Peak flow was recorded at 0.27l/h and atmospheric pressure was recorded between 986mb to 1011mb.

3.3.13 Evidence of Contamination

Some obvious signs of contamination were identified locally within the Made Ground soils encountered during the field work. This relates to significant hydrocarbon staining and odour within two trial pits (TP4 and CBR5) positioned next to a historic concrete bund situated at the north of the site. In addition, some man-made materials were encountered within the Made Ground such as brick, concrete, ash, slag and slate with occasional cobbles and boulder size fragments of concrete.

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4 GEO-ENVIRONMENTAL TESTING

Geo-environmental laboratory testing was scheduled by Geo-Integrity on thirteen soil samples recovered during the fieldwork. The testing was carried out at a MCERTS and UKAS accredited laboratory. The results are presented in the Appendices.

Thirteen soil samples were tested for a varied suite containing the following:

- Metals and inorganic substances
- Speciated Polyaromatic Hydrocarbons (PAH)
- Benzene, Toluene, Ethylbenzene and Xylene (BTEX)
- Total Petroleum Hydrocarbons (TPH), with eight band split
- In addition, the three Made Ground samples were tested for the presence of asbestos

Two samples of Made Ground taken from TP4 which identified significant hydrocarbon staining and odour were specifically tested for aliphatic and aromatic petroleum hydrocarbons.

Two samples of Made Ground taken from trial pits situated adjacent to the two soakaway pits SA2 and SA3 were tested for leachates to aid with the risk assessment to controlled waters.

Four samples were tested for a suite of hydrocarbons, volatile organic compounds (VOCs), Semi-volatile organic compounds (SVOCs) as part of the UKWIR Suite to assess whether barrier pipe is required for underground water pipes.

Three groundwater samples were collected and tested for a suite of chemicals in accord with the environmental quality standards for fresh water including a range of heavy metals, TPH, a range of PAH's, dissolved organic carbon, pH, a range of essential minerals including calcium, potassium, magnesium and sodium and chemical oxygen demand to assess the risk to controlled waters.

In addition, WAC testing was undertaken on two near surface samples of Made Ground to aid with waste classification.

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5 GEOTECHNICAL INTERPRETIVE SECTION

5.1 GENERAL GROUND CONDITIONS INTERPRETATION

This intrusive investigation identified concrete hardstanding across the majority of the eastern side of the site and part of the proposed activity field at the southern end of the site, associated with the historic gravel extraction activities. The lateral extent of concrete is shown on the hardstanding plan within Appendix A. The thickness of the concrete ranged from 0.05m and 0.70m.

Made Ground soils were also encountered across the entire site from ground level and underlying the hardstanding. Made Ground soils were generally recorded down to depths between 1.00m and 2.00m bgl, however some areas encountered locally deeper Made Ground including BH3 and BH4 down to depths of 2.45m and 3.45m bgl which were located along the eastern side of the site.

Reworked soils were located locally along the northern boundary becoming thicker westwards. These reworked natural gravels were encountered down to depths ranging between 2.45m and 3.25m bgl interpreted to reflect the infilling processes which was noted on the historical OS maps from 2001.

The first natural soil encountered is a consistent layer of Alluvium which is present across the entire site. Alluvium was encountered down to depths ranging between 1.30m and 4.50m bgl. Given the high organic content this material is considered to be highly compressible and unsuitable as a founding stratum due to unacceptable settlements.

This was underlain by a consistent medium dense to dense granular layer of superficial gravel known as the Shepperton Gravel Member down to depths ranging between 6.10m and 8.00m bgl.

The superficial gravels were underlain by structureless chalk comprising layers of gravelly silt (Grade Dm) and silty gravel (Grade Dc) down to the base of the exploratory holes in excess of 15.00m bgl. BH1 encountered a weak zone between 7.00m and 8.50m bgl indicated by low SPT ‘N’ values of 0 and 4 interpreted localised zone of weakness at the top of the formation in this area. No other significant zones of weakness were encountered across the site within this material which supports the conclusions of the natural cavities risk assessment that there is no anticipated risk of subsidence from natural cavities beneath the site.

Groundwater was encountered as water strikes ranging between 1.00m and 4.90m bgl and standing levels between 1.20m and 4.60m bgl within the Made Ground, Alluvium and Shepperton Gravel Member soils across the entire site. Subsequent groundwater monitoring recorded standing

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water levels between 0.75m and 2.39m bgl. It is considered the groundwater is in continuity with Broadwater Lake.

5.2 EXCAVATIONS

Conventional plant should be sufficient for the excavation of the underlying soils at the site, however breaking equipment will be required within the areas highlighted yellow on the hardstanding plan. Given the granular nature of the Made Ground soils it is likely shallow excavations will be unstable in the short term, therefore likely requiring trench support.

Excavations should remain dry down to a depth of 0.75m bgl, taken from the shallowest groundwater reading during winter when it is considered the wettest period of the year.

5.3 FOUNDATIONS

This ground investigation has identified variably deep Made Ground and Reworked Ground overlying highly compressible soft Alluvium accompanied with shallow groundwater levels of which is considered to be in continuity with the adjacent lake. Therefore, the ground conditions listed above will be problematic for shallow foundations and it is likely alternative foundations such as piles will be required for the proposed development.

The deep boreholes (BH1-BH9) undertaken as part of this ground investigation were positioned in areas where proposed structures were proposed to aid with foundation design. However, given the development proposal has changed the majority of the larger structures are proposed to be constructed on proposed reclaimed land forming the extension to the north of the peninsula. This area was not covered by this intrusive investigation. Therefore, it is considered further ground investigation will be required to form an accurate foundation solution. Further deep boreholes in this area to locate the depth of the underlying chalk will be required.

5.3.1 Shallow Foundations

Given the presence of thick near surface Made Ground, Reworked Ground and Alluvial soils it is considered shallow foundations will be unsuitable for settlement sensitive structures due to unacceptable total and differential settlements under applied foundations loadings.

