Interpretative Ground Investigation Report

Sidlesham Landfill Site, Pagham Harbour Nature Reserve, West Sussex

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Produced for
SEEDA and West Sussex County Council

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1 Introduction

1.1 Background

1.1.1 Mouchel Parkman Services Limited (now Mouchel Limited) was appointed by South East of England Development Agency (SEEDA) and West Sussex County Council (WSCC) on 7th March 2007 to undertake a visual inspection and limited surface water sampling assessment and an intrusive ground investigation at the Sidlesham landfill site, Pagham Harbour Nature Reserve, West Sussex.

1.1.2 The Phase 1 visual inspection and limited surface water sampling has been undertaken, and a draft report was issued on 2nd April 2007, reference 721334/R/1A.

1.1.3 This document reports the findings of the intrusive investigation. The works have been undertaken in accordance with:

- Brief from SEEDA received on 9th February 2007;
- Proposal in response to the above referenced brief dated 1st March 2007;
- Proposal dated 30th May 2007 to extend the scope of the ground investigation to include 17 hectares of adjacent land;
- Proposal dated 14th June 2007 to provide associated ecological assessment and support for the intrusive ground investigation;
- Proposal for changes to scope of works, dated 23rd July 2007 and confirmation of Option 4 as the preferred choice, received 31st July 2007.

1.2 Development Proposals

1.2.1 SEEDA are working in partnership with the Pagham Harbour Project Team (West Sussex County Council, the Environment Agency and the Royal Society for the Protection of Birds) to investigate the former Sidlesham landfill site and establish the potential options for remediating the site with a view to redevelop the existing visitor centre at the nature reserve and extend public access to the land. Six potential locations for a new visitor centre were provided within the Brief.

1.2.2 In order to develop a feasibility plan for the improvement of the site, a visual inspection and intrusive investigation are required to gather information on the topography, soil, waste and geotechnical properties of the landfill and the risks posed by the landfill to human health and the environment. This information will be used by the Pagham Harbour Project Team to assist in identifying the most appropriate location for the new centre, car park and public open space, and assist in the development of a detailed design and construction plan for the most appropriate location.

1.2.3 As part of the remediation options for the landfill, there is the potential for the acquisition of up to 17 hectares of farmland to the north of the landfill site, which could be incorporated into the Nature Reserve. This may provide a source of capping material for the landfill and allow the development of a wetland environment within the Reserve. A ground investigation was required to determine the chemical and geotechnical suitability of the top 1-2 metres of soil in this area for this use on the landfill.

1.3 Objectives and Scope

1.3.1 The objectives of the ground investigation, as identified within the brief from SEEDA dated 9th February 2007 are to:

- Determine the thickness and chemical quality of soil across the landfill site and adjacent land;
- Determine the thickness and chemical quality of the landfill material and geology beneath the landfill;
- Installation of permanent monitoring boreholes on the landfill site;
- Investigation of the groundwater quality beneath the landfill site;
- Monitor the presence, flow rates and concentration ranges of landfill gas beneath the landfill site;
- Investigate the geotechnical properties of the landfill and the top 1-2m of soil on the adjacent land;
- Monitor the flow regime of groundwater beneath the landfill site.

1.3.2 The scope of this report is to provide:

- Findings of the intrusive investigation;
- Revision of the Conceptual Model prepared during the Phase 1 surface water sampling;
- Assessment of the risks to controlled water and human health;
- Assessment of the geotechnical properties of the landfill and underlying strata;
- Recommendations for further investigation and monitoring;
- Assessment of the suitability of the top 1-2m on the adjacent land for use as a cap;
- Recommendations for remediation.

1.4 Limitations

1.4.1 This report is presented to South East of England Development Agency and West Sussex County Council in respect of Sidlesham landfill site, Pagham Harbour Nature Reserve, West Sussex and may not be used or relied on by any other person or by the client in relation to any other matters not covered specifically by the scope of this report.

1.4.2 Notwithstanding anything to the contrary contained in the report, Mouchel Limited is obliged to exercise reasonable skill, care and diligence in the performance of the services required by South East of England Development Agency, West Sussex County Council and Mouchel Limited shall not be liable except to the extent that it has failed to exercise reasonable skill, care and diligence, and this report shall be read and construed accordingly.

1.4.3 This report has been prepared by Mouchel Limited. No individual is personally liable in connection with the preparation of this report. By receiving this report and acting on it, the client or any other person accepts that no individual is personally liable whether in contract, tort, for breach of statutory duty or otherwise.

2 Site Location, Description and Background Information

2.1 Site Location

2.1.1 The landfill site is located adjacent to the B2145 (Sidlesham Road) between Chichester and Selsey Bill, West Sussex. The National Grid Reference of the current visitor centre is SZ856966. The site comprises approximately 11.4 hectares (28.17 acres) and lies in a predominantly flat low lying area. As a result of the landfilling, however, the central southern part of the site (an area fenced off from public access) is up to 3 metres higher than the surrounding land. A Site Location Plan is provided in Appendix 1.

2.1.2 The area of adjacent land on which the additional ground investigation was undertaken is located to the north of the landfill site, and comprises approximately 17 hectares (42 acres) of privately owned farmland.

2.2 Site Description

2.2.1 The landfill site forms part of Pagham Harbour Nature Reserve, and the visitor centre and associated car parking is present in the north-western part of the site. Public access on and around the site is via footpaths, and much of the southern part of the site is fenced with a 1m high wooden post and rail fence to discourage public access. A separate fenced area is present along the western part of the site known as the Discovery Area, which has been used for school and educational visits. Vegetation type and cover is variable across the site, with trees in the south, open ground with a predominantly nettle cover in the central part and brambles with some grass cover in the north.

2.2.2 The landfill site was a civic amenity tip during the 1960's and 1970's, and the nature of the waste placed within the tip is understood to have been mainly domestic/household waste. Evidence from historical plans and photographs indicates the area was previously a lagoon, separated from the harbour by a tramway; the former route of which forms the eastern boundary of the site today.

2.2.3 The harbour comprises a mixture of salt marsh and mudflats and lies approximately 1m lower than the footpath along the eastern boundary of the site (on the line of the former tramway). A surface water drain, the Red Barn Ditch which is tidally influenced crosses east-west through the northern part of the site.

2.2.4 The adjacent land to the north of the landfill site comprises flat low-lying land divided into three fields; northern, middle and southern. The site is bounded to the east by residential properties along Mill Lane road and to the south by a footpath. To the west, the farmland is bounded by Sidlesham Road (B2145) and in the south-west corner by Saliota Nursery and the landfill site. Historical plans provide no evidence of this site being used for any purpose other than agriculture.

2.3 Background Information

2.3.1 The Phase 1 Assessment was undertaken in March 2007, and the report provides a summary of the history, geology, hydrology, hydrogeology, ecology and surface water assessment undertaken for the site. The Phase 1 Assessment Report, dated April 2007 reference 721334/R/1A is to be referred to in conjunction with this report.

2.4 Summary of Preliminary Conceptual Model

2.4.1 The drainage channel (Red Barn Ditch) which crosses the site is tidally influenced, and given the proximity of the landfill to the tidally influenced waters of Pagham Harbour, it was considered likely that any water/leachate within the landfill will be in hydraulic continuity with the harbour and other surface waters in the vicinity of the landfill. A salt and freshwater mixing zone is present across part of the landfill site (as indicated by the results of the surface water sampling in March 2007).

