Compass Geotechnical

Geotechnical, Geoenvironmental and Civil Engineering Consultants

REPORT ON A PHASE 2 GROUND INVESTIGATION AND CONTAMINATION ASSESSMENT FOR A PROPOSED MIXED-USE DEVELOPMENT AT FORMER CHAMBERS BUS DEPOT, CHURCH SQUARE, BURES, SUFFOLK, CO8 5AB

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1. INTRODUCTION AND OBJECTIVES

1.1 This report has been prepared on instructions given by the Client, Rose Builders Limited (Riverside House, Riverside Avenue East, Lawford, Essex, CO11 1US).

1.2 The site is located on the north eastern side of High Street and immediately to the north of the B1508 (Church Square) in the north of the village of Bures, Suffolk as shown on Figure 1, Appendix (i). Bures lies approximately 9km to the south of Sudbury and 16km to the north west of Colchester. As shown on Figure 2, Appendix (i), the site is irregular in shape comprising a number of buildings and areas of hard standing formerly used as a bus depot. The site is at and around National Grid Reference 590750, 124090 and covers an area of around 0.32ha (Reference 1).

1.3 The site has been the subject of a previous desk study as referenced below.

- Compass Geotechnical Limited Report on a Phase 1 Desk Study and Risk Assessment For A Proposed Mixed-Use Development at Former Chambers Bus Depot, Church Square, Bures, Suffolk, CO8 5AB. Report No: 212945A dated September 2021.

1.4 Outline proposals are to redevelop the front (west) section of the site for retail/commercial use with residential above and housing with private gardens to the rear (east). A plan showing the proposed layout is presented as Figure 6, Appendix (i).

1.5 The initial aims of the intrusive investigation were to:

- Investigate the ground and groundwater conditions so that suitable methods of design and construction may be adopted for the redevelopment of the site.
- Undertake materials property testing and contamination testing of samples recovered from an intrusive investigation.
- Recover samples from interceptors and catchpits around the site.
- Install gas collection wells (also used for groundwater monitoring) and monitor on a regular basis.
- Provide information for the assessment of contamination.
- Assess the nature, extent and severity of any contamination at the site.
- Undertake Waste Acceptance Criteria (WAC) tests for the classification of materials for disposal off site.
- Undertake risk assessments.
- Appraise remedial options.
- Present an interpretative report on the findings.

Following discovery of hydrocarbon impacted soils and potential risks to the groundwater, the scope of the investigation was increased as discussed in Section 5.

1.6 The investigation, assessment and reporting has been carried out in general accordance with the following:

- BS 5930:2015+A1:2020. Code of Practice for Ground Investigations.
- BS EN ISO 14688-1:2018. Geotechnical investigation and testing – Identification and classification of a soil – Part 1: Identification and description.
- BS EN ISO 14688-2:2018. Geotechnical investigation and testing – Identification and classification of a soil – Part 2: Principles for a classification.
- BS EN ISO 22476-2:2005+A1:2011. Geotechnical investigation and testing – Field testing – Part 2: Dynamic Probing.
- BS EN ISO 22476-3:2005+A1:2011. Geotechnical investigation and testing – Field testing – Part 3: Standard Penetration Test.
- BS EN ISO 14689:2018. Geotechnical investigation and testing – Identification and classification of rock – Part 1: Identification and description.
- BS EN ISO 22475-1:2006. Geotechnical investigation and testing – Sampling methods and groundwater measurements – Part 1: Technical principles for execution.
- BS 1377-9:1990. Soils for civil engineering purposes – Part 9 In-situ tests.
- BS EN 1997-1:2004+A1:2013 Eurocode 7: Geotechnical design – Part 1: General Rules.
- NA to BS EN 1997-1:2004+A1:2013. UK National Annex to Eurocode 7: Geotechnical design – Part 1: General Rules.
- BS EN 1997-2:2007. Eurocode 7: Geotechnical design – Part 2: Ground investigation and testing.
- NA to BS EN 1997-2:2007. UK National Annex to Eurocode 7: Geotechnical design – Part 2: Ground investigation and testing.
- BS 10175:2011+A2:2017. Investigation of Potentially Contaminated Sites – Code of Practice.
- BS 8576:2013 Guidance on Investigations for ground gases – Permanent gases and Volatile Organic Compounds (VOCs).
- BS 8485:2015 + A1:2109. Code of practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings.
- Environment Agency 2010 GPLC3 Reporting Checklists.

2. FINDINGS OF THE DESK STUDY

2.1 The following is based on information contained in the report of Section 1.3.

2.2 It is believed that most of the site was owned by H Chambers from at least 1877. Originally, the site was operated as a horse drawn bus service but also rented out horses and traps, provided livery stables and ran a saddlery business. Motorised buses were operated from 1918 onwards and it is believed that Chambers also operated a haulage business, however the depot has not been used by buses since approximately

2012. The historical maps obtained as part of the desk study indicate that the site was initially developed with several buildings to the west adjacent to the road and in the north west with an enclosed field with isolated trees to the east. A fire in 1927 destroyed some of the buildings, which were replaced with the large workshop structure currently present.

A 500 gallon petrol tank was installed at the site in 1922 and this is thought to have been towards or in the south western corner but no definitive location for the tank was uncovered during the desk study phase. Further information from Trading Standards, Suffolk County Council, suggests that the petrol tank was converted to diesel in 1971 and the former site owners have confirmed that two small diesel tanks were located in the large workshop building. Reference should be made to the Phase 1 Desk Study report for a full description of the site history and salient features.

2.3 The walkover survey undertaken as part of the desk study identified some potential significant sources of contamination including localised staining on the workshop floor, the area around the bus wash, possible made ground in the east of the yard area, areas of scalpings, and potential fuel storage. However, no definitive evidence of the location of any fuel tanks was found during the walkover survey

2.4 Geological information (e.g. Reference 2) indicates that the site is underlain by solid deposits of the Thanet Formation and Lambeth Group (undifferentiated) in the east and the Lewes Nodular Chalk Formation and Seaford Chalk Formation (undifferentiated) in the west. The solid deposits are shown as overlain by River Terrace Deposits and further superficial deposits including Head to the east and Alluvium to the west. It is thought that River Terrace deposits are around 13m thick in the area of the site.

2.5 Published sources on the occurrence of radon and the need for protection measures in new dwellings (Reference 3) indicate that radon protection measures may be necessary. The Phase 1 desk study confirmed that the site in an area where up to 1 to 3% of homes are estimated to be at or above the action level for radon protection. Advice should be sought from the Building Control Department of the Local Authority to determine if radon protection measures are normally adopted in the area, or consideration could be given to obtaining a definitive detailed radon assessment report for the site.

2.6 The desk study indicates that the solid deposits below the site are classed as a Principal Aquifer and the Superficial deposits as a Secondary A Aquifer. Overall, the groundwater vulnerability is classed as High Vulnerability Secondary Aquifer and the site lies in a groundwater source protection zone – Total Catchment Zone 3.

2.7 The available map information indicates that the closest surface feature is the River Stour flowing south around 70m to the west of the site. The River Stour is of River Quality C.

2.8 No landfill sites, waste transfer stations or similar operations are documented within influencing distance of the site.

2.9 The desk study highlighted some potential risks to end users, construction workers, buildings and services and the groundwater and the water environment primarily associated with the former bus garage activities and recommended an intrusive investigation along with monitoring of ground gases.

3. SITE RECONNAISANCE

3.1 As shown on Figure 2, Appendix (i), the site is irregular in shape and is accessed directly from High Street/Church Square in the south western corner via a concrete accessway leading to a large gate beyond which is the main yard area. To the north of the accessway is Knowle House originally dating from at least 1877 and subsequently extended. The ground floor rooms at the western end of Knowle House appear to have been used as offices whilst the remainder provide living accommodation and a kitchen with bedrooms and a bathroom above. A domestic heating oil tank is present at the eastern end of Knowle House. Reference should also be made to the annotated site plan (Figure 5, Appendix (i)) which highlights a number of the features described below.

On the northern side of Knowle House is a large steel frame workshop/bus garage building with ACM cladding and roof with doors which open directly onto Church Square/High Street. The north western corner, which appears to have been part of an additional single storey structure (former shop) now incorporated into the main building, was used as a parts store, paint store and possible spray painting area. An oil drum and tins of paint were noted in the store and an air compressor was present next to the northern wall. Some localised oil staining was noted on the concrete floor of the main workshop and an interceptor system is present close to the road in the west. To the rear (east) is a more recent extension containing a hydraulic bus lift and wooden covered inspection pits. Externally, between the workshop buildings and the northern boundary is a narrow concrete covered yard.

The western section of the main yard area immediately beyond the large gate is surfaced with concrete. The concrete yard extends around Knowle House to the rear and south of the workshop buildings where a second hydraulic bus lift is present. On the southern side of the yard is a single storey concrete panel structure containing a wooden work bench and a timber and metal frame lean-to structure with a corrugated metal roof. The floor is part dirt, part concrete and part asphalt and a number of calor gas and argon cylinders were noted.

In the central section of the site is a concrete lined inspection pit close to the northern boundary. To the south of the inspection pit is a bus wash with a small corrugated steel shed housing a pump, a water tank and a 45 gallon drum possibly containing detergent. On the western side of the bus wash is a covered collection system for the run-off water and a number of manhole covers, possibly indicating the location of an interceptor, are present around the bus wash. It is understood that a further

inspection pit, now infilled, lies to the south of the bus wash. On the southern side of the yard is a tall lean-to structure with corrugated metal cladding and a dirt floor. At the northern end of the lean-to is a mound of rubble, several tyres and boat beyond which is a single storey garage or store building consisting of a wooden frame with corrugated metal sides and a concrete floor.

The central and eastern sections of the main yard are surfaced with gravel and planings. There is some evidence to suggest ground levels may have been raised locally towards the rear of the yard.

3.2 The site is located in the centre of the village of Bures with residential properties immediately to the north, south and east.

3.3 The topography of the general area slopes down gently to the west and south west towards the River Stour.

4. SITE WORK – INITIAL PHASE

4.1 The initial phase of investigation included thirteen exploratory holes (WS1 to WS13) undertaken by windowless sampling techniques to a maximum depth of 5.0m. The very dense nature of the deposits below the site limited the depth of some of the boreholes. The boreholes were to provide information from across the site for both geotechnical and contamination assessments and the rationale for the location of the exploratory holes is summarized in Table 4.1 below.

Table 4.1 Rationale for Initial Exploratory Holes

Position	Purpose		Gas Monitoring Point Installed	Location and Reason
	Geotechnical	Contamination		
WS1, WS8, WS9, WS10	Y	Y	WS1	Rear Yard – made ground
WS2		Y	WS2	Bus wash and interceptors
WS3		Y		Heating oil tank
WS4		Y	WS4	Area of former fuel tank
WS5, WS6, WS7, WS11, WS12	Y	Y	WS11	Bus garage – internal holes
WS13		Y		Small yard to north of bus garage – former asbestos covered structure

In all of the exploratory holes, other than those in the rear yard area, the surface concrete was cored out by the drilling rig. Continuous samples were recovered from the full depth of all the window sample holes and standard penetration tests (SPTs) were undertaken at regular intervals in WS1 and WS5 to WS12 which are in the areas

of proposed construction. The continuous samples were logged and sub-sampled by an experienced geologist.

4.2 Samples for contamination testing from all the exploratory holes were sealed into amber glass jars to prevent sample deterioration and placed in cool boxes for transport to the laboratory as quickly as possible. All contamination samples were taken in appropriately sized containers and where necessary headspace and storage times were minimized. Representative small, disturbed samples were also recovered from the strata encountered.

4.3 Gas monitoring points were installed in WS1, WS2, WS4 and WS11. The installations comprised a slotted pipe with pea gravel surround below 1m depth. The upper 1m of the installation comprised a plain pipe with a bentonite surround and a gas tight valve was fitted at the top of the pipe. A lockable cover was concreted in flush with the existing ground surface. Full details of the installations are given on the relevant windowless sample hole logs of Appendix (ii).

4.4 All of the soil samples were screened for Volatile Organic Compounds (VOC) using a PhotoIonisation Detector (PID).

4.5 Samples of the liquid remaining in the interceptors inside the bus garage close to the western boundary were recovered and submitted to the laboratory for analysis. In addition, a sample from the catch pit in the inspection pit on the northern side of the bus wash was recovered for analysis.

4.6 The sampling from the interceptors was undertaken on 27th October 2021 and the boreholes were drilled on 4th and 9th November 2021.

4.7 Subsequently, visits were made to site on 16th November, 24th November, 20th December 2021, 7th January, 14th January and 14th February 2022 to record ground gases and groundwater levels. During the monitoring visits, levels of methane, carbon dioxide, oxygen, carbon monoxide and hydrogen sulphide were recorded using a GA5000 gas analyser. Measurements of gas flow rates and atmospheric pressure were also undertaken. The level of any groundwater present was also measured using a dip meter. The results of the gas monitoring are included as Appendix (iv). On 9th December levels of VOCs were measured in each of the monitoring points using a PID and the results are presented in Appendix (vii).

4.8 The investigation and sampling strategies were to obtain representative samples of any fill and natural deposits and to recover materials for soil property and contamination analysis and appraisal. The investigation was in general accordance with the documents of Section 1.6.

4.9 All of the samples were transported to the laboratory for detailed examination and selected samples were programmed for testing.

4.10 Details of the strata encountered in the initial exploratory holes are given on the windowless sample hole logs presented in Appendix (ii) and the positions of the holes are shown on Figure 3, Appendix (i). The PID screening results are presented in Appendix (v), the gas monitoring results in Appendix (vi) and the VOC measurements in Appendix (vii).