Shallow reinforced raft foundations may be considered for small, low-bearing structures where a small amount of settlement can be tolerated, while keeping differential settlement to a minimum. A reinforced raft foundation could be considered founded within the underlying near surface Made

Ground or Reworked Ground. The following measures should be taken prior to construction of the raft:-

- Excavation of the underlying soil to a depth of 1.00m with heavy proof rolling of the resultant sub-grade.
- Making up the void with a Type 1 aggregate, properly rolled and reinforced with geotextile at 0.30m centres.
- Engineer designed reinforced raft foundation in accordance with NHBC Standards Chapter 4.4.

The amount of settlement will be reflective of the properties of the engineered fill. Consideration should also be given to the shallow groundwater levels (~0.75m bgl) which further limit the suitability of shallow foundations.

5.3.2 Piled Foundations

This intrusive investigation was tailored to the previous development proposal and therefore preliminary working loads for piles were calculated for specific areas of the peninsula where structures were proposed. The updated development proposal (shown in Appendix A) indicates the majority of the structures are located on a proposed extension to the northern side of the peninsula. As discussed above further investigation will be required to form a suitable foundation design in this area of reclaimed land.

However, for reference the preliminary working loads for specific areas of the peninsula investigated by this investigation are provided below.

Given the variable near surface ground conditions located across the peninsula, working loads for a range of pile depths and sizes have been calculated using specific boreholes as shown in the table below.

Location	**Boreholes**
North-west corner	BH8 and BH9
Centrally along the northern boundary	BH7
North-east corner	BH5 and BH6
Centrally along the southern boundary	BH2
Centrally along the eastern boundary	BH3 and BH4

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Piles would extend through the Made Ground, Reworked Ground, Alluvium and Shepperton Gravel Member and terminate within the underlying Upper Chalk.

The advice of specialist piling contractors should be sought to formulate a suitable piling technique and type for the ground conditions encountered at this site, before commencement of the works.

It is anticipated that a CFA pile system will be the most appropriate on this site given the ground conditions. The ground water is likely to be relatively static given the fact it is considered to be in continuity with the adjacent lake. However, care should be taken to ensure that washing away of concrete does not take place which could weaken the pile, also known as 'necking'.

The following table provides working loads for a range pile diameters and depths for the specified areas. The working loads are based on the skin friction of the superficial gravel and the base resistance of the Upper Chalk. The Made Ground and Reworked Ground soils have been ignored as part of the calculations and a negative skin friction has been applied to the Alluvial soils.

(Location)	Depth of the pile (m bgl)	Founding Stratum	Pile Working Loads (kN)		
			Pile diameter 300mm	Pile diameter 450mm	Pile diameter 600mm
North-west corner (BH8 and BH9)	7.5	Upper Chalk	35	85	150
	10	Upper Chalk	35	85	150
	12.5	Upper Chalk	65	150	270
Centrally north (BH7)	7.5	Upper Chalk	30	80	140
	10	Upper Chalk	60	140	260
	12.5	Upper Chalk	60	140	260
North-east corner (BH5 and BH6)	7.5	Upper Chalk	45	95	175
	10	Upper Chalk	55	130	230
	12.5	Upper Chalk	70	160	280
Centrally south (BH2)	7.5	Upper Chalk	25	70	140
	10	Upper Chalk	35	85	160
	12.5	Upper Chalk	35	100	185
Centrally east (BH3 and BH4)	7.5	Upper Chalk	40	90	160
	10	Upper Chalk	50	120	220
	12.5	Upper Chalk	65	160	280

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An overall FOS of 3.0 has been applied

The proposed development indicates there are no buildings structures located within the area surrounding BH1. However, should the proposed development change to including buildings structures in this area further investigation is likely to be required given the zone of weakness identified between 7.00m and 8.50m bgl.

5.4 FLOOR SLAB DESIGN

Floor slabs at the site should be suspended given the general depth of Made Ground across the site.

The advice given within the NHBC Standards regarding the construction of floor slabs should be followed.

5.5 SULPHATE ATTACK ON UNDERGROUND CONCRETE

Sulphate tests were undertaken to give an indication of the aggressivity of the ground in relation to buried concrete, as set out in the Building Research Establishment (BRE) Special Digest 1 (2005) Concrete in Aggressive Ground, Part 1: Assessing the aggressive chemical environment.

Therefore in accordance with the BRE Special Digest, these results have been given in the table below, in relation to strata type and required Design Sulphate Class and site Aggressive Chemical Environment Classification (ACEC).

Strata	Design Sulphate Class	Aggressive Chemical Environment Classification
Made Ground	**DS-1**	**AC-1**
Reworked Ground	**DS-2**	**AC-2**
Alluvium	**DS-2**	**AC-2**
Shepperton Gravel Member	**DS-1**	**AC-1**
Upper Chalk	**DS-1**	**AC-1**

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5.6 ACCESS ROADS AND PARKING

Seven Plate Load (equivalent CBR) Tests were undertaken at depths ranging between 0.10m and 0.45m bgl. Three plate load tests were undertaken on the concrete including CBR2 – CBR4 at depths ranging between 0.10m and 0.20m bgl and recorded equivalent CBR values between 9.95% and 41.87%.

The remaining four plate load tests were undertaken within the Made Ground soils and recorded equivalent CBR values between 5.24% and 19.47%.

Laboratory CBR tests were undertaken on selected near surface samples. The Made Ground samples recorded CBR values between 0.5% and 22.1% and the Reworked Ground samples recorded CBR values between 35.3% and 73.4%.

Made Ground has been proven across the site, and given the unknown origin of the soil, its variability and the likelihood and proven possibility for soft-spots, we recommend that any areas of soft or deleterious material should be excavated, replaced with a properly compacted coarse-grained fill and proof rolled prior to construction.

In addition, to avoid uneven and excessive settlement in hard-standing areas it is recommended that the following precautions are taken:-

- Heavy proof-rolling of the exposed sub-grade strata
- Excavation of soft spots encountered and replacement with well compacted granular material
- The usage of a geo-textile separator layer above the sub-grade.
- A design CBR value of 5% is adopted

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5.7 INFILTRATION

Appropriately designed sustainable drainage systems (SuDS) are more sustainable than using piped drainage to local sewer systems. However, infiltration measures close to buildings may result in undermining of foundations and softening of soils leading to instability. Attenuation measures should be located at suitable distances from foundations and infrastructure.

