

Advanced Investigation Works for New Municipal Offices, Yellowways, Rochdale

Ground Investigation Interpretative Report

August 2009

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New information, changed practices or new legislation may necessitate revised interpretation of the report after the date of its submission.

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EXECUTIVE SUMMARY

Introduction	Mouchel was commissioned by its joint venture partner, The Impact Partnership on the 17 th March 2009 to undertake a geo-environmental assessment of a site located off Smith Street, Rochdale for Rochdale Metropolitan Borough Council. The site is proposed to be redeveloped as the New Municipal Offices comprising office blocks up to nine storeys high with associated car parking.
Desk Study Findings	<p>The site is located approximately 0.5km to the south of Rochdale town centre, adjacent to Smith Street and Milton Street, is centred on NGR SD 899 134 and covers approximately 0.34 hectares.</p> <p>The North area (to the north of Slack Street) is currently occupied by an office with associated car park, a small car park used by Mecca Bingo and an area of gravel surfacing where a building was recently demolished. The South area (to the south of Slack Street) is currently used as a car park. The site has formerly been occupied by mills, tobacco works, bus station / depot, works buildings and a warehouse.</p> <p>There is Japanese Knotweed present on the site which has been previously treated but has reappeared.</p> <p>The River Roch is located immediately adjacent to the west of the site and the site is underlain by alluvial and glacial deposits over Lower Coal Measures bedrock which is a minor aquifer. The shallow groundwater beneath the site is thought to be in hydraulic continuity with the river and there is evidence of localised artesian conditions.</p>
Ground Investigation	An intrusive investigation was undertaken by Soil Mechanics Ltd between 12th and 22nd May 2009. A number of trial pits and cable percussion boreholes (plus one with rotary follow on) were completed within the North area to a maximum depth of 4m bgl and 17.8m bgl respectively. A number of trial pits were excavated within the South area to supplement those excavated during the previous 2006 investigation (Mouchel Parkman, August 2006 – Geo environmental Interpretative Report, Yelloways Development (Report Reference: 760140/R/02C) in order to delineate the area affected by hydrocarbon contamination that was noted previously. In addition, a further cable percussion borehole was installed for groundwater monitoring purposes within the South area at a point down the hydraulic gradient as requested by the Environment Agency. Soil samples were obtained from the exploratory holes for subsequent chemical and geotechnical analysis. Gas / groundwater monitoring wells were installed within all the boreholes were possible and a 6 week period of monitoring was undertaken following completion of the works.
Ground Model	The whole site comprises level to very slightly sloping ground. The geological sequence comprises made ground overlying alluvium of sand, silt and clay associated with the adjacent River Roch which is further underlain by bedrock of siltstone, sandstone and mudstone (Coal Measures). Heavy metal and polyaromatic hydrocarbon contamination is higher in areas containing high proportions of ashy material. Ashy material appeared to be more prevalent in the North area. Petroleum hydrocarbon contamination was noted as sheens and odours and was widespread across the South site. Carbon dioxide was noted across the site at concentrations of up to 9.7%.
Human Health Risk Assessment – Soil and Gas	A generic quantitative human health risk assessment was undertaken on soil analysis results from both the 2006 and 2009 investigations. The site was split into North and South areas for assessment due to the differing previous historical uses in these areas as well as physical differences in the made ground composition. The soil results were assessed against published Soil Guideline Values (SGVs) and where these were not available, against Mouchel derived Generic Assessment Criteria (GACs). With regard to the North area, there is a risk to human health present from benzo(a)pyrene present within the Made Ground. There is no risk to human health from the made ground and natural material present in the South area. With regard to ground gas, there is methane up to 0.2%, carbon dioxide up to 9.7% and a maximum flow rate of 4.2l/hr. Using the Modified Wilson and Card Classification which is suitable for commercial buildings, the site is classified as Characteristic Situation 3 which is likely to require gas protection measures including a proprietary gas resistant membrane and passively ventilated or positively pressurised underfloor subspace with monitoring facility. It should be noted that these measures may not be required if undercroft car parking is present.

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Controlled Waters Risk Assessment	A detailed quantitative groundwater risk assessment has been undertaken using the Environment Agency Remedial Targets Methodology. Soil leachate and groundwater analysis results were screened against generic values for controlled waters. In this case, Environmental Quality Standards were used where available. A number of contaminants of concern (COC's) were identified – metals, petroleum hydrocarbon fractions and polycyclic aromatic hydrocarbons during the Tier 1 and 2 screening. Modelling of these COCs was undertaken to derive site specific Remedial Target Values (RTVs) for both soil and groundwater. The soil and groundwater analysis results were reassessed using the site specific RTV's. It should be noted that a number of COCs were discounted at this stage as the travel time to the River Roch was in excess of 500 years by which point degradation is likely to have occurred. However, there is a risk to the River Roch from cyanide, naphthalene, phenol and the aliphatic EC5-6 petroleum hydrocarbon fraction. As such, remediation of the site to prevent pollution of controlled waters is likely to be required.
Geotechnical Assessment	Characteristic geotechnical parameters to be used for the design works have been derived from the findings of the site investigations and subsequent laboratory testing. These parameters have been derived for the made ground, alluvial sand, alluvial gravel, alluvial clay and bedrock. It should be noted that as well as perched groundwater within the made ground and alluvial deposits, there are artesian conditions within the bedrock. Groundwater control measures will be required for excavations and sump pumping is likely to be suitable for shallow excavations. The design sulphate classification for foundation soils is DS-3. The Aggressive Chemical Environment for Concrete (ACEC) classification for the site, assuming mobile groundwater is AC-3.
Remediation	<p>Remediation is required due to the risk to human health and controlled waters from contaminants present on site. With regard to human health due to the proposed end use of the site as office buildings and car parking and the nature of the contaminant posing the risk (Benzo(a)pyrene), it is likely that the presence of hardstanding and the use of clean cover within landscaping areas will be sufficient to mitigate the risk.</p> <p>With regard to controlled waters, there are a number of remedial options that would potentially be suitable. It is likely that a permeable reactive barrier combined with vacuum extraction would be most suitable for this site, however; ex situ bioremediation may also be an option. This would need to be confirmed by a detailed options appraisal.</p>
Geotechnical Design	The made ground is not considered to represent a suitable founding stratum for any structures with significant imposed loads or those sensitive to settlement. The requirement for a car park undercroft will mean that the building will be founded on columns which would be piled into bedrock. There may be a need for ground beams between the columns to tie them together and distribute loads onto piles. Due to the artesian conditions there would be a preference for driven piles. However there is a desire for ground source heating and consideration of incorporation of 'loops' within piles may warrant a closer look at CFA cast in situ piles. The presence of contamination and underground obstructions such as former foundations should be taken into account when designing a suitable foundation technique.
Conclusions	A risk to human health exists from contaminants within the made ground in the North Area. A risk to controlled waters, namely, the River Roch exists from widespread cyanide, phenol, naphthalene and petroleum hydrocarbon contamination and as such, remediation is required. The made ground is not considered to be a suitable founding stratum and as such, deep foundations such as basement rafts with thickened beams between columns founded on deeper soils or piled foundations will be required. Gas protection measures may be required within the floor slabs depending on whether undercroft car parking is present.
Recommendations	Further intrusive investigation is recommended to determine the potential for use of ground source heating within the proposed development or possibly to prove the feasibility of a particular remediation technology. The use of ground penetrating radar may be necessary to determine the location of underground structures such as former foundations, basements, tanks and vehicle maintenance pits. No further detailed quantitative risk assessments are required. The presence of organic contamination at the site means that specialist water mains pipework will be required. The remediation strategy requires confirmation via a detailed options appraisal and discussions with the Environment Agency followed by subsequent agreement from both the Environment Agency and the Local Council Contaminated Land Officer.

1 Introduction

1.1 Terms of Reference

Mouchel was commissioned by its joint venture partner, The Impact Partnership on the 17th March 2009 to undertake a contaminated land assessment of a site located off Smith Street, Rochdale for Rochdale Metropolitan Borough Council. The site is known as 'Yellowways', after the bus station that was formerly present.

1.2 Development Proposals

The site is proposed to be developed as the new Municipal Offices with associated car parking. These are understood to be up to 9 storeys in height and probably incorporating undercroft car parking. A definitive plan for the development was still in a process of evolution at the time of issue of this report.

Section 57 of the Environment Act 1995 adds Part 2A (ss.78A-18YC) to the Environmental Protection Act 1990 and contains the legislative framework for identifying and dealing with contaminated land. Where development is undertaken on land which may be affected by contamination, specific guidance has been published from the Office of the Deputy Prime Minister in Annex 2 of Planning Policy Statement 23 (PPS 23). This links the contaminated land regime within the development process.

The presence of contaminants which may pose a risk to human health or the environment is a material planning consideration and it remains the responsibility of the developer to ensure safe development. To distinguish from the statutory term "Contaminated Land", and to reflect the broader scope of planning, PPS23 refers to "land affected by contamination". For planning, it should be considered whether the level of contamination is low relative to the level of risk and the concern is for the site's proposed use, not its current use. This is opposite to Part 2A which considers high levels and the current use of the site.

1.3 Previous Studies

Details of previous studies undertaken on the site are given below:

- Mouchel, June 2009 – Yellowways, Rochdale – Preliminary Risk Assessment Desk Study. Report Ref: 701368/R/01.
- White Young Green, March 2008 – Desk Top Study Report, Mecca Car Park, Slack Street, Rochdale.

- Mouchel Parkman, August 2006 – Geo environmental Interpretative Report, Yelloways Development (Report Reference: 760140/R/02C)

The interpretation and conclusions contained in this report rely on the factual information collected through these reports in addition to that collected in this investigation.

1.4 Objectives and Scope

It is proposed to develop the site at Yelloways, Rochdale for offices and associated car parking. The development plan is not yet fully confirmed but it is known that it will extend beyond the South area of the site which was investigated by Mouchel in 2006. It is expected to be up to nine storeys in height and may contain undercroft car parking as well as potentially utilising a ground source heating system.

The purpose of this report is to assess the site for all aspects relating to land affected by contamination in the planning context. It will also further assess the ground based environmental and geotechnical risks, constraints and liabilities associated with the redevelopment of the site.

The client has requested that the following works are undertaken:

- Completion of the recommended additional environmental investigation within the South area of the site. The scope of this investigation was outlined in a letter dated 16th October 2006 from Melanie Wrigley (Mouchel Parkman) to Gerry Connell (Liverpool 2020). A copy of this letter is included in Appendix A of this report.
- Completion of a geo-environmental and geotechnical investigation within the North area. This covers the area to the north of the Slack Street and is bounded by Smith Street, Milton Street, Ink Street and the River Roch river wall.
- Preparation of an Interpretative Report to cover the combined sites including human health, groundwater and gas risk assessments, outline foundation assessments and remedial options.

It should be noted that flooding risk is beyond the scope of this report and was the subject of a separate assessment of the South area in 2006.

2 Desk Study Findings

2.1 Introduction

Mouchel (formerly Mouchel Parkman) have already completed a desk study and ground investigation with subsequent reporting for the South area. In addition, Mouchel have undertaken a Desk Study to cover the North area (June 2009, reference 701368/R/01).

2.2 Site Location

The site is located approximately 0.5km to the south of Rochdale town centre, adjacent to Smith Street and Milton Street. The site is centred on National Grid Reference SD 899 134 (389920, 413430) and covers approximately 0.34 hectares. Figure 1 shows the location of the site.

2.3 Site Description

2.3.1 South Area

The site description is based on observations made at the time of the 2009 site investigation. The area to the south of Slack Street is currently used as a car park with a surface covering of hardcore and a small area of concrete. The car park is fenced but is not secure as the gated entrance off Slack Street is not locked. The presence of Japanese Knotweed was noted in a number of locations within bunds of material that are adjacent to the southern and western boundaries as well as running north – south across the car park. Water in puddles on the surface of car park near the river is being replenished from below and is evidence of localised artesian conditions. There is a slipway down to the River Roch located in the north western corner of the car park. There are locked, metals gates present at the top of the slipway to prevent unauthorised access.

2.3.2 North Area

There is an office building located in the north western part of this area to the west of Ink Street. There is also an adjacent car park with a rough tarmac and gravel surface. Sandstone boulders are situated along the eastern boundary of the car park adjacent to Ink Street to prevent unwanted vehicular access.

The area to the north east of this area comprises an area of level ground surfaced with gravel. A building was recently demolished in this part of the site. Sandstone boulders are located around the boundaries adjacent to Ink Street, Smith Street and Milton Street.

There is also a tarmaced, walled car park located to the north of the Yellowways car park and to the south of the level area of gravel. This is used by Mecca Bingo.

The River Roch is located immediately adjacent to the western boundary of the North and South area and southern site boundaries of the South area and flows in a westerly direction. There is a weir adjacent to the western site boundary of the South area.

2.4 Summary of Preliminary Ground Model

The site has been in industrial / commercial usage since the late 1800's. The South area was formerly occupied by mills and a tobacco works prior to the development of a bus depot in the late 1950's. The bus depot included maintenance and repair operations as well as refuelling. The 2006 investigation of this section of the site highlighted the presence of heavy metal, polyaromatic hydrocarbon and petroleum hydrocarbon contamination within the soils and groundwater.

The North area has formerly been occupied by a works building (with unspecified use) and a warehouse. No investigation of this area has been undertaken prior to the recent investigation reported in this document but there is the potential for contaminants such as heavy metals, hydrocarbons and asbestos to be present due to the site having been previously developed.

The soils across the site are classified as having a high leaching potential, which is described as providing little protection and readily transmitting a wide range of pollutants due to their rapid drainage and low attenuation potential. However, it should be noted that caution has been applied by the Environment Agency during classification due to the urban setting. A worst case scenario has been assumed.

The drift geology across the whole site area is expected to comprise Glacial Sands and Gravels with the underlying solid geology being Lower Coal Measures. The Coal Measures are considered to be a minor aquifer. The presence of the River Roch adjacent to the site means that alluvial deposits are also likely to be present on site.

The made ground under the whole site will be variable in density and as such, the bearing capacity of this strata will also be variable. This and the underlying drift deposits are unlikely to be able to support the loadings from a 5 storey building. The geotechnical ground conditions are also affected by the local presence of artesian water as detected in the 2006 investigation of the South area.

The River Roch is situated immediately adjacent to the site boundary. The findings of the 2006 investigation suggest that the shallow groundwater beneath the site is in hydraulic continuity with the river with the hydraulic gradient being in a north westerly direction.

2.5 Summary of Preliminary Pollutant Linkages

A Conceptual Site Model (CSM) was compiled in accordance with BS10175 and CLR11 at the desk study stage. This CSM builds on the ground model by identifying the potential sources, receptors and pathways.

For there to be an environmental liability, there must be a source i.e. something capable of causing pollution or harm, a receptor and a viable pathway between them i.e. a pollutant linkage. If one of these elements is missing, there can be no significant risk. If all are present, then the magnitude of the risk is a function of the magnitude and mobility of the pollutant, the sensitivity of the receptor and the nature of the migration pathway.

2.5.1 Sources

There is known contamination present in the South area as identified during the 2006 investigation. The North area has been formerly occupied by a works and warehouse, both of which may have led to contamination of the site.

2.5.2 Receptors

Potential receptors include:

- Site users
- Controlled waters – River Roch
- Controlled waters – Groundwater in minor aquifer
- Infrastructure – for example, service pipes / water mains

2.5.3 Pathways

Potential pathways are listed below:

- Direct contact with contaminated soil
- Ingestion of the contaminated soil
- Inhalation of contaminants within the contaminated soil and groundwater
- Vertical and lateral migration of potentially hazardous ground gas.
- Leaching and migration of contaminants into the River Roch and the minor aquifer

2.6 Summary of Geotechnical Considerations

There were no significant hazards relating to ground dissolution, landslide, running sands and shrinking / swelling clays identified at desk study phase from the Envirocheck Report. A moderate hazard with regard to compressible ground was noted for the north western part of the site. It is likely that bearing capacity will be variable across the site due to the variable density of the made ground present.