2.4.2 The waste material is likely be resting on estuarine clays, which may prevent downward migration of any leaching contaminants into the underlying minor aquifer comprising sandy clays with sands and gravels (Quaternary deposits). Any contamination that does enter the minor aquifer is restricted in moving vertically downward by the presence of the Eocene deposits.

2.4.3 It is noteworthy that the Eocene strata at the site comprise both the Bracklesham Beds and the London Clay. In the southern sector of the site, underlying the former landfill, the Eocene strata comprise the Bracklesham Beds. These are a series of clays and marls, with sandy and lignitic beds. The clays are brown, laminated and highly plastic whilst the sand layers are green due to the high glauconite content. In the northern sector, (termed The Adjacent Land in this report) the underlying geology is London Clay. This is a stiff, fissured, bluish clay which becomes brown when weathered and contains nodules of pyrite and crystals of selenite along with large concretions.

2.4.4 Infiltrating rainwater or tidally influenced groundwater may leach contamination from the waste material and due to the intermixing of fresh and salt water may eventually enter the surface water bodies in the vicinity of the landfill.

2.4.5 The contents of the uncapped landfill were unknown, and contact with the contaminated soils and leachate via inhalation, oral intake and/or dermal contact may pose a risk to the public and staff using the site.

2.4.6 The likelihood of generation of landfill gas is moderate to high. Given the lack of sub-floor voids below the buildings on the site or depressions in the landfill surface, there is a low risk from accumulation of landfill gases in such areas. Given the uncapped nature of the site, the main pathway for movement of the landfill gases is likely to be into the atmosphere.

2.5 Services Information

2.5.1 Copies of public utility services plans were obtained and reviewed during the design of the ground investigation. Exploratory holes were placed away from all known services.

3 Ground Investigation

3.1 Introduction

3.1.1 With reference to the brief as summarised in section 1.1.3, a ground investigation was designed to:

- confirm the underlying chemical and geotechnical ground conditions within and beneath the landfill and on the adjacent land;
- provide monitoring installations for measurement of gas concentrations and collection of water samples for chemical analysis.

3.1.2 This was achieved using the following scope of works:

3.1.3 Landfill site:

- 7 cable percussive sample boreholes (three deep into the natural strata beneath the landfill and four shallow, to the base of the landfill only);
- 8 trial pits to the base of the landfill;
- In-situ and laboratory Geotechnical testing/analysis;
- Chemical analysis on retrieved samples;
- Installation of gas and groundwater monitoring points.

3.1.4 Adjacent Land:

- 7 trial pits to approximately 3m depth;
- 7 window sample holes to approximately 3m depth;
- Geotechnical and chemical analysis on selected samples.

3.2 Fieldwork

3.2.1 The ground investigation was undertaken between 10th September 2007 and 9th October 2007 by Norwest Holst (an approved Contractor under the Mouchel Quality Management System) and was monitored on site by a representative from Mouchel. The investigation was carried out in general accordance with the following standards:

- BS EN ISO 14688-1:2002 Geotechnical testing and investigation – Identification and classification of soil - Part 1: Identification and description;
- BS EN ISO 14688-2: 2004: Geotechnical testing and investigation – Identification and classification of Soil Part 2 Principals for a classification;
- BS EN ISO 14689-1:2003 Identification and Classification of Rock Part 1 Identification and Description.

3.2.2 Table 3:1 provides a summary of the exploratory hole references, dates of excavation/drilling and the maximum depth reached. The locations of the exploratory holes are shown on the Drilled Exploratory Hole Locations and Constraints Plans (Drawing reference 721334/M/12 (landfill) and 721334/M/13 (adjacent land)) presented in Appendix 2.

Table 3:1 Summary of Site Activities

Activity	Date Undertaken	Exploratory Hole Reference	Maximum Depth
Trial Pitting	10th - 14th September 2007	TP01 to TP03, TP05,TP08, TP11,TP13, TP15 (landfill site); TP16 to TP22 (adjacent land)	5.10m 3.8m
Cable Percussive Boreholes	17th - 24th September 2007	BH01 to BH07 (landfill)	15.40m
Window Sampling	27th September 2007	WS01 to WS07 (adjacent land)	3.00m
Cable Percussive boreholes (re-drill)	8th – 9th October 2007	BH2a, BH4a, BH6a and BH7a (landfill)	6.50m

3.2.3 On the landfill site, cable percussive boreholes BH01 to BH06 were located at each of the six potential visitor centre locations, with BH07 and the trial pits TP01 to TP03, TP05, TP08, TP11, TP13 and TP15 positioned to obtain general information across the remainder of the site.

3.2.4 All trial pits and boreholes except BH01, BH03 and BH05 were excavated /drilled to the base of the landfill only. BH01, BH03 and BH05 were drilled into the natural strata beneath the landfill.

3.2.5 Boreholes BH2a, BH4a, BH6a and BH7a were drilled adjacent to BH2, BH4, BH6 and BH7 for the purpose of providing 90mm diameter installations to facilitate groundwater monitoring from the landfill.

3.2.6 All boreholes were completed with installations comprising slotted and plain HDPE pipework as follows:

- BH01, BH03 and BH05: 19mm diameter gas monitoring installation through the landfill, and 90mm diameter groundwater monitoring installation in natural strata;
- BH02, BH04, BH06 and BH07: 19mm diameter gas monitoring installation through landfill;
- BH02a, BH04a, BH06a and BH07a: 90mm diameter groundwater monitoring installation through landfill.

3.2.7 Details of response zones and bentonite seals are provided in the Norwest Holst Factual Report, in Appendix 3

3.2.8 On the adjacent land, window samples WS01 to WS07 and trial pits TP16 to TP22 were located to give a good spread of positions across the three fields.

3.3 Gas and Groundwater Monitoring

3.3.1 Following completion of the site works, six dataloggers and pressure transducers were installed to monitor groundwater levels at 15 minute intervals, one in each of BH01, BH02a, BH03, BH04a, BH05a and BH07a for a period of one week between 22nd and 29th October 2007.

3.3.2 Following removal of the dataloggers, gas and groundwater level monitoring was undertaken from all boreholes on the following dates:

- 6th November 2007;
- 15th November 2007;
- 30th January 2008;
- 5th February 2008.

3.3.3 The results of the gas monitoring are presented in Appendix 5 and the groundwater monitoring and data logger results are presented in Appendix 6.

3.4 Chemical Laboratory Testing

3.4.1 During the ground investigation a range of representative soil samples from the landfill and natural ground were collected, together with representative samples of the water within the landfill obtained during excavation of the trial pits. During the gas and groundwater monitoring visits, water samples were collected from each of the seven boreholes.

3.4.2 All samples were stored in airtight containers appropriately labelled, and transported under completed chain of custody documentation to Scientific Analysis Laboratories (SAL). Scientific Analysis Laboratories are UKAS and MCERTs accredited and are an approved contractor under the Mouchel Quality Management System.

Soils

3.4.3 A total of 53 soil samples were scheduled for testing. A summary of the analysis undertaken and the origin of the samples are shown in Table 3:2.