Given the high water table and general depth to natural soils it was not possible to undertake infiltration testing within the natural soils. Therefore, infiltration tests were undertaken within the near surface Made Ground soils covered by SA2 and SA3 and Alluvium within SA1.

Currently rainwater is continuously infiltrating through the Made Ground soils so the proposed development is unlikely to impact this. However, as part of this investigation leachate testing has also been undertaken on Made Ground soils to assess the risk of conventional soakaways within Made Ground to controlled waters given the proximity to Broadwater Lake and the underlying principle aquifer. The results of the leachate tests are discussed within section 6.2.

The general methods set out in BRE 365 Digest were followed and the infiltration rates for each BRE 365 test are presented below and the graphs are shown in Appendix B.

Test Location	**Infiltration Rates (m/s)**			
	Test 1	Test 2	Test 3	Average
SA1	No recorded drop in water level over 44 hours	-	-	-
SA2	$2.94x10^{-4}$	$1.99x10^{-4}$	$1.95x10^{-4}$	$2.29x10^{-4}$
SA3	$5.72x10^{-4}$	$1.99x10^{-4}$	$3.53x10^{-4}$	$3.74x10^{-4}$

The results indicate three repeat infiltration tests were completed within the Made Ground soils of SA2 and SA3 as required by the guidance within BRE 365 Digest. As such it is considered conventional soakaways are viable at this site within the Made Ground soils.

The results are presented in Appendix B.

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Given the water table is located well above the chalk interface and there is no evidence of dissolution features at this site the risk of soakaways reactivating existing dissolution features is considered to be negligible.

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5.8 GAS PROTECTION

The risk of ground gases impacting the site was assessed by reference to the paper “A pragmatic approach to ground gas risk assessment for the 21st Century” Card and Wilson, 2011. And determined that the site may be at risk from ground gases should deepened Made Ground soils be encountered.

Four gas monitoring visits were undertaken alongside groundwater monitoring within BH3, BH6 and BH9 to provide a preliminary review of the ground gas regime at the site between 09/03/2023 and 29/03/2023. Methane was recorded between below detection limits and 0.6% in all visits with lower exposure limits between 13.6% and 15.7%; carbon dioxide was recorded between 0.1% and 0.8% with oxygen between 0.6% and 19.3%. Peak flow was recorded at 0.27l/h and atmospheric pressure was recorded between 986mb to 1011mb.

Therefore, the worst-case gas screening value (GSV) is 0.00216.

Based on the conditions measured during the monitoring visits carried out to date, in accordance with BS8485:2015 and CIRIA C665, 2007 this would be considered as a Characteristic Situation 1 (CS1) due to no significantly elevated levels recorded.

It is considered further investigation may be required given the potential sources of gas present both on-site and off-site. Further investigation will likely involve additional monitoring visits within the standpipes already installed. Additional monitoring wells may also be requested in the wider site area.

The site is located in an area where less than 1% of homes exceed the action level of 200Bq/m^3 for radon gas, and therefore no radon protection measures are necessary in the construction of new dwellings or extensions.

The area of Made Ground impacted by hydrocarbons may cause a vapour risk, however given this area is proposed to be a mixture of hardstanding and soft landscaping with no proposed structures as such there is currently no risk to the end users. Should the proposed development change to include buildings in this area where vapours can enter confined rooms further assessment by a suitably qualified engineer should be undertaken.

Full details of gas concentrations and gas flow data recorded during the monitoring visits are given in Appendices.

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6 GEO-ENVIRONMENTAL INTERPRETATIVE SECTION

6.1 RISKS TO HUMAN HEALTH

6.1.1 Introduction

Environment Agency guidance LCRM *Land Contamination: Risk Management*, (EA, 2019), states that human health risk assessment should be undertaken by a tiered approach using the source-pathway-receptor principle. A desk study constitutes the first tier, and this was previously undertaken by Geo-integrity Ltd., ref. 22-10-12, dated November 2022.

The conclusions of this phase were that:-

"Given the proposed development of the site will be mainly commercial with some minor residential end usage, it is considered that there is a low to moderate risk to end users. However, the risk of encountered localised pockets of contamination is considered to be moderate to high. There is also a perceived moderate risk of contamination sources that may be affecting the Principal groundwater Aquifer beneath the site and as the site is in a Source Protection Zone, this would need to be dealt with as part of the development."

It was determined that there are several primary potential sources of contamination on-site relating to:

- *"Historical Hydrocarbons within the ground from the human history in the area of aggregate processing*
- *Historic asbestos within any made ground from human history in the area of aggregate processing*
- *Historic metals and PAH's within any made ground from human history in the area of aggregate processing*
- *PCB's from the on-site electricity sub-station*
- *Ground gas from on and off-site landfill sites*
- *Elevated levels of contaminants associated with the on-site landfill"*

Results are analysed under the second tier, known as a Generic Quantitative Risk Assessment (GQRA), which uses generic guideline values to compare site chemical data against, and the final tier would be a Detailed Quantitative Risk Assessment (DQRA), which use data derived from the ground investigation to assess risks to identified receptors.

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The assessment included in this report comprises a GQRA, which is undertaken by comparing soil contaminant concentrations from this investigation with conservative Generic Assessment Criteria (GAC). GAC for various land use and exposure scenarios have been selected from the following sources:

- CL:AIRE Category 4 Screening Levels (C4SL);
- LQM Suitable for Use Levels (S4UL);
- CL:AIRE/EIC/AGS GAC

The GAC have been derived using the Environment Agency Contaminated Land Exposure Assessment (CLEA) model, for a range of land uses and exposure scenarios, including:

- Residential with the consumption of home-grown produce;
- Residential without the consumption of home-grown produce;
- Commercial;
- Allotments;
- Public Open Space near residential housing (POS_{resi}); and
- Public Open Space public park scenario (POS_{park})

Given the proposed development will be mainly commercial with some minor residential end-use both a “Commercial” and “residential with the consumption of home-grown produce” land-use scenario has been selected, for this assessment.