There are no issues relating to coal mining on this site.

Previous investigations undertaken at the site have encountered artesian conditions which will have implications geotechnically.

The former presence of buildings on the site mean that buried obstructions such as old foundations can be expected.

2.7 Summary of Waste and Sustainability Considerations

During the remediation (if required) and proposed redevelopment of the site, material may need to be removed to landfill. Therefore, consideration will need to be given to the testing of the material for suitability for landfill. Any material to be disposed of off site will need to be assessed to establish the material's acceptability to landfill by comparison with the limiting concentrations within the Landfill Regulations (England and Wales) 2004 and the Landfill (England and Wales) (Amendment) Regulations 2005.

Samples can be submitted for Waste Acceptance Criteria (WAC) analysis (in accordance with testing method BS EN 12457-3) in order to assess the material's acceptability to landfill.

In addition, as of 30th October 2007, all material sent to landfill must be pre-treated prior to disposal and since November 2008 is subject to landfill tax.

2.8 Summary of Safety, Health and Environment Considerations

With respect to the ground investigation, the majority of the site would be classified as YELLOW in accordance with the SISG "Guidance Notes for the Safe Investigation by Drilling of Landfills and Contaminated Land". However, in the areas where hydrocarbon contamination is present or suspected, the classification should be increased to RED.

Site personnel involved with the investigation and subsequent redevelopment works should be appropriately qualified with experience of working on contaminated sites.

Appropriate personal protective equipment should be worn by persons working on site and a reasonable standard of hygiene should be maintained. To eliminate the risk of hand to mouth transfer of potentially harmful material, smoking, eating and drinking should be prohibited within the site area.

The presence of Japanese Knotweed was noted in the South area during the 2006 investigation and this was subsequently treated. A number of areas within the bunded material on this car park showed signs of re-emergence at the time of the 2009 investigation. These areas will be required to be sprayed up to highlight the presence and investigation should not be carried out in these areas.

2.9 Services Information

Service plans showing the location of various services on the site were provided to Mouchel by the client prior to the site works commencing.

The following list outlines the plans that were consulted prior to and during the site investigation:

- United Utilities – Electricity
- United Utilities – Sewers
- United Utilities – Water mains
- Virgin Media
- British Telecommunications
- National Grid - Gas

3 Ground Investigation

3.1 Design Rationale and Scope

The preliminary conceptual site model identified a number of potential pollutant linkages and consideration has been given to which of these are most likely to be 'significant' and the level of detailed information required to prove or disprove this in each case.

Within the South area, trial pits were undertaken to further delineate the extent of the previously identified hydrocarbon contamination as well as to attempt to uncover the source. In addition, one cable percussion borehole was drilled adjacent to the River Roch in a location known to be down the hydraulic gradient. A groundwater / gas monitoring standpipe was installed to aid with determining whether the hydrocarbon contamination was migrating towards and potentially entering the river. Soil samples were taken from the trial pits for subsequent chemical analysis for selected determinands.

Trial pits, cable percussion and rotary cored boreholes were undertaken within the North area in order to investigate the physical and chemical ground conditions in relation to the proposed redevelopment of the site. The boreholes were installed with standpipes to enable monitoring of gas concentrations and flow rates, as well as groundwater depths and flow direction. Subsequent chemical and geotechnical testing was undertaken on samples obtained from the North area area.

Water samples were obtained from the boreholes across the site as well as from three points (upstream, downstream and at the foot of the concrete slipway) from the River Roch to establish the whether the quality of the river water was being impacted by the site.

3.2 Fieldwork

The intrusive investigation was undertaken by Soil Mechanics Ltd in accordance with BS5930:1999 and BS10175:2001 between 12th and 22nd May 2009, and was designed and monitored full time by Mouchel. Soil Mechanics are competent contractors and are an approved supplier under the Mouchel Quality Management System. Method statements were supplied by Soil Mechanics Ltd for approval prior to the works commencing on site.

The investigation comprised exploratory holes as summarised in the table below. The location of the exploratory holes from the 2009 investigation as well as those undertaken in 2006 is shown on Figure 2 of this report.

Table 1: Summary of Site Activities

Activity	Date Undertaken	Exploratory Hole Reference	Maximum Depth
Trial Pits – South area	12 th – 18 th May 2009	OS1(A), OS2(A), OS2(B), TP2(A), TP2(B), TP2(C), TP2(D), TPBH2B(A), TPBH2B(B), TPBH2B(C), TP3(A), TP3(B), TP3(C), TP3(D), TP4(A), TP4(B), TP4(C), TP4(D), TP4(E), TP4(F), TPBH4(A), TPBH4(B), TPBH4(C), TPBH4(D), TP5(A), TP5(B), TP5(C)	3.00m
Cable Percussion Boreholes – South area	14 th – 15 th May 2009	BHA, BHAA	8.20m
Trial Pits – North area	19 th – 21 st May 2009	TPA – TPH, TPJ - TPK	4.00m
Cable Percussion Boreholes – North area	15 th – 21 st May 2009	BHB - BHE	7.50m
Rotary Cored Boreholes – North area	19 th – 20 th May 2009	BHD	17.80m

The trial pits excavated within the South area were started from the position of exploratory holes that encountered contamination during the 2006 Mouchel investigation. The trial pits were undertaken as either trenches or as a series of pits extending away from the previous exploratory hole location dependent on the ground conditions especially the inflow of groundwater into the pits. The trial pit references refer to the original exploratory hole reference with an additional alphabetical suffix. The exception are trial pits OS1(A) and OS2(A) – (B), where the 'OS' refers to former oil stores identified on an historical plan of the former bus station that were being investigated by these pits.

The trial pits and borehole locations within the North area were positioned to provide general coverage across this area as there were no features requiring targeting identified during the desk study stage. The trial pit and borehole locations references used during the 2009 investigation of the extended area were alphabetical so that they are not confused with numerical referencing system used during the 2006 investigation. There has been no TPI included as this may be confused with TP1.

BHAA, BHB and BHC have 50mm gas / groundwater standpipes to facilitate post site works monitoring and groundwater sampling. The table below gives details of the gas / groundwater monitoring installations that have been installed during the 2009 investigation as well as the remaining serviceable boreholes from the 2006 investigation.

Table 2: Summary of Gas / Groundwater Monitoring Installations

Exploratory Hole Reference	Size / Type of Installation	Response Zone Stratum	Level of Response Zone (m bgl)	Level of Response Zone (m OD)
BHAA (2009)	50mm Standpipe	Made Ground	1.00 – 4.50	118.57 – 115.07
BHB (2009)	50mm Standpipe	Made Ground	1.00 – 2.50	118.22 – 116.72
BHC (2009)	50mm Standpipe	Made Ground	1.00 – 1.50	118.50 – 117.50
BH1 (2006)	50mm Standpipe	Made Ground / Natural Sand and Gravel	0.60 – 3.60	119.00 – 116.00
BH4 (2006)	50mm Standpipe	Made Ground / Natural Sand and Gravel	1.00 – 4.00	118.64 – 115.64

Appendix B contains the Factual Ground Investigation Report prepared by Soil Mechanics Ltd.

The installations were monitored for gas and groundwater level on a weekly basis for a period of 6 weeks. The dates that the monitoring was carried out on are listed below along with whether groundwater samples were obtained for subsequent analysis.

- 4th June 2009
- 10th June 2009 (plus groundwater sampling)
- 17th June 2009 (plus groundwater sampling)
- 24th June 2009 (plus groundwater sampling)
- 1st July 2009
- 10th July 2009

The gas / groundwater monitoring records are presented as Appendix C of this report.

The boreholes were monitored for methane, carbon dioxide, oxygen, carbon monoxide, hydrogen sulphide, flow rate and atmospheric pressure using a GA2000 infrared gas analyser. Groundwater levels were monitored using a dipmeter.

3.3 Chemical Laboratory Testing

Soil samples were obtained from the trial pits across the site for chemical analysis. A total of 36 no. soil samples were collected from the South area as well as a further 22 no. soil samples from the North area.

Groundwater samples were retrieved from boreholes BHAA, BH1 and BH4 on three occasions during the monitoring period. In addition, samples of water from the River Roch at three locations adjacent to the site were also obtained on three occasions.

The samples obtained were stored in airtight containers which were appropriately labelled, and transported under completed chain of custody documentation to Alcontrol Laboratories of Hawarden, who are an appropriately accredited laboratory for the required analysis and are an approved supplier under the Mouchel Quality Management System.

3.3.1 Soils

The table below describes the suites of chemical analysis that were undertaken on soil samples obtained during the 2009 investigation.

Table 3: Summary of Soils Analysis

Suite Reference	Analysis Suite	No. samples scheduled
Suite 1 – General Soil Suite	Metals (boron, arsenic, cadmium, chromium, hexavalent chromium, copper, lead, mercury, nickel, selenium, zinc), total sulphate, easily liberated sulphide, thiocyanate, free cyanide, total cyanide, total sulphur, pH, total monohydric phenols (speciated phenols – TP4(A) – (F)only), petroleum hydrocarbons (PH, as gasoline range organics, diesel range organics, benzene, toluene, ethylbenzene, xylene other than when hydrocarbon contamination was noted within North area area), speciated 16 polyaromatic hydrocarbons (USEPA), soil organic matter, asbestos screen (extended area only)	30 – Used on samples obtained from the North area as well as from TP4(A) – (F) within the South area.
Suite 2 – Hydrocarbon Solvent Suite	Petroleum hydrocarbons by TPHCWG method with banded C5-C35 aliphatic / aromatic split, benzene, toluene, ethylbenzene, xylenes, speciated 16 polyaromatic hydrocarbons (USEPA), volatile organic compounds (only in vicinity of former paint stores)	36 – Used on samples obtained from the trial pits excavated across the South area.
Suite 3 – Waste Acceptance Criteria Solid Suite	Total organic carbon, loss on ignition, benzene, toluene, ethylbenzene, xylene, mineral oil (C10-C40), total 17 polyaromatic hydrocarbons, pH, acid neutralisation capacity to pH4 and pH6, polychlorinated biphenyls (7 congeners)	Selected samples – 1 from South area and 1 from North area.

The results of the chemical analysis on the soil samples are presented in Appendix D.

3.3.2 Leachate

The table below describes the suites of chemical analysis performed on leachate obtained from the soil samples during the 2009 investigation.

Table 4: Summary of Leachate Analysis

Suite Reference	Analysis Suite	No. samples scheduled
Suite 1 – General Leachate Suite	BS EN 12457-1 2:1 leachate preparation, metals (arsenic, cadmium, chromium, copper, mercury, nickel, lead, selenium, zinc, boron, hexavalent chromium), sulphate, total monohydric phenols, sulphide, thiocyanate, total cyanide, free cyanide, free sulphur, diesel range organics, gasoline range organics, benzene, toluene, ethylbenzene, xylene, speciated 16 polyaromatic hydrocarbons, pH	11 – Samples obtained from the North area only
Suite 2 – Waste Acceptance Criteria Leachate Suite	BS EN 12457-3 2 batch eluate leachate preparation, metals (arsenic, barium, cadmium, chromium, copper, mercury, molybdenum, nickel, lead, antimony, selenium, zinc, boron), chloride, fluoride, sulphate, total dissolved solids, total monohydric phenols, dissolved organic carbon, pH	Selected samples – 1 from South area and 1 from North area.

The results of the chemical analysis on the leachate samples are presented in Appendix D.

3.3.3 Groundwater / Surface Water

Samples of groundwater were retrieved from the three installations within the boreholes drilled during this investigation. In addition, samples were also taken from the two installations that remain in the South area from the 2006 investigation.

Samples of surface water were taken from the River Roch at three locations adjacent to the site boundary.

Table 5 Summary of Groundwater Analysis

Suite Reference	Analysis Suite	No. samples scheduled
Suite 1: - Groundwater Suite	Metals (arsenic, boron, cadmium, chromium, copper, lead, magnesium, nickel, selenium, zinc, mercury, hexavalent chromium), ammonium, sulphate, sulphide, speciated phenols, thiocyanate, total cyanide, free cyanide, chloride, free sulphur, nitrate, pH, petroleum hydrocarbons by TPHCWG method with banded C5-C35 aliphatic / aromatic split, benzene, toluene, ethylbenzene, xylenes, speciated 16 polyaromatic hydrocarbons (USEPA), whole oil analysis (where free product present)	BH1, BH4 and BHAA – on 3 occasions
Suite 2 – Surface Water Suite	Metals (arsenic, boron, cadmium, chromium, copper, lead, nickel, selenium, zinc, mercury, hexavalent chromium), sulphate, speciated phenols, thiocyanate, total cyanide, free cyanide, free sulphur, pH, petroleum hydrocarbons by TPHCWG method with banded C5-C35 aliphatic / aromatic split, benzene, toluene, ethylbenzene, xylenes, speciated 16 polyaromatic hydrocarbons (USEPA)	Upstream, base of slipway and downstream – on 3 occasions

The results of the chemical analysis on the water samples are presented in Appendix D.

3.4 Geotechnical Laboratory Testing

Disturbed and undisturbed soil samples that were representative of the differing strata types present on site were collected from the North area during this investigation. Samples were not obtained from the South area as a geotechnical assessment was completed for this part of the site during the 2006 investigation.

Samples were appropriately labelled and stored on site prior to being transported to Soil Mechanics' geotechnical laboratory for analysis. The geotechnical laboratory is appropriately accredited to undertake the required testing and Soil Mechanics are an approved supplier under the Mouchel Quality Management System.

The table overleaf gives details of the type and number of geotechnical tests that were scheduled.

Table 6: Summary of Geotechnical Laboratory Testing

Geotechnical Test	Test method	No. samples scheduled
Classification/Compaction		
Moisture Content	BS1377: Part 2: 1990; Clause 3	14
Liquid / plastic limits	BS1377: Part 2: 1990	14
Particle size distribution	BS1377: Part 2: 1990; Clause 9	7
Strength / Consolidation		
Undrained triaxial (total) strength	BS1377, (1990) part 7	2
Point Load		12
Unconfined compressive strength		4
1-D oedometer		2
Chemical (tests on soil and groundwater)		
BRE SD1 Suite - Total / water soluble sulphate, pH, Total sulphur, Magnesium, Chloride	TRL Report 447	13
Organic matter content		3

The results of the geotechnical testing undertaken are presented within Soil Mechanics' Factual Report in Appendix B.

4 Ground Model

4.1 Topography and Geomorphology

The whole site comprises level to very slightly sloping ground. There is a slope of approximately 1m from east to west across the site. Within the North area, the part of the site used as a car park by Mecca Bingo is level but is approximately 0.6 – 1.0m higher than the surrounding ground level.

An earth bund is present adjacent to the southern and western boundaries of the South area as well as running north – south across the car park area.

4.2 Geology

The geological sequence within the South area comprised made ground (with significant hydrocarbon contamination in places), overlying alluvium of sand and silt. This is as expected from a review of the site history and previous investigation as well as the published geology and the location of the site adjacent to the river.

Within the North area, the geological sequence comprises made ground overlying alluvium of sand and silt and clay which is further underlain by bedrock of siltstone, sandstone and mudstone. This sequence is as expected from a review of the site history, published geology and the location of the site adjacent to the river.

4.2.1 *Made Ground*

Made ground was encountered within all the exploratory holes excavated across the South area. The surfacing material which was present in all holes except TP OS2(B) and TP2(B), consisted of a gravel hardcore comprising macadam planings, concrete and stone. This material was noted between depths of 0.00m below ground level (bgl) and 0.50m bgl.

There were two types of made ground within this area of the site as expected from the previous investigation: granular and cohesive.