Table 3:2. Summary of Chemical Soil Analysis

Suite Reference	Number of samples scheduled	Analysis Suite
Suite 1 – Soils from landfill site	18	Asbestos (screen only); Metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, zinc); pH; moisture content, Benzene, Toluene, Ethyl Benzene, Meta/Para-Xylene Ortho-Xylene (BTEX); Methyl-tert-Butyl Ether (MTBE); Gasoline Range Organics (GRO); speciated Polycyclic Aromatic Hydrocarbons (PAH, USEPA 16); TPH (Fractionated C5 – C35)
Suite 2 – Landfill site (natural soils beneath landfill)	7	Fraction of Organic Carbon (Foc)
Suite 3 – Adjacent land – Soil quality	14	Arsenic, cadmium, chromium, copper, lead mercury, nickel, selenium, zinc, pH, chloride, sulphate, magnesium, phosphorous, potassium, calcium, nitrogen, electrical conductivity, organic matter, particle size distribution, texture, total organic carbon, soil organic matter, moisture content, Total Petroleum Hydrocarbons (TPH total) and Polycyclic Aromatic Hydrocarbons (PAH, USEPA 16).
Suite 4 – Adjacent Land – Pesticide suite	5	Aldrin, Atrazine, Azinphos methyl, chlordane, cypermethrin, DDD, DDE, DDT, diazinon, dichlorvos, dieldrin, dimethoate, endosulphan, endrin, fenitrothion, heptachlor, heptachlor epoxide, hexachlorocyclohexane, malathion, mevinphos, parathion, permethrin, pirimiphos methyl, prometryn, propazine, simazine, terbutryn, trietazine, cyfluthrin, hexachlorobenzene.

Groundwater and Leachate

3.4.4 A total of 19 groundwater samples collected from the landfill site were scheduled for chemical analysis;

- Five samples collected during the ground investigation from trial pits on the landfill site;
- Seven samples from each of the two rounds of groundwater monitoring.

3.4.5 A total of 3 soil samples were scheduled for leachate analysis and tested for determinants as shown in Table 3:3.

Table 3:3 Summary of Chemical Water/Leachate Analysis

Suite Reference	Number of samples scheduled	Analysis Suite
Suite 5 - standard water / leachate suite	21 (one sample was not scheduled for this suite)	Arsenic, cadmium, chromium, copper, lead, nickel, zinc, nitrate, nitrite, phosphate, Sulphate ion, Biological Oxygen Demand, Chemical Oxygen Demand, Electrical Conductivity, pH, Alkalinity by HC03 and Ammonium. Suspended solids on five water samples collected from landfill during ground investigation.
Suite 6 - TPH	9	TPH (Fractionated C5 – C35).

3.4.6 The results of the soil and water chemical analysis are presented in Appendix 4.

3.5 Geotechnical Laboratory Testing

3.5.1 A range of representative samples from within the made and natural ground were collected during the ground investigation, appropriately labelled and stored before being transported by Norwest Holst to their laboratories for analysis. Norwest Holst are UKAS accredited and are an approved contractor under the Mouchel Quality Management System.

3.5.2 A total number of 106 soil samples, both of made ground and natural strata, were recovered during the fieldwork and a selection were tested for the laboratory analysis as shown in Table 3:4 and Table 3:5.

Table 3:4 Summary of Geotechnical Testing – Landfill Site

Test Type	Number of Tests
Moisture Content	46
Atterbergs	11
Bulk Density	18
Organic Matter	10
Compaction –Oedometer	9
Quick Undrained Triaxial	9
Sulphate/pH – Special Digest:1	11

Table 3:5 Summary of Geotechnical Testing – Adjacent land

Test Type	Number of Tests
Moisture Content	28
Atterbergs	20
Particle Size Distribution	14
California Bearing Ratio - Remoulded	5
Compaction – 2.5kg Hammer	9

3.5.3 The results of the geotechnical analysis are presented in Appendix 3.

4 Ground Investigation Results – Landfill Site

4.1 Geology

4.1.1 The geological sequence identified during the ground investigation broadly concurs with the published geological information, as summarised in the Phase 1 report. The waste material (made ground) typically lies upon Quaternary Tidal Deposits which in turn overlie Eocene sandy clays, however, the Quaternary Deposits are absent from the sequence in BH01.

4.1.2 The 1:50,000 geological map (sheet 317/332 "Chichester and Bognor", Solid and Drift, 1996, 1:50,000) indicates the Eocene Deposits to vary between the landfill site and the adjacent land, as mentioned in Chapter 2. The solid deposits are gently folded into an east-west trending anticline (axis to the north of the site) and the site sits on the southern flank. The younger Bracklesham Beds outcrop across the southern half of the landfill site, whilst the older London Clay is recorded to outcrop across the northern half of the landfill and the adjacent land. The intermediate Woolwich and Reading Beds are absent from the outcrop sequence in the vicinity of the site and eastwards along the southern flank of the anticline toward Portsmouth.

4.2 Made Ground

4.2.1 Made ground (landfill waste) was encountered in all exploratory holes and comprised a variable mixture of demolition rubble, plastic, wood, glass, metal, paper and textiles. The main constituents were sand, clay and gravel size fragments of glass, house bricks, concrete, ceramics, quartz and metals, although locally other materials were also identified.

4.2.2 Degradable materials with the potential to generate landfill gases (wood, paper and textiles) were encountered in the majority of exploratory holes, with significant quantities being recorded in BH2, TP2, TP8, TP11 and TP15 (central eastern part of the site) and TP13 (central southern part of the site).

4.2.3 The greatest thickness (in excess of 5m) was found in the central part of the site to the south of the drainage ditch (Red Barn Ditch), around BH02, BH05, BH07, TP11 and TP15. The maximum thickness encountered was 6.5m in BH05, in the centre of the site.

4.2.4 To the north of the drainage ditch (Red Barn Ditch), the three exploratory holes undertaken in this area (TP1, TP8 and BH1) recorded a consistent waste thickness of around 4m. The base of the landfill was recorded at -1.08m, -1.44m and -1.03m OD respectively).

4.2.5 The thickness of the waste material reduced to the south (maximum 3.5m thick to a depth of -0.54m OD in BH04) and west (approximately 1.5m thick in both TP5 and BH06 (depths of 0.81m OD and 0.90m OD respectively).

4.2.6 Review of the depth in mOD of the base of the waste material shows it is deepest (>-1m OD) in the area to the north of the Red Barn Ditch and the central eastern part to the south of the channel, around BH02, TP2 and BH05. The depth of the base of the landfill generally decreases westwards and the shallowest area is found in BH06 in the west of the site (+0.9m OD). This generally correlates with the variations in thickness of the waste material as discussed above (see contour plot of base of landfill waste in Appendix 8).

4.3 Tidal River Deposits (Quaternary)

4.3.1 This deposit was proved beneath the made ground in all but three locations – BH01 (absent from sequence) and TP01 and TP02 (both holes terminated within the made ground).

4.3.2 The deposit typically comprised very soft clay containing variable amounts of sand, shell fragments, organic matter and more rarely gravel. Occasional thin bands of silty sand were also encountered. Below -3.64m OD in BH05 the deposit consisted of a thin layer of medium dense gravel over loose silty, fine to medium sand to -6.14m OD.