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6.2 RESULTS OF CHEMICAL TESTING

Thirteen near surface soil samples were chemically tested the details of which are specified in section 4. The samples tested include:

Made Ground Samples:

- TP1 at a depth of 0.50m bgl
- TP10 at a depth of 0.80m bgl
- TP12 at a depth of 0.80m bgl
- TP6 at a depth of 0.50m bgl
- TP9 at a depth of 1.40m bgl
- TP14 at a depth of 0.60m bgl
- TP5 at a depth of 0.50m bgl
- TP3 at a depth of 1.20m bgl
- TP4 at a depth of 0.75m bgl
- TP4 at a depth of 2.00m bgl
- CBR5 at a depth of 0.75m bgl
- TP2 at a depth of 0.50m bgl

Natural Soil Sample

- TP13 at a depth of 1.30m bgl

The above samples were screened against the relevant GAC for a ‘Commercial’ land use scenario as described above and identified no significantly elevated levels.

The above samples were also screened against the relevant GAC for a “residential with the consumption of home-grown produce” land-use scenario and identified elevated levels of polyaromatic hydrocarbons (not deemed a risk see section 6.2.3) within four Made Ground samples and total petroleum hydrocarbons within three Made Ground Samples.

6.2.1 Asbestos

Screening for the presence of asbestos indicated no asbestos was present within each of the twelve Made Ground samples tested.

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6.2.2 *Total Petroleum Hydrocarbons*

The intrusive investigation identified a localised area of hydrocarbon odour and staining within TP4 and CBR5 situated adjacent to a historic concrete bund located at the north of the site. As such specific testing including an assessment of both aromatic and aliphatic hydrocarbons was undertaken on three representative samples. When compared to the relevant S4UL's for a 'Commercial' land-use scenario no significantly elevated levels were recorded.

Hydrocarbon levels were much higher within the Made Ground soil samples taken from TP4 and CBR5 compared to the rest of the site, being located adjacent to the historic bund identified at the north of the site. The levels were below the relevant S4UL's for a 'Commercial' land-use scenario and therefore there is no risk to the end users for a proposed commercial site.

However, when compared to a "residential with the consumption of home-grown produce" land-use scenario elevated levels of TPH were encountered within TP4 and CBR5.

A total of three samples recorded elevated levels of total petroleum hydrocarbons including two samples taken from TP4 at depths of 0.75m and 2.00m bgl and one sample taken from CBR5 at a depth of 0.75m bgl. Elevated levels of TPH C8 – C10, TPH C10 – C12, TPH C12 – C16, TPH C16 – C21, TPH C21 – C35. The table below shows the range of elevated levels, the number of samples elevated and the relevant GAC.

TPH Band	No. of samples exceeded (out of thirteen)	Recorded Elevation Range (mg/kg)	Relevant GAC (mg/kg)
TPH C8 – C10	2	76 - 86	27
TPH C10 – C12	2	400 - 490	74
TPH C12 – C16	3	600 – 4500	140
TPH C16 – C21	3	1000 – 6900	260
TPH C21 – C35	1	3400	1100

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6.2.3 Polyaromatic Hydrocarbons (PAHs)

Elevated levels of polyaromatic hydrocarbons were encountered within four out of the thirteen samples tested when compared to the GAC for a “residential with the consumption of home-grown produce” land-use scenario. Four sample recorded elevated levels of dibenz(a,h)anthracene and one sample recorded elevated levels of three PAHs including benzo(b)fluoranthene, benzo(a)pyrene and dibenz(a,h)anthracene.

Dibenz(a,h)anthracene was recorded to be elevated within four samples taken from TP5 at a depth of 0.50m bgl, TP14 at a depth of 0.60m bgl, TP4 at a depth of 2.00m bgl and CBR5 at a depth of 0.75m bgl. Elevated levels ranged between 0.25mg/kg and 1.2mg/kg.

Three PAH’s were elevated within one sample taken from CBR5 at a depth of 0.75m bgl. Thes included dibenz(a,h)anthracene recorded at 1.2mg/kg, benzo(b)fluoranthene recorded at 6.1mg/kg with the relevant GAC being 2.6mg/kg and benzo(a)pyrene recorded at 4.7mg/kg with the relevant GAC being 2.2mg/kg.

Due to the conservative approach to calculating the S4UL‟s we have decided to use the C4SL for BaP as a surrogate marker for the PAH mixture encountered on site. In order to do this the three criteria below need to be met:-

- The SM (BaP) must be present in all soil samples.
- The profile of the different PAH relative to BaP should be similar in all samples.
- The PAH profile in the soil samples should be similar to that used in the pivotal toxicity study on which HBGV was based i.e. the Culp study.

This was the case within all samples where PAHs were encountered and the soil concentration of BaP in all cases was less than the relevant C4SL of 5mg/kg. Therefore, it is considered that the risk to end users of the site was below the C4SL level which is defined as “there is no risk that land poses a significant possibility of significant harm”, therefore in line with DEFRA authorised guidance we consider that the PAHs do not cause a risk to end users across the site. The BaP Surrogate Marker calculation sheets are including in Appendix C.

6.2.4 Polychlorinated Biphenyls

One sample of Made Ground taken from TP14, positioned adjacent to the on-site electricity substation, at a depth of 0.60m was tested for PCB’s and recorded below detectable limits for each of the twelve congeners.

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6.2.5 *Natural Soil*

The natural soil sample recovered from the underlying Alluvium recorded no significantly elevated levels of contaminants and therefore poses no significant risk to human health or the environment.

6.2.6 *On-site Landfill*

The previous desk study identified an unregistered historic landfill which covers the south-east corner of the peninsula (a landfill plan is shown in Appendix A) and extends eastwards where a lake currently exists . Exploratory holes BH3, TP12, TP11 and TP10 were positioned within the boundary along the eastern side of the peninsula to assess the ground conditions and collect samples for laboratory testing.

The ground condition indicated Made Ground soils down to a maximum depth of 2.45m bgl comprising loose sandy gravels with some anthropogenic material including brick, concrete with some slag and ash. The composition of the Made Ground and depth gave no clear indication that a historic landfill is still present along the east side of the peninsula. In addition, no significantly elevated levels of contaminants were recorded within the Made Ground samples taken from TP10 at a depth of 0.80m bgl and TP12 at a depth of 0.80m bgl.