5. SITE WORK – SECOND PHASE

5.1 During the initial phase of investigation hydrocarbon impacted soils were encountered in WS4 towards the south western corner of the site close to Knowle House in the area of the suspected below ground fuel tank. The impacted soils were present both above and below the water table and, with the agreement of the Client, a second phase of investigation was undertaken to determine the spread of the hydrocarbon contamination and assess the potential impact on the groundwater.

5.2 The second phase of investigation included four boreholes (BHA to BHD) drilled to 6.0m depth by light cable percussive methods with installation of groundwater monitoring points in each of the four boreholes. The installations comprised a slotted pipe with pea gravel surround below 2m depth. The upper 2m of the installation comprised a plain pipe with a bentonite surround and a lockable cover was concreted in flush with the existing ground surface. The boreholes were located in the south west of the site between Knowle House and the site boundaries but some of the positions were restricted by the presence of buildings. Full details of the ground conditions and the installations are given on the relevant borehole logs of Appendix (iii) and the location of the boreholes is shown on Figure 3, Appendix (i).

5.3 Small disturbed samples were recovered at 0.5m intervals during drilling and all samples were screened on site using a PID as a guide to the vertical extent of any contamination encountered. Samples for laboratory testing were also recovered at regular intervals from the boreholes, sealed into amber glass jars to prevent sample deterioration and placed in cool boxes for transport to the laboratory as quickly as possible. All contamination samples were taken in appropriately sized containers and where necessary headspace and storage times were minimized.

5.4 During drilling of the boreholes the former owner visited the site and confirmed the approximate position of the fuel tank in the south western corner adjacent to Knowle House, and indicated the location of two further below ground tanks inside the bus garage as well as the former position of an above ground tank outside the rear of the bus garage. It is also understood that there is a very thick area of concrete, formerly the base to a pill box, adjacent to the site boundary with the adjoining property to the south. Subsequently the position of the below ground fuel tank in the south western corner of the site has been confirmed by ground probing radar along with a possible tank within the bus garage.

5.5 As part of this second phase of investigation five trial pits/trenches (TP1 to TP5) were dug by a mechanical excavator to a maximum depth of 3.44m bgl. TP1 to TP3 were located in the rear yard area to examine the materials in bulk excavation. TP4 was dug to the

south of the existing bus wash in an area thought to have been an inspection pit. TP4 was of limited depth due to the presence of concrete slabs associated with an older bus wash structure. TP5 was located adjacent to the plinth for the former above ground tank outside the rear of the bus garage. The trial pit logs are included in Appendix (iv) and their location is shown on Figure 3, Appendix (i).

5.6 Samples of the liquid remaining in two of the chambers of the external interceptor adjacent to the existing bus wash were recovered and submitted to the laboratory for analysis.

5.7 Subsequently, site visits were made on 23rd February and 4th March 2022 to recover samples of the groundwater from BHA to BHD. Dedicated sampling equipment was used to extract groundwater from each of the boreholes to prevent cross-contamination. The wells were purged and developed prior to sampling in accordance with best practice. The groundwater samples were recovered in amber glass jars and vials and delivered to the laboratory on the same day for analysis. The depth of the groundwater was recorded using a dip meter and the results of the groundwater monitoring are including in Appendix (viii).

6. LABORATORY WORK

6.1 Detailed below in Table 6.1 is the material property testing undertaken as part of the initial phase of investigation:

Table 6.1 Summary of Material Property Tests

Material Property Test	Number of Tests Natural Soils
Natural Moisture Contents	3
Liquid and Plastic Limits	3
Wet Sieve Preparation	3
Particle Size Distribution (wet sieve)	6
Soluble Sulphate Content	7
pH Value	7

6.2 The following testing was undertaken during both phases of investigation on samples of the made ground, disturbed ground and natural soils encountered to determine possible contamination at the site:

Table 6.2 Summary of Laboratory Contamination Tests

Contamination Test	Number of Tests Made Ground	Number of Tests Disturbed Ground	Number of Tests Natural Soils
Suite of Heavy Metals	12	6	2
pH Value	12	6	2
Speciated PAH	11	2	
TPH Banded (C8-C40)	10	6	8
TPH CWG and BTEX			13
Asbestos Screen	20		
Waste Acceptance Criteria	3		
Organic Matter Content			2

6.3 Six samples of the liquids remaining in the interceptors and catch pits were taken and tested for TPH CWG and BTEX.

6.4 Eight samples of the groundwater taken from BHA to BHD on two occasions were tested for TPH CWG and BTEX.

6.5 The material property test results are included as Appendix (ix), the soil contamination test results including the WAC test results are presented in Appendix (x) and the results for the liquids in the interceptors and catch pits are contained in Appendix (xi).

6.6 The laboratory testing was undertaken during the period 28th October 2021 to 10th March 2022.

6.7 The testing was undertaken at UKAS and MCERTS accredited laboratories.

7. ENGINEERING ASSESSMENT AND RECOMMENDATIONS

7.1 Soil Profile

The surface conditions across the site were variable. At the eastern end of the site the surfacing to the open yard typically comprised asphalt planings (WS1 and WS8 to WS10 and TP1 to TP3). The planings were generally around 0.08 to 0.4m thick however, in WS1 in the north eastern corner the planings were noted as pockets and inclusions in the made ground present from surface. Over the remainder of the external areas concrete was present at surface and the main bus garage had a concrete floor. The concrete varied in thickness, being thinnest (90 and 200mm) inside the oldest section of the garage building and the thicker concrete, up to 400mm thick, present external to the structures.

Beneath the surface materials in all of the exploratory holes, variable made ground was encountered comprising demolition rubble, clays, silts, sands and gravels with inclusions of brick, concrete, tile, shell, coal, mortar and fragments of ACM sheet. In TP3 and TP5 towards the rear of the site, significant volumes of made ground were found containing large pieces of metal, concrete fragments up to boulder size, bus parts, timber, rubber matting and ACM. The made ground was found to varying depths, typically between 0.52 and 1.35m but extended to at least 2.50m bgl in TP3 and TP5. Reference should be made to the individual exploratory hole logs for a full description of the materials present.

Beneath the made ground, materials which have been designated disturbed ground were encountered in all of the positions other than WS4, WS12, WS13, BHA, BHB and TP1 to TP5. The disturbed ground comprised either clays or sands with rare inclusions of brick or other man made artifacts and the disturbed ground extended to depths between 0.82 and 1.90m bgl. A limited number of in-situ tests were carried out in the made ground and disturbed ground. The logs suggest an SPT N value of 4 indicating these upper materials are relatively loose or weak.

Underlying the made ground and disturbed ground were natural deposits thought to represent the River Terrace Deposits. These materials were mainly granular in nature comprising sands and gravels in varying proportions. Locally horizons of gravel in a clay matrix were noted particularly in WS11 and WS13 in the west and north of the site. The upper materials in WS4, WS5 and BHA in the south and west of the site comprised slightly gravelly silty sandy clays which extended to around 2.0m depth. Reference should be made to the individual exploratory hole logs for a full description of the materials present. The geotechnical parameters for the River Terrace Deposits are summarized in Table 7.1 below and on the plot of SPT N Value against depth included in Appendix (xiii).

Table 7.1 Geotechnical Parameters for River Terrace Deposits

Parameter (units)	Results	Classification	Comments
Undrained Shear Strength Cu (kPa) Cohesive deposits			Soft and firm based on examination
SPT N Value Granular deposits	General range 10 – 67 minimum - 4 maximum - 74	Generally medium dense to very dense Very loose/loose Very dense	 WS12 @ 2m WS11 @ 2m (gravel)

Parameter (units)	Results	Classification	Comments
Particle Size Distributions		GRAVEL in a clay matrix Very sandy GRAVEL SAND and GRAVEL Very gravelly SAND	See individual logs for full description
Water Content (%)	18.7		
Liquid Limit (%)	23	CL Soils Non-shrinkable	Based on 1 clayey sample. Plasticity tests on clay matrix in gravels = CL soils
Plastic Limit (%)	17		
Plasticity Index (%)	6		
Modified Plasticity Index (%)	5		
Organic Matter Content (%)	<0.40 – 1.1		
Soluble Sulphate Content SO_4 (g/l)	<0.010 – 0.17	AC-1	
pH Value	7.9 – 9.1		

The strata assessed as River Terrace Deposits were proved to the full depth of the investigation (6.0m). From the BGS records of boreholes nearby, it is believed that the River Terrace Deposits extend to around 13m bgl.

7.2 Ground Contamination Observations

Within the made ground, possible ACM was noted in WS2, WS7, and in TP3. Highly variable made ground including bus parts was found in TP3 and TP5 extending to at least 2.5m bgl and the remains of a bus wash was found in TP4 to the south of the existing bus wash. Locally in the made ground slightly ashy and burnt materials were also noted.

In the natural soils, staining and hydrocarbon odours were noted in WS4 (1.62-2.38m), BHA (1.9-2.5m) and BHB (2.5-3.5m) in the south western corner of the site. PID screening of the samples indicated elevated levels of VOCs in WS4 (0.5-3.0m), BHA (2.5-4.0m) and BHB (3.5-4.0m) with a highest reading of 252.3ppm in WS4 at 2.15-2.2m depth.

7.3 Groundwater Conditions

In the majority of the exploratory holes no groundwater seepages were encountered during the investigations. Water seepages were recorded in WS2 of the initial phase of investigation at around 3.50m bgl. In the deeper holes (BHA to BHD) of the second investigation any groundwater seepages were masked by the addition of water to aid drilling in the denser granular soils.

During the monitoring period, a shallowest standing water level of 2.76m bgl was recorded in BHA with the depth to the groundwater reasonably consistent in BHA to BHD and WS2.

It should be borne in mind that groundwater conditions can vary with seasonal and other effects and thus at times may be at variance with the conditions noted at the time of the site work.

7.4 Excavations

Random falls and collapse of vertical excavation faces can be expected in the made ground, disturbed ground and natural materials dependent on the depth of excavation, the length of time excavations stand open, and the incidence of any groundwater entries.

Consideration should be given to providing at least intermittent to close support in deepened vertical sided excavations where personnel are required to enter. The adequacy of all excavation support should be continually inspected by experienced personnel. Excavations into any deeper made ground are likely to be particularly unstable and collapse readily particularly as inclusions of up to boulder size are present.

7.5 Structural Foundations

It is understood that the development is to comprise houses of traditional construction in the rear portion of the site and a retail/commercial unit with residential above in the front (western) section. Foundation recommendations for buildings take account of the following:-

- Ultimate Limit State (ULS) (stability)
- Serviceability Limit State (SLS) (settlements and ground movements)

The ULS assessment of stability examines the bearing resistance of the ground. The SLS assessment limits the settlements to assessed acceptable limits. The SLS also requires that suitable foundation depths and construction are adopted to cater for the potential ground movements due to the presence of trees and other major vegetation (including future planting) in close proximity to the proposed buildings.

The near surface deposits at the site are highly variable with deep made ground (>2.5m) in places, disturbed ground and natural, predominantly granular, soils. In TP3 and TP5 towards the rear of the site where the made ground is thickest, obstructions and potentially deleterious materials were encountered such as large pieces of metal, concrete up to boulder size, bus parts, timber, rubber matting and ACM. Consideration needs to be given to removal of at least the worst of the materials before construction commences in order to ease foundation operations. There are also a number of inspection pits up to 1.2m deep, bus lifts, a bus wash and a former bus wash, two sets of interceptors and associated pipework, at least two below ground fuel tanks, along with the foundations to the existing bus garage buildings and to Knowle House, and possibly the foundations to a pill box in the southern corner of the site all, of which will need to be removed as part of the redevelopment. The removal of the below ground construction, interceptors, inspection pits, bus washes, tanks, other obstructions and otherwise unsuitable materials is likely to result in significant disturbance to large areas of the site and thus influence the selection of foundation solutions. Careful consideration will need to be given to the choice of foundations for the different parts of the development taking account of the potential disturbance. Careful site preparation prior to development is essential.

The natural soils which underlie the site generally comprise predominantly granular deposits of the River Terrace Deposits which are typically in a medium dense to very dense state of compaction. These deposits should be suitable as a bearing stratum for traditional strip, trench fill or pad foundations bearing at typical depths of around 1 to 2m below existing ground level, depending on the proposed loadings. However, care should be taken not to over deepen foundations due to the presence of the groundwater table at around 2.75m depth. A characteristic angle of shearing resistance of 30° has been adopted based on the lower SPT values within the upper 1m. Calculations suggest that a preliminary design bearing resistance of around 125kPa would be acceptable for a strip foundation, 0.6m wide, bearing on the medium dense granular deposits at around 1.0m depth. Under these conditions the footing would have an adequate factor of safety against shear failure and settlements should be limited to less than 25mm. The ULS and SLS calculations are presented in Appendix (xiv). It may be possible to justify an increase in design bearing resistance if foundations are carried down to around 2m depth where slightly more competent strata are present. In this case a design bearing resistance of up to 300kPa would be considered appropriate provided the sands are in a medium dense or dense state of compaction. For square pad foundations of side 2m a design bearing resistance of 200kPa would be considered appropriate at around 1.0m bgl and again it may be possible to justify higher loadings at around 2.0m bgl.

Where deep areas of made ground are present and/or the ground is likely to be disturbed to significant depth due to removal of below ground structures and obstructions, shallow foundations may not be suitable depending on proposed finished ground levels. Deepened trench fill foundations could be considered but this may entail founding at or below the water table which may be impractical in the relatively permeable granular deposits present.