4.3.3 The base of this deposit was proved in BH03 (south-eastern boundary) at 8m bgl (-5.10m OD) and BH05 (centre of site) at 11.5m bgl (-6.14m OD).

4.4 Bracklesham Beds (Eocene)

4.4.1 These deposits, encountered beneath the Quaternary deposits in BH03 and BH05, and directly beneath the Made Ground (landfill waste) in BH01 (from 4.7m bgl, -1.03m OD) comprised layers of firm, variously coloured orange and grey sandy clays with pockets and partings of sand. In BH01 bands of very clayey sand were also present interbedded with the sandy clay layers.

4.5 Groundwater

4.5.1 Within the natural strata beneath the landfill, groundwater strikes were encountered in BH01 and BH03. Both strikes resulted in fast inflow from the Bracklesham Beds, where after 20 minutes the water level had risen 3m to -1.67m OD (within the same deposit) and 5m to -2.8m OD (within the overlying Alluvium) respectively.

4.5.2 Within the made ground, groundwater was encountered in all exploratory holes during the intrusive works, although the nature of inflow varied with no obvious pattern across the site. During the groundwater monitoring, groundwater levels within the made ground were found to be approximately 1.5m bgl in all except BH02 and BH07, where it was encountered at approximately 3m bgl.

4.5.3 The average depth to groundwater in metres below ground level (bgl) was calculated from the groundwater monitoring undertaken between November 2007 and February 2008. The results show shows the greatest depth to groundwater in the central eastern part of the site (between 2.5m and 3m bgl around BH02, BH05 and BH07). In the north and south of the site the depth to groundwater is between 1.5m and 2m (BH01, BH03 and BH04) and in the west (BH06) the depth to groundwater is typically around 1m bgl or less.

4.5.4 The depths to groundwater correlate well with the topography of the site, where the greatest depth to groundwater is found in the areas of the highest topography (BH02, BH05 and BH07).

4.5.5 The depths to groundwater in metres bgl measured during the monitoring visits correlate well with the groundwater level results recorded during the period of datalogging between 22nd and 29th October 2007. The datalogger results for BH01, BH03 and BH05, screened within the natural strata beneath the landfill show an asymmetrical cyclical variation in height of 0.05m (BH05) 0.15m (BH03) and 0.3m (BH01). No noticeable variation in height of the groundwater table was identified in BH02, BH04 and BH07.

4.5.6 The depth to groundwater measured in BH01, BH03 and BH05 represent the head level of the aquifer within the natural strata beneath the site and those in BH02, BH04 and BH07 the level of the groundwater within the landfill.

4.5.7 Comparison of these results against the known tidal variations for Pagham Harbour confirms a tidal influence in the aquifer beneath the site, and no influence within the perched waters in the landfill.

4.6 Observation of Potential Contaminants

4.6.1 The waste material is naturally a potential source of a number of contaminants, and an assessment of these is undertaken in Section 6 below. Aside from this, during the intrusive investigation a hydrocarbon odour was noted within TP01 (1.7m bgl), TP02 (from 2.5m bgl) and in BH07 (0.3m – 3.45m bgl).

4.6.2 During the groundwater monitoring visits, an odour was recorded in BH2a and BH04a during the first round only and in BH07a during both rounds. Pieces of plastic floating within the water were identified in BH01, BH03 and BH05 (deep boreholes).

4.7 Underground Structures and Services

4.7.1 No underground services or structures were encountered.

4.8 Ground Gas

4.8.1 Four gas monitoring rounds were undertaken, 6th and 15th November 2007, 30th January 2008 and 5th February 2008. These are referred to in date order, with the first round being on 6th November 2007.

4.8.2 In general the concentrations of methane (CH_4) and carbon dioxide (CO_2) were greater within the first two monitoring rounds (6th and 15th November 2007) and less during the second two rounds (30th January and 5th February 2008).

4.8.3 The greatest concentrations of methane (8.2% and 6.0%) were encountered in BH02 during the first two rounds of monitoring. With the exception of the concentrations in BH05 (4.2%) and BH07 (1.3%) on 15th November 2007, all other methane concentrations are less than 1.1%.

4.8.4 The greatest and most consistent concentrations of carbon dioxide are recorded in BH02 (between 11% and 22%), BH01 (between 12% and 15%) and BH07 (between 8% and 15%). In BH04 and BH05, the carbon dioxide concentrations during the first and second rounds were significantly higher (15%-19%) than during the last two rounds (2% - 4%). In BH03 and BH06, the carbon dioxide concentrations are consistently low (3% and 6% respectively) and the results from the last round of monitoring are both very low (around 0%).

4.8.5 Oxygen concentrations vary significantly across the site, from around 0% in BH02 and 3% in BH01 to concentrations in excess of 15% in BH04, BH03, BH05 (second two rounds of monitoring only) and BH06 (last round of monitoring only). Concentrations are generally consistent between monitoring rounds in all monitoring locations, with the exception of BH04, BH05 and BH07, where concentrations vary between rounds of up to one order of magnitude (e.g., 1% to 11%).

4.8.6 The flow rates (litres / hour) are highest in BH02 and BH05 (maximum recorded peak flows of 0.7l/hr and 0.8l/hr respectively). Flow rates in all other locations were less than 0.2l/hr.

4.8.7 The pressure trend during the monitoring was rising during the first three rounds and falling during the last round (5th February 2008).

4.8.8 No concentrations of hydrogen sulphide or carbon monoxide were recorded.

4.8.9 The relative concentration of gases recorded within the landfill is consistent with the recognised models of variations in landfill gas generation over time, indicating this 30-40 year old landfill site is now in an anerobic phase (Phase IV) producing predominantly carbon dioxide and methane. This is typical of landfills greater than 20 years old, which can continue to emit gas for up to a 40-year period, or longer depending on the quantity of degradable materials present.

4.8.10 The full ground gas monitoring results are presented in Appendix 5.

5 Ground Investigation Results – Adjacent Land

5.1 Geology

5.1.1 The geological sequence identified during the ground investigation broadly concurs with the published geological information, as summarised in the Phase 1 report. The sequence typically comprised topsoil overlying sandy clays of Quaternary age. The underlying bedrock at this location comprises the Eocene London Clay, as mentioned in Chapter 2 and described in full in paragraph 4.1.2.

5.2 Topsoil

5.2.1 Topsoil was present across the adjacent land to a maximum thickness of 0.6m (average 0.4m) with the base of this deposit varying between 3.69m and 1.86m OD.

5.3 Made Ground

5.3.1 A layer of material considered to be made ground 1.1m thick was encountered in TP17, where grey and black sandy clay, containing gravel size fragments of quartz and possible coal was present below the topsoil to 2.25m OD. Made ground was not encountered in any of the other exploratory holes on this site.

5.4 Tidal River Deposits (Quaternary)

5.4.1 Found beneath the topsoil in all but TP17, where it was encountered beneath the made ground, this deposit comprised irregular layers of generally firm, slightly sandy to sandy clay with varying amounts of gravel and shell fragments. Some bands / lenses of sand and gravel were also present.

5.4.2 The base of this deposit was proved in all but WS01 and WS05 at levels ranging from 2.42m to -0.07m OD. This deposit is typically thickest in the central part of the site (>2.6m in WS01 and WS05), thinning toward the site boundaries, where a minimum thickness of 0.4m in WS07 was recorded in the south-east of the site.