6.3 RISK TO END USERS

Given the findings of the desk study, walkover survey, intrusive investigation and laboratory testing it is considered that the risk of contamination to construction workers, end users and surrounding residents from the proposed commercial development at this site is low. However, given the updated development proposal will include minor residential land-uses including camping areas it is considered there may be a risk to the end users from localised hotspots of contamination. This ground investigation identified elevated levels of hydrocarbons locally at the north of the peninsula surrounding a historic bund. Given the limitations outlined within section 3.2 it is considered there may be additional hotspots of contamination within both the peninsula and the wider site area.

Therefore, it is considered some remedial measures may be required to protect the end users of the site. Currently a single hotspot has been identified surrounding the concrete bund shown on the remedial plan.

The on-site landfill indicated by the previous desk study located at the south-east corner of the peninsula was investigated with a deep borehole and trial pits. No significant evidence of landfill material was encountered. The desk study information indicates it was run between 1993 and 2004

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and was used to dispose non-biodegradable waste therefore the risk of elevated levels of contaminants is unlikely to be significant. The historic landfill does extend eastwards underlying a lake. Further investigation could be undertaken to assess the ground conditions below the lake immediately east of the peninsula.

We recommend that the conclusions of this report are agreed with the relevant Local Authority at the earliest stage, to reduce potential delays to the development.

6.3.1 Reducing Risk to End Users

To break the exposure pathways to site users, it is considered that the pathway between the zoned area of impacted Made Ground soils and the end users needs to be broken (area shown on the remedial plan in Appendix A).

To remediate the zoned area of Made Ground impacted by hydrocarbons shown on the remedial plan, a cover system could be engineered within areas of soft landscaping where there is a risk. It is considered that any disturbance or intermixing of soils is unlikely to exceed 600mm depth from earthworm activity, double digging and root depth as stated in “Cover Systems for Land Regeneration" prepared by RSK ENSR Ltd. Therefore, a cover system would require 600mm layer of clean cover, consisting of at least 150mm of topsoil and 450mm of clean imported clay. This cover system is not required in areas of hardstanding (driveways, paving areas and under the building), where this will break the pathway between contaminated soils and site users.

During the development it is recommended that this process of placing the cover layer is tightly monitored and recorded (soil tests, photographs, depth measurements etc) as a verification report will be required to prove its existence to Local Authorities or financing organisations (mortgage companies etc).

6.3.2 Reducing Risk to Construction Workers

For the construction workers, remedial measures would not be in place when they undertake the site work and therefore different measures should be taken to reduce the risk of coming into contact with the soil and break the pollutant linkage with these receptors.

To reduce the risk to as low as reasonably practicable for the construction workers it is recommended that high standards of personal hygiene should be maintained amongst the site personnel at all times. All personnel coming into contact with the soil, ground workers in particular, should be instructed to use gloves when on site to avoid dermal contact and restrict inadvertent

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hand-to-mouth ingestion. Washing facilities should be provided for the site staff to use, and should be used prior to eating or smoking. Reference should be made to the HSE Document, “Protection of Workers and the General Public during Development of Contaminated Land”.

It is however recommended that a watching brief for undiscovered contamination is included in the Works Method Statement. Given the long human history of the surrounding area, it is always possible that some previously undiscovered contamination may be encountered. If this is the case, the area should be isolated and contact be made to a suitably qualified professional for further advice. This is particularly important if the contamination is possibly ACM or liquid based.

6.4 POST REMEDIATION VERIFICATION

Any remedial measures undertaken at the site will require independent verification once completed to satisfy the relevant regulatory authorities and other interested parties, including future owners of the site, banks, insurers, and mortgage companies. This usually involves a small validation investigation to confirm that the recommended work has been successful.

6.5 RISK TO CONTROLLED WATERS

6.5.1 Preliminary Analysis

The assessment of risks to controlled waters follows guidance provided by the Environment Agency and DEFRA in association with the Contaminated Land (England) Regulations 2000 (SI 2000/227). This guidance is Environment Agency’s Remedial Targets Methodology Hydrogeological risk assessment for contaminated land (2006), as such these procedures have been followed.

The previous phase I desk study (ref. 22-10-12) identified the following:

- The site is underlain by a “Secondary A” Aquifer associated with the Superficial Aquifer, overlying a Principal Aquifer associated with the Upper Chalk
- The site is located within a source protection zone (SPZ1 – Inner Catchment)
- The nearest active groundwater abstraction licenses are within 100m south of the site run by Affinity Water at Northmoor Pumping Station
- There are no surface water abstraction licenses recorded within 1000m of the site
- The fieldwork undertaken by this phase II investigation indicated that groundwater levels were recorded at a shallowest depth of 0.75m bgl and it is considered the groundwater is in continuity with Broadwater Lake

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The previous desk study indicated there is a moderate risk of contamination sources that may be affecting the Principal Aquifer beneath the site. Therefore, as part of this investigation groundwater monitoring, sampling and testing has been undertaken.

The groundwater monitoring has indicated groundwater generally flows south.

6.5.2 Chemical Testing

Leachate tests were undertaken on two Made Ground samples taken from TP1 at a depth of 0.50m and TP2 at a depth of 0.50m bgl. Leachate tests were undertaken as part of the controlled waters risk assessment to investigate the risk of placing soakaways in the granular Made Ground soils. The results indicated marginally elevated levels of chromium, copper, nickel, lead and zinc when compared to the EQS values for fresh water, however when compared to the limit values for United Kingdom Drinking Water Standards (UKDWS) none were significantly elevated.

Groundwater samples taken from BH3, BH6 and BH9 were tested for a general suite of contaminants including heavy metals, TPH, a range of PAH's, dissolved organic carbon, pH, a range of essential minerals including calcium, potassium, magnesium and sodium and chemical oxygen demand to assess the risk to controlled waters.

The results were compared to EQS for freshwaters and screening values from the UKDWS. The majority of the determinants were recorded below their respective screening values when compared to both the EQS and UKDWS and were generally below the limit of detection.