It is thought unlikely that raft/reinforced type foundation in conjunction with ground improvement such as vibro-compaction or vibro-replacement would be impractical as the existing fill in the deeper areas would not be readily treatable by such techniques, though the advice of a specialist contractor could be sought regarding the effectiveness of such a solution after ground conditioning as discussed above.

Alternatively, it may be appropriate to consider a piled foundation with piles taken down to bear in the medium dense or dense granular deposits of the River Terrace Deposits or underlying materials. The boreholes of the investigation extend to only 6.0m bgl but as a guide, if such deposits continue with depth, based on the available information, for a 0.3m diameter pile extending 6m a carrying capacity of around 200kN would be considered appropriate. However, in order to provide a cost effective pile design, further investigation should be undertaken at the site to obtain parameters for pile design and to confirm the strata below 6.0m depth. Although a driven pile would be suitable in the granular deposits it may not be acceptable because of the proximity of adjacent buildings. The alternatives include screw, bored or augered piles. The advice of a specialist piling contractor should be sought given the ground and groundwater conditions. Due to the potential for below ground obstructions allowance should be made for abortive piling.

7.6 Ground Floor Slabs

Given the presence of significant volumes of made ground, ground floor slabs for the houses are likely to best be constructed as suspended. Consideration also needs to be given to possible venting of ground gases including radon (see sections 2.5 and 11.4). In this event a suitable void may be required below a suspended floor.

For the commercial/retail structure the design of the floor slab will depend on the span and required performance. If a piled foundation is to be adopted then consideration could be given to a piled floor slab although this may not be cost effective. It may be more appropriate to consider a ground bearing floor slab constructed on compacted stone.

7.7 Chemical Attack on Concrete

Laboratory determinations of soluble sulphate content have been undertaken on samples of the natural clay soil present at the site. Reported concentrations were between <0.010 and 0.17g/l SO_4 in association with alkali pH values.

In accordance with BRE Special Digest 1 (Reference 7) the site has been classed as 'natural ground' the groundwater regime is considered 'mobile' as permeable strata are present on site.

Comparison of the characteristic sulphate contents for the soil (based on the mean of the highest two results) and pH concentrations with Table C1 of Reference 7 suggests the ACEC class for the site is AC-1.

7.8 Soakaways

Although the natural granular soils below the site are likely to be suitable for disposal of surface water by soakaway the presence of deep made ground, contamination (and possible enhanced spreading) and a relatively shallow groundwater table may preclude the use of soakaways.

7.9 Road Pavement Design

Much of the near surface soils comprise highly variable made ground or disturbed ground and as such for preliminary design purposes a CBR value of less than 2% should be assumed. Following demolition and clearance of the site, in-situ testing should be carried out along the road alignment and in parking areas to confirm conditions.

8. CONTAMINATION ASSESSMENT - SOILS

8.1 Assessing Contamination

The processes for assessing contamination should be based on the protection of human health, building materials and the environment using the SOURCE-PATHWAY-

RECEPTOR concept. The sources, pathways and receptors relevant to the site are identified using a conceptual site model as outlined in Guidance for the Safe Development of Housing on Land Affected by Contamination (Reference 8) although it

is recognized that the development includes a commercial/retail element as well as residential with private gardens. Reference is also made to the procedures in the Environment Agency Land Contamination Risk Managements (Reference 9), BS 10175:2011+A2:2017 (Reference 4), and the DEFRA Contaminated Land Statutory Guidance (Reference 40). Reference should be made to the original desk study report for full details of the conceptual model.

8.2 Discussion of Results

The results of the contamination testing of the soils are discussed in the following sections. Laboratory contamination testing has been carried out on samples of the made ground, disturbed ground and natural soils encountered during both phases of investigation as a check on conditions. The soils have been tested for a variety of contaminants and comments are made on the spatial distribution of the contaminants along with an indication of whether the results are elevated in relation to guideline values. In this instance, as an initial appraisal, the guideline values used are the critical concentrations for a residential end use with consumption of home grown vegetables. Reference should be made to Section 8.3 for a detailed explanation of critical concentrations. Although the second phase of the investigation was primarily to assess possible risks to the groundwater the results obtained have been used in the following assessment of risks to human health and other identified receptors.

8.2.1 Made Ground

A variable thickness of made ground was encountered across the entire site. As well as the elevated concentrations of some contaminants (see Table 8.1 below) demolition waste and other unsuitable materials were found in the made ground.

Table 8.1 Elevated Results Made Ground

Determinand	Minimum Concentration (mg/kg)	Maximum Concentration (mg/kg)	Critical Concentration (mg/kg)	Number of Samples Exceeding Critical Concentration
Lead	44	**480**	200	3/12
Benzo[a]anthracene	<0.10	**7.6**	2.2	1/10
Benzo[b]fluoranthene	<0.10	**8.5**	2.6	4/10
Benzo[a]pyrene	<0.10	**7.1**	2.2	3/10
Dibenz(a,h)Anthracene	<0.10	**1.1**	0.24	5/10
TPH >C16-21	<1.0	**420**	260	1/10
Asbestos	Not Present	**Present**	Absence	4/20

The analysis of the made ground indicates the presence of elevated concentrations of lead, some of the individual PAH congeners along with asbestos in the form of ACM

and loose fibres (TP5). There is no discernable pattern to the distribution of contaminants in the made ground and it is unlikely that worst case conditions have been identified to date.

The full test results for the made ground are discussed and presented in section 8.3.1.

8.2.2 Disturbed Ground

No elevated concentrations of heavy metals, PAHs or TPHs were identified in the samples of the disturbed ground analysed from the site.

The full test results for the disturbed ground are discussed and presented in section 8.3.2.

8.2.3 Natural Soils

No elevated levels of heavy metals were identified in the samples of natural soils tested. However, locally in the south western corner of the site TPHs were detected in the natural soil with some concentrations elevated above the critical concentrations as summarized in Table 8.2 below.

Table 8.2 Elevated Results Natural Soils

Determinand	Minimum Concentration (mg/kg)	Maximum Concentration (mg/kg)	Critical Concentration (mg/kg)	Number of Samples Exceeding Critical Concentration
Aliphatic TPH >C10-C12	<1.0	**780**	130	1/13
Aromatic TPH >C8-C10	<1.0	**53**	34	2/13
Aromatic TPH >C10-C12	<1.0	**560**	74	2/13
Aromatic TPH >C12-C16	<1.0	**2100**	140	3/13
Aromatic TPH >C16-C21	1.0	**1100**	260	1/13

The elevated hydrocarbons were found in WS4 (1.6 and 2.15m) and BHA (4.0m) close to the location of the below ground fuel tank in the south western corner of the site. Very low concentrations were also reported at 4.0m depth in BHB located a short distance from BHA.

In addition to the contaminants listed in Table 8.2 above, very low concentrations of ethylbenzene and xylene were also identified in some of the samples tested. Whilst the reported concentration do not exceed the current guideline values their presence is of concern as they may indicative of more problematic conditions.. The full test results for the natural soils are discussed and presented in section 8.3.3.

8.3 Risk Estimation

Part IIa of the Environmental Protection Act 1990 provides the main regulatory regime for the identification and remediation of contaminated land. However, there is no

single methodology covering all aspects of the assessment of potentially contaminated land and groundwater. Therefore, the approach adopted for this investigation is made up of a number of procedures designed to protect human health, building materials and the environment. All of the procedures are based on a risk assessment methodology centred on the identification and analysis of source-pathway-receptor linkages and take account of the procedures outlined in Guidance for the Safe Development of Housing on Land Affected by Contamination (Reference 8). Reference is also made to the procedures in the Environment Agency Land Contamination Risk Management (Reference 9), and the DEFRA Contaminated Land Statutory Guidance (Reference 40). The sources-pathways and receptors relevant to the site were identified in the desk study along with details of the initial conceptual site model.

To assess potential risks, samples from the site have been analysed for a range of general contaminants based on assessed recent and previous uses. Consideration has also been given to the requirements of Reference 39 for the selection of water supply pipes. However, it should be noted that the desk study and assessments have not highlighted potential sources for some of the contaminants contained in Reference 39. Testing has been carried out on samples from the made ground, disturbed ground and natural soils. In accordance with current practice (Reference 8) where sufficient results are available they have been statistically analysed. However, where targeted sampling has been carried out or where only a few results are available they have been compared directly with published critical concentrations. The approach is based on the methodology set out in the CL:AIRE document Profession Guidance: Comparing Soil Contamination Data with a Critical Concentration (Reference 10). The guidance allows examination of the robustness of the data set, the identification of statistical outliers and the use of appropriate statistical techniques based on the distribution of the data set (whether normal or non-normal). The guidance can be used to determine:

- Whether land is suitable for a new use under the land use planning system (Planning Scenario).

Or

- Whether land falls within the scope of Part 2A of the Environment Protection Act 1990 (Part 2A Scenario).

In this case the Planning Scenario is appropriate as the site is to be redeveloped.

The selection of appropriate critical concentrations of contaminants for the assessment of risks to human health is based on the CLEA guidance (References 11 to 13). This was updated in autumn 2008 and replaces all previous guidance. This most recent guidance allows derivation of Soil Guideline Values (SGVs) based on: generic assumptions about the fate and transport of chemicals in the environment; a generic conceptual model for site conditions and human behaviour to estimate exposure to soil contaminants for those living, working and/or playing on contaminated sites over a long period of time; and Health Criteria Values that represent a tolerable or minimal risk to health from chronic exposure.

The Environment Agency published SGVs for eleven contaminants (References 14 to 35), including mercury and nickel which have now been withdrawn, and was proposing to publish further SGVs during 2010 but has not done so to date. The former guidelines (Reference 36), the recent DEFRA Category 4 Screening Levels (Reference 37) and the recent LQM/CIEH S4ULs (Reference 38) have been used as initial screening values in the following assessments where no new SGVs have been published. The LQM/CIEH Suitable for Use Levels (S4ULs) also include criteria for the eleven contaminants covered by the SGVs but take into account more recent research on contamination. Site Specific Assessment Criteria (SSAC) and Generic Assessment Criteria (GACs) for individual contaminants can be derived using CLEA v1.07.

The published criteria relate to standard land uses for residential end use (both with and without uptake of vegetables), allotments, commercial/industrial use, and public open space including amenity areas within residential developments and public parks. The residential end use criteria are protective of the health of young children (0 to 6 years) and assume daily exposure to contaminants over a six year period. The commercial/industrial use relates to adults and is for exposure durations based on a standard working week. The proposed development is partly for a residential end use with private gardens and partly for a retail/commercial end use with residential above. In the following assessments the most stringent guideline values for a residential end use with consumption of home grown produce has been used.

8.3.1 Human Health Risk Assessment – Made Ground

The assessment of possible risks to human health from the soils at the site is based on the 'suitability for use' as described in Section 8.3. Table 8.3 below summarises the outcome of the comparison of the results for heavy metals from the made ground. Although twelve samples have been analysed the results have been compared directly with the critical concentrations. The critical concentrations relate to a residential end use with uptake of homegrown produce.

Table 8.3 Comparison of Data for Metals – Made Ground

Determinand	Minimum Concentration (mg/kg)	Maximum Concentration (mg/kg)	Critical Concentration (mg/kg)
Arsenic	6.7	13	37
Cadmium	<0.10	0.64	11
Chromium VI	<0.50	<0.50	6
Copper	53	380	2400
Mercury	<0.10	0.88	1.2
Nickel	11	67	180
Lead	44	**480**	200
Selenium	<0.20	0.33	250
Zinc	34	360	3700
pH	8	10.1	

The analysis indicates that concentrations of lead are elevated in the made ground and are likely to pose unacceptable risks to residential end users. For comparison the guideline values for lead for a commercial end use are 2330mg/kg. None of the other heavy metals appear elevated in comparison with the critical concentrations.

Ten samples of the made ground were screened for PAHs and the results are summarised in Table 8.4 below.

Table 8.4 Comparison of Data for PAHs – Made Ground

Determinand	Minimum Concentration (mg/kg)	Maximum Concentration (mg/kg)	Critical Concentration (mg/kg)
Naphthalene	<0.10	<0.10	2.3
Acenaphthylene	<0.10	<0.10	170
Acenaphthene	<0.10	<0.10	210
Fluorene	<0.10	<0.10	170
Phenanthrene	<0.10	17	95
Anthracene	<0.10	4.2	2400
Fluoranthene	<0.10	20	280
Pyrene	<0.10	18	620
Benzo[a]anthracene	<0.10	**7.6**	2.2
Chrysene	<0.10	6.9	15
Benzo[b]fluoranthene	<0.10	**8.5**	2.6
Benzo[k]fluoranthene	<0.10	3.7	77
Benzo[a]pyrene	<0.10	**7.1**	2.2
Indeno(1,2,3-c,d)Pyrene	<0.10	5	27
Dibenz(a,h)Anthracene	<0.10	**1.1**	0.24
Benzo[g,h,i]perylene	<0.10	4.0	320

The results for the PAHs indicate some elevated levels of the individual congeners in the made ground suggesting possible risks to end users.

Ten samples of the made ground were screened for TPHs using banded analysis. The results are detailed in Table 8.5 below along with the relevant critical concentrations assuming worst case conditions of a soil organic matter content of 1%.