The granular made ground had a sand / gravel matrix with varying quantities of the following constituents: brick, ash, clinker, concrete, wood, slag, floor tiles, sandstone, timber, slate, rope, metal fragments, metal pipework, ceramic, plastic, paving slabs, siltstone and kerbstones. This material was encountered in all holes between depths of 0.00m bgl and 2.60m bgl. There was a hydrocarbon odour and sheen within this material in places across the site but more commonly this seemed to be focused in the southern part of this area.

A clayey made ground which was locally sandy and / or gravelly with brick, sandstone and glass was noted in a number of pits across the site, namely, TPBH4(A), TPHBH4(C), TP2(A), TP2(B), TP4(B), TP5(A), BHA and BHAA at depths of between 0.60m bgl and 4.70m bgl. There was a hydrocarbon odour and sheen in places, commonly in the northern part of this area.

In addition, there were concrete floors, brick walls (old foundations) and sandstone setts bound in tar noted at varying depths across the whole of the this part of the site.

Made ground was encountered in all the exploratory holes excavated across the North area. The surfacing material, where present, comprised macadam and hardcore, which was locally ashy. There was also sandstone flagstones with underlying sand bedding in material noted in one place under the current surfacing material.

Within the western part of this area which is occupied by an office building and associated car parking, the made ground has a sand / gravel matrix with much demolition type material e.g. concrete and brick fragments, sandstone, slate. There was a significant proportion of ash, clinker and coal present within the made ground in this area. There was also a clayey made ground with brick, clinker, sandstone, mudstone and coal encountered between depths of 1.20m bgl and 2.60m bgl in this part of the site. A hydrocarbon odour was also noted within both the granular and cohesive made ground in BHB.

The granular made ground underlying the area used as a car park by Mecca Bingo had a similar general composition but there was a significantly lower ash and clinker content.

Within the north eastern part of this area, the made ground also comprises a sand and gravel matrix but this material visually has a higher proportion of demolition type material with little ash, clinker and coal. It should be noted that buildings were recently demolished (completed by early May 2009) in this area of the site and this is likely to account for the differences in the made ground noted.

The granular made ground also included varying proportions of mudstone, siltstone, metal, wire, charcoal, wood, plastic, ceramic tiles, pottery fragments and glass as well as shoes and a metal fire grate. This strata was encountered at depths of between 0.00m bgl and 2.90m bgl.

4.2.2 Alluvium

The part of the investigation undertaken within the South area was carried out as a supplementary investigation to that undertaken in 2006, in order to delineate the area affected by hydrocarbon contamination. As such, not all holes were extended down into the alluvium.

Where the alluvium was encountered on this part of the site, it comprised layers of sand, silt or clay. The sand was encountered between depths of 0.70m bgl and in excess of 8.20m bgl. In central parts of this area, there was a hydrocarbon odour and sheen noted within the material. The silt was encountered between depths of 1.10m bgl and in excess of 2.80m bgl. There was an isolated area of hydrocarbon odour and sheen noted within TP OS2(A). The clay was encountered between depths of 1.60m bgl and 8.10m bgl. There was an isolated area of hydrocarbon odour and sheen within TPBH4(B) in the central part of this area.

The alluvium beneath the North area was encountered in all the exploratory holes with the exception of TPK which was terminated within the made ground due to the presence of a metal manhole cover at depth. The alluvium comprises layers of varying thickness of sand, silt and clay, although not all types were encountered at each location.

The sand was relatively widespread across this area and was encountered between depths of 1.70m bgl and 4.20m bgl. The silt was only located within BHC, BHE and TPJ at depths of between 2.20m bgl and in excess of 3.50m bgl. This may represent a linear (west – east) trending lens of silt. The clay was located across the site at depths of between 1.0m bgl and 7.30m bgl.

Hydrocarbon odour and staining was noted within the silty alluvium in TPJ.

4.2.3 Coal Measures

Bedrock was not encountered within the South area as part of this investigation. Previously bedrock was noted to occur between depths of 11.50m bgl and 12.20m bgl.

Within the North area, both BHD and BHE were drilled to target the bedrock. Weathered siltstone was encountered at between 7.20m bgl and 7.30m bgl in these holes. BHD was extended into the rock by rotary coring techniques and encountered a sequence of interbedded siltstone, sandstone and mudstone, all of which were considered weak in strength.

4.3 Groundwater

Within the South area, perched groundwater was encountered within the made ground across the site. In the southern part of this area, there does not appear to be a distinct direction of groundwater flow. This appears to be due to the significant amount of underground obstructions such as old floors, walls and foundations. However, within the northern part of this area where there are less underground obstructions to impede groundwater flow the hydraulic gradient appears to be in a northwesterly direction.

With regard to shallow groundwater within the alluvial deposits, this was not encountered within the majority of the trial pits due to the shallow depths they were terminated at. However, where groundwater was noted, this appears to suggest the hydraulic gradient is towards the northwest.

Within the North area, perched water was only noted in the made ground in one hole, TPJ, as a slow seepage at the base of the made ground. Shallow groundwater was present within the alluvium across this area at depths of between 2.60m bgl and 3.50m bgl. The hydraulic gradient appears to be to the northwest.

The deeper groundwater present within the bedrock (minor aquifer) is under considerable pressure as artesian conditions were encountered in both BHD and BHE when the bedrock was reached. Similar conditions were encountered on the South area during the 2006 investigation.

It should also be noted that water was seen to be continually flowing across the surface of the South area from a point on the surface that is in close proximity to one of the rotary boreholes (BH2B) that was grouted up after artesian conditions were encountered during the 2006 investigation. This would suggest that this borehole was not grouted up adequately to seal the hole made and prevent the upwelling of groundwater in this area.

4.4 Chemical Distribution

Heavy metals and polyaromatic hydrocarbon (PAH) concentrations appear to be higher in areas where ash and clinker were noted such as in the north west of the North area.

Petroleum hydrocarbon concentrations are understandably higher in areas where visual and olfactory signs of hydrocarbon such as odours and sheens, were present. Higher concentrations of hydrocarbons were also found in areas where tarmac fragments and planings were noted within the made ground.

Hydrocarbon contamination was most widespread within the South area which was formerly occupied by a bus depot including refuelling facilities.

4.5 Ground Gas

Varying levels of methane, carbon dioxide and oxygen were noted across the site over the 6 weekly monitoring rounds. However, there are no trends apparent relating the concentrations and flow rates to the atmospheric pressure or ground surface conditions at the time of these visits.

5 Human Health Risk Assessment

5.1 Soils

There is the potential for risk to human health to occur on the whole Yelloways development site from contaminated soils.

5.1.1 Methodology

Based on the findings of the Initial Conceptual Site Model and Preliminary Risk Assessment of this site, a Generic Quantitative Risk Assessment for human health has been undertaken and comprises the following:

- Selection of appropriate generic screening values for human health assessment;
- Creation of relevant datasets from which to undertake the assessment;
- Assessment of contamination distribution and comparison of site data to screening values using the mean and maximum value test in accordance with CL:AIRE / CIEH guidance document.
- Assessment of risks to receptors;
- Determination of requirements for further investigation or remediation.

Selection of Soil Screening Values

The previously published Soil Guideline Values (SGV's) have been withdrawn as they no longer reflect the new approach to contaminated land assessment. Currently, there has only been a small number of SGV's published using the new approach. A revised version of the CLEA software has been released by the Environment Agency (CLEA v1.04) along with a handbook which allows practitioners to derive their own Generic Assessment Criteria (GAC's) that follow this updated approach.

Given that the site is to be redeveloped for use as an office building with associated car parking, published SGV's for a commercial / industrial end use derived using the new approach have been used for the initial assessment of the soil results obtained. In the absence of published SGV's, Mouchel have derived GAC's using the updated approach and revised software. A detailed description of the derivation of GAC's by Mouchel has been included in Appendix E.

Creation of Relevant Datasets

In accordance with the published guidance, statistically valid datasets should be used to undertake a 'mean value' and a 'maximum value' test and the normalised upper bound concentrations (95% upper confidence limit) of the arithmetic mean concentration (with the exception of lead) are the used to determine whether the concentrations exceed the relevant screening value for planning purposes.

Although the whole site area will be redeveloped for a common end use, for screening purposes the site has been split into the South area and the North area. This decision was based on the former uses of the site with the North area being formerly occupied by warehouses, works and a church while the South area was previously mills then a bus depot. Also, the made ground in each of these areas appears to be different in terms of composition.

In addition, the results were split into made ground and natural deposits within each of the two areas.

Assessment

Screening tables displaying the results of the 'mean value' and 'maximum value' tests for each dataset have been produced and are presented in Appendix F.

The assessment of the South area incorporates the chemical analysis undertaken during the 2006 investigation with those obtained during this investigation.

With regard to non-detects, these have been included within the dataset at the value of the method detection limit.

In relation to outliers, when these are present within a dataset, a check was made of the field records i.e. logs, to determine the presence of something that may be contributing to the value obtained. Unless it was determined that the outlier is the result of a reporting error or represents a part of a separate dataset, the value will remain within the dataset for assessment.

As the site is to be redeveloped, the purpose of the assessment is to determine whether there is a 95% probability that the true population mean falls below the critical concentration e.g. screening value, that the site is 'clean' and suitable for use.

5.1.2 *Summary of Results*

South Area

Assessment has been undertaken of the samples obtained from the made ground and natural deposits in the South area.

Within both the made ground and the natural deposits, there are no determinands where the 95% UCL exceeds the screening value. However, there is a potential chromium hotspot associated with the made ground at TP2.

North Area

Assessment has been undertaken of the samples obtained from the made ground and natural deposits at the North area.

The table below summarises the contaminants of concern i.e. those where the 95% UCL exceeds the screening value.

Table 7: Summary Exceedances Table for North area Area – Made Ground

Determinant	Screening value (mg/kg)	Range of concentrations (mg/kg)	Normalised 95% UCL of mean (mg/kg)	Location and depth of outliers, if present
Benzo[a]pyrene	14.41	0.02 - 210	37.57	None present

Within the natural deposits, there are no determinands where the 95% UCL exceeds the screening value.

5.1.3 *Discussion / Conclusions*

The assessment shows that there is a potential risk to human health from benzo(a)pyrene within the made ground of the North area. Benzo(a)pyrene concentrations failed the mean value test with no outliers present, therefore, there is a contamination issue across the whole of the North area rather than being related to isolated hotspots of contamination.

5.2 Ground Gas

5.2.1 Methodology

A ground gas risk assessment has been undertaken in general accordance with CIRIA document C665:2007, "Assessing Risks Posed By Hazardous Ground Gases To Buildings". Our assessment comprises the following:

- Review of results;
- Calculation of Gas Screening Values for methane (CH₄) and carbon dioxide (CO₂)
- Assessment of risks from ground gas
- Development options (if required).

5.2.2 Review of Field Data

Methane, carbon dioxide, oxygen, hydrogen sulphide and carbon monoxide were monitored for on six occasions on a weekly basis following the completion of the site works. A GA 2000 infrared gas analyser was used to undertake the monitoring. The gas analyser is fully calibrated and also has an internal flow pod to measure any gas flow present.

Atmospheric pressure ranged from 999mb to 1017mb across the monitoring visits, with both rising and falling pressure trends in the days preceding the visits. It should be noted that none of the monitoring visits were undertaken under worst case conditions of pressure below 999mb and falling.

The table below summarises the range of concentrations detected during the monitoring visits. The full monitoring records are presented in Appendix C.

Table 8: Gas Monitoring Summary

BH Ref	Methane %	Carbon Dioxide %	Oxygen %	Carbon Monoxide ppm	Hydrogen Sulphide ppm	Flow Rate l/hr
1	0.0 – 0.2	0.2 – 0.7	0.6 – 10.9	All 0	All 0	-4.5 – 4.2
4	0.0 – 0.1	1.8 – 2.6	12.8 – 17.8	All 0	All 0	-0.2 – 0
AA	All 0	0.5 – 4.6	4.4 – 17.7	All 0	All 0	-0.1 – 0
B	All 0	2.2 - 9.7	8.8 – 19.3	All 0	All 0	-0.4 – 0
C	All 0	0.2 – 2.7	16.5 - 21	All 0	All 0	0 – 0.1

5.2.3 Calculation of Gas Screening Values

The gas monitoring data obtained during the weekly visits has been used to give a semi-quantitative estimate of risk for the site. The characterisation process employs the maximum concentrations and flow rates to generate Gas Screening Values (GSV's). A characteristic situation classification is then given using the Modified Wilson and Card Classification to assess the likely protection measures required depending on the level of risk identified. This information is crucial in providing proposals for any necessary remedial options.

The Gas Screening Values are presented in the following tables and have been calculated using the data from the six monitoring rounds.

Table 9: Gas Screening Value for Methane

Location	Highest measured CH ₄ concentration (%)	Flow Rate (l/h)	GSV	Risk Classification	Characteristic situation
1	0.2	4.2	0.84	Moderate	3
4	0.1	0	0	Very low	1
AA	0	0	0	Very low	1
B	0	0	0	Very low	1
C	0	0.1	0	Very low	1

Table 10 Gas Screening Value for Carbon Dioxide

Location	Highest measured CO ₂ concentration (%)	Flow Rate (l/h)	GSV	Risk Classification	Characteristic situation
1	0.7	4.2	2.94	Moderate	3
4	2.6	0	0	Very low	1
AA	4.6	0	0	Very low	1
B	9.7	0	0	Very low	1
C	2.7	0.1	0.27	Low	2

5.2.4 Assessment of oxygen (O₂), carbon monoxide (CO) and hydrogen sulphide (H₂S)

EH40/2005 Workplace Exposure Limits (HSE 2005) has been used to assess the risk to human health from carbon monoxide (CO), hydrogen sulphide (H₂S) and oxygen (O₂). The exposure limits relate to conditions in a workplace and therefore are not directly applicable to soil gas concentrations. However they can be used to identify which gases do not present a risk and which may require further assessment and are particularly relevant when considering the risks to a commercial/industrial development. A summary of the gas concentrations recorded during the six rounds of monitoring and the assessment criteria are presented in Table 8 above, and are assessed in the table below.

Table 11: Summary O₂, CO and H₂S Results and Assessment Criteria

Parameter	Minimum Recorded Value	Maximum Recorded Value	8-hour TWA exposure limit	15-minute exposure limit	Minimum concentration (Mines & Quarries Act)
Oxygen	0.6%	21%	n/a	n/a	19%
Carbon Monoxide	All 0 ppm		30ppm	200ppm	n/a
Hydrogen Sulphide	All 0 ppm		5ppm	10ppm	n/a

5.2.5 Discussion

From the assessment of the gas monitoring results, it can be seen that the made ground on the site is producing carbon dioxide and on occasions, flow is present.

Although it should be noted that the assessment is conservative as it employs the maximum gas concentrations and flow rate, it has indicated that gas protection measures would be required as the site has been classified as Characteristic Situation 3. This requires the following protection measures for a commercial building:

- Reinforced concrete cast in situ floor slab (suspended, non suspended or raft) with at least 1200g damp proof membrane (DPM), or
- Beam and block or pre cast concrete slab and minimum 2000g DPM / reinforced membrane, plus

- All joints and penetrations sealed,
- Proprietary gas resistant membrane and passively ventilated or positively pressurised underfloor subspace with monitoring facility.

It should be noted that the building may contain undercroft car parking areas. These protection measures would not be required in these areas as the occupied building floor area would not be in contact with or close to the gassing ground.

5.2.6 Conclusions

Based on the findings above, there is a potential pollutant linkage with regard to gas risk and protective measures may be required as part of the construction of the buildings.