5.5 Eocene Deposits (London Clay)

5.5.1 This deposit is characterised by a generally firm, brown orange mottled grey slightly sandy clay with thin partings of sand. All exploratory holes except WS01 and WS05 terminated within this deposit at a maximum depth of -1.04m OD in TP22 (southern-most extent of the site).

5.6 Groundwater

5.6.1 Groundwater seepage was encountered in WS1, WS3, WS4, WS5 and WS6, within or close to the base of the Quaternary Deposits. The depth to groundwater strike (no rise in level after twenty minutes occurred) ranged from 1.74m OD in the north of the site (WS1) to 1.06m OD in the south-east (WS5). Dampness was encountered at 2.5m depth (0.92m OD) in TP19, also within the Quaternary Deposits. No groundwater was encountered in the remaining trial pits.

5.6.2 No groundwater monitoring points were installed on this site.

5.7 Observation of Potential Contaminants

5.7.1 With the exception of the coal fragments within the made ground encountered in TP17, no evidence of any potential contamination was identified.

5.8 Underground Structures and Services

5.8.1 A clay drainage pipe was encountered at 0.6m in TP19.

5.9 Ground Gas

5.9.1 No gas monitoring was undertaken (no monitoring points were installed).

6 Geotechnical Assessment – Landfill Site

6.1 Introduction

6.1.1 The redevelopment of the existing visitor centre at the nature reserve will be constrained by the geotechnical parameters of the old landfill material and the in-situ soils underneath. This section will examine the geotechnical parameters of the soils present, examine their physical characteristics in terms of strength and deformability, and present the viable foundation solutions.

6.2 Made Ground

6.2.1 As reflected in the descriptions of this material in section 4.2, the made ground is highly variable, both laterally and vertically. The thickness is widely variable ranging from 1.5m to 6.5m and averages 4.7m. In terms of a design thickness, given that six different sites are being evaluated, each site will be assessed individually.

Table 6:1 Geotechnical Parameters Made Ground

	Min	Max	Mean	No. of Tests	Design Values
Layer Thickness (m)	1.5	6.5	4.7	n/a	**By Site**
Natural Moisture Content (%)	9.9	88	36.4	17	**40**
Liquid Limit (%)	51	78	64.5	2	**70**
Plasticity Index (%)	29	52	40.5	2	**45**
SPT N Value	0.5	14	6.5	26	**6**
Derived Undrained Shear Strength C_u (kPa)	2.3	63	26	26	**25**
Water Soluble Sulphates (mg/l)	161	3910	1504	6	**3910**

6.2.2 The moisture contents recorded were widely variable ranging from 9.9% to 88%, reflecting the variable nature of the material. There is no clear correlation with depth despite the site largely being an old coastal lagoon at or just above sea level. If the extreme values are ignored, the typical value is 40%.

6.2.3 Due to the fact that it is highly unlikely this layer will found any of the proposed elements of the project only two samples of the made ground were taken for testing plasticity. The analysis suggests that the material is of high to very high plasticity.

6.2.4 The relative density of this material as measured by the Standard Penetration Test (SPT) N Values was found to be very loose/very soft to medium dense/firm, with values ranging from 0.5 to 14 and an average of 6.

6.2.5 The undrained shear strength of the material can be estimated from the Standard Penetration Test N Value (N) using the empiricism C_u = 4.5*N (after Stroud and Butler 1975). This yields a typical value of 25kPa.

6.2.6 However, to take a conservative approach, an N Value of 0.5 means that the Standard Penetration Test sampler is falling under its own weight suggesting that this landfill waste has no shear strength.

6.2.7 If excavation of the made ground is required, removal of the surface materials can be handled by back acting JCB type excavators. However given the variable nature of made ground, sidewalls may require bracing if left open for extended periods.

6.2.8 The samples of the made ground subject to sulphate testing under BRE Special Digest 1:2005 ‘Concrete in Aggressive Ground’ shows water soluble sulphates range between 3100 and 6000 mg/l giving a Design Sulphate Class of DS-4. The pH analysis gives a corresponding ACEC class of AC-4.

6.3 Tidal River Deposits (Quaternary)

6.3.1 A summary of the geotechnical parameters along with the selected design parameters of the tidal river deposits is presented in Table 6.2 below.

Table 6:2 Geotechnical Parameters Tidal River Deposits

	Min	Max	Mean	No. of Tests	Design Values
Layer Thickness	3.3	5	4.1	n/a	**By Site**
Natural Moisture Content (%)	22	65	37.3	7	**40**
Liquid Limit (%)	31	68	44	5	**45**
Plasticity Index (%)	14	41	23	5	**23**
SPT N Value	0.5	18	5.6	9	**6**
Derived Undrained Shear C_u (kPa)	2.3	81	25	9	**25**
Measured Undrained Shear C_u (kPa)	12	60	35	3	**30**
Water Soluble Sulphates (mg/l)	9	585	347	5	**585**

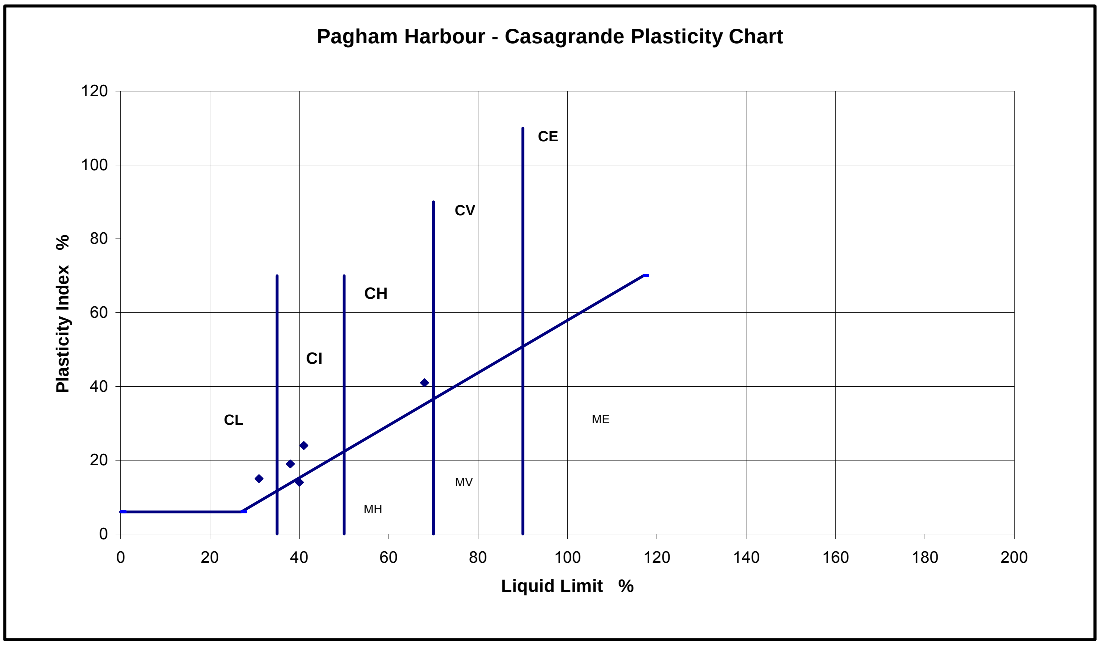
6.3.2 The tidal deposits are sandy clays. This material is below the groundwater table and the variations in moisture content are therefore a function of grading of the material (proportions of granular to fine grained cohesive material) and porosity. The typical value is 40%.