Table 8.5 Comparison of Data for TPHs – Made Ground

Determinand	WS1 0.90-1.00m mg/kg	WS2 0.2-0.5m mg/kg	WS3 0.35-0.75m mg/kg	Critical Concentration mg/kg
TPH >C8-C10	< 1.0	< 1.0	< 1.0	27
TPH >C10-C12	< 1.0	< 1.0	< 1.0	74
TPH >C12-C16	< 1.0	< 1.0	< 1.0	140
TPH >C16-C21	< 1.0	< 1.0	< 1.0	260
TPH >C21-C35	< 1.0	< 1.0	< 1.0	1100
TPH >C35-C40	< 1.0	< 1.0	< 1.0	1100
Hazard Index (HI)	n/a	n/a	n/a	

Table 8.5 Continued

Determinand	WS7 0.1-0.3m mg/kg	WS9 0.25-0.35m mg/kg	WS12 0.2-1.0m mg/kg	Critical Concentration mg/kg
TPH >C8-C10	< 1.0	< 1.0	< 1.0	27
TPH >C10-C12	< 1.0	< 1.0	4	74
TPH >C12-C16	< 1.0	< 1.0	62	140
TPH >C16-C21	7.6	< 1.0	**420**	260
TPH >C21-C35	96	< 1.0	460	1100
TPH >C35-C40	5.5	< 1.0	12	1100
Hazard Index (HI)	0.12	n/a	**2.54**	

Determinand	TP2 0.25-0.35m mg/kg	TP3 0.2-1.0m mg/kg	TP3 0.2-0.3m mg/kg	TP5 0.1-0.2m mg/kg	Critical Concentration mg/kg
TPH >C8-C10	< 1.0	< 1.0	< 1.0	< 1.0	27
TPH >C10-C12	< 1.0	< 1.0	< 1.0	< 1.0	74
TPH >C12-C16	< 1.0	< 1.0	< 1.0	< 1.0	140
TPH >C16-C21	< 1.0	14	8.1	5.7	260
TPH >C21-C35	< 1.0	260	23	9.7	1100
TPH >C35-C40	< 1.0	150	< 1.0	< 1.0	1100
Hazard Index (HI)	n/a	0.43	0.05	0.03	

The results from the made ground indicate the presence of some hydrocarbons in the samples from WS7 0.1-0.3m, WS12 0.2-1.0m, TP3 0.2-1.0m, TP3 0.2-0.3m and TP5 0.1-0.2m depth. The majority of the results do not exceed the relevant critical concentrations for the individual carbon bands however it is only the sample from WS12 which appears to be of concern as the concentration in the C16-21 carbon band does exceed the relevant critical concentration. TPHs in the ranges C16-21 and C31-35 are elevated however, these hydrocarbons are not volatile and are unlikely to give rise

to risks associated with inhalation. Discussions with the laboratory indicate that the hydrocarbons identified are likely to be PAHs rather than petroleum hydrocarbons.

In line with good practice, consideration has been given to possible cumulative effects with calculation of the Hazard Index (HI) (Reference 41). The majority of the samples do not exhibit cumulative effects as the HI is less than one. However, in the sample from WS12 0.2-1.0m depth there are potential cumulative effects. However, as indicated above the hydrocarbons are indicative of PAHs rather than TPH so this may not be the case.

Twenty samples of made ground from across the site were screened for asbestos and both asbestos cement sheeting fragments (chrysotile) and loose chrysotile fibres were detected in four locations. It is likely that more asbestos is present in the made ground across the site.

8.3.2 Human Health Risk Assessment – Disturbed Ground

Disturbed ground has been found in several locations across the site. The assessment of possible risks to human health from the soils at the site is based on the 'suitability for use' as described in Section 8.3. Table 8.6 below summarises the outcome of the comparison of the results for heavy metals from the made ground. As six samples have been analysed the results have been compared directly with the critical concentrations. The critical concentrations relate to a residential end use with uptake of homegrown produce.

Table 8.6 Comparison of Data for Heavy Metal – Disturbed Ground

Determinand	Minimum Concentration (mg/kg)	Maximum Concentration (mg/kg)	Critical Concentration (mg/kg)
Arsenic	4.1	9.7	37
Cadmium	<0.10	0.16	11
Chromium VI	<0.50	<0.50	6
Copper	23	56	2400
Mercury	<0.10	0.3	200
Nickel	9.6	15	1.2
Lead	16	100	180
Selenium	<0.20	0.26	250
Zinc	32	110	3700
pH	7.9	10.1	

The results do not indicate any elevated concentrations of heavy metals and no risks to end users have been identified.

Three samples of the disturbed ground have been tested for PAHs and the results are summarized in Table 8.7 below.

Table 8.7 Comparison of Data for PAHs – Disturbed Ground

Determinand	Minimum Concentration (mg/kg)	Maximum Concentration (mg/kg)	Critical Concentration (mg/kg)
Naphthalene	<0.10	<0.10	2.3
Acenaphthylene	<0.10	<0.10	170
Acenaphthene	<0.10	<0.10	210
Fluorene	<0.10	<0.10	170
Phenanthrene	<0.10	<0.10	95
Anthracene	<0.10	<0.10	2400
Fluoranthene	0.24	1.3	280
Pyrene	0.28	1.5	620
Benzo[a]anthracene	<0.10	<0.10	7.2
Chrysene	<0.10	<0.10	15
Benzo[b]fluoranthene	<0.10	<0.10	2.6
Benzo[k]fluoranthene	<0.10	<0.10	77
Benzo[a]pyrene	<0.10	<0.10	2.2
Indeno(1,2,3-c,d)Pyrene	<0.10	<0.10	27
Dibenz(a,h)Anthracene	<0.10	<0.10	0.24
Benzo[g,h,i]perylene	<0.10	<0.10	320

The reported concentrations of PAHs are low and do not indicate risks to end users.

Six samples of the disturbed ground have been screened for TPHs using banded analysis (C8-C40). The results are detailed in Table 8.8 below along with the relevant critical concentrations assuming worst case conditions of a soil organic matter content of 1%.

Table 8.8 Comparison of Data for TPHs – Disturbed Ground

Determinand	WS2 1.0-1.2m mg/kg	WS7 0.65-0.75m mg/kg	WS8 0.4-0.65m mg/kg	Critical Concentration mg/kg
TPH >C8-C10	< 1.0	< 1.0	< 1.0	27
TPH >C10-C12	< 1.0	< 1.0	< 1.0	74
TPH >C12-C16	< 1.0	< 1.0	< 1.0	140
TPH >C16-C21	< 1.0	< 1.0	< 1.0	260
TPH >C21-C35	< 1.0	< 1.0	< 1.0	1100
TPH >C35-C40	< 1.0	< 1.0	< 1.0	1100
Hazard Index (HI)	n/a	n/a	n/a	

Table 8.8 Continued

Determinand	WS5 0.8-1.0m mg/kg	WS11 1.15-1.25m mg/kg	BHC 1.0-m mg/kg	Critical Concentration mg/kg
TPH >C8-C10	< 1.0	< 1.0	< 1.0	27
TPH >C10-C12	< 1.0	< 1.0	< 1.0	74
TPH >C12-C16	< 1.0	< 1.0	< 1.0	140
TPH >C16-C21	< 1.0	< 1.0	23	260
TPH >C21-C35	< 1.0	< 1.0	64	1100
TPH >C35-C40	< 1.0	< 1.0	8.8	1100
Hazard Index (HI)	n/a	n/a	0.15	

Only very low concentrations of TPHs were reported in BHC at 1.0m depth in the disturbed ground, no other TPHs were detected in the samples analysed.

In line with good practice, consideration has been given to possible cumulative effects with calculation of the Hazard Index (HI) (Reference 41). None of the samples exhibit cumulative effects as the HI is less than one and no risks to end users have been identified.

8.3.3 Human Health Risk Assessment – Natural Soils

The assessment of possible risks to human health from the soils at the site is based on the 'suitability for use' as described in Section 8.3. Table 8.9 below summarises the outcome of the comparison of the results for heavy metals from the natural ground. As two samples have been analysed the results have been compared directly with the critical concentrations.

Table 8.9 Comparison of Data for Metals – Natural Soils

Determinand	Minimum Concentration (mg/kg)	Maximum Concentration (mg/kg)	Critical Concentration (mg/kg)
Arsenic	7.2	7.3	37
Cadmium	0.12	0.15	11
Chromium VI	<0.50	<0.50	6
Copper	12	15	2400
Mercury	<0.10	0.13	1.2
Nickel	11	12	180
Lead	23	82	200
Selenium	<0.20	<0.20	250
Zinc	43	48	3700
pH	8.1	8.3	

None of the individual results for the heavy metals are above the critical concentrations and no risks to end users have been highlighted.

Eight samples of the natural soils were screened for TPHs using banded analysis (C8-C40). The results are detailed in Table 8.10 below along with the relevant critical concentrations assuming worst case conditions of a soil organic matter content of 1%.

Table 8.10 Comparison of Data for TPHs – Natural Soils

Determinand	WS3 1.65-1.75m mg/kg	WS5 1.8-1.95m mg/kg	WS6 2.55-2.75m mg/kg	WS8 1.2-1.3m mg/kg	Critical Concentration mg/kg
TPH >C8-C10	< 1.0	< 1.0	< 1.0	< 1.0	27
TPH >C10-C12	< 1.0	< 1.0	< 1.0	< 1.0	74
TPH >C12-C16	< 1.0	< 1.0	< 1.0	< 1.0	140
TPH >C16-C21	< 1.0	< 1.0	< 1.0	< 1.0	260
TPH >C21-C35	< 1.0	< 1.0	< 1.0	< 1.0	1100
TPH >C35-C40	< 1.0	< 1.0	< 1.0	< 1.0	1100
Hazard Index (HI)	n/a	n/a	n/a	n/a	

Determinand	WS12 1.3-1.5m mg/kg	WS13 1.35-1.4m mg/kg	BHA 2.0-m mg/kg	TP1 0.7-0.8m mg/kg	Critical Concentration mg/kg
TPH >C8-C10	< 1.0	< 1.0	< 1.0	< 1.0	27
TPH >C10-C12	< 1.0	< 1.0	< 1.0	8.6	74
TPH >C12-C16	< 1.0	< 1.0	< 1.0	12	140
TPH >C16-C21	< 1.0	< 1.0	< 1.0	71	260
TPH >C21-C35	< 1.0	< 1.0	< 1.0	190	1100
TPH >C35-C40	< 1.0	< 1.0	< 1.0	20	1100
Hazard Index (HI)	n/a	n/a	n/a	0.67	

The results from the natural soils indicate the presence of a limited amount of hydrocarbons in the sample tested from TP1 0.7-0.8m depth however none of the results exceed the relevant critical concentrations and do not suggest risks to end users. In line with good practice, consideration has been given to possible cumulative effects with calculation of the Hazard Index (HI) (Reference 41). As the HIs are less than one there are no cumulative effects.

Where more severe hydrocarbon contamination was suspected from visual and olfactory evidence and from the PID screening results thirteen samples were analysed in detail using TPH CWG with BTEX tests. The results are summarized in Table 8.11 and Table 8.12 below.

Table 8.11 Summary of TPH CWG Analysis – Natural Soils

Determinand	WS2 3.55-3.65m mg/kg	WS4 1.0-1.1m mg/kg	WS4 1.65-1.85m mg/kg	WS4 2.15-2.2m mg/kg	Critical Concentration mg/kg
Aliphatic TPH >C5-C6	< 1.0	< 1.0	< 1.0	< 1.0	42
Aliphatic TPH >C6-C8	< 1.0	< 1.0	< 1.0	< 1.0	100
Aliphatic TPH >C8-C10	< 1.0	< 1.0	< 1.0	280	27
Aliphatic TPH >C10-C12	< 1.0	3.0	**160**	**780**	130
Aliphatic TPH >C12-C16	< 1.0	190	710	2900	1100
Aliphatic TPH >C16-C21	< 1.0	230	1000	3700	65000
Aliphatic TPH >C21-C35	< 1.0	< 1.0	400	1300	65000
Aliphatic TPH >C35-C44	< 1.0	< 1.0	< 1.0	< 1.0	65000
Aromatic TPH >C5-C7	< 1.0	< 1.0	< 1.0	< 1.0	70
Aromatic TPH >C7-C8	< 1.0	< 1.0	< 1.0	38	130
Aromatic TPH >C8-C10	< 1.0	< 1.0	< 1.0	**53**	34
Aromatic TPH >C10-C12	< 1.0	< 1.0	**100**	**560**	74
Aromatic TPH >C12-C16	< 1.0	< 1.0	**340**	**2100**	140
Aromatic TPH >C16-C21	< 1.0	< 1.0	< 1.0	**1100**	260
Aromatic TPH >C21-C35	< 1.0	< 1.0	< 1.0	520	1100
Aromatic TPH >C35-C44	< 1.0	< 1.0	< 1.0	< 1.0	1100
Hazard Index	n/a	0.20	**5.68**	**48.21**	-