Marginally elevated levels of heavy metals were encountered including copper, manganese and nickel as shown in the table below:

Heavy Metal	**Recorded Value Range (µg/l)**	**Number Exceedences**	**EQS Freshwater (µg/l)**	**UKDWS (µg/l)**
Copper	<0.50 – 1.80	1	1(bioavailable)	2000
Manganese	150 - 760	3	123(bioavailable)	50
Nickel	3.2 – 4.8	2	4(bioavailable)	20

6.5.3 The Metal Bioavailability Assessment Tool (M-BAT)

To assess the bioavailability we have used The Metal Bioavailability Assessment Tool (M-BAT), the results are shown in Appendix C. The results show the bioavailable nickel falls below the site-specific PNEC for dissolved nickel.

The results for manganese show one of the levels now falls below the specific PNEC for dissolved manganese. The bioavailable manganese concentrations have been reduced to between 135µg/l and 350µg/l with the specific PNEC for dissolved manganese ranging between 123µg/l and 266µg/l. Therefore, it can be seen the levels of manganese are only marginally elevated.

The results show copper is still very marginally elevated above the specific PNEC for dissolved Copper. The bioavailable copper concentration remained 1.80µg/l with the specific PNEC for dissolved copper being 1µg/l.

6.5.4 Risk to Controlled Waters Conclusions

Underlying Principal Aquifer

Given the results of the chemical testing it is considered the proposed development is unlikely to pose a significant risk of significant harm to the underlying principal aquifer. This is based on evidence that from the leachate tests no significantly elevated levels were recorded when compared to the UKDWS. In addition, the groundwater samples also recorded no significantly elevated levels of contaminants when compared to the UKDWS other than manganese.

Manganese occurs naturally in many waters but is usually removed during treatment. Black deposits of manganese dioxide can cause discoloured water and the standard is set by UKDWS for aesthetic reasons. Therefore, the overall risk to the underlying principal aquifer from the proposed development is considered to be very low.

Broadwater Lake

Given the results of the chemical testing it is considered the proposed development is unlikely to pose a significant risk of significant harm to the adjacent freshwater lake (Broadwater Lake).

The leachate tests recorded marginally elevated levels of heavy metals including chromium, copper, nickel, lead and zinc when compared to the EQS values for fresh water. In addition, copper and manganese were also marginally elevated within the groundwater samples.

The leachate tests have proved the Made Ground contains quantities of five leachable heavy metals. However, the number of elevated levels recorded within the underlying groundwater which is considered to be in continuity with the adjacent lake were limited to just two heavy metals including copper and manganese which were only marginally elevated once the bioavailability assessment had been completed.

To say there is no risk at all would not be accurate however based on the fact the site has and is currently allowing rainwater to percolate through the near surface soils it is considered the proposed developed will pose no additional risk to the adjacent lake. In fact the proposed commercial development is likely to improve the overall site conditions by removing parts of the Made Ground, during the excavation of soils from the construction of foundations, roads and pavements. The proposed increased hardstanding cover will also reduce leaching activity within the near surface Made Ground soils.

Therefore, the overall risk to the adjacent freshwater lake (Broadwater Lake) from the proposed development is considered to be low.

The Environment Agency is the regulatory body charged with protection of controlled waters and may be a consultee in the planning process. We recommend that the conclusions of this report are agreed with the relevant Local Authority at the earliest stage, to reduce potential delays to the development. It is possible the local authority may request further testing given marginally elevated levels of heavy metals have been recorded.

Suitability of Conventional Soakaways

Based on the findings of the chemical testing it is considered there are some quantities of leachable heavy metals within the near surface Made Ground soils. Therefore, it is considered conventional soakaways are not suitable within the near surface soils as this will increase leaching activity.

OR

Based on the findings of the chemical testing it is considered there are some quantities of leachable heavy metals within the near surface Made Ground soils. However, given the fact the site actively allows rainwater to percolate through the near surface soils constructing conventional soakaways within the near surface soils will pose no additional risk to controlled waters. Therefore, it is considered conventional soakaways are suitable within the near surface soils.

The Environment Agency is the regulatory body charged with protection of controlled waters and may be a consultee in the planning process. We recommend that the conclusions of this report are agreed with the relevant Local Authority at the earliest stage, to reduce potential delays to the development.

6.6 RISK TO UNDERGROUND WATER SUPPLY PIPES

Based upon the guidance document from the UK Water Industry Research (UK WIR), 'Contaminated Land Assessment Guidance', February 2014, and the results of the samples tested from the site, it is considered that conventional PE water pipes will not be suitable at this site due to elevated levels of hydrocarbons within the Made Ground soils as shown in the table below.

Test Group	PE Threshold	Range of Elevated Levels	Number of exceedances
EC10-16 TPH	10mg/kg	10 – 4990mg/kg	7
EC16-40 TPH	500mg/kg	2100 – 10300mg/kg	
VOC	2µg/kg	31µg/kg	1
SVOC	2mg/kg	10.06mg/kg	1

Therefore, it is recommended barrier pipe is used across the site. This should be confirmed with the local water company as not all authorities use this guidance.

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7 WASTE DISPOSAL CLASSIFICATION

7.1 INTRODUCTION

Excavation for foundations or services will produce waste soil and possibly other waste streams. As a waste producer you have a duty of care under section 34 of the Environmental Protection Act 1990 to ensure, amongst other things that these wastes are:-

- Correctly stored
- Correctly classify
- Handed only to an authorised person
- Disposed of properly.

To aid with these obligations we have used HazWasteOnline to undertake the Hazard Assessment Screen as part of this investigation, to establish whether the sampled soils should be considered as either hazardous or non-hazardous waste. This classification process is in line with the Environment Agency's guidance WM3 "Guidance on the classification and assessment of waste", Version 1.2,2021.

7.2 RESULTS OF HAZARD ASSESSMENT

The twelve Made Ground samples and one natural sample analysed for the human health risk assessment, listed in section 7.2, have been classified using HazWasteOnline. This intrusive investigation identified three Made Ground soil types across the site which have all been sampled and tested to provide a waste classification for landfill disposal.

The full results of the HazWasteOnline analyses can be seen in the Appendices.