6.3.3 The range of grading of the material is reflected in the Atterberg Limits results where the plasticity indices range from 14 to 41 averaging 23. The Casagrande Chart below in Figure 6.1 shows the deposits to be generally of low to intermediate plasticity, with one result suggesting the material may be of high plasticity in places.

6.3.4 It is noteworthy that the design moisture content approaches the design liquid limit reflecting the semi-fluid nature of these deposits.

6.3.5 This is reflected by the results of the Standard Penetration Test undertaken within this material. The relative density, as measured by the Standard Penetration Test N Values, range from 0.5 to 18 with an average of 6. As with the made ground above, these soils are generally very soft and only marginally improve with depth.

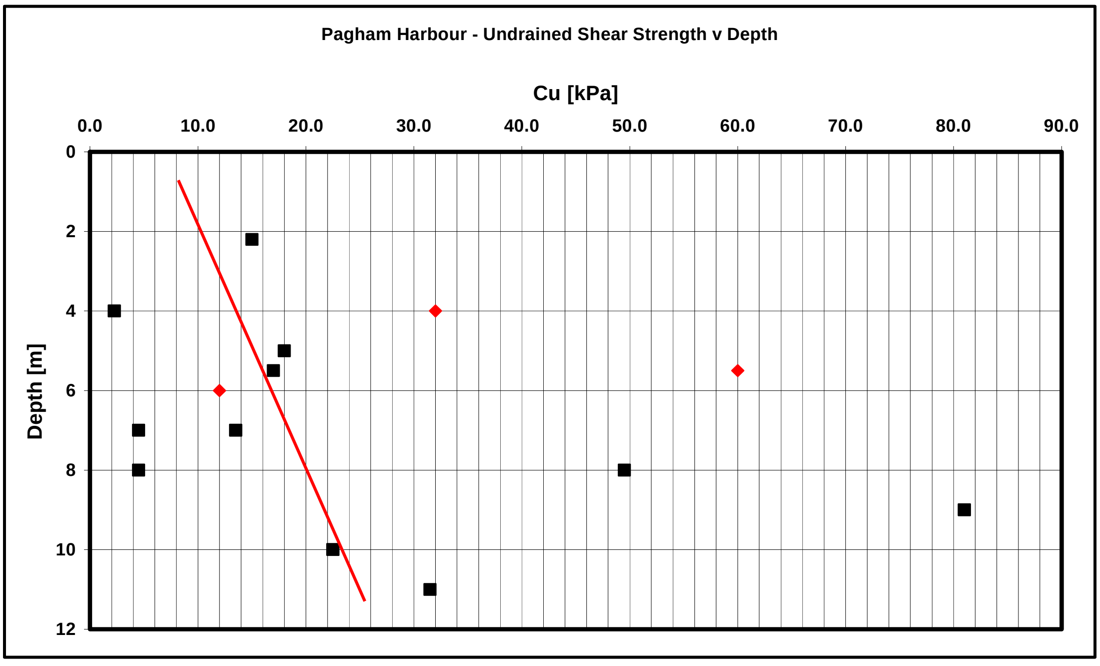
Figure 6:1 Casagrande Chart for Geotechnical Layer 2 – Tidal Deposits



6.3.6 The measured undrained shear strength (C_u) from laboratory triaxial tests has a range of 12 to 60 kPa (as shown in table 6:2 and as represented by the red dots in Figure 6:2) with a corresponding design value of 30 kPa.

6.3.7 The undrained shear strength can also be estimated from the Standard Penetration Test N Value (N) using the empiricism C_u = 4.5*N (after Stroud and Butler 1975) as shown in table 6:2 and as represented by the black squares in Figure 6:2). This yields a typical value of 25kPa.

Figure 6:2 Undrained Strength v Depth – Tidal Deposits



6.3.8 The bearing capacity of this material can be assessed in two ways. Applying the measured design undrained shear strength value of 30kPa into the Brinch Hansen equation for bearing capacity yields a safe bearing capacity of 50kPa. If the more granular horizons are considered and the bearing capacity is derived from the N Value using Q_{safe} = 10.5*N (after Peck et al. 1967), the design N Value of 6 yields a safe capacity of 63 kPa.

6.3.9 In either case these bearing capacities are low. In addition, these tidal deposits are submerged soils and given their low bearing capacity would not be recommended as founding strata.

6.3.10 Where buried concrete may come into contact with these deposits, samples subject to sulphate testing under BRE Special Digest 1:2005 'Concrete in Aggressive Ground' give a design water soluble sulphates value of 585 mg/l and therefore a Design Sulphate Class of DS-2 is appropriate. The pH analysis gives a corresponding ACEC class of AC-2.

6.4 Bracklesham Beds (Eocene)

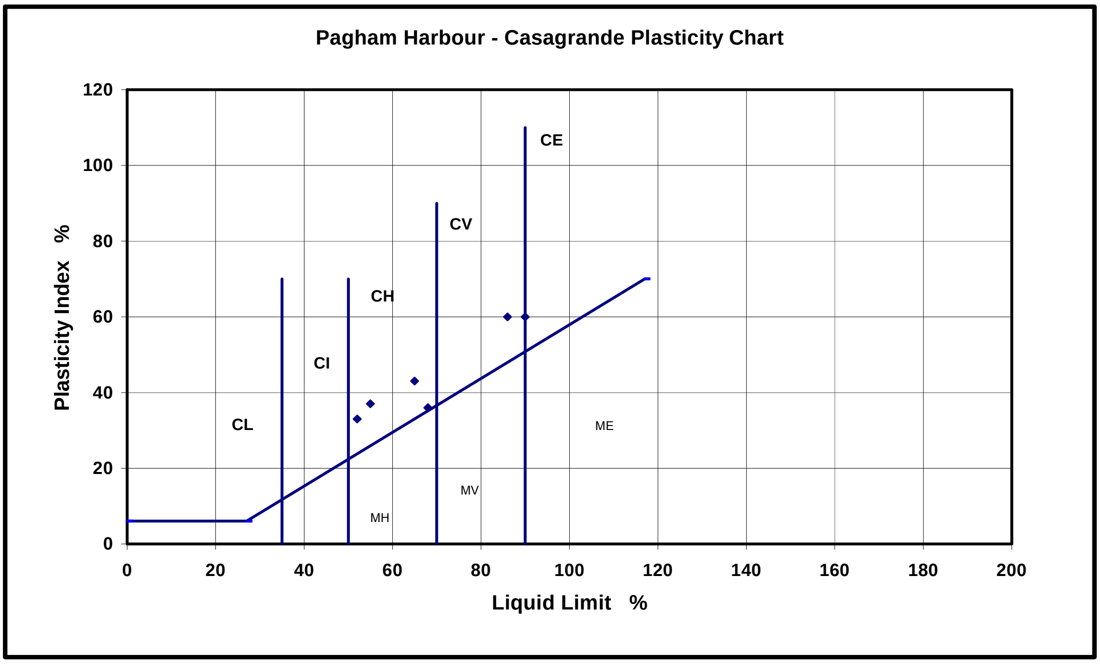
6.4.1 A summary of the geotechnical parameters along with the selected design parameters of the Bracklesham Beds is presented in Table 6.3 below. The base of the Bracklesham Beds was not proven during drilling.