Determinand	BHA 3.0m mg/kg	BHA 4.0m mg/kg	BHA 5.0m mg/kg	BHB 3.5m mg/kg	Critical Concentration mg/kg
Aliphatic TPH >C5-C6	< 1.0	< 1.0	< 1.0	< 1.0	42
Aliphatic TPH >C6-C8	< 1.0	< 1.0	< 1.0	< 1.0	100
Aliphatic TPH >C8-C10	< 1.0	< 1.0	< 1.0	< 1.0	27
Aliphatic TPH >C10-C12	< 1.0	120	< 1.0	< 1.0	130
Aliphatic TPH >C12-C16	410	880	< 1.0	< 1.0	1100
Aliphatic TPH >C16-C21	430	1000	< 1.0	< 1.0	65000
Aliphatic TPH >C21-C35	< 1.0	130	< 1.0	< 1.0	65000
Aliphatic TPH >C35-C44	< 1.0	< 1.0	< 1.0	< 1.0	65000
Aromatic TPH >C5-C7	< 1.0	< 1.0	< 1.0	< 1.0	70
Aromatic TPH >C7-C8	< 1.0	< 1.0	< 1.0	< 1.0	130
Aromatic TPH >C8-C10	< 1.0	< 1.0	< 1.0	< 1.0	34
Aromatic TPH >C10-C12	< 1.0	38	< 1.0	< 1.0	74
Aromatic TPH >C12-C16	48	**280**	< 1.0	< 1.0	140
Aromatic TPH >C16-C21	< 1.0	70	< 1.0	< 1.0	260
Aromatic TPH >C21-C35	< 1.0	< 1.0	< 1.0	< 1.0	1100
Aromatic TPH >C35-C44	< 1.0	< 1.0	< 1.0	< 1.0	1100
Hazard Index	0.72	**4.52**	n/a	n/a	

Table 8.11 Continued

Determinand	BHB 4.0m mg/kg	BHB 4.5m mg/kg	BHB 6.0m mg/kg	BHC 3.5m mg/kg	BHD 3.5m mg/kg	Critical Concentration mg/kg
Aliphatic TPH >C5-C6	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	42
Aliphatic TPH >C6-C8	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	100
Aliphatic TPH >C8-C10	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	27
Aliphatic TPH >C10-C12	22	< 1.0	< 1.0	< 1.0	< 1.0	130
Aliphatic TPH >C12-C16	44	< 1.0	< 1.0	< 1.0	< 1.0	1100
Aliphatic TPH >C16-C21	33	< 1.0	< 1.0	< 1.0	< 1.0	65000
Aliphatic TPH >C21-C35	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	65000
Aliphatic TPH >C35-C44	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	65000
Aromatic TPH >C5-C7	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	70
Aromatic TPH >C7-C8	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	130
Aromatic TPH >C8-C10	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	34
Aromatic TPH >C10-C12	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	74
Aromatic TPH >C12-C16	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	140
Aromatic TPH >C16-C21	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	260
Aromatic TPH >C21-C35	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	1100
Aromatic TPH >C35-C44	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	1100
Hazard Index	0.21	n/a	n/a	n/a	n/a	-

Table 8.12 Summary of BTEX Analysis – Natural Soils

Determinand	WS2 3.5-3.65m µg/kg	WS4 1.0-1.1m µg/kg	WS4 1.65-1.85m µg/kg	WS4 2.15-2.2m µg/kg	Critical Concentration µg/kg
Benzene	< 1.0	< 1.0	< 1.0	< 1.0	87
Toluene	< 1.0	< 1.0	< 1.0	< 1.0	130000
Ethylbenzene	< 1.0	34	2.5	< 1.0	47000
m & p-Xylene	< 1.0	170	90	2.5	56000
o-Xylene	< 1.0	< 1.0	< 1.0	3.2	60000
Methyl Tert-Butyl Ether	< 1.0	< 1.0	< 1.0	< 1.0	-

Determinand	BHA 3.0m µg/kg	BHA 4.0m µg/kg	BHA 5.0m µg/kg	BHB 3.5m µg/kg	Critical Concentration µg/kg
Benzene	< 1.0	< 1.0	< 1.0	< 1.0	87
Toluene	< 1.0	< 1.0	< 1.0	< 1.0	130000
Ethylbenzene	< 1.0	< 1.0	< 1.0	< 1.0	47000
m & p-Xylene	< 1.0	< 1.0	< 1.0	< 1.0	56000
o-Xylene	< 1.0	< 1.0	< 1.0	< 1.0	60000
Methyl Tert-Butyl Ether	< 1.0	< 1.0	< 1.0	< 1.0	-

Table 8.12 Continued

Determinand	BHB 4.5m µg/kg	BHB 6.0m µg/kg	BHC 3.5m µg/kg	BHD 3.5m µg/kg	Critical Concentration µg/kg
Benzene	< 1.0	< 1.0	< 1.0	< 1.0	87
Toluene	< 1.0	< 1.0	< 1.0	< 1.0	130000
Ethylbenzene	< 1.0	< 1.0	< 1.0	< 1.0	47000
m & p-Xylene	< 1.0	< 1.0	< 1.0	< 1.0	56000
o-Xylene	< 1.0	< 1.0	< 1.0	< 1.0	60000
Methyl Tert-Butyl Ether	< 1.0	< 1.0	< 1.0	< 1.0	-

The detailed hydrocarbon analysis has indicated elevated levels of some carbon bands at depth in WS4 and BHA in proximity to the below ground fuel tank adjacent to Knowle House. Some very low concentrations were reported in BHB but these are of little concern. No evidence of hydrocarbon impact was found in BHC and BHD. However, some of the results in WS4 and BHA exceed the critical concentrations for the individual hydrocarbon bands suggesting risks to end users. Given the depth to the contamination, this is more likely to be through inhalation of indoor air rather than risks from direct contact with the soils. Where the HI is greater than one there are also potential cumulative risks.

It should be noted that the above assessment is a generic assessment for risks through a number of different pathways and assumes that the contamination is located within the upper 1m. As the contamination is present at depths greater than 1m it might be more appropriate to derive site-specific assessment criteria for these contaminants assuming risks are from the inhalation of vapour pathway only. The derivation of such site-specific assessment criteria is beyond the scope of this report.

Although some low concentrations of BTEX were reported in the samples analysed from WS4 these are significantly less than the critical concentrations and not deemed to pose risks to end users.

The laboratory has confirmed that the hydrocarbons are diesel. Although the presence of very low concentrations of BTEX may also indicate a ‘petrol’ element.

The investigations to date have not identified hydrocarbons elsewhere at the site other than in the south western corner associated with the below ground fuel tank. It is thought that this tank has leaked at some point in the past. No evidence of hydrocarbons was found to the north inside the garage structure, where it is known that a further tank or tanks are present, although some of these exploratory holes were of limited depth. In BHC and BHD further to the east and north east of the tank there was no evidence of hydrocarbons in the soils and it is thus thought that the contamination is restricted to the south western corner of the site and associated with the small below ground fuel tank. However, at this stage further hydrocarbon contamination in the soils and/or groundwater at the site cannot be discounted.

9. CONTAMINATION ASSESSMENT – GROUNDWATER

9.1 Analysis of Groundwater

To date samples of groundwater have been recovered from BHA to BHD on two occasions and analysed for TPH CWG and BTEX. The results are summarized in Table 9.1 below and the full results included in Appendix (xii).

Table 9.1 Groundwater Monitoring 23 February 2022

Determinand	BHA µg/l	BHB µg/l	BHC µg/l	BHD µg/l
Aliphatic TPH >C5-C6	160	< 0.10	< 0.10	< 0.10
Aliphatic TPH >C6-C8	670	< 0.10	< 0.10	< 0.10
Aliphatic TPH >C8-C10	320	< 0.10	< 0.10	< 0.10
Aliphatic TPH >C10-C12	3000	450	< 0.10	< 0.10
Aliphatic TPH >C12-C16	18000	2700	< 0.10	< 0.10
Aliphatic TPH >C16-C21	24000	3200	< 0.10	< 0.10
Aliphatic TPH >C21-C35	8300	1500	1400	< 0.10
Aliphatic TPH >C35-C44	< 0.10	< 0.10	< 0.10	< 0.10
Total Aliphatic Hydrocarbons	54000	7900	1400	< 5.0
Aromatic TPH >C5-C7	270	< 0.10	< 0.10	< 0.10
Aromatic TPH >C7-C8	310	< 0.10	< 0.10	< 0.10
Aromatic TPH >C8-C10	860	< 0.10	< 0.10	< 0.10
Aromatic TPH >C10-C12	2200	250	< 0.10	< 0.10
Aromatic TPH >C12-C16	20000	2500	< 0.10	< 0.10
Aromatic TPH >C16-C21	21000	2800	< 0.10	< 0.10
Aromatic TPH >C21-C35	2700	< 0.10	< 0.10	< 0.10
Aromatic TPH >C35-C44	< 0.10	< 0.10	< 0.10	< 0.10
Total Aromatic Hydrocarbons	47000	5500	< 5.0	< 5.0
Total Petroleum Hydrocarbons	100000	13000	1400	< 10
Benzene	< 1.0	< 1.0	< 1.0	< 1.0
Toluene	< 1.0	< 1.0	< 1.0	< 1.0
Ethylbenzene	< 1.0	< 1.0	< 1.0	< 1.0
m & p-Xylene	< 1.0	< 1.0	< 1.0	< 1.0
o-Xylene	< 1.0	< 1.0	< 1.0	< 1.0
Methyl Tert-Butyl Ether	< 1.0	< 1.0	< 1.0	< 1.0

Table 9.1 Groundwater Monitoring 4 March 2022

Determinand	BHA µg/l	BHB µg/l	BHC µg/l	BHD µg/l
Aliphatic TPH >C5-C6	< 0.10	< 0.10	< 0.10	< 0.10
Aliphatic TPH >C6-C8	< 0.10	< 0.10	< 0.10	< 0.10
Aliphatic TPH >C8-C10	55	< 0.10	< 0.10	< 0.10
Aliphatic TPH >C10-C12	670	260	< 0.10	< 0.10
Aliphatic TPH >C12-C16	3800	1900	< 0.10	< 0.10
Aliphatic TPH >C16-C21	4700	2500	< 0.10	< 0.10
Aliphatic TPH >C21-C35	2300	1300	< 0.10	< 0.10
Aliphatic TPH >C35-C44	< 0.10	< 0.10	< 0.10	< 0.10
Total Aliphatic Hydrocarbons	12000	6000	< 5.0	< 5.0
Aromatic TPH >C5-C7	< 0.10	< 0.10	< 0.10	< 0.10
Aromatic TPH >C7-C8	< 0.10	< 0.10	< 0.10	< 0.10
Aromatic TPH >C8-C10	210	< 0.10	< 0.10	< 0.10
Aromatic TPH >C10-C12	610	190	< 0.10	< 0.10
Aromatic TPH >C12-C16	4900	1900	< 0.10	< 0.10
Aromatic TPH >C16-C21	4900	2200	< 0.10	< 0.10
Aromatic TPH >C21-C35	1300	560	< 0.10	< 0.10
Aromatic TPH >C35-C44	< 0.10	< 0.10	< 0.10	< 0.10
Total Aromatic Hydrocarbons	12000	4900	< 5.0	< 5.0
Total Petroleum Hydrocarbons	23000	11000	< 10	< 10
Benzene	< 1.0	< 1.0	< 1.0	< 1.0
Toluene	< 1.0	< 1.0	< 1.0	< 1.0
Ethylbenzene	< 1.0	< 1.0	< 1.0	< 1.0
m & p-Xylene	< 1.0	< 1.0	< 1.0	< 1.0
o-Xylene	< 1.0	< 1.0	< 1.0	< 1.0
Methyl Tert-Butyl Ether	< 1.0	< 1.0	< 1.0	< 1.0

The results confirm the presence of significantly elevated levels of hydrocarbons in the groundwater in BHA and BHB in the south western corner close to the below ground fuel tank. There was no evidence of hydrocarbons in BHD and very low levels were detected in BHC on the first round of monitoring only.

The laboratory chromatogram confirms that the hydrocarbons in BHA and BHB are diesel and the pattern of results is similar to that observed in the soils in BHA and WS4.

9.2 Initial Assessment of Groundwater Results

To assess the degree of contamination in the groundwater the results have been compared with the UK Drinking Water Standards (DWS) (contained in Reference 47) as there are no published guideline values specifically for groundwater. This is a stringent approach and is carried out as an initial screening of the results.

The DWS for hydrocarbons is 10µg/l (0.01mg/l) and all of the results for the individual carbon bands exceed this; the total concentrations of hydrocarbons, 100000µg/l in BHA and 13000µg/l in BHB, are far in excess of the DWS. These reported concentrations of hydrocarbons may indicate the presence of free product on the groundwater surface.

As the groundwater in the south western corner of the site has been impacted with hydrocarbons a further, more detailed assessment of the groundwater will be required to determine if remedial action is necessary. Such a detailed assessment is beyond the scope of this report. Whilst the contamination appears to be localized in the south western corner, there are concerns that the suspected source of the contamination, the below ground fuel tank, is located adjacent to the western site boundary and as such contamination could have migrated off-site to the south and west. Based on the topography of the area it is likely that the groundwater flow directions is to the south or west away from the main part of the site and the findings of the current investigations tend to support this contention.

However, the fuel tank(s) at the site have not been in use for some time and as the site is no longer active there is no replenishment of the source of the hydrocarbons and the observed contamination is both localized to around WS4 and BHA and historic. Nevertheless, the groundwater beneath the site is sensitive and the River Stour lies a short distance to the west.

The detailed assessment of the significance of groundwater contamination is normally based on guidance published by the Environment Agency (Reference 48). This approach includes assessment of the sensitivity of the groundwater environment and potential receptors including the groundwater resource itself, any abstractions and other uses locally and well as migration to surface water courses. However, the overriding principle for hazardous substances, which include hydrocarbons, is that any further entry into the groundwater is minimized. Furthermore, there should also be no deterioration in the status of groundwater body and further pollution should be limited by minimizing the expansion of the plume. There should also be no sustained or upward trends in pollutant concentrations. A full assessment of the impact on the groundwater would require some additional groundwater sampling and testing and derivation of site specific parameters such as groundwater flow direction, hydraulic conductivity in order to assess if remedial action is required. (see further discussion in Section 13).