5.3 Other Risks to Human Health

With regard to water mains, organic contamination can permeate water main pipes and lead to the contamination of drinking water on sites. In this case, organic contamination is present across the site at concentrations above the action levels provided by United Utilities in the 'Task Instruction: Pipe Material Selection for Contaminated Land'. As such, it is likely that specialist water mains pipework will be required. In addition, there may be the need for clean trench backfill material due to the presence of arsenic.

6 Controlled Waters Risk Assessment

6.1 Methodology

Based on the Preliminary Risk Assessment and Ground Model for this site, a Tier 1 Screening Assessment has been undertaken in general accordance with Environment Agency guidance Remedial Targets Methodology, Hydrogeological Risk Assessment for Land Contamination, 2006.

The methodology comprises:

- identification of potential pollutant linkages;
- selection of appropriate generic screening values for controlled waters;
- screening measured concentrations of soil leachate and groundwater against the generic screening values;
- assessment of contaminant distribution and risk to receptors;
- identification of contaminants of concern and relevant pollutant linkages;
- identification of potential contaminants and pollutant linkages which are no longer of concern.

Where measurements have been taken on site, these will be referred to in m bgl. However, for modelling purposes such as calculating hydraulic gradient, these measurements have been converted to m AOD.

6.1.1 *Identification of Potential Pollutant Linkages*

The preliminary risk assessment for the site identified potential pollution linkages relating to controlled waters, namely the risk to the River Roch from the leaching and migration of contaminants present on site. Perched water was encountered from 0.3m bgl, probably associated with underground structures, however the main shallow aquifer was identified between 1.7 and 2.2m bgl, locally in the made ground, but mainly associated with the sand alluvium layer. The groundwater within the predominantly sand alluvium is in continuity with the river and therefore was not considered separately. Within the Coal Measures stratum the groundwater is artesian with a clay aquitard (alluvium / possibly glacial till, largely impermeable) between this groundwater body and that of the sand and gravel alluvium. Thus, given its confined, artesian status it was not considered as at risk from shallow groundwater contamination.

We have therefore defined the geology as comprising a granular made ground unsaturated zone (sandy limestone hardcore, gravelly sand of brick, slag, ash and clinker) and granular silty SAND alluvium with some gravel, locally sandy gravel, saturated zone below. The base of this aquifer is determined by the alluvial / till clay aquitard comprising firm dark brown locally laminated clay.

6.1.2 Selection of Generic Screening Values

The soil leachate results from both areas of the site as well as groundwater samples obtained from the South area have been screened against Environmental Quality Standards (EQS) where available, to assess the risk to the River Roch. Where EQS were not available, EQS values from other countries such as Canada or UK drinking water standards have been used in their place.

6.1.3 Screening

Screening tables have been produced for the Tier 1 assessment of both the soil leachate and the groundwater samples. These tables are presented in Appendix G of this report. A summary of the exceedences of the screening values are included in the table below.

Table 12: Soil Leachate Exceedences – Whole Site

Determinant	Screening Value (µg/l)	Range of Concentrations (µg/l)	Number of Exceedences	Location of Exceedences
Copper	6	1.6 - 553	13 / 18	TPA 1.8m, TPB 0.5m, TPC 1.0m, TPD 1.5m, TPE 1.0m, TPF 0.5m, TPG 1.5m, TPK 1.8m, BHE 0.8m, TP1 0.5m, TP2 1.6m, TP3 0.7m, TP5 1.4m
Selenium	1	<1 - 7	6 / 18	TPA 1.8m, TPC 1.0m, TPD 1.5m, TPE 1.0m, TP5 1.4m, TP6 1.5m
Sulphate	400,000	8000 – 1,300,000	7 / 18	TPC 1.0m, TPD 1.5m, TPE 1.0m, TPF 0.5m, TPG 1.5m, TPJ 2.2m, TP6 0.5m
pH	<6 - >9	7.36 – 10.67	2 / 18	TPF 0.5m, TPK 1.8m
Gasoline Range Organics (C4-C12)	10	<10 - 570	4 / 11	TPC 1.0m, TPE 1.0m, TPF 0.5m, TPK 1.8m
PH – Aliphatics C21 – C35	10	<10 - 16	1 / 9	TP1 0.5m
PH – Aromatic C12-C16	10	<10 - 159	2 / 9	TP2 1.6m, TP3 0.7m
PH – Aromatic C16-C21	10	<10 - 87	2 / 9	TP2 1.6m, TP3 0.7m
Anthracene	0.012	<0.01 – 0.512	9 / 18	TPE 1.0m, TPF 0.5m, TPJ 2.2m, TPK 1.8m, TP1 0.5m, TP2 1.6m, TP3 0.7m, TP5 1.4m, TP6 1.5m
Benzo(a)anthracene	0.018	<0.01 – 0.099	5 / 18	TPB 0.5m, TP1 0.5m, TP3 0.7m, TP5 1.4m, TP6 1.5m
Benzo(a)pyrene	0.015	<0.009 – 0.045	4 / 18	TPB 0.5m, TP3 0.7m, TP5 1.4m, TP6 1.5m
Fluoranthene	0.04	<0.01 – 1.13	7 / 18	TPB 0.5m, TPF 0.5m, TPH 0.6m, TPJ 2.2m, TP3 0.7m, TP5 1.4m, TP6 1.5m
Pyrene	0.025	<0.01 – 1.423	9 / 18	TPB 0.5m, TPF 0.5m, TPH 0.6m, TPJ 2.2m, TP1 0.5m, TP2 1.6m, TP3 0.7m, TP5 1.4m, TP6 1.5m

Table 13: Groundwater Exceedences – South area Only

Determinant	Screening Value (µg/l)	Range of Concentrations (µg/l)	Number of Exceedences	Location of Exceedences
Selenium	1	<1 - 2	2/9	BH4, BHAA
Ammonium	1,000	600 – 5,100	2 / 3	BH1, BHAA
Anthracene	0.012	0.14 - 400	9 / 9	BH1, BH4, BHAA
Benzo(a)anthracene	0.018	0.26 - 75	9 / 9	BH1, BH4, BHAA
Benzo(a)pyrene	0.015	0.32 - 48	9 / 9	BH1, BH4, BHAA
Fluoranthene	0.04	0.74 - 170	9 / 9	BH1, BH4, BHAA
Fluorene	3	0.077 - 610	4 / 9	BH1, BH4, BHAA
Phenanthrene	0.4	0.38 - 810	8 / 9	BH1, BH4, BHAA
Pyrene	0.025	0.74 - 310	9 / 9	BH1, BH4, BHAA
Acenaphthene	5.8	0.046 - 270	2 / 9	BH4
Naphthalene	10	<0.1 - 170	2 / 9	BH4, BHAA
Gasoline Range Organics (C4-C12)	10	<10 – 28,000	2 / 9	BH4
Aliphatic C5-C6	10	<10 - 62	2 / 9	BH4
Aliphatic C6-C8	10	<10 – 1,700	2 / 9	BH4
Aliphatic C8-C10	10	<10 – 4,100	2 / 9	BH4
Aliphatic C10-C12	10	<10 – 6,400	2 / 9	BH4
Aliphatic C12-C16	10	<10 – 990,000	3 / 9	BH4
Aliphatic C16-C21	10	<10 – 1,100,000	3 / 9	BH4
Aliphatic C21-C35	10	<10 – 370,000	3 / 9	BH4
Aromatic C8-C10	10	<10 – 6,200	2 / 9	BH4
Aromatic C10-C12	10	<10 – 9,600	2 / 9	BH4
Aromatic C12-C16	10	<10 – 54,000	3 / 9	BH4
Aromatic C16-C21	10	<10 – 140,000	4 / 9	BH4, BHAA
Aromatic C21-C35	10	<10 – 120,000	4 / 9	BH4, BHAA

6.1.4 Contaminant Distributions and Risk to Receptors

Leachable PAH's have been identified above the relevant screening values across the whole of the site. These are likely to be due to the presence of ash and hydrocarbon contamination within the made ground and in some places, the natural alluvium.

With regard to petroleum hydrocarbons (PH), the analysis indicates that these are variable when it comes to leachability. There are areas of relatively high soil petroleum hydrocarbons concentrations that are not producing elevated concentrations within the leachate however; there are areas with lower soil concentrations that are producing elevated leachate concentrations. The concentrations in the groundwater onsite are far higher than those within the soil leachate which suggests that direct migration of hydrocarbon into the groundwater is the more prevalent process rather than by leaching from the soil, a conclusion reached in both 2006 and 2009. This is borne out by the presence of free product on the surface of the water table (BH4), and sheens in 2006 within TP3, TP5 and TP7. This was observed during the 2006 investigation and lead to the current investigation, to identify whether tanks or other structures were leaking hydrocarbons directly into the groundwater, rather than concentrations leaching from soil.

Both PAH and petroleum hydrocarbon contamination at elevated levels have been detected in the borehole down the predicted hydraulic gradient immediately adjacent to the river (BHAA).

6.1.5 Identification of Contaminants of Concern and Relevant Pollutant Linkages

The Tier 1 screening of the soil leachate and groundwater results has indicated that there is a potential for pollutant linkages to exist with regard to the following contaminants of concern entering the River Roch.

Soil Leachate Contaminants of Concern

- Copper – Whole site
- Selenium – North area (isolated within one trial pit)
- Sulphate – North area plus isolated with South area
- pH – Isolated within two parts of North area
- Gasoline Range Organics (C4-C12) – North area
- Petroleum Hydrocarbon – Aliphatic C21-C35 – South area (isolated to one trial pit)
- Petroleum Hydrocarbon – Aromatic C12-C16 – Isolated within two parts of South area
- Petroleum Hydrocarbon – Aromatic C16-C21 - Isolated within two locations within the South area

- Anthracene – Whole site
- Benzo(a)anthracene – western part of South area plus isolated within one trial pit in North area
- Benzo(a)pyrene - western part of South area plus isolated within one trial pit in North area
- Fluoranthene – North area and western part of South area
- Pyrene – Whole site

Groundwater Contaminants of Concern

It should be noted that groundwater has only been assessed from the South area as no groundwater was present to be sampled from the installations within the North site area.

- Ammonium – Whole South area
- Anthracene – Whole South area
- Benzo(a)anthracene – Whole South area
- Benzo(a)pyrene – Whole South area
- Fluoranthene – Whole South Area
- Fluorene – Whole South Area
- Phenanthrene – Whole South Area
- Pyrene – Whole South Area
- Acenaphthene – Central part of South Area only
- Napthalene – Central part of South area and downgradient adjacent to river
- Gasoline Range Organics (C4-C12) – Central part of South area only
- Petroleum Hydrocarbon – Aliphatic C5-C6 – Central part of South area only
- Petroleum Hydrocarbon – Aliphatic C6-C8 – Central part of South area only
- Petroleum Hydrocarbon – Aliphatic C8-C10 – Central part of South area only

- Petroleum Hydrocarbon – Aliphatic C10-C12 – Central part of South area only
- Petroleum Hydrocarbon – Aliphatic C12-C16 – Central part of South area only
- Petroleum Hydrocarbon – Aliphatic C16-C21 – Central part of South area only
- Petroleum Hydrocarbon – Aliphatic C21-C35 – Central part of South area only
- Petroleum Hydrocarbon – Aromatic C8-C10 – Central part of South area only
- Petroleum Hydrocarbon – Aromatic C10-C12 – Central part of South area only
- Petroleum Hydrocarbon – Aromatic C12-C16 – Central part of South area only
- Petroleum Hydrocarbon – Aromatic C16-C21 – Central part of South area and downgradient adjacent to river
- Petroleum Hydrocarbon – Aromatic C21-C35 – Central part of South area and downgradient adjacent to river

6.1.6 Identification of Potential Contaminants and Pollutant Linkages which are no Longer of Concern

There is not considered to be the potential for a pollutant linkage to exist with regard to controlled waters from the following contaminants:

- Arsenic
- Boron
- Cadmium
- Chromium
- Lead
- Nickel

- Zinc
- Mercury
- Nitrate
- Chloride
- Benzene
- Toluene
- Ethylbenzene
- Xylene
- Petroleum Hydrocarbon– Aromatic C6-C7
- Petroleum Hydrocarbon – Aromatic C7-C8
- Acenaphthylene
- Benzo(b)fluoranthene
- Benzo(ghi)perylene
- Benzo(k)fluoranthene
- Chrysene
- Dibenzo(ah)anthracene
- Indeno(123cd)pyrene

As such, these determinands have been excluded from further study.

6.2 Tier 2 and Tier 3 Risk Assessment

6.2.1 Soil and Groundwater Assessment Methodology

The P20 methodology assumes at Tier 1 that the compliance point for soil contaminants is pore water. Thus the soil contaminant concentration is partitioned to pore waters as dissolved phase contamination and these are compared to the chosen water target value (in this case EQS).

At Tier 2, the assumption is that the pore water will be leached by infiltrating rainfall to the water table and will be diluted, with no attenuation or degradation occurring. The now diluted pore water concentration is compared again to the chosen water target value.

In the case of groundwater samples at Tier 2; these are directly compared against the chosen water target value.

Tier 3 for both groundwater samples and soil samples requires taking the calculated diluted concentrations (soils) and the sampled groundwater concentrations and migrating the concentrations to a chosen compliance point. During migration, attenuation and dispersion is considered. Dependant on the level of information for the site, degradation may be considered.

Each tier of the model calculates a Remedial Target Value (RTV) for soil or groundwater. Soil RTVs are calculated for Tiers 2 and 3 of the model. Groundwater RTVs are calculated for Tier 3 only.

Contaminants, which exceed Tier 3 RTVs, pose a risk for water resources; however in some cases travel times are excessive. For many contaminants, although the RTV is exceeded, the attenuation and retardation that occurs, means that degradation will occur before this contaminant can reach the compliance point. For those contaminants that will migrate readily, the response is then to consider additional modelling using more site-specific data, or consider remediation options that will remove the source or block the pathway.

6.2.2 Groundwater Flow and Directions

During the original investigation in 2006, mean water levels obtained during site works and four monitoring rounds in June 2006, were plotted using SURFER (see August 2006 report, Report Reference: 760140/R/02C). For the assessment of impaction on the River Roch these results were modelled from the alluvial deposits. Perched water in the made ground is present but is assumed to be in hydraulic conductivity with the sand alluvial deposits.

The following exploratory hole and river (R) water levels were used:

TP1 – 118.1 mAOD	TP8 – 117.26 mAOD
BH1 – 117.6 mAOD	TP9 – 117.24 mAOD
TP3 – 118.54 mAOD	R1 – 118.03 mAOD
BH4 – 117.84 mAOD	R2 – 118.07mAOD
TP7 – 118.11 mAOD	R3 – 116.16 mAOD

In addition to these water levels, an assessment was made of the maximum water level for TP4. Water was not encountered within this pit; however the pit was not of a significant depth. Therefore the deepest point excavated to during the site investigation and the point at which water had still not been encountered in the trial pit was used (116.68m AOD).

Other exploratory holes were not included in the contouring exercise because it could not be ensured that they were natural groundwater levels and they were more likely to be perched levels resulting from subsurface structures. The shallow groundwater level at BH3 was also removed from the data set as it was unusually high and could indicate a degree of influence of the upwards hydraulic gradient from the artesian groundwater at depth or conversely, could be as a result of the leakages emanating from the temporary pipework supplying the porta-cabins that were present in the contractors enclosure in the east of the South area, adjacent to BH3. These leaks were clearly visible during the site works in 2006 and were causing water to pond on the surface of the site within the compound area.

The SURFER plots modelled during the 2006 works showed that the shallow groundwater appears to be flowing towards the north, north west, away from the river running along the south of the site and towards the stretch of the river that passes the north west corner of the site.

The observed flow pattern would suggest that the natural alluvium (sands) below the site are in hydraulic continuity with the River Roch and that a proportion of the baseflow from the river is cutting off the bend in the river and instead of flowing around the site and over the weir, is flowing under the site. Assuming this to be the case, the baseflow water from the river appears to be crossing into the site boundary from the river at approximately the eastern side of TP1 and flowing towards TP8, from the south towards the north/northwest. This would also correlate with the observations in TP9 that the inflowing water was entering the trial pit only from the southwestern corner.