Table 6:3 Geotechnical Parameters Bracklesham Beds

	Min	Max	Mean	No. of Tests	Design Values
Natural Moisture Content (%)	24	48	33.5	12	35
Liquid Limit (%)	52	90	70	6	70
Plasticity Index (%)	33	60	45	6	45
SPT N Value	2	22	15	11	10
Derived Undrained Shear C_u (kPa)	9	99	65	11	60
Measured Undrained Shear C_u (kPa)	32	92	54	7	50
Water Soluble Sulphates (mg/l)	168	551	421	4	551

6.4.2 The Bracklesham Beds are slightly sandy clays and have less granular content than the overlying tidal deposits. The Atterberg Limits support this reduced granular content with higher plasticity indices ranging from 33 to 60 averaging 45. The Casagrande Chart presented in Figure 6.3 below shows the beds to be of high to very high plasticity.

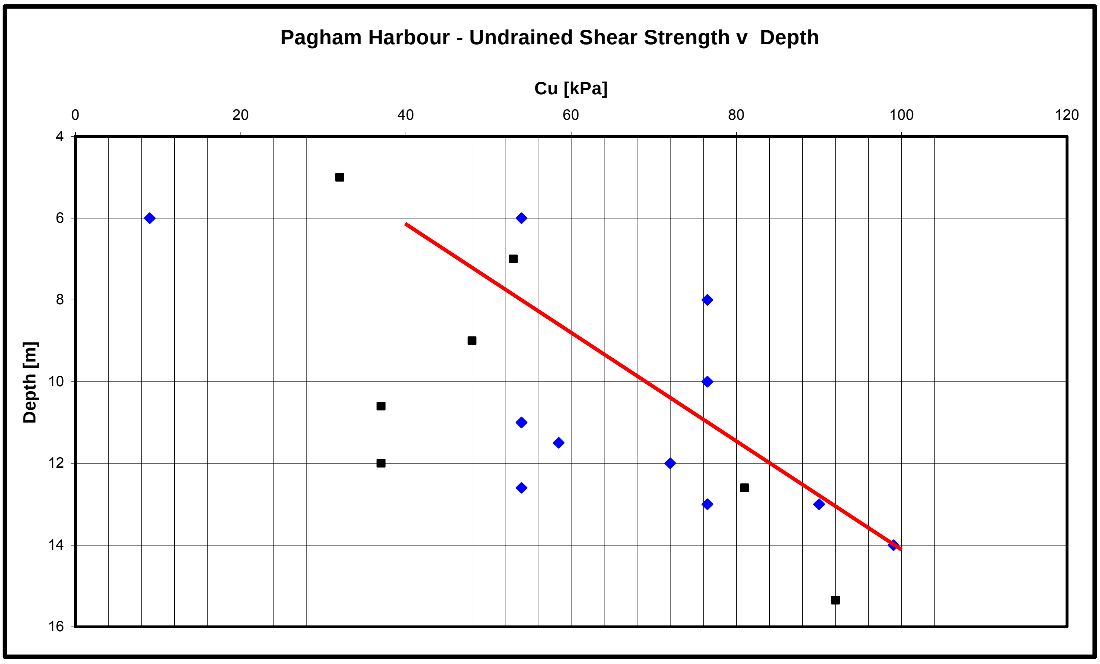
Figure 6:3 Casagrande Chart – Bracklesham Beds



6.4.3 The undrained shear strength (C_u) of the Bracklesham Beds, using both derived and measured values, range from 9 to 99 kPa. The average undrained shear strength is between 50 and 60kPa, for the measured and derived values, respectively. The mean of these values is 55kPa.

6.4.4 The measured undrained shear strength and the derived undrained shear strength (after Stroud and Butler 1975) are plotted on the graph of undrained shear strength versus depth (Figure 6.4). Measured undrained shear strength is plotted as black squares and derived undrained shear strength values are plotted as blue diamonds.

Figure 6:4 Undrained Strength v Depth – Bracklesham Beds



6.4.5 The apparent trend line in Figure 6.4 suggests a strength depth relationship of 40 + 7.5D kPa beyond 6m bgl.

6.4.6 Where buried concrete may come into contact with these deposits, samples subject to sulphate testing under BRE Special Digest 1:2005 'Concrete in Aggressive Ground' give a design water soluble sulphates value of 551 mg/l and corresponding Design Sulphate Class of DS-2. The pH analysis gives a resultant ACEC class of AC-2.

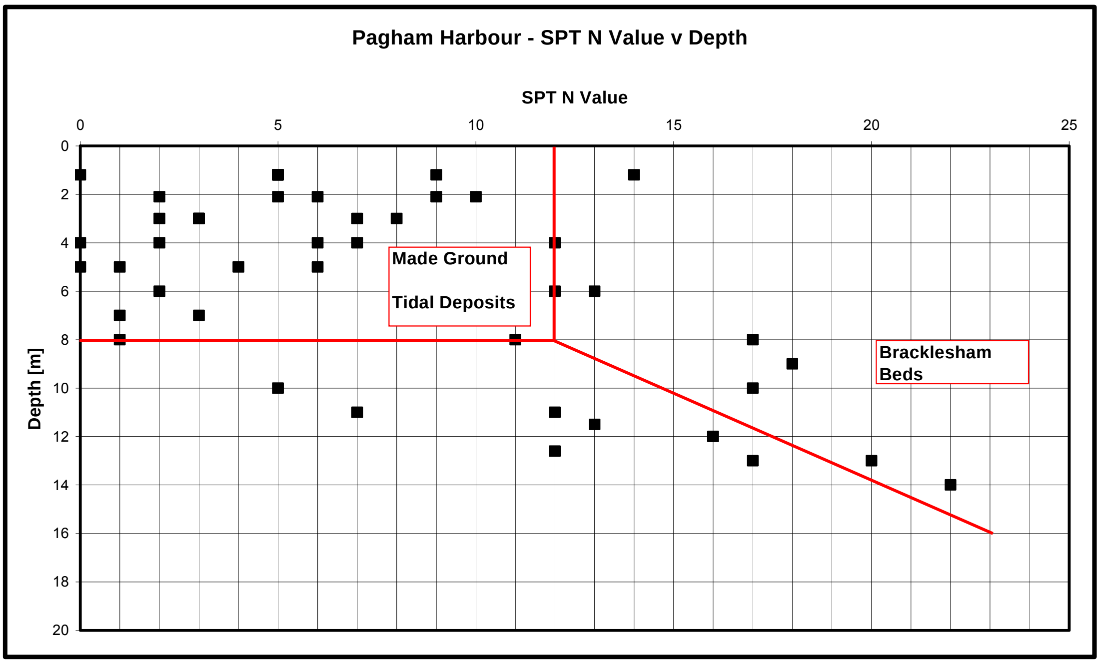
6.4.7 Where pyrite is present in the ground it is essential to take into account the total potential sulphate content which might result from oxidation following ground disturbance. Pyrite is present within the Bracklesham Beds. This may therefore increase the design sulphate class if the concrete is exposed to ground which has been disturbed to the extent that the pyrite oxidises.