10. INTERCEPTORS AND CATCH PITS

10.1 Samples of the liquids retained in the interceptor inside the bus garage, the interceptor close to the bus wash in the centre of the site, a soakaway and the catch pit in the external inspection pit have been recovered any analysed for hydrocarbons. The results are summarized in Table 10.1 below. The sampling locations are shown on Figure 4, Appendix (i).

Table 10.1 Summary of Analysis of Water in Interceptors and Catch Pits

Determinand	Catch Pit µg/l	Soakaway µg/l	IN1 µg/l	IN2 µg/l	Cell 1 µg/l	Cell 3 µg/l
Aliphatic TPH >C5-C6	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Aliphatic TPH >C6-C8	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Aliphatic TPH >C8-C10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Aliphatic TPH >C10-C12	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Aliphatic TPH >C12-C16	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Aliphatic TPH >C16-C21	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Aliphatic TPH >C21-C35	< 0.10	230	< 0.10	< 0.10	< 0.10	< 0.10
Aliphatic TPH >C35-C44	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Total Aliphatic Hydrocarbons	< 5.0	230	< 5.0	< 5.0	< 5.0	< 5.0
Aromatic TPH >C5-C7	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Aromatic TPH >C7-C8	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Aromatic TPH >C8-C10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Aromatic TPH >C10-C12	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Aromatic TPH >C12-C16	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Aromatic TPH >C16-C21	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Aromatic TPH >C21-C35	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Aromatic TPH >C35-C44	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Total Aromatic Hydrocarbons	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0
Total Petroleum Hydrocarbons	< 10	230	< 10	< 10	< 10	< 10
Benzene	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Toluene	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Ethylbenzene	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
m & p-Xylene	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
o-Xylene	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Methyl Tert-Butyl Ether	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0

The sample recovered from the soakaway contained some very low concentrations of hydrocarbons in the aliphatic C35 to C44 range. No other hydrocarbons were detected in the samples analysed.

Care should be taken when removing the interceptors, catchpits and soakaway along with associated pipework to ensure no hydrocarbons are accidently released into the ground.

11. GROUND GASES AND VOCs

11.1 Monitoring for ground gases has been undertaken on six occasions during different weather and atmospheric pressure conditions. During the monitoring period the gas regime in WS1 in the north eastern corner of the rear yard was significantly different from the regime found in WS2, WS4 and WS11 located in the central and western sections of the site.

No methane was recorded in any of the monitoring positions however, in WS1 carbon dioxide levels were consistently elevated with concentrations between 6.4 and 9.1%, elsewhere at the site carbon dioxide levels were between 1.3 and 3.8%. Concentrations of oxygen were generally slightly depleted to near normal in air. No carbon monoxide or hydrogen sulphide were reported during the monitoring period and gas flow rates were around 0.1 to 0.3l/h or not detected.

11.2 On 9th December 2021, levels of VOCs in the monitoring points were taken using a PID. The results are presented in Appendix (vii) and no VOCs were recorded in WS1, WS2 and WS11. However, in WS4 a concentration of up to 88.5ppm was recorded towards the base of the monitoring point. The VOCs recorded are thought to be associated with the presence of light phase hydrocarbons in the soils in WS4.

11.3 In order to assess the ground gas regime appropriate to the site, the guidance of BS8485:2015+A1:2019 (Reference 46) has been followed which requires a robust assessment of the data, consideration of the reliability of the data and consideration of a conceptual model of the source of any ground gases and possible pathways for gas migration. The assessment of the gas regime and the need or otherwise for gas protection measures is based on the calculation of the hazardous gas flow rate (Q_{hg}) and derivation of the Gas Screening Value (GSV). As required by BS8485:2015+A1:2019, in calculating the Q_{hg} where no gas flow has been recorded the detection limit of the instrument has been used and the Q_{hg} has been calculated for each and every monitoring event.

Calculations from the data available to date suggest a Q_{hg} for methane of up to 0.0006l/hr and a Q_{hg} for carbon dioxide of up to 0.0273l/hr in WS1 and 0.0068l/hr elsewhere at the site. These indicate a very low hazard potential for the site and an initial site characteristic Gas Screening Value (GSV) of <0.07 which equates to Characteristic Gas Situation of CS1. The data has been used to derive a maximum implied Characteristic Gas Situation for both methane and carbon dioxide which also indicates a classification of CS1. A plausible worst-case condition check has been carried out which also falls within CS1.

11.4 The results of the gas monitoring in WS2, WS4 and WS11 do not indicate the need to install gas protection measures. However, in WS1 concentrations of carbon dioxide were consistently above 5% and the guidance states that consideration should be given to increasing the classification to CS2 where gas protection measures would be required. WS1 is located in the rear yard area where the houses are to be located and deep made ground is known to be present. It would, thus, be considered appropriate to install gas protection measures in the proposed dwellings in the east of the site although this will depend on site conditioning operations and the removal of any deleterious materials. For the commercial/retail structure in the west gas protection measures are not deemed necessary. However, reference should be made to Section 11.6 for risks associated with hydrocarbons vapours.

11.5 Based on the available information, for the dwellings in the east of the site gas protections measures should be designed in accordance with BS8485:2015+A1:2019 (Reference 46) and should include a minimum of two protective elements such as a ventilated sub floor void and a proprietary gas membrane. The installation of gas protection measures should be independently checked and verified in accordance with the requirements of BS8485:2015+A1:2019.

11.6 The VOCs recorded in WS4 suggest the presence of hydrocarbon vapour in the ground in this location associated with the impacted soils. The assessment of the laboratory test results from WS4, and the nearby BHA, in Section 8.3.3 confirm there are potential risks to end users from inhalation of indoor air due to the hydrocarbons in the ground and also in the groundwater. Depending on the proposed construction in this part of the site it may be necessary to install vapour protection measures to prevent ingress of hydrocarbon vapours into structures. Although as discussed in Section 8.3.3 consideration could be given to the derivation of site-specific assessment criteria for the hydrocarbons present in the south western corner to establish if vapour protection measures are required.

12. RISK EVALUATION

The purpose of the risk evaluation is to assess whether there are any unacceptable risks to potential receptors from contamination at the site. The risk evaluation considers individually the receptors and pathways identified in the original conceptual model and represents a further refinement of the model. The updated conceptual model is discussed in Section 13. In the made ground elevated levels of lead, some PAHs and TPHs are present along with asbestos. No contamination was identified in the disturbed ground. The contamination testing has indicated elevated levels of hydrocarbons in the natural soils in the south west of the site (WS4 and BHA) and in the groundwater in BHA and BHB. In addition, the groundwater in the south western corner is impacted with hydrocarbons and elevated carbon dioxide levels have been found in the eastern (rear) section of the site associated with deep made ground. Asbestos has also been noted in the construction of the existing buildings. It is also known that other fuel tanks, both above and below ground level, were/are present on site however, no significant contamination has been identified to date associated with these other tanks.

Table 12.1 Risk Evaluation

Receptor	Risk Evaluation
Site Workers	Risks to site workers are considered to come through direct and indirect contact with contaminated soils either by direct skin contact, inhalation of dust/vapour or ingestion by hand to mouth transfer. In order to minimize risks and in accordance with good practice gloves, boots and overalls should be worn to reduce the risks of skin contact. A high standard of personal hygiene should be maintained on site to reduce risks of hand to mouth transfer.
End Users	Risks to end users usually come from direct contact with the ground, ingestion or inhalation of soil particles/vapour or indirect contact such as ingestion of plants or vegetables grown in contaminated soils. Where the site is to be covered by proposed buildings and other hard cover there is not deemed to be a viable pathway by which end users could come into direct contact with the underlying soils. However, in garden and soft landscaping areas there is the potential for end users to come into contact with soils. Potential risks to end users have been identified in the made ground across the site and remedial measures are considered necessary (see Section 13). The hydrocarbons present in the soils and groundwater in the south west of the site could give rise to risks through inhalation of indoor air and further assessment and/or remedial measures are considered necessary. Risks associated with elevated levels of carbon dioxide in the east of the site have been identified and gas protection measures are deemed necessary (see Section 11.4).
Building Materials	Guidance provided by Anglian Water (Reference 39) based on UKWIR 10/WM/03/21 Guidance for the Selection of Water Supply Pipes to be used in Brownfield Sites suggests extensive testing for a wide range of contaminants however, the desk study has not indicated sources for all of the contaminants. The soil testing has found concentrations of organic contaminants (PAH and TPH) in the made ground and TPHs in the natural soils which would indicate the need for barrier pipe. The results should be forwarded to the water supply company for their comment.
Local Environment	Groundwater resources and surface water can be affected by the migration of contaminants. The solid deposits below the site are classed as a Principal Aquifer and the Superficial deposits as a Secondary A Aquifer.

Receptor	Risk Evaluation
	Overall, the groundwater vulnerability is deemed to be High Vulnerability Secondary Aquifer and the site lies in a groundwater source protection zone – Total Catchment Zone 3. The River Stour is around 70m to the west of the site. The soils and groundwater in the south west of the site are impacted with hydrocarbons and there are risks to the wider water environment.

13. UPDATED CONCEPTUAL SITE MODEL

The investigations carried out to date have identified the presence of contamination, including lead, TPH, PAH and asbestos in the near surface made ground along with associated elevated ground gases in the east of the site. Hydrocarbon impacted natural soils are present at depth below the south western corner and there is also evidence of hydrocarbons in the groundwater in this locatlity. Potential risks to end users from hydrocarbon vapours were also identified. No other risks were identified in the natural soils at the site. The updated conceptual model of pollution linkages is detailed in Table 13.1 below.

Table 13.1 Updated Conceptual Model of Pollution Linkages

Sources Potentially Present	Receptors	Pathways	Qualitative Assessment of Risk
Lead, PAH and TPH in made ground	End Users – On site	Contact with soils, ingestion, dust inhalation in garden and landscape areas.	Low to moderate risk in garden and landscape areas
	Controlled Waters	Migration	Low to Negligible risk
	Buildings/services	Ingress into water supply pipes	Negligible with appropriate selection of water supply pipes
	Construction workers	Contact with soils	Negligible with appropriate PPE
	End Users – Off Site	Migration	Negligible Risk

Sources Potentially Present	Receptors	Pathways	Qualitative Assessment of Risk
Asbestos broken fragments of sheeting and loose fibres in made ground. Other sources of asbestos on site and likely within made ground	End Users – On Site Construction workers	Inhalation of fibres Inhalation of fibres	Negligible following identification, removal and site clearance Very Low Risk with appropriate safe working practices, protection measures and PPE
Elevated Carbon Dioxide in east of site	End Users – On site Construction workers	Ingress into indoor air Inhalation in confined spaces	Moderate Risk - gas protection measures required Very Low with safe systems of work
Hydrocarbon impacted soils (WS4 and BHA) and impacted groundwater (BHA and BHB)	End Users – On site Controlled Waters Buildings/services Construction workers End Users – Off Site	Inhalation in indoor air No direct contact due to depth to contamination Migration Ingress into water supply pipes Contact with soils and inhalation Migration	Moderate Risk in south western corner Moderate to High Risk Negligible with appropriate selection of water supply pipes Negligible with appropriate PPE and safe working methods Low Risk

14. DISCUSSION AND REMEDIATION

The form of development, including commercial/retail in the west and residential in the east means that a proportion of the site is to be covered by buildings and other hard standing. In areas of hard standing there is little risk of direct contact between the end users and the underlying soils could occur. However, in garden and soft landscaping areas in order to negate risks from the direct contact pathway some remedial action will be necessary and would likely entail removal of the near surface made ground and, if necessary, part of the upper natural deposits so that a clean cover of materials, at least 0.6m thick can be provided. Some areas of made ground may need to be removed entirely due to the presence of unsuitable materials either from contamination and/or they present an obstruction to foundation construction as in the east of the site.

Risks to end users associated with elevated levels of carbon dioxide in the east of the site have been identified and it is recommended that gas protection measures are installed in the houses in the east. Gas protection measures should be designed, installed, check and verified in accordance with BS8485:2015+A1:2019 (Reference 46).

Potential risks to end users have also been identified associated with vapours from the hydrocarbons impacted soils and groundwater in the south western corner of the site. As discussed in Section 8.3.3 further assessment of possible risks is required along with the derivation of site-specific assessment criteria for the vapour intrusion pathway only. Depending on the proposed construction and remediation in this part of the site, it may be necessary to install vapour protection measures in the commercial/retail structure.

Risks to controlled waters have been identified and the initial monitoring indicates that the groundwater has been impacted with hydrocarbons locally in the south west of the site associated with the below ground fuel storage tank. There is no evidence of significant migration of hydrocarbons to the east into the main part of the site. It is possible however that hydrocarbons have migrated to the south and west off site.

Although other below ground fuel tanks are present on site and an above ground fuel tank has been removed from adjacent to the exterior of the bus garage no evidence of contamination in proximity to the other tanks has been found to date.