Hydraulic gradients could then be calculated from the groundwater contours using SURFER. An overall average gradient of 0.042 was chosen.

6.2.3 *Plume Dimensions*

The majority of the soil in the South area showed organic contamination in varying amounts. Therefore the majority of the South area was considered as a soil plume for the soil leachate calculations. The plume was therefore considered to include as its boundaries; Slack Street to the north, the east side of Milton Street forming the eastern boundary, and the River to the south. TP1 and BH2, 2A, 2B were not identified as contaminated, and thus this corner of the site was removed for consideration, as far as the weir. The River Roch to the north of the weir forms the western boundary. This provides a soil source area of 2,914m².

Based on both current and 2006 data, the shallow groundwater contamination spatial pattern was not clear. Since the EA guidance discusses ‘core plumes’ for dimensions, the ‘core’ soil plumes were used as indicators of groundwater contamination. Two plumes were identified; one encompassing BH4, TP5, TPBH4A, TPBH4B, TPBH4C, TPBH4D, TP5A, TP5B and TP5C, and the second encompassing TP2, TP3, TP3A, TP3B, TP3D and TP2B. The first plume is approximately 25m by 25m, and the second 20m by 23m. For the Tier 3 groundwater assessment, a plume of 625m² was considered with its edge approximately 12m from the river. BHAA was noted to be contaminated and is adjacent to the weir. Risk assessment was not undertaken on this hole as it is assumed that this source will have to be removed due to the close proximity to the river.

6.2.4 Site Specific Assessment

It was assumed that the made ground contaminants from the site could leach vertically downward into the sand alluvium and migrate laterally via the groundwater to the River Roch.

To assess the risk, soil properties for both the made ground and alluvium were collated as well as the chemical properties of the individual CoCs. The justified data pertaining to the physical properties used within the model are presented in the table below.

Table 14: Groundwater Risk Assessment Soil Parameters

Required Data	Notation	Value	Justification
Made Ground Water filled porosity	θ_w	0.260	Calculated from site specific moisture content and bulk density
Made Ground Air filled porosity	θ_a	0.154	Calculated from site specific moisture content and bulk density
Made Ground Dry Bulk Density	ρ g/cm ³	1.63	Measured value
Alluvium Effective porosity	n	0.2	Literature value. Should be less than total porosity. Site specific total porosity 0.302
Alluvium Dry Bulk Density	ρ g/cm ³	1.94	Measured value
Alluvium Saturated Aquifer Thickness	d_a m	2.05	Average of top of water table to top of aquitard clay (1.87 to 2.17m)
Alluvium Hydraulic Conductivity	K m/d	0.031	Site Specific values using Hazens Law on site specific particle size distribution results
Alluvium Hydraulic Gradient	i	0.042	Site Specific values from water level contours
Alluvium	Mz	2.05	Model calculated (thickness of aquifer)

Required Data	Notation	Value	Justification
Mixing Zone Depth	m		
Infiltration	Inf m/d	0.001743	MORECs Effective Rainfall 1984-2003 yearly average (636.2mm/yr)

The made ground and sand alluvium from a selection of boreholes was analysed for moisture content and bulk density. Therefore this was used to calculate water filled porosity. Based on this value, a voids ratio could be calculated to obtain air filled porosity. The total porosity was calculated as 0.414 for the made ground and 0.302 for the sand alluvium. An estimate was made for effective porosity (porosity discounting blind pore spaces), based on the site description of silty medium to coarse SAND with some gravel.

Hazen's Law was applied to the results of the particle size distribution test results from the alluvial sand deposits to obtain an average hydraulic conductivity of $3.6 \times 10^{-7} \text{m/s}$ (0.031m/d). A literature value for the drift deposits would be expected to be between 5×10^{-4} and $9 \times 10^{-7} \text{m/s}$, which correlates with the site results for this lithology.

Infiltration figures were obtained from the Meteorological Office. The 20 year average effective rainfall (infiltration) for MORECS square 98 was 636.2mm/year.

6.2.5 Chemical Parameter Justifications

Chemical parameters, where possible were obtained from UK sources. For organic contaminants the organic carbon partition coefficient (Koc) and dimensionless Henry's Law constant were required. Decay constants for the identified CoC's are not known. A site specific value for fraction of organic carbon (foc) was used (0.011 for sand alluvium). For inorganic contaminants, the soil water partition coefficient (Kd) is required.

The EQS values were obtained from the latest Statutory Instrument for Surface Waters (1998, SI Number 389), then where not available the previous Statutory Instrument (1992, SI number 337), and if these were not available for the CoC, a more conservative UK drinking water standard, or Canadian aquatic life guideline value was used. The hardness data of 76mg/ for the River Roch was obtained from the Environment Agency website, therefore a hardness screening value of >50-100mg/l was used for the hardness related metals. Based on biological monitoring data from the Environment Agency website the River Roch is assumed to be suitable for cyprinid (coarse) fish only.

Table 15: Summary of Chemical Data

Contaminant	Screening Values			Henry's Law Dimensionless	Koc (l/kg)	Kd (l/kg)
	EQS	Other	Source			
	(mg/l)	(mg/l)				
Selenium		0.001	CCME 2007	N/A	N/A	50
Copper	0.006			N/A	N/A	127
Ammonium		1.0	Freshwater fish Directive (l)	N/A	N/A	3.2
Cyanide	0.001*	0.05	DWS SI 3184, 2000	N/A	N/A	9.9
Phenol		0.004	CCME 2007	0.00000835	83.18	-
Anthracene		0.000012	CCME 2007	0.0016	29512.09	-
Acenaphthene		0.0058	CCME 2007	0.00492	7079.46	-
Benzo(a)pyrene		0.000015	CCME 2007	0.00000176	128824.96	-
Benzo(a)anthracene		0.000018	CCME 2007	0.0000316	77624.72	-
Fluoranthene		0.00004	CCME 2007	0.0000629	18197.01	-
Pyrene		0.000025	CCME 2007	0.0000564	16218.10	-
Fluorene		0.003	CCME 2007	0.000000031	13803.84	-
Naphthalene	0.01			0.00662	645.65	-
Phenanthrene		0.0004	CCME 2007	0.00131	22908.68	-
Aliphatic >C5-6**		0.01	DWS SI 1147, 1989	33	794.33	-
Aliphatic >C6-8**		0.01	DWS SI 1147, 1989	50	3981.07	-
Aliphatic >C8-10**		0.01	DWS SI 1147, 1989	80	31622.78	-
Aliphatic >10-12**		0.01	DWS SI 1147, 1989	120	251188.64	-
Aliphatic >C12-16**		0.01	DWS SI 1147, 1989	520	5011872.34	-
Aliphatic >c16-21**		0.01	DWS SI 1147, 1989	4,900	630957344.5	-
Aliphatic >C21-35**		0.01	DWS SI 1147, 1989	4900	630957344.5	-
Aromatic >C8-10**		0.01	DWS SI 1147, 1989	0.48	1584.89	-
Aromatic >C10-12**		0.01	DWS SI 1147, 1989	0.14	2511.89	-
Aromatic >C12-C16**	-	0.01	DWS SI 1147, 1989	0.053	5011.87	-
Aromatic >C16-C21**	-	0.01	DWS SI 1147, 1989	0.013	15848.93	-
Aromatic >C21-C35**		0.01	DWS SI 1147, 1989	0.00067	125892.54	-

* Proposed EQS - R&D Technical Summary PS310

** DWS for 'total dissolved and emulsified hydrocarbons' – applicable to totals but used also for individual fractions.

6.2.6 *Model Data*

For the Tier 3 soil and groundwater assessment, the Ogata-Banks equation was used. This is the Environment Agency's preferred analytical solution for calculating Tier 3 remedial targets where the aquifer is reasonably homogeneous.

Dispersion estimates were based on Xu & Eckstein. Dispersion refers to the in situ mixing that results as a groundwater flows through a soil. Dispersion results in the three-dimensional spreading of the dissolved contaminants, but does not affect the total dissolved mass of contaminants present. Dissolved concentrations from the leading edge of the plume generally decrease as the chemical moves away from the source.

The three main factors determining dispersion are varying pore size, tortuosity and friction within the pore spaces.

A number of approaches exist for determining dispersivity. Xu & Eckstein (1995) was used, as the model has received greater statistical analysis. Xu & Eckstein has slightly increased longitudinal dispersion and slightly less vertical & transverse dispersivity, thus providing worst-case chronic exposure estimates at the point of exposure.

For hydrocarbons, 1D vertical dispersion is used, as these are primarily dissolved light non-aqueous phase liquid (LNAPLs) and will remain close to the top of the water table. For all other contaminants, 2D vertical dispersion was used.

6.3 Remedial Target Values

The soil calculations obtained from the 'new P20' spreadsheets provide at each tier the theoretical soil concentration at the source which allows the EQS at each tier to be met, and using the soil concentration, the calculated water concentration.

For waters at tier 3, the concentration at the compliance point is calculated from the plume concentrations. For this assessment the plume core concentration was deemed to be the maximum groundwater concentration for that contaminant. For the soil, the maximum soil concentration is utilised from plume 1 and plume 2. Figure 3 shows the location and extent of the plumes.

Additionally for those contaminants that exceed the EQS at the compliance point, the time to impact can be calculated to see if the probability that the potential risk will occur is realistic.

The 'new P20' spreadsheets and the results of the Tier 3 screening for soils are presented in Appendix H and I respectively.

Table 16: Tier 3 Soil and Groundwater Remedial Target Values

CoC	RTV Soil (mg/kg)	RTV water (µg/l)	Travel Time to Roch (years)
Selenium	0.0513	1.04	2450
Cyanide	0.0103	1.04	490
Copper	0.762	6.26	6800
Ammonium	3.41	1040	162
Acenaphthene	0.463	5.8	3820
Benzo(a)pyrene	0.0217	0.015	69600
Benzo(a)anthracene	0.0157	0.018	41800
Anthracene	0.00399	0.012	15900
Fluorene	0.466	3.00	7450
Naphthalene	0.0741	10.0	353
Phenanthrene	0.103	0.40	12300
Fluoranthene	0.0082	0.040	9800
Pyrene	0.00457	0.025	8720
Phenols	0.00431	4.0	49.9
PH Aliphatics (EC5-6)	0.118	10	433
PH Aliphatics (EC6-8)	0.49	10	2150
PH Aliphatics (EC8-10)	3.62	10	17100
PH Aliphatics (EC10-12)	28.4	10	135000
PH Aliphatics (EC12-16)	564	10	2700000
PH Aliphatics (EC16-35)	71000	10	3400
PH Aromatics (ECEC8-10)	0.18	10	857
PH Aromatics (EC10-12)	0.284	10	1360
PH Aromatics (EC12-16)	0.565	10	2700
PH Aromatics (EC16-21)	1.78	10	8530
PH Aromatics (EC21-35)	14.20	10	67600

** Travel time in excess of 500 years – degradation is likely to have occurred within that time*

The Tier 3 screening values in the above table and the reassessment of the soil results in Appendix I indicate that there are likely to be risks to groundwater posed by the presence of elevated concentrations of cyanide, ammonium, naphthalene, phenols and the aliphatic EC5-EC6 petroleum hydrocarbon fraction. Other hydrocarbons identified were of lower solubility and therefore are unlikely to migrate within the next 500 years.

The transport of the metals is limited by the hydrochemical conditions (pH, redox) in the groundwater. Precipitation or co-precipitation of the metals as the dominating process in the aquifer is not considered in the P20 calculations. RTVs calculated for metals are therefore likely to be conservative. Similarly biodegradation of hydrocarbons is not considered and again the RTV's will be conservative; anything with a travel time in excess of 500 years is likely to degrade before reaching the river and as such, has not been screened.

6.4 Remedial Target Values - Discussion

Both PAH and PH contamination at elevated levels has been detected in the borehole down the predicted hydraulic gradient immediately adjacent to the river (BHAA). BHAA was noted to be contaminated and is adjacent to the river. Risk assessment was not undertaken on this exploratory hole location as it is assumed that this source will have to be removed due to its proximity to the river. Although the hydrocarbons may undergo degradation and be of low solubility, a preferential pathway at this distance cannot be ruled out.

The results in the above table 16 indicate that there are likely to be risks to groundwater posed by the presence of elevated concentrations of cyanide, ammonium, naphthalene, phenols and the aliphatic EC5-EC6 petroleum hydrocarbon fraction. Other hydrocarbons identified were of lower solubility and therefore are unlikely to migrate across the site within the next 500 years. The travel time was based on the river being only 12m from the plume.

However, both the 2006 and 2009 investigation noted that soil and soil leachate could not account for the contaminant loading within the groundwater. The concentrations found within the groundwater are higher than would be expected, and thus the source for much of the dissolved phase contamination is not the unsaturated soil zone. It therefore seems more likely that the source of the shallow groundwater contamination is not the unsaturated made ground. The 2006 investigation noted Gasoline Range Hydrocarbons, however the 2009 investigation has characterised the hydrocarbons as being weathered and degraded diesel/diesel residues.

The 2009 investigation therefore was conducted to try and find the source of the contamination. Considering the historic use of the site, possible explanations for such a source were considered to be an underground storage tank or something smaller such as an interceptor within the old drainage system that was not cleared out when the bus station was demolished. Although brick and concrete structures were observed, no tanks were encountered although free product was noted in the soil in the vicinity of one of the former oil / fuel stores. It is therefore likely that contamination is relatively immobile, and has pooled in certain areas due to the remains of below ground foundations etc.

Although it is considered that much of the hydrocarbon contamination towards the centre of the site is unlikely to impact the river under current conditions, any redevelopment may form preferential pathways. There are also aesthetic issues during flood events, when hydrocarbons may be floated to ground level and possible impact on site services. Therefore organic contamination remediation is required which will deal with not only the phenols and the naphthalene, but also with the elevated areas of PH in the two plumes and around BH AA.

7 Geotechnical Assessment

Geotechnical 'characteristic' parameters used for the design works have been derived from:

- The results of geotechnical laboratory testing,
- Atterberg Limit results and their published correlations of Plasticity Index and effective angle of shearing resistance (BS 8002), and
- Standard Penetration Test 'N' values and published correlations for undrained shear strength (c_u), Co-efficient of volume compressibility (m_v) and drained and undrained angle of shearing resistance (for non-cohesive soils)

Where no field or laboratory data was available, geotechnical parameters were estimated from published reference data.

7.1 Made Ground

Made ground was encountered at the surface in all exploratory holes to depths of between 0.4m to 4.7m below ground level and comprised sandy, silty gravel and gravelly clay with cobbles and occasional boulders. The material included limestone, sandstone, hardcore, cobbles, stone setts, tarmac, concrete, brick, timber, coal, glass, metal, pottery, ash, slag and clinker, and was frequently oily. The remains of former foundations were also noted in some trial pits (e.g. concrete slab) and boreholes BH2A and BH2B were terminated at 2.00m bgl on an unknown obstruction and 0.10m bgl on a concrete obstruction respectively.

In borehole BHE, a 1.00m thick layer of very soft slightly gravelly sandy silt was encountered within the made ground at 1.60m below ground level.

Twelve standard penetration tests (SPT) recorded 'N' values from 2 to 50 blows for 300 mm penetration, with an average value of 18. Two tests recording blows of 50 reached refusal (on cobbles or a boulder of brick) whereby the test was stopped before full penetration was achieved due to a high blow count. However, the unit is also described as soft, very soft and uncompacted in places.

Due to the variable nature of the deposit, this stratum is considered to have a low bearing capacity and to be unsuitable for spread foundations sensitive to settlement. Therefore soil parameters are not presented other than a representative bulk unit weight of 18kN/m^3 .