The HazWasteOnline classification summary sheet from this investigation provides a waste classification of non-hazardous waste for ten soil samples including nine Made Ground samples and one natural soil sample. However, three Made Ground soil samples provided a waste classification of hazardous waste.

The three Made Ground samples which were classified as hazardous were taken from TP4 and CBR5 where significant hydrocarbon staining and odour was encountered. The hazwaste online assessment has declared these three samples contain three hazardous properties including:

- HP3(i): Flammable "flammable liquid waste: liquid waste having a flash point below 60°C or waste gas oil, diesel and light heating oils having a flash point > 55°C and <= 75°C"

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- HP7: Carcinogenic "waste which induces cancer or increases its incidence"
- HP 11: Mutagenic "waste which may cause a mutation, that is a permanent change in the amount or structure of the genetic material in a cell"

7.2.1 Waste Acceptance Criteria (WAC) Testing Results

To further classify the waste soil for landfill disposal, Waste Acceptance Criteria (WAC) testing has been carried out on one worst case Made Ground sample taken from TP4 within soils impacted by hydrocarbons at a depth of 0.75m. In addition, WAC testing was undertaken on a representative Made Ground sample taken from TP12 at a depth of 0.80m bgl.

The Made Ground soils impacted by hydrocarbons identified within TP4 and CBR5 were originally classified as hazardous waste from the hazwasteonline assessment. The second stage in classification utilises the WAC test results to determine whether the material is classified as either stable non-reactive hazardous waste in a non-hazardous landfill or hazardous waste. The WAC test results indicate there are no elevated levels when compared to the limit values for stable non-reactive hazardous waste. A remedial plan showing the area comprising Made Ground soils impacted by hydrocarbons is shown in Appendix A.

The remaining near surface Made Ground soils have been originally classified as non-hazardous waste from the hazwasteonline assessment. The second stage in classification utilises the WAC test results to determine whether the material is classified as either inert or non-hazardous waste. The WAC testing has recorded no significantly elevated levels and therefore the near surface Made Ground soils can be classified as inert.

Additionally, it is considered that the underlying natural soils beneath the site qualify in accordance with EU Council Decision 2003/33/EC para. 2.1.1. “uncontaminated soil can be classified as inert without testing”.

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As such, given the testing results, currently the underlying soils from the site are considered to be classified as follows:-

Strata	Description of Material	Classification	List of Waste code	Recommended Landfill Tax Rate
Made Ground/Reworked Ground	Naturally occurring soils and stones with man-made materials including brick	Inert	17 05 04	Lower Rate
Made Ground (Locally impacted by Hydrocarbons, area shown on plan in Appendix A)	Naturally occurring soils and stones with man-made materials including brick and trace amounts of asbestos (0.001%)	Stable Non-reactive hazardous waste in non-hazardous landfill	17 05 03	Standard Rate
Natural Soil	Naturally occurring soils and stones (subsoil)	Inert	17 05 04	Lower Rate

All wastes removed from site should be consigned, transported and disposed of in full accordance with all relevant UK legislation.

7.3 RE-USE OF MATERIAL ON SITE

Currently, if surplus arisings are ‘fit for re-use’ on the site and have not been treated, its re-use is allowed within the planning law. If it needs treating prior to re-use, exemptions can be sought from the Environment Agency to allow this activity.

Based upon the human health and groundwater risk assessments, the underlying Made Ground soil is currently considered to be suitable for re-use on a commercial/residential land-use scenario. However, the locally impacted Made Ground is not suitable for re-use, the extent of this material is shown in Appendix A on the remedial plan. This analysis is, however, dependent on the agreement of the Local Authority.

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8 CONCLUSIONS AND RECOMMENDATIONS

We recommend a watching brief should be undertaken during the construction phase, and if during development any previously undiscovered contamination (including visual or olfactory evidence) is found then site management should be immediately informed and inspection by a suitably qualified person should be undertaken.

Barrier pipe will be required at this site due to elevated levels of hydrocarbons, SVOC's and VOC's within the Made Ground soils.

This first phase of intrusive investigation was undertaken solely on the accessible areas of the peninsula. The data collected to date is sufficient to support the conclusions of this report. The surrounding area of the site mainly covered by the lake and islands is not covered by this investigation and it is anticipated further investigation will be required prior to construction works commencing.

Given the development proposals have changed this has altered the location of the proposed buildings. It is considered further investigation including boreholes will be required prior to the development works immediately north of the peninsula where it is proposed to extend the peninsula and construct commercial structures.

This ground investigation has identified a single hotspot of contamination associated with elevated levels of hydrocarbons identified within two exploratory holes surrounding a concrete bund situated at the north of the peninsula. It is considered remedial measures will be required to protect against the end users of the site which overall is deemed to be commercial with minor residential land-use associated with camping areas. It may be requested to undertake additional testing in areas across the peninsula and the wider site area which were previously inaccessible during this intrusive investigation. It is understood additional intrusive investigations are being undertaken by HydroGeo associated with sampling the lake bed covering the area surrounding the peninsula.

A preliminary assessment of the gas regime was undertaken at the site which identified low gas levels indicating a CS1 site, however it may be requested to undertake additional monitoring visits within the standpipes previously installed and/or installation of additional standpipes in the wider site area.

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The on-site historic landfill recorded in the previous desk study was not found to extend onto the peninsula. Further investigation could be undertaken prior to the development phase to assess the ground conditions below the lake immediately east of the peninsula.