At this stage consideration should be given to at least one further round of groundwater sampling and testing to confirm the degree of contamination in the groundwater. Normal practice would then dictate that the Local Authority, and through them the Environment Agency are consulted and an assessment of the groundwater is carried out in accordance with the Environment Agency Remedial Targets Methodology (Reference 48) to determine if remediation of the soil and/or groundwater is required to protect water resources and the nearby River Stour. As the groundwater in BHA appears to have been impacted to a significant degree such an assessment is likely to show that remedial action to clean up the soils and possibly the groundwater is necessary. However, further investigation of the full extent of the contamination may be difficult as the source lies adjacent to the site boundary and it may be difficult to gain permission of fine suitable locations for boreholes off site. Perhaps following discussions with the local authority, as a pragmatic way forward, consideration could be given to a clean up strategy to remove the worst of the impacted soils above the water table and to remove or encapsulate the tank to limit the degree of any future contamination. Other options might include bioremediation of the impacted soils, pump and treat the impacted groundwater or preferably monitored natural attenuation as hydrocarbons naturally decay with time.

Risks to construction workers can be negated by the use of safe systems of work, appropriate PPE and a high standard of hygiene. Particular attention should be given to risks associated with vapour inhalation in confined spaces such as excavation trenches. Safe systems of work should be drawn up including emergency evacuation procedures and a permit to work system.

An asbestos survey of the existing buildings should be undertaken by a suitably experienced contractor, prior to demolition, to identify the type and amount of asbestos present and to advise on its safe removal and disposal. An asbestos discovery plan should also be drawn up so that further occurrences of asbestos can be safely dealt during development of the site.

Following demolition of the structures and clearance of the site a detailed inspection should be undertaken by a suitably qualified and experienced geo-environmental engineer to identify any further sources of contamination.

There is the potential for further, as yet unidentified contamination to be present at the site particularly given the previous use as a bus garage. A watching brief should be maintained throughout the development and if further contamination is found or suspected the geo-environmental engineer should be notified immediately so appropriate action can be taken.

There are a number of below ground structures including former fuel tanks and interceptors which will need to be removed as part of the development. A careful strategy should be drawn up for the excavation and removal of such structures given the potential for further contamination. Following removal of the below ground structures the resulting excavations should be carefully inspected by a suitably qualified and experienced geo-environmental engineer to identify any impacted soils and advise on the need for any further remediation.

Given the volumes of material involved consideration should be given to a sustainable remedial strategy including on site sorting and screening of materials and re-use where possible to minimize the amount sent to landfill.

15. DISPOSAL OFF SITE

15.1 Given the presence of contamination in the made ground including asbestos, some of the materials at the site are likely to be classed as hazardous for removal to landfill. Any natural soils significantly impacted with hydrocarbons are also likely to be classed as hazardous.

15.2 Three Waste Acceptance Criteria (WAC) tests have been undertaken on samples of the made ground. Two of the results exceed the inert waste category and are classed as non-hazardous for disposal at landfill. The results should be forwarded to the receiving landfill for their comment and classification.

16. CONCLUSIONS

16.1 The site is complex with a long history of industrial use as a bus garage and a number of sources of contamination have been identified during the current investigation. However, it is unlikely that worst case conditions have been encountered to date and further contamination is likely to be present.

16.2 The ground conditions include variable depths of made ground overlying disturbed ground and natural granular strata. The made ground is at least 2.5m deep in places and includes volumes of unsuitable materials such as concrete boulders, bus parts as well as asbestos.

16.3 There are several below ground structures including interceptors, fuel tanks and suspected fuel tanks, inspection pits, bus lifts and existing foundations which will need to be removed as part of the development. Removal of these structures is likely to disturb the ground to significant depth.

16.4 A piled foundation is likely to be the favoured foundation solution at least for parts of the site although traditional strip, trench fill or pad foundations may be considered in parts. Further deep boreholes will be required to provide geotechnical information for the design of piles.

If a piled foundation solution is to be adopted a piling risk assessment should be carried out. The piling system adopted should not increase the risk of contamination being transported by creating new pathways.

16.5 Due to the presence of contamination and significant volumes of made ground, soakaways are not recommended at the site.

16.6 Much of the near surface soils comprise highly variable made ground or disturbed ground and as such for preliminary design purposes a CBR value of less than 2% should be assumed. After demolition and clearance of the site in-situ testing should be carried out along the road alignment and in parking areas to confirm conditions following conditioning and remediation.

16.7 The investigations to date have identified contamination in the made ground including lead, PAHs, TPH and asbestos. Remedial action will be necessary in garden and landscaped areas to safeguard the health of residential end users.

16.8 Hydrocarbon contamination of the soils and groundwater has been found in the south west of the site in proximity to the below ground fuel tank. Further assessment of the contamination is required along with, possibly, remediation. However, the location of the fuel tank close to the site boundary will make remediation difficult and a pragmatic approach should be considered.

16.9 Risks associated with hydrocarbon vapours have been identified and it may be necessary to include a vapour barrier in the retail/commercial unit in the west of the site. Although a more detailed assessment may show this is not necessary.

16.10 The presence of elevated levels of carbon dioxide suggests gas protections measures are necessary in the houses in the east of the site.

16.11 Radon protection measures may be required.

16.12 An asbestos survey of the existing buildings should be undertaken by a suitably experienced contractor, prior to demolition, to identify the type and amount of asbestos present and to advise on its safe removal and disposal. An asbestos discovery plan should also be drawn up so that further occurrences of asbestos can be safely dealt during development of the site.

16.13 Further inspections will be required as demolition, clearance and development progresses to identify any further sources of contamination. Close attendance by a geo-environmental engineer will be required during removal of interceptors, fuel tanks and other below ground structures.

16.14 Prior to any remedial operations being undertaken a Remediation Method Statement should be drawn up. Any remedial measures undertaken will need to be independently checked and validated to the satisfaction of the Local Authority, NHBC and other statutory bodies. Any remedial works should be independently checked and verified by a suitably experienced Engineer and a validation report drawn up on completion of the work.

16.15 Some of the materials at the site are likely to be classed as hazardous for removal from site. Any natural soils significantly impacted with hydrocarbons are also likely to be classed as hazardous.

16.16 Given the volumes of material involved consideration should be given to a sustainable remedial strategy including on site sorting and screening of materials and re-use where possible to minimize the amount sent to landfill.

R. Foord BSc, MSc, MCSM, CGeol, FGS

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The report and/or opinion will be prepared and written for the specific purposes and/or development stated in the document and in relation to the nature and extent of proposals made available to us at the time of writing. The recommendations should not be used for other schemes on or adjacent to the site.

The report is based on the ground conditions encountered in the exploratory holes together with the results of field and laboratory testing in the context of the proposed development. Conditions between exploratory holes have been interpolated, however soil conditions are highly variable and may differ from the interpolation. There may be conditions, appertaining to the site, which may not be revealed by the investigation, and which may not be taken into account in the report.

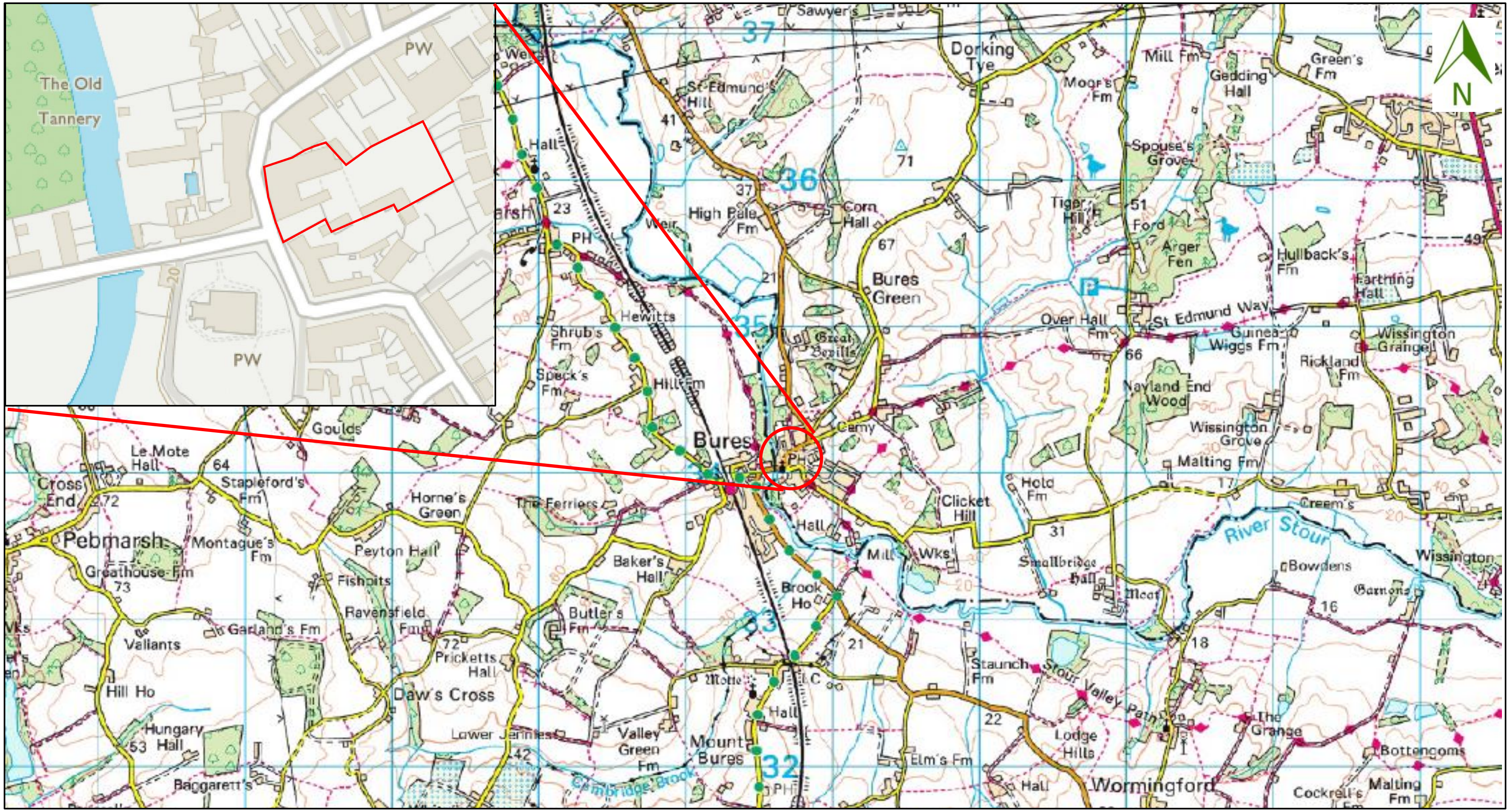
The accuracy of the results reported will depend on the technique of measurement, investigation and test used and these values should not be regarded necessarily as characteristic of the strata as a whole. Where such measurements are critical, the technique of the investigation will need to be reviewed and supplementary investigation undertaken in accordance with the advice of the company where necessary.

The economic viability of the proposal referred to in the report, or of the solutions put forward to any problems encountered, will depend on very many factors in addition to the geotechnical considerations hence its evaluation will be outside the scope of the report.

Where any data supplied by the Client or from other sources, including previous site investigations, have been used it has been assumed that the information is correct. No responsibility can be accepted by Compass Geotechnical Limited for inaccuracies in the data supplied by any other party.

The investigation does not include the identification of Japanese Knotweed. Any such survey should be undertaken by a specialist.

Appendix (i)
Figures



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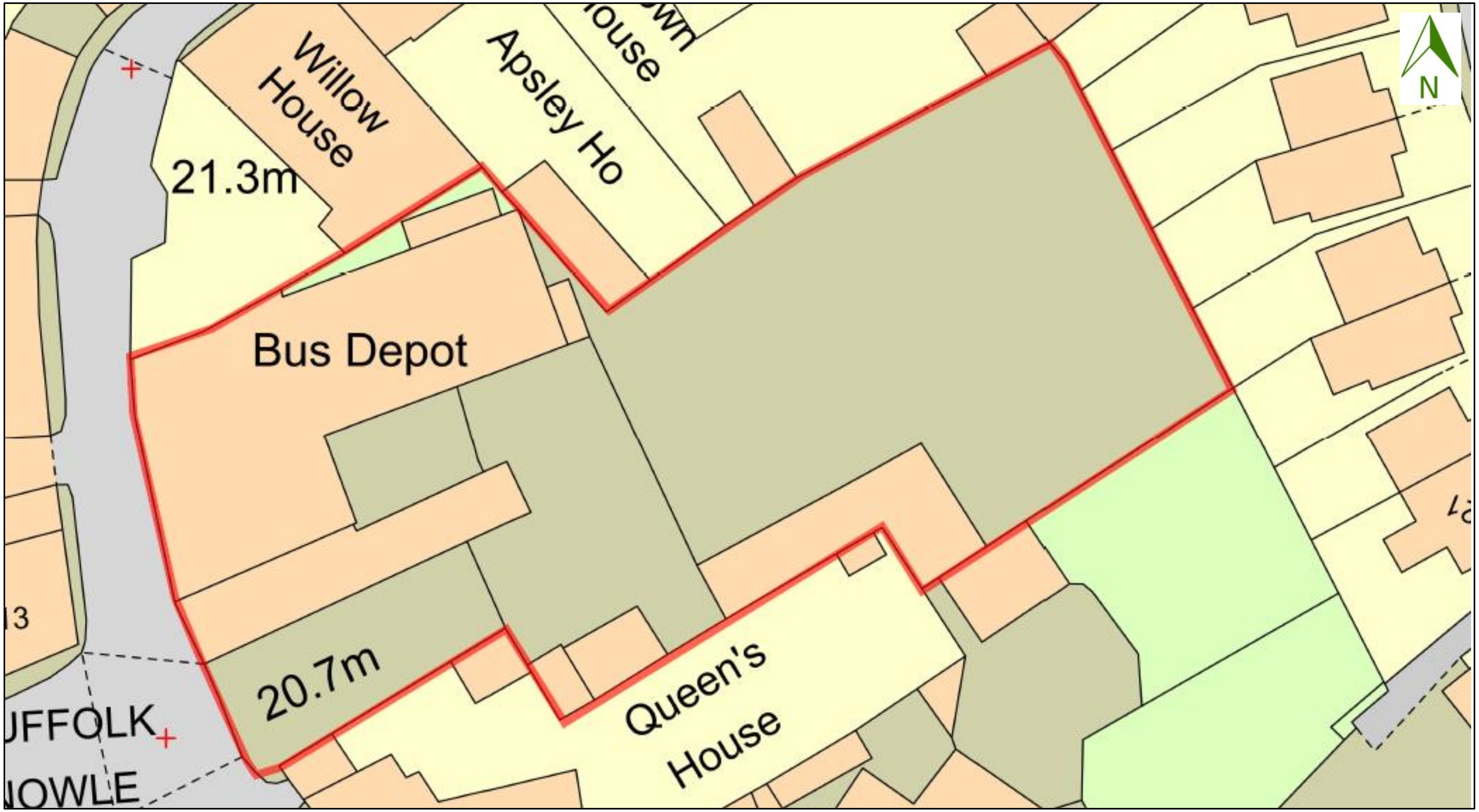
	Date	June 2022
	Not to Scale	