7.2 Alluvial Sand

7.2.1 Description

Sand was generally encountered beneath the made ground across most of the site varying in thickness between 0.20m and 2.40m.

In the South area, sand was also encountered as a layer on top of the bedrock up to 2.30m thick. This material was often silty and was shown to comprise 48% silt in BH3 in a sample at 9.50m to 9.95m depth.

An organic odour was noted within some of the upper layers in TPs 4, 7, 8, 9.

7.2.2 Classification

The plot of the Particle Size Distribution curve results obtained for the sand / sandy gravel is shown in the chart below, inspection of which shows the following typical proportions:

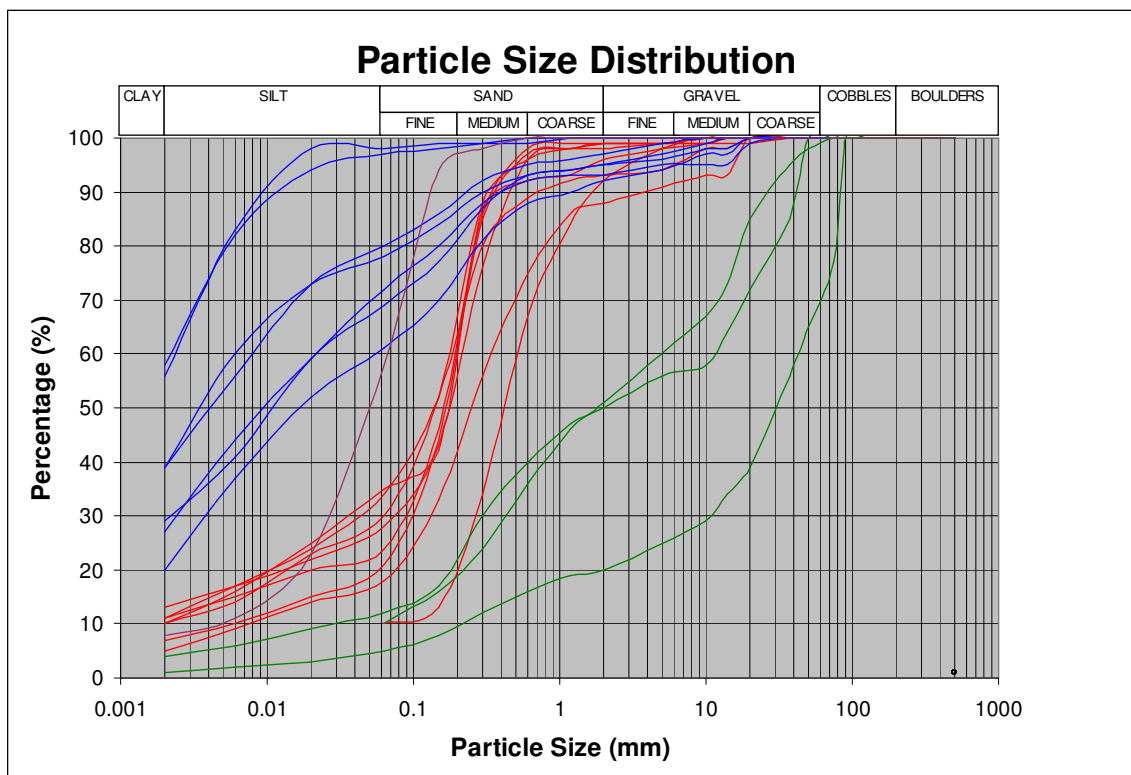
Silt & Clay 10 to 58% Average 29%

Sand 42 to 82% Average 67%

Gravel 0 to 12% Average 4%

Cobbles 0%

The soil may therefore be classified as a silty to very silty, slightly gravelly, sand (BS5930:1999).



Clay ——— Sand ——— Sandy gravel ——— Lower silty sand ———

7.2.3 Moisture Contents

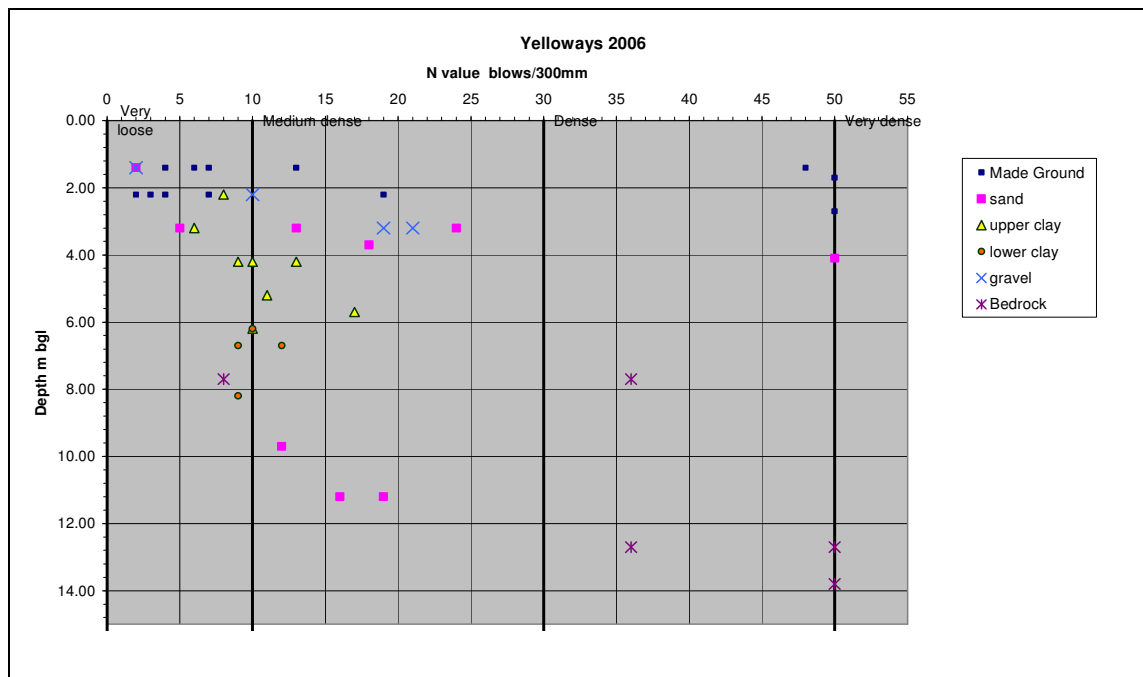
Moisture content ranged from 9.7% to 31% with an average of 22.8%.

7.2.4 SPT 'N' Values

Thirteen standard penetration tests (SPT) recorded a broad scatter of SPT 'N' values from 2 (where the material was very silty) to 50 (refusal) blows for 300 mm penetration, with an average value of 18. The chart below presents the results.

SPT N value corrections for rods, overburden, etc were not used on the basis that if they were corrected then the characteristic SPT N value would result in an over conservative characteristic value being taken through to the geotechnical design stage

It is recommended from the above, that a representative SPT N value of 15 is adopted.



7.2.5 CBR Tests

CBR tests carried out in the laboratory on seven samples of gravelly sand from depths of between 0.5m and 1.2m, gave results of between 0.24% (at 24% moisture content) and 44% (at 11% moisture content) with an average of 19.9%.

7.2.6 Angle of Shearing Resistance

The particle size distribution tests undertaken recorded variable grading classifications. In accordance with Table 3 of BS 8002:1994 'Code of Practice for Earth retaining structures', BSI, London a critical state angle of shearing resistance of 33° (30°+0+2) is recommended.

Based on this an angle of shearing resistance of 32° should be adopted as an overall design value for this stratum.

A summary of the geotechnical parameters along with the selected characteristic parameters of the material is presented in the table below.

Table 17: Summary of Characteristic Geotechnical Parameters – Alluvial Sand

Properties	Min	Max	Mean	No. of Tests	Characteristic Value / Classification
Bulk unit weight (KN/m ³)	-	-	-	-	18 above water table 20 below water table
Natural Moisture Content (%)	9.7	31	22.8	7	23
SPT 'N' Value (blows per 300mm)	2	50	18	9	15
CBR(%)	0.24	44	19.9	7	4
Critical Internal Angle of Friction (derived in accordance with BS 8002:1994) (degrees)	-	-	-	-	32

7.3 Alluvial Gravel

7.3.1 Description

Sandy gravel was encountered within four of the boreholes and one trial pit beneath a thin layer of the alluvial sand. The material was generally described as medium dense dark grey and brown slightly silty and silty sandy subrounded fine, medium and coarse gravel, or sand and gravel. In borehole BH1 the description includes with many cobbles. The gravel thickness ranged from 0.80m to 2.50m.

7.3.2 Classification

The plot of the three particle size distribution curve results obtained for the sandy gravel is shown in the chart in Section 7.2.2, inspection of which shows the following typical proportions:

Silt & Clay 5 to 12% Average 9%

Sand 15 to 41% Average 31%

Gravel 45 to 50% Average 47%

Cobbles 0%

The soil may therefore be classified as slightly silty, slightly sandy to sandy gravel (BS5930:1999). However, it should be noted that a description of the material has indicated the presence of cobbles.

7.3.3 Moisture Content

Moisture content measured in two samples was 17%.

7.3.4 SPT 'N' Values

Three standard penetration tests (SPT) recorded values from 10 to 21 with an average of 17. A value of 2 was obtained for another test at the top of this stratum at a depth which coincided with a groundwater strike and is therefore likely to have been influenced by the loosening effect of the water. This result has therefore been excluded from further analysis.

Results indicate a general increase with depth. However, due to the small amount of results a single value is considered appropriate for design purposes.

The chart in Section 7.2.4 above presents the results.

SPT N value corrections for rods, overburden, etc were not used on the basis that if they were corrected then the characteristic SPT N value would result in an over conservative characteristic value being taken through to the geotechnical design stage.

It is recommended from the above, that a representative SPT N value of 17 is adopted.

7.3.5 Angle of Shearing Resistance

The particle size distribution tests undertaken recorded variable grading classifications. In accordance with Table 3 of BS 8002:1994 'Code of Practice for Earth retaining structures', BSI, London a critical state angle of shearing resistance of 33° ($30^\circ + 1 + 2$) is recommended.

Based on this an angle of shearing resistance of 33° should be adopted as an overall design value for this stratum.

A summary of the geotechnical parameters along with the selected characteristic parameters of the material is presented in the table below.

Table 18 Summary of Characteristic Geotechnical Parameters – Alluvial Gravel

Properties	Min	Max	Mean	No. of Tests	Characteristic Value / Classification
Bulk unit weight (KN/m ³)	-	-	-	-	18 above water table 20 below water table
Natural Moisture Content (%)	17	17	17	2	17
SPT 'N' Value (blows per 300mm)	10	21	17	3	17
Critical Internal Angle of Friction (derived in accordance with BS 8002:1994) (degrees)	-	-	-	-	33

7.4 Alluvial Clay

7.4.1 Description

Clay was encountered within all boreholes at depths of between 1m and 4.2m below ground level with thickness ranging between 0.2m and 7.2m.

The stratum can generally be split into two layers. The upper layer of the clay stratum is described as very soft, soft to firm, firm and stiff, brown slightly gravelly clay and was, between 0.2m and 3.6m thick. This material is also often described as organic and sometimes as silt. The lower clay, between 0.8m and 4.4m thick, are described as soft to firm, firm and stiff thinly laminated slightly sandy slightly gravelly clay.

7.4.2 Classification

The plot of the Particle Size Distribution curve results obtained for the alluvial clay is shown in the chart in Section 7.2.2 above, inspection of which shows the following typical proportions:

Silt & Clay 61 to 98% Average 41%

Sand 2 to 31% Average 17%

Gravel 0 to 8% Average 4%

Cobbles 0%

The soil may therefore be classified as slightly sandy, slightly gravelly clay (BS5930:1999).

7.4.3 Atterberg Limits

Plasticity index and liquid limit values indicate the upper clay to be generally low to intermediate plasticity.

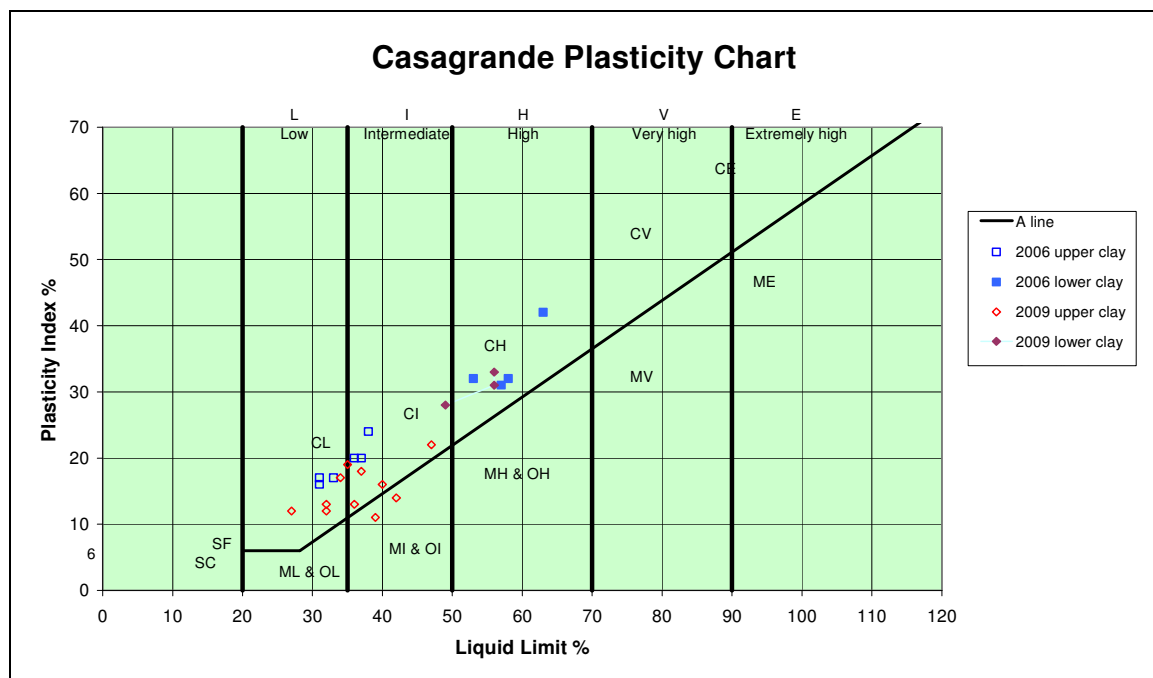
Plasticity index values for the upper clay range between 11 and 24% with an average of 16.5% and a moderately conservative design value of 18%.

The lower clay is shown to be generally intermediate to high plasticity with plasticity index values ranging between 28 and 42% with an average of 33% and a moderately conservative design value of 35%.

Two samples of the upper clay plot just below the A-line as silts or organic clays.

Two samples of the upper clay plot just below the A-line as silts or organic clays.

The liquid limit and the plasticity index are plotted on a plasticity chart shown below.



7.4.4 Moisture Content

The moisture content results generally indicate a decrease with depth.

Moisture content values for the upper clay ranged between 15% and 42% with an average of 26%.

Moisture content values for the lower clay ranged between 22% and 35% with an average of 30%.

7.4.5 SPT 'N' Values

Eight standard penetration tests (SPT) undertaken within the upper clay recorded general increase of SPT 'N' values with depth from 6 to 17 blows for 300 mm penetration, with an average value of 11.

It is recommended from the above, that a characteristic SPT N value design line $x = 1.778y - 1.533$ is adopted for the upper clay where $x = N$ value and $y = \text{depth}$.

The chart in Section 7.2.4 above presents the results.

Four standard penetration tests (SPT) undertaken within the lower clay recorded a narrow scatter of results with no noticeable increase with depth. Values ranged between 9 to 12 blows for 300 mm penetration, with an average value of 10. It is recommended from the above, that a characteristic SPT N value of 10 is adopted for the lower clay.