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APPENDIX A

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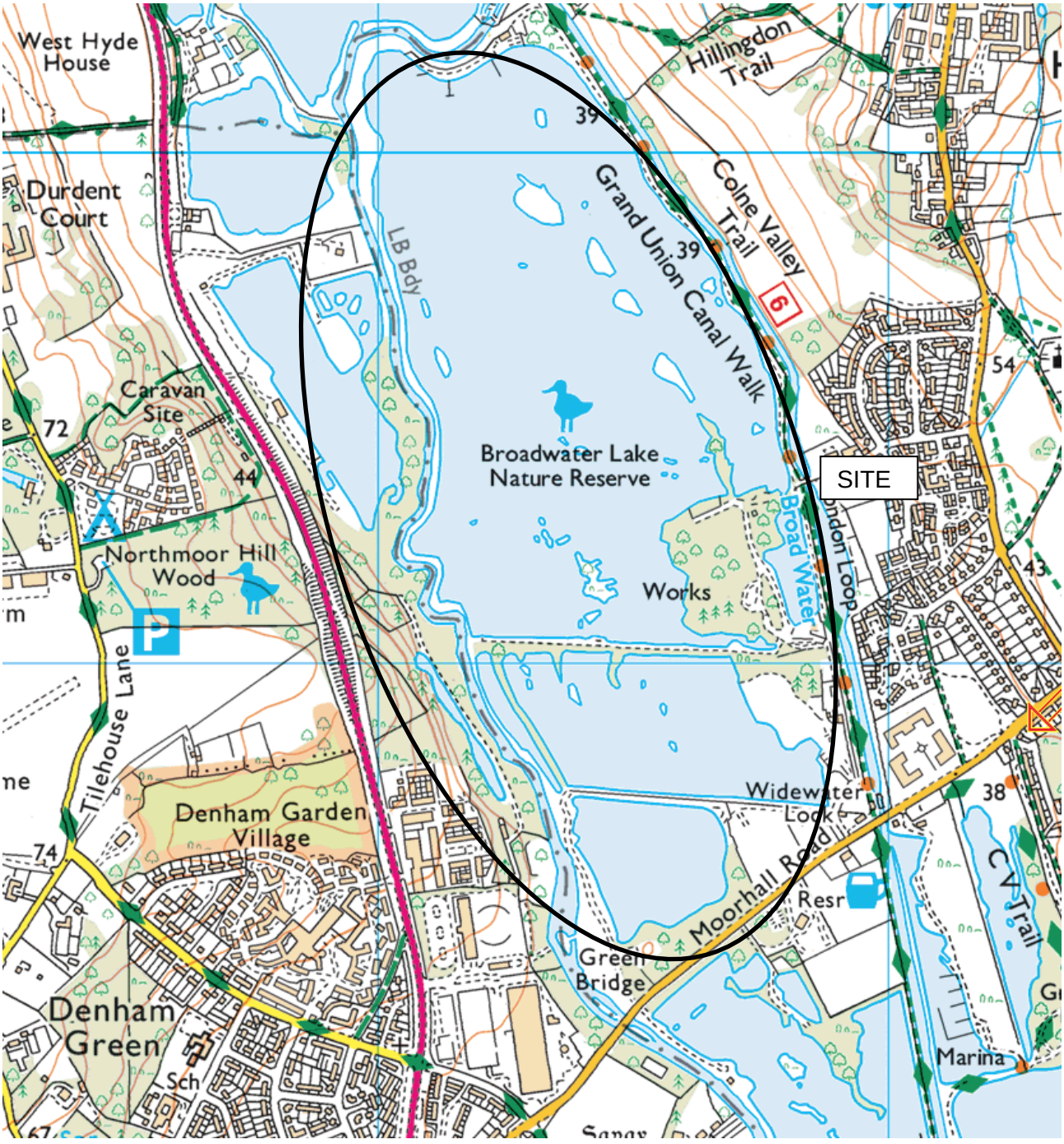
Site Plan



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TP1

TP2

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TP3

TP3

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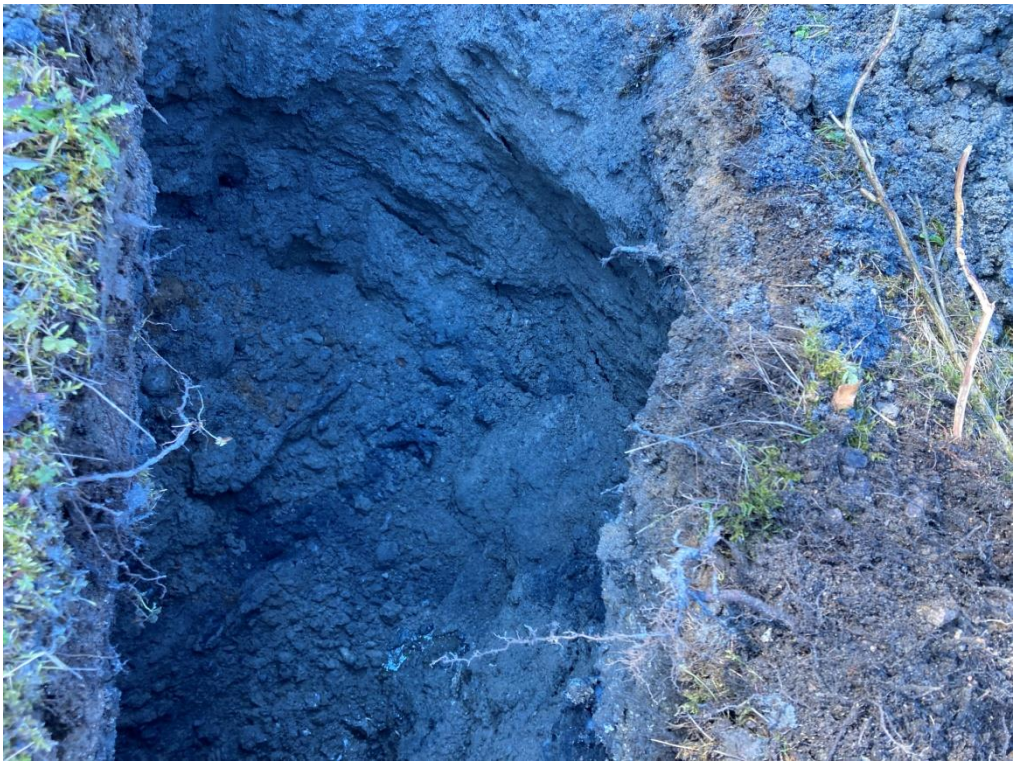
TP4



TP4

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TP4 and historic bund

TP5

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TP6

TP7

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TP8

TP9

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TP10

TP12

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TP12

SA1

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SA2

SA3

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CBR1

CBR2

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CBR3

CBR4

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CBR5

CBR5

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CBR6

CBR7

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