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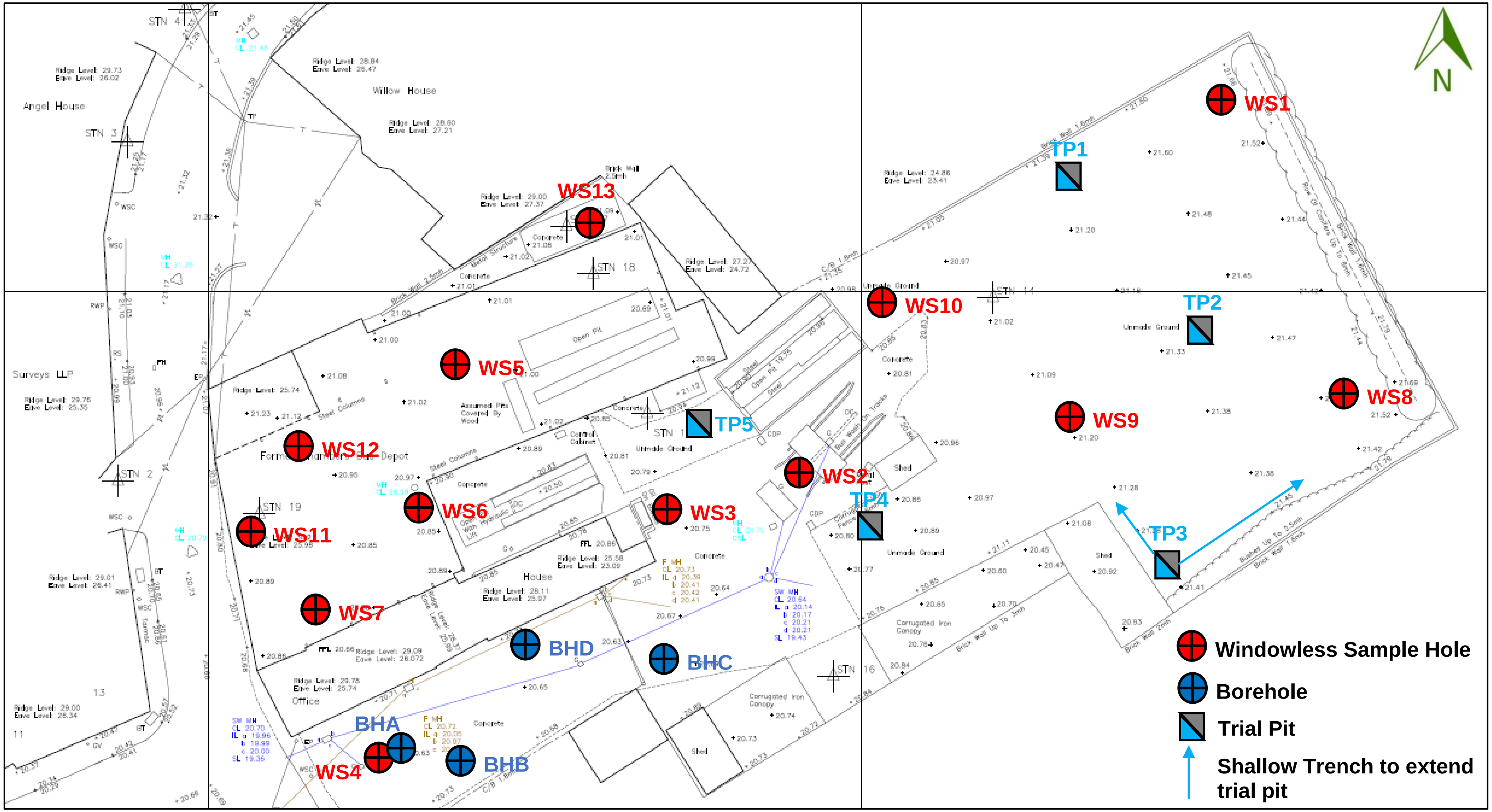

Extract from Randall Surveys Existing Site Layout Drawing No: 16449/OG/1 dated June 2021	**Figure 3**	Exploratory Hole Plan
	Date	June 2022
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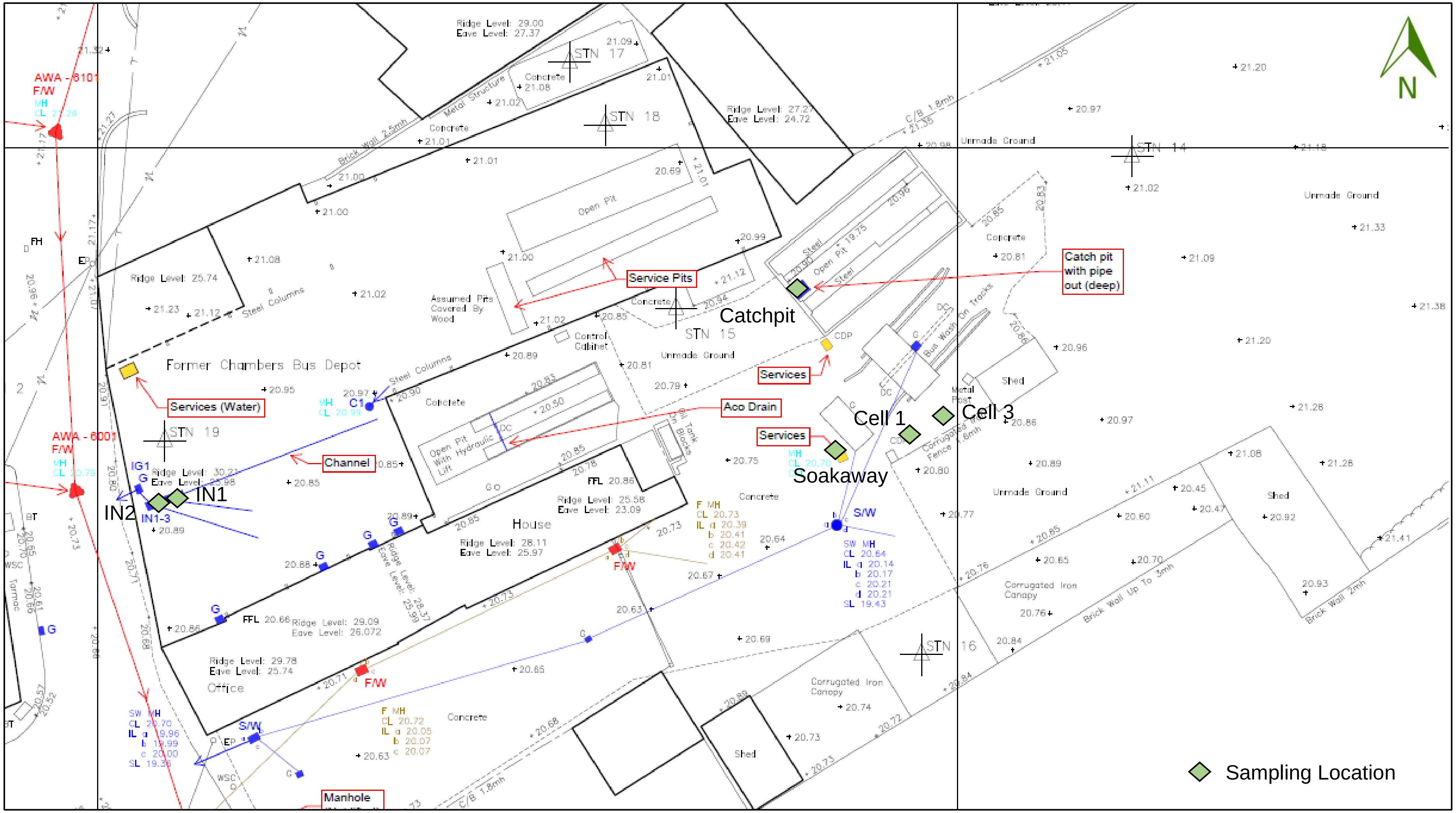
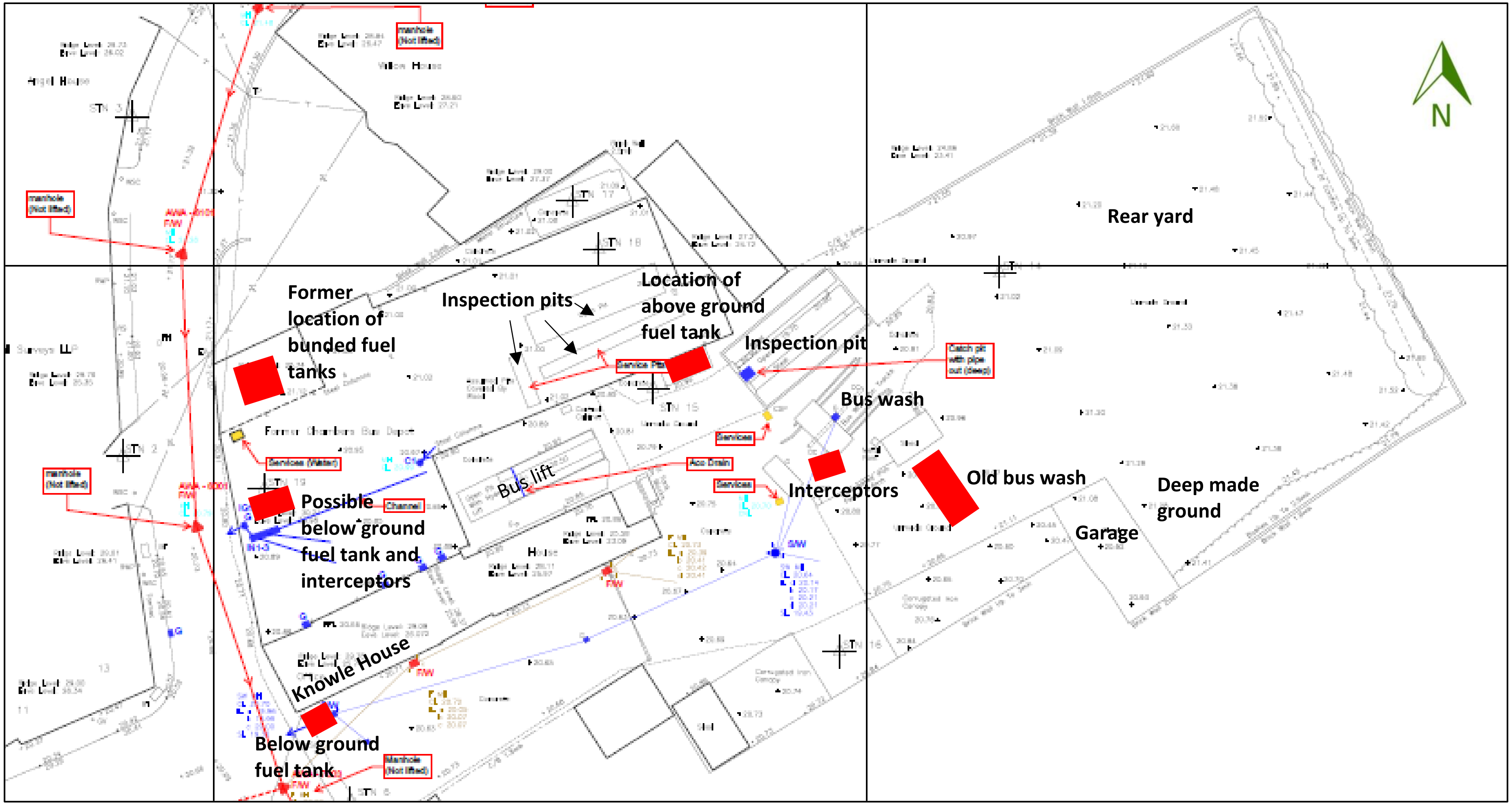


Extract from Randall Surveys Existing Site Layout Drawing No: 16449/OG/1 dated June 2021 with additional drainage	**Figure 4**	Interceptor Sampling Plan
	Date	June 2022
	Not to Scale	



Extract from Randall Surveys Existing Site Layout Drawing No: 16449/OG/1 dated June 2021 with additional drainage	**Figure 5**	Annotated Site Plan
	Date	June 2022
	Not to Scale	

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	Date	June 2022
	Not to Scale	