SPT N value corrections for rods, overburden, etc were not used on the basis that if they were corrected then the characteristic SPT N value would result in an over conservative characteristic value being taken through to the geotechnical design stage.

7.4.6 Shear Strength Properties

Undrained shear strength has been measured in the laboratory by triaxial test. Seven tests on the upper clay gave results ranging between 56 and 98 kN/m² with an average of 77kN/m².

Adopting the relationship between undrained shear strength and Standard Penetration Test N Value (N) using the empiricism $C_u = 5.5 \cdot N$ (after Stroud and Butler 1975) values ranging between 33 and 94kN/m² were obtained with an average of 58kN/m².

A combination plot of the above results indicates an increase in undrained shear strength with depth according to the equation;

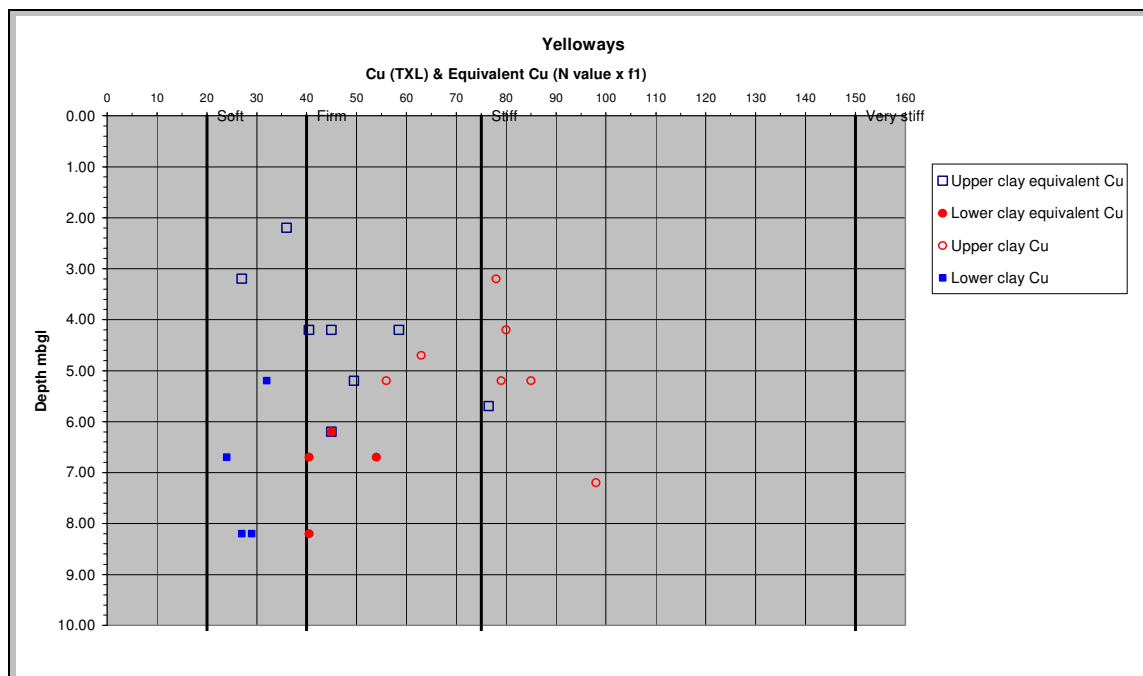
$$x = 7.14y + 32.9 \text{ where } x = C_u \text{ (kN/m}^2\text{) and } y = \text{depth (m).}$$

Four tests on the lower clay gave results ranging between 24 and 32 kN/m² with an average of 28kN/m².

Adopting the relationship between undrained shear strength and Standard Penetration Test N Value (N) using the empiricism $C_u = 4.5 \cdot N$ (after Stroud and Butler 1975) values ranging between 41 and 54kN/m² were obtained with an average of 45kN/m².

The results show a general scatter with no apparent increase with depth.

Using the method described in EC7 and the above results a characteristic value of 31kN/m^2 is obtained and is recommended for design purposes. The chart below presents the results.



7.4.7 Consolidation Tests

Two laboratory oedometer consolidation tests undertaken on samples of the base of the upper clay were undertaken.

Values of the coefficient of volume compressibility m_v of 0.16 and $0.17\text{m}^2/\text{MN}$ were obtained for the upper clay over the stress range p_o to $p_o+100\text{kN/m}^2$.

No tests were undertaken on the lower clay. From the plasticity results and published relationships a value of $0.2\text{m}^2/\text{MN}$ is considered appropriate for design purposes.

7.4.8 Angle of Shearing Resistance

Based on the characteristic value of plasticity index derived above, a design effective angle of shearing resistance of 30° is recommended for the upper clay.

Based on the characteristic value of plasticity index for the lower clay of 31% , a design effective angle of shearing resistance of 25° is recommended for the lower clay.

7.4.9 Bulk Unit Weight

Values of bulk unit weight have been derived from the results of triaxial compression tests and published values including those in BS 8002.

A summary of the geotechnical parameters along with the selected characteristic parameters of alluvial clay is presented in the table below.

Table 19: Summary of Characteristic Geotechnical Parameters – Upper Alluvial Clay

Properties	Min	Max	Mean	No. of Tests	Characteristic Value / Classification
Bulk unit weight (KN/m ³)	-	-	-	-	19
Natural Moisture Content (%)	15	42	26	20	-
Plastic Limit (%)	14	28	19	17	-
Liquid Limit (%)	27	47	35	20	low to intermediate compressibility
Plasticity Index (%)	11	24	16.5	17	18
Plasticity Classification (CL, CI, CH, ML, MI, MH etc)	CL	CI			CL-CI
Liquidity Index (%)	0	1.27	-	-	-
SPT 'N' Value (blows per 300mm)	6	17	11	8	$x = 1.778y - 1.533$ x = N value y = depth
Laboratory Undrained Shear Strength Cu (kPa)	56	96	77	7	$x = 7.14y + 32.9$ x = Cu (kN/m ²) y = depth (m)
Consolidation (Oedometer) (m ² /MN) (Range p _o to p _o + 100kN/m ²)	0.16	0.17	-	-	-
Angle of Friction (derived from plasticity index) (degrees)	-	-	-	-	30

Table 20: Summary of Characteristic Geotechnical Parameters – Lower Alluvial Clay

Properties	Min	Max	Mean	No. of Tests	Characteristic Value / Classification
Bulk unit weight (KN/m ³)	-	-	-	-	18
Natural Moisture Content (%)	22	35	30	8	-
Plastic Limit (%)	21	26	23	7	-
Liquid Limit (%)	49	63	56	7	Intermediate to high compressibility
Plasticity Index (%)	28	42	33	7	35
Plasticity Classification (CL, CI, CH, ML, MI, MH etc)	CI	CH	CI to CH		
Liquidity Index (%)	0.038	0.375	-	-	-
SPT 'N' Value (blows per 300mm)	9	12	10	4	10
Laboratory Undrained Shear Strength Cu (kPa)	41	54	45	4	31
Consolidation (Oedometer) (m ² /MN)	-	-	-	-	0.3
Angle of Friction (derived from plasticity index) (degrees)	-	-	-	-	25

7.5 Bedrock

7.5.1 Description

Bedrock comprising weathered sandstone or mudstone was encountered in BH2B and BH3A at 12.2m and 11.5m depth respectively (107.57 and 108.74 mOD) in the south area. In the North area rock comprising siltstone and mudstone was encountered in BHD and BHE at shallower depths of 7.3m and 7.2m depth respectively (112.40 and 112.10 mOD). The material was highly to completely weathered at rock head. The sandstone is described as weak to strong, the mudstone weak to extremely weak and the siltstone as extremely to very weak. The recovered material was generally non-intact.

Five SPTs in the rock recorded N-values generally ranging between 36 at the top of the bedrock to values in excess 50 blows for less than 300 mm penetration. One SPT recorded a value of 8 blows within the top of the rock stratum in extremely weak siltstone.

Interbedded moderately strong sandstone and weak to very weak mudstones was encountered in BH2B. In BH3A, moderately weak to weak sandstone and weak to very weak mudstone was encountered.

The rock was cored to a maximum depth of 19.5m (100.27mOD) with solid core recovery of between 0% and 67%, and a maximum of 5% RQD (Rock Quality Designation).

No laboratory tests have been undertaken in the bedrock. Unconfined compressive strength and point load tests could not be undertaken due to the poor condition of the material. Moderately conservative design parameters have been presented in the table below for the bedrock below the significantly weathered very weak upper layers.

Table 21: Summary of Characteristic Geotechnical Parameters – Bedrock

Material	Bulk unit weight (KN/m ³)	Unconfined compressive strength (MPa)
Mudstone / siltstone	20	1
Sandstone	22	12.5

7.6 Groundwater Impact

Perched groundwater was encountered at a number of locations within the made ground from 0.3m depth. Deeper groundwater was encountered within natural strata generally as slight to fast inflow, at depths of between 1.1m and 11.0m below ground level. The groundwater flow direction is generally from the south east to the north west across the site where groundwater in continuity with the river crosses the site between the site boundaries adjacent to the river.

Artesian groundwater was encountered within the bedrock at rock head in boreholes BHA, BH1, BH4 and BHE. Boreholes BH2B and BH3A were terminated upon encountering a granular layer believed to be above the bedrock in order to avoid the artesian groundwater. The water level in BHE rose to 0.5m above ground level during boring.

Installations within boreholes BH1 (3.6m depth within made ground and gravelly sand) and BH4 (4.0m depth within made ground and gravel / sand) have recorded water levels of between 2.13m and 2.14m bgl (average 117.46mOD, BH1) and between 1.70m and 1.84m bgl (average 117.84mOD, BH4).

For preliminary design purposes, a groundwater level of 1m bgl is recommended for shallow excavations within the superficial deposits and an artesian piezometric level within the rock.

Groundwater control measures will be required for excavations. Sump pumping is likely to be suitable for shallow excavations.

7.7 Aggressive Ground Soil Chemistry

Chemical testing was carried out on a total of 19 samples in accordance with BRE Special Digest 1, 2005 'Concrete in Aggressive Ground'.

The testing was carried out in accordance with the requirements of a brownfield suite as follows; total and soluble sulphate content, soluble chloride content, soluble magnesium content, soluble nitrate content, soluble ammonia content and elemental sulphur content. The range of results is presented in the table below.

Table 22: Summary of Results of BRE Special Digest 1 Chemical Testing for Concrete Classification

Chemical Test	Value	
	Minimum	Maximum
pH	6.6	10.3
Soluble Sulphate (mg/l)	23	3.800
Total Sulphate BRE (%)	0.005	0.694
Total Sulphur (%)	0.01	0.54
Soluble Magnesium (mg/l)	1.0	36.1
Soluble Nitrate (mg/l)	0.2	55.6
Soluble Chloride (mg/l)	4.0	93

The aggressiveness of the chemical environment with respect to buried concrete has been assessed in accordance with BRE Special Digest 1 – Concrete in Aggressive Ground, 2005. Characteristic values of 2524mg/l for soluble sulphate, 6.76 for pH, 26.8mg/l for soluble magnesium and 1.19% for total potential sulphur have been determined. Oxidisable sulphides have also been determined; the results ranged from 0.175% to 1.434%.

Based on the soluble sulphate results, the sulphate classification for the foundation soils is DS-3. A significant number of samples contain oxidisable sulphides greater than 0.3% indicating pyrite to be present, therefore the sulphate classification has also been determined based on total potential sulphate. The sulphate classification based on total potential sulphate for the foundation soils is DS-3.

The design sulphate classification for the foundation soils is DS-3. The Aggressive Chemical Environment for Concrete (ACEC) classification for the site, assuming mobile groundwater is AC-3.

8 Land Contamination Risks and Remediation Requirements

8.1 Revised Conceptual Model

Based on the findings of the human health and controlled waters risk assessments, the conceptual model remains unchanged from that displayed as Figure 5 within the Desk Study Report.

8.2 Discounted Pollutant Linkages

Of the potential pollutant linkages identified in Section 2.5 of this report, only that relating to pollution of the minor aquifer can be discounted. This is due to the presence of artesian pressures which mean that downward migration of contaminants into the aquifer is likely to be prevented by the upward movement of the aquifer water.

8.3 Remaining Potential Pollutant Linkages

The following potential pollutant linkages have been proven to exist on the site:

- Site users of the proposed offices / car parking are at risk from direct contact, ingestion and inhalation of soil containing concentrations of benzo(a)pyrene which pose a risk to human health – Remediation is likely to be required.
- Site users of the proposed offices are at risk from the migration of potentially hazardous ground gas – Protective measures recommended.
- The River Roch is at risk from migration of contaminants including cyanide, ammonium, phenols, naphthalene and petroleum hydrocarbons (aliphatic EC5-EC6) – Remediation is likely to be required.
- Infrastructure such as water mains and foundations is at risk from contaminants within the soil / groundwater on site – specialist concrete and pipework recommended.

8.4 Remediation Requirements

8.4.1 Human Health – Soils

Within the North area, benzo(a)pyrene is present at concentrations that pose a risk to human health given the proposed end use of office buildings with associated car parking. However, the presence of hardstanding (both the building and car park surfacing material) will remove the pathway as the main exposure contributions relate to direct soil ingestion and dermal contact.

Clean cover material is likely to be required in areas of landscaping.

8.4.2 Human Health – Ground Gas

Assessment of the ground gas and flow readings obtained during the monitoring period have identified that there is a risk to human health from ground gas.

The following protection measures are likely to be required as part of the building construction where the building floor will be in contact with the gassing ground:

- Reinforced concrete cast in situ floor slab (suspended, non-suspended or raft) with at least 1,200g damp proof membrane (DPM), or
- Beam and block or pre cast concrete slab and minimum 2,000g DPM / reinforced membrane, plus
- Proprietary gas resistant membrane and passively ventilated or positively pressurised underfloor subspace with monitoring facility.

It should be noted that the building may contain undercroft car parking and as such, these gas protection measures would not be required in these areas.

8.4.3 Controlled Waters

There is site wide soil contamination comprising cyanide, phenols, naphthalene and aliphatic EC5-EC6 petroleum hydrocarbons that poses a risk to the River Roch via leaching and migration within the groundwater. The cyanide contamination is isolated to one localised part of the South area.

There are a number of remedial options that would be potentially suitable:

- **Soil Washing** – This method is suitable for soil contamination only and would treat the cyanide, naphthalene and petroleum hydrocarbon contamination. The soil is ‘washed’ to separate out the fines (<63µm) which the contamination has adhered to. The material would require excavation prior to treatment and the fines would require disposal. This treatment is only cost effective where treatment volumes exceed 5,000 to 10,000m³. There may not be enough material on the site requiring treatment to make this a cost effective solution and the plant required to undertake this treatment takes up a relatively large area. There is a need for a mobile plant licence from the Environment Agency to undertake this treatment.
- **Excavation and Disposal** – The contaminated material could be excavated and disposed of off site at a suitably licensed landfill facility. This option is not considered to be sustainable due to the need to send otherwise treatable material to a landfill and then the requirement for clean backfilling material to be provided. In addition, some of the material is likely to be deemed hazardous waste and may not be suitable for landfilling; therefore requiring another disposal route such as incineration.
- **Monitored Natural Attenuation** – This option would treat the organic contamination but not the cyanide. It could be applied to the contaminated soils that are situated away from the boundary but would not be suitable for those located adjacent to the river. It is not possible to guarantee that contaminants would not reach the river via preferential pathways. This is not considered to be a suitable remedial option.
- **Ex Situ Bioremediation** – Biopiles would be suitable to treat the organic contamination but not the cyanide. Soil is excavated and formed into linear heaps (biopiles) then nutrients and / or engineered bacteria plus air are introduced which allow for the growth of bacteria which consume the contamination. The treatment method works well when there is a coarser, granular fraction which is the case for the material on this site. There may be an issue regarding the surface area that is required to carry out this treatment (each biopile would be approximately 5 – 10m wide and 15 – 30m long) as well as the length of time needed (approximately 12 weeks).

- **In Situ Bioremediation** – This technique works both above and below the water table. Nutrients are added to enhance the natural bioactivity and / or there can be the addition of engineered bacteria. For use below the water table, it is common to add the nutrients / bacteria to boreholes installed up gradient allowing them to pass through the site via the groundwater before being pumped from down gradient wells and then recirculated. However, given the proximity of the river, river water may enter the extraction boreholes so this option would require sheet piling around the river boundary to prevent extraction of river water.
- **In Situ Vacuum Extraction** – This remedial method would treat the organic contamination but not cyanide. Dual vacuum extraction could be employed to strip / vacuum extract volatiles from the soil as well as pumping and skimming of free product present on the water table. This technique is known to work well in granular soils as are present on this site. Generally an impermeable site surface is required but this site may be suitable despite having granular capping material. The treatment time is likely to be in the order of 15 to 20 weeks and a mobile plant licence would from the Environment Agency be required to undertake this type of remediation. This technique is often employed to remediate former fuel stations.
- **Thermal Desorption** – This technique works well on granular soils but can only be employed on unsaturated material i.e. that taken from above the water table. The material is excavated, treated by being exposed to heat and then can be used to backfill the excavated area. A mobile plant licence from the Environment Agency is required and this treatment would only be viable with a large amount of material to be treated.
- **Containment** – Sheet piling around the site could be used to ‘contain’ the contamination and prevent it from entering the river. The piles would be installed into the underlying clay. However, this would interfere with the flow of water across the site. Should the artesian aquifer be breached, the contained site could fill up with deep groundwater. This method could be used as a temporary measure to allow another remediation technique to be employed such as in situ bioremediation.

- **Permeable Reactive Barriers** – A permeable reactive barrier prevents or reduces the contaminant migration whilst still allowing groundwater to flow through the barrier. The reactive materials either immobilise or transform pollutants, such that the treated groundwater down gradient of the barrier should not pose an unacceptable risk to the river. The most common design of permeable reactive barrier are ‘funnel and gate’ and ‘continuous’ barriers. ‘Funnel and gate’ permeable reactive barriers comprise impermeable walls, such as sheet piles and slurry walls, which direct the contaminated groundwater towards a ‘gate(s)’ that contain the reactive material. ‘Continuous’ permeable reactive barriers transect the pollutant plume flowpath with an unbroken wall of permeable materials that are combined with reactive materials. For example, a pea gravel and reagent filled trench that is constructed across the groundwater flow direction. A continuous barrier would be the better option for this site. This method would treat all the contaminants requiring remediation.

It is likely that the most suitable option for this site would be the combination of a continuous permeable reactive barrier and dual vacuum extraction as it is able to both treat the free product and work with the groundwater flow at the site to remediate the hydrocarbon contamination. Ex situ bioremediation may also be an option dependent upon whether the soil treatment would be able to achieve the remedial target values. However; this would have to be confirmed by a detailed options appraisal and consultation with a remediation contractor, bearing in mind the complexities of the site with the proximity of the River Roch, the artesian water conditions and the presence of Japanese Knotweed.

8.5 Combined Human Health and Controlled Waters Remediation Strategy

The following remedial works are recommended at this site:

- Clean fill materials to be used in landscaping areas.
- Incorporation of gas protection measures into the building should the final design include building floor slabs being in contact with the gassing ground.
- Remediation of the soil and groundwater using a combined approach of permeable reactive barrier and dual vacuum extraction.

It should be noted that regulator approval of the remediation strategy would be required as well as post remediation validation.

8.6 Sustainability and Waste Management Considerations

8.6.1 Design

The design of the remedial works should be one that minimises the amount of material that requires disposing of off site to landfill. The two methods suggested would negate the need to remove and dispose of large amounts of material off site other than the arisings from the excavation of the trench for the permeable reactive barrier.

8.6.2 Reuse of Materials on Site

Should the proposed remedial techniques be employed the material could remain in situ on site.

8.6.3 Waste Classification

The made ground and natural materials in both the North and South areas have been assessed to determine whether they would be classed as hazardous waste. The results of this assessment are presented in Appendix J.

Waste classification was undertaken by comparison of the soil analysis results with the hazardous waste threshold concentrations in accordance with published guidance and the risk phrases as provided by the Approved Supply List (8th Edition).

The material's acceptability to landfill has also been established by comparison of Waste Acceptance Criteria (WAC) test results with the concentrations within the Landfill Regulations (England and Wales) 2004 and the Landfill (England and Wales)(Amendment) Regulations 2005.

The purpose of the chemical testing is to establish whether the material contains dangerous substances at a concentration that would classify the material as 'hazardous'. For classification purposes of hazardous properties, potential worst case substances are assumed in line with Environment Agency guidance. For example, cadmium is assumed to be cadmium oxide or hydroxide rather than cadmium sulphate. The metal concentrations are converted to represent the most hazardous metal species, as the actual metal species is not known. The substances are then compared against the hazardous waste threshold limits for the fourteen hazardous properties.

Some of the material within the made ground in the vicinity of BHE on the North area is considered to be hazardous due to the presence of ecotoxic concentrations of zinc.

Within the South area, the made ground is considered to be hazardous in the following areas:

- TP2 at 0.4m – Carcinogenic and mutagenic concentrations of chromium.

- TP4 at 1.6m – Carcinogenic concentrations of diesel.

The material in the natural deposits in the vicinity of TP5 at 1.4m is considered to be hazardous due to ecotoxic concentrations of zinc.

One WAC test was undertaken on material from both the North and South areas. This indicated that the material in the North area would be suitable for acceptance to landfill, however, that from the South area may not be due to the high total organic content of the material.

It should be noted that the WAC analysis was completed on discreet soil samples taken from a point on the site rather than a composite sample of material to be disposed of.

9 Geotechnical Design

9.1 Foundation Analysis and Recommendations

It is understood that the proposed development is a Municipal Office Building which is likely to comprise two linked buildings of between 7 and 9 storeys constructed from a concrete frame with pre-stressed concrete floor slabs. There may be undercroft parking at existing ground level and offices will start on the first floor. Ground source heat pumps and a biomass boiler may be used.

The findings of the ground investigation will require further review to enable detailed design once the proposed construction details are confirmed.

Due to the variable nature of the made ground, inclusion of deleterious matter, and variable consistency / degree of compaction this stratum is considered not to represent a suitable founding stratum for any structures with significant imposed loads or those sensitive to settlement. Therefore, the main structures proposed are likely to require deep foundations in the form of basement rafts with thickened beams between columns founded on the deeper soils or with piled foundations.

The construction of piles can create pathways for contamination migration from made ground in to the underlying bedrock. The good practice guidance provided by the Environment Agency (Environment Agency 2001) on piling should be adhered to.

Lightly loaded structures with generous settlement tolerances such as small control rooms may be suitable for adoption of shallow spread foundations placed within the made ground.

The possible presence of former foundations, basements, underground tanks or vehicle maintenance pits should be considered when designing a suitable foundation technique. It may be necessary to locate these structures using techniques such as ground penetrating radar.

9.1.1 *Piled Foundations*

Consideration could be given to utilising piled foundations to transfer the structural load down to the bedrock beneath the made ground and soft, compressible soils. The carrying capacity would be provided by a combination of shaft friction and end bearing resistance within the sandstone, mudstone and siltstone bedrock.

The artesian groundwater conditions may cause difficulties the construction of any form of cast-in-situ pile.

Driven pre-cast or H-section piles are likely to be suitable dependant upon the sensitivity to vibration of adjacent structures such as neighbouring buildings and the river training walls.

Continuous flight auger piles are likely to be feasible. Bored cast-in-situ piles would prove difficult due to the artesian conditions. Particular care would be required during construction of any cast in place piles (such as temporary casing where possible, bentonite support and tremieing of concrete) to cater for the artesian groundwater conditions.

The made ground is understood to have been in place across the majority of the site for some considerable time and it is therefore considered that the majority of self compaction and consolidation of the underlying sand and soft clay is likely to have taken place. However, where made ground has been placed more recently, in the northern part of the site to the east of Ink Street, the effects of negative skin friction due to the made ground and underlying sand and soft clay would have to be considered during pile design.

Design of the foundations could be undertaken once the details of the proposed structures and associated features have been confirmed and would require further examination of the ground investigation data. The advice of specialist contractors should be sought to formulate the most economic and satisfactory piling scheme.

Ground source heating is understood to be under consideration. This may take the form of ground loops incorporated within the piles. Pre-cast driven piles would not allow such installations as they would have to be installed on site during pile construction requiring specialist installation. There may be the potential for the use of geothermal piles however; advice from specialist contractors would need to be sought.

9.1.2 Floor Slab

Conventional ground bearing floor slabs are likely to experience potentially significant total and differential settlement as a result of the variability in the near surface ground conditions. The inherent variability of settlement is difficult to predict and it would also be proportional to imposed floor slab loading.

Suspended floor slabs are considered appropriate with intermediate piles and capping beams designed on the same basis as the main foundations where the spans are too great for economic simple slab design.

9.1.3 Other Engineering Considerations

The above assessment is to provide indicative information for estimating / feasibility evaluation only. The advice of specialist contractors should be sought to formulate the most economic and satisfactory piling scheme.

Groundwater is likely to be present within excavations greater than 1.0m depth. Dewatering or water exclusion measures such as those for piling techniques mentioned above may be required to ensure construction can be achieved in the dry.

It should be noted that the groundwater is likely to be in continuity with the river and therefore will be subject to variations with river level.

An appropriate California Bearing Ratio (CBR) value for pavement construction, which should be adopted for preliminary design purposes, would be 2% for the Made Ground.

A Coal Authority Report was obtained for the site. It reported no significant related risks to the development and confirmed the following:

- The property is not within the zone of likely physical influence on the surface from past or present underground or opencast coal workings, and
- The Coal Authority has no knowledge of any mine entries within, or within 20 metres of, the boundary of the property / site.

Records do not indicate any subsidence or damage claims for the property.

9.2 Concrete Classification

The results from the laboratory chemical testing for aggressive chemical environment for concrete classification have been assessed in accordance with BRE Special Digest 1.

The design sulphate classification for the foundation soils is DS-3. The Aggressive Chemical Environment for Concrete (ACEC) classification for the site, assuming mobile groundwater is AC-3.

9.3 Excavation Stability

It is understood that the proposals for undercroft car parking are for ground level structures. Excavations with sloping sides are not considered appropriate due to the shallow groundwater present at the site. However, should a shallow excavation be required then this may be achievable dependant upon the depth proposed, the proximity of the site boundary and the suitability of dewatering techniques. Otherwise, for any deeper excavations, temporary support such as sheet pile walls could be adopted. Alternatively, should deeper excavations be proposed, an embedded wall design using a reinforced concrete diaphragm wall or contiguous or secant bored pile walls should be considered. Permanent sheet pile walls may also be feasible and are likely to be less costly.

10 Conclusions

10.1 Ground Model

The whole site comprises level to very slightly sloping ground. The geological sequence comprises made ground overlying alluvium of sand, silt and clay which is further underlain by bedrock of siltstone, sandstone and mudstone.

Heavy metal and polyaromatic hydrocarbon contamination is higher in areas containing high proportions of ashy material. Ashy material appeared to be more prevalent in the North area. Petroleum hydrocarbon contamination was noted as sheens and odours and was widespread across the South site.

Carbon dioxide was noted across the site at concentrations of up to 9.7%.

10.2 Human Health Assessment

A generic quantitative human health risk assessment was undertaken on soil analysis results from both the 2006 and 2009 investigations. The site was split into North and South areas for assessment due to the differing previous historical uses in these areas as well as physical differences in the made ground composition. The soil results were assessed against published Soil Guideline Values (SGVs) and where these were not available, against Mouchel derived Generic Assessment Criteria (GACs). With regard to the North area, there is a risk to human health present from benzo(a)pyrene present within the Made Ground and as such, remediation will be required. There is no risk to human health from the made ground and natural material present in the South area.

With regard to ground gas, there is methane up to 0.2%, carbon dioxide up to 9.7% and a maximum flow rate of 4.2l/hr. Using the Modified Wilson and Card Classification which is suitable for commercial buildings, the site is classified as Characteristic Situation 3 which will require gas protection measures including a proprietary gas resistant membrane and passively ventilated or positively pressurised underfloor subspace with monitoring facility. It should be noted that these measures may not be required if undercroft car parking is present.

10.3 Controlled Waters Assessment

A detailed quantitative groundwater risk assessment has been undertaken using the Environment Agency Remedial Targets Methodology. Soil leachate and groundwater analysis results were screened against generic values for controlled waters. In this case, Environmental Quality Standards were used where available. A number of COCs were identified – metals, petroleum hydrocarbon fractions and polyaromatic hydrocarbons during the Tier 1 and 2 screening.

Modelling of these COCs was undertaken to derive site specific RTVs for both soil and groundwater. The soil and groundwater analysis results were reassessed using the site specific RTV's. It should be noted that a number of COCs were discounted at this stage as the travel time to the River Roch was in excess of 500 years by which point degradation is likely to have occurred.

However, there is a risk to the River Roch from cyanide, naphthalene, phenol and the aliphatic EC5-6 petroleum hydrocarbon fraction. As such, remediation of the site to prevent pollution of controlled waters will be required.

10.4 Geotechnical Assessment

Characteristic geotechnical parameters to be used for the design works have been derived from the findings of the site investigations and subsequent laboratory testing. These parameters have been derived for the made ground, alluvial sand, alluvial gravel, alluvial clay and bedrock. It should be noted that as well as perched groundwater within the made ground and alluvial deposits, there are artesian conditions within the bedrock. Groundwater control measures will be required for excavations and sump pumping is likely to be suitable for shallow excavations. The design sulphate classification for foundation soils is DS-3. The Aggressive Chemical Environment for Concrete (ACEC) classification for the site, assuming mobile groundwater is AC-3.

The made ground is not considered to represent a suitable founding stratum for any structures with significant imposed loads or those sensitive to settlement. As such, the main structures proposed are likely to require deep foundations in the form of basement rafts with thickened beams between columns founded on the deeper soils or piled foundations. The presence of contamination and underground obstructions such as former foundations should be taken into account when designing a suitable foundation technique.

11 Recommendations

11.1 Further Intrusive Investigations

With regard to risk to human health and controlled waters, no further intrusive investigations are required.

However, there is the possibility that ground source heating may be used within the proposed development. As such, a test borehole should be drilled to approximately 100m depth. This will provide values for the site specific thermal conductivity and thermal resistance of the borehole which will enable the number and configuration of boreholes to service the heating and cooling demands of the building to be established.

With regard to the possible presence of former foundations, basements, underground tanks or vehicle maintenance pits should be considered when designing a suitable foundation technique. It may be necessary to locate these structures using techniques such as ground penetrating radar.

11.2 Remedial Requirements

The remediation strategy can be finalised following a detailed options appraisal and discussion with the Environment Agency.

Subsequently this strategy will require agreement with the Environment Agency as well as the Local Authority Contaminated Land Officer.

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Appendix A Site Investigation Recommendations (2006)

Appendix B Factual Ground Investigation Report (Soil Mechanics Ltd), 2009

Appendix C Gas / Groundwater Monitoring Records

Appendix D Chemical Analysis Results

Appendix E Mouchel GAC Derivation Methodology

Appendix F Human Health Screening Tables

Appendix G Controlled Waters Screening Tables – Tier 1/2

Appendix H P20 Spreadsheets

Appendix I Controlled Waters Screening Tables – Tier 3

Appendix J Waste Classification Assessment