6.5 Summary Results of In-situ Testing for all Strata

6.5.1 The Standard Penetration Test N Values were analysed for all the strata; Made Ground; River Tidal Deposits and Bracklesham Beds, at the site within the landfill area.

6.5.2 The analysis represented by Figure 6.5 shows the made ground and river tidal deposits extending from 1m bgl to 8m bgl, with the SPT N Value less than 10 and some as low as 0.5. Below this the Bracklesham Beds appear to gain strength with depth fairly rapidly with an estimated projected blow count of 20 at 14m bgl.

Figure 6:5 Standard Penetration Test N Value v Depth – All Strata



6.6 Groundwater

6.6.1 Groundwater was encountered during drilling in BH01 (at -4.33m AOD) and BH03 (at -9.70m AOD) within the Bracklesham Beds. The groundwater was encountered within the frequent partings of course grey sand. Over a period of 20 minutes the inflow of water was rapid with water level rising between 2.5m (BH01) and 6.9m (BH03).

6.6.2 Perched water was encountered with the landfill in BH05 (at 0.36m AOD) in material described as very sandy slightly gravelly clay with waste debris, and within all of the trial pits (between 1.56 and 0.96m AOD). Within the trial pits inflow into the excavations was generally found to be moderate to fast.

6.6.3 The long term monitoring shows that the head of groundwater within the Bracklesham Beds and the head of leachate within the landfill stand within 1m of each other, within the landfill, at a level of between 1.25m and 2m AOD.

6.6.4 In the event that any excavation works are required for foundations or services, appropriate groundwater control measures will be necessary.

Table 6:4 Groundwater Levels

Borehole / Trial Pit	Ground Level m AOD	Water Strike mbgl (m AOD)	Standing level after 20 mins mbgl (m AOD)	Installation Response Zone mbgl	Highest Water Level Monitored (m bgl)	Lowest Water Level Monitored (mbgl)
BH 01	3.67	8.00 (-4.33) BB	5.5 (-1.83)	7.5 – 15 (BB)	1.60	2.02
BH 02A	4.49			2.0 - 5.0 (L/F)	2.28	2.80
BH 03	2.90	12.60 (-9.70) BB	5.7 (-2.80)	7.0 - 10.0 (TRD/BB)	1.53	1.79
BH 04A	2.96			1.0 – 3.0 (L/F)	0.98	1.49
BH 05	5.36	5.00 (0.36) L/F	4.3 (1.06)	8.5 – 11.5 (TRD)	3.58	4.14
BH 06A	2.39			0.5 – 2.0 (L/F)	0.30	1.19
BH 07A	4.97			2.0 – 5.0 (L/F)	2.38	3.03
TP 01	3.02	1.50 (1.52) L/F (Fast inflow)				
TP 02	4.64	3.20 (1.44) L/F (Moderate inflow)				
TP 03	3.10	1.90 (1.20) L/F (Fast inflow)				
TP 05	2.41	1.20 (1.21) L/F (Fast inflow)				
TP 08	2.86	1.30 (1.56) L/F (Moderate inflow)				
TP 11	5.50	3.30 (1.20) L/F				
TP 13	3.91	2.50 (1.41) L/F				
TP 15	4.96	4.00 (0.96) L/F (Slow inflow)				

- L/F - Landfill, TRD – Tidal River Deposits, BB – Bracklesham Beds

6.7 Foundation Analysis and Recommendations

6.7.1 The ground conditions encountered in boreholes BH02 to BH06 are generally consistent, with made ground underlain by tidal river deposits which are in turn underlain by the Bracklesham Beds. In BH01, the tidal river deposits are absent from the sequence.

6.7.2 The upper 8m generally comprise made ground and tidal river deposits with Standard Penetration Test N Values averaging 6. The made ground is highly variable, both laterally and vertically. In addition, both the made ground and underlying tidal river deposits are very soft/very loose, the tidal river deposits also being submerged soils. On loading, the soils will settle excessively, and within the variable made ground the movement will be differential and therefore traditional shallow foundations are inappropriate within the shallow soils.

6.7.3 The consistently poor soil conditions limit the foundation options. In cases where there are sequences of very soft or unpredictable ground, there are several options including soil replacement, soil improvement, shallow raft foundation solution or transferring the load to the depth via a piled foundation solution.

6.7.4 In considering soil replacement, there is a balance between the depth of soil to be replaced and the net increase in loading depending on the nature of the imported soil, such that excessive settlement is avoided. In the absence of a building footprint or anticipated loads it is difficult to predict the volume of soil which would require replacement.

6.7.5 Any soils excavated from within the landfill would be classed as waste and technically should be disposed off site as waste, which would have a cost implication. However, as the site is a landfill, negotiation with the Environment Agency may conclude that any movement of the waste on site be classed as re-profiling.

6.7.6 Likewise, if it can be determined that any excavated Tidal River Deposits can be treated i.e. dried, and used elsewhere, in accordance with the design of the redevelopment it may be possible to obtain a Waste Management Licence Exemption from the Environment Agency.

6.7.7 However, taking the most conservative assumptions, the coefficients of volume compressibility of the shallow soils are high and variable and it is considered that settlements are likely to be intolerable.

6.7.8 The use of soil improvement methods using stone columns or other densification methods tends to be solutions that enhance the global stability of a site. The stone columns are used to reinforce cohesive soils to provide adequate support for relatively light foundation loads. This method is not suitable for higher loadings as the imposed stresses are not transferred to the underlying competent strata at depth. The columns also act as a drain accelerating the rate of consolidation of the soil.

6.7.9 In very soft cohesive soils there can be insufficient lateral confinement to hold the stone columns in place. On loading, the columns can spread laterally into the surrounding soils and the soft clay squeezes into the voids of the column. The overall affect of installing the column then in essence increases the vertical loading on the underlying soils. The scale of the visitor centre would not in our opinion justify the use of this technique.

6.7.10 Raft foundations are used on soils of low bearing capacity, whereby the foundations pressures are spread over a wide area. Furthermore, a raft can be used on soils of variable compressibility to minimise the differential settlement of the foundation slab.

6.7.11 A raft, constructed on an elevated platform of approved engineering fill would be suitable for the proposed visitor’s centre if the building is of sufficiently light loading i.e. constructed of lightweight structure of wood or similar material, and distributed evenly thus minimising the thickness and reinforcement necessary in the foundation slab and thus its self weight.

6.7.12 Otherwise, if loading of the building is significant, further consideration will be needed to the nature of construction of the raft. The partial rigidity of a slab and beam construction in essence bridges over the more compressible soils or alternatively, a reinforced steel slab can be constructed to avoid excessive deflection and structural failure of the raft.

6.7.13 Both forms of construction will have associated cost implications and further assessment will be necessary once the size of the footprint of the building and the structural column loads are known.

6.7.14 Settlement analysis including the time allowed for any surcharging would be critical in the design of such a structure. If sufficient time is allowed between the construction of the platform and the erection of the structure, the applied surcharging will trigger settlement. The amount of settlement occurring pre construction will be a function of time and amount of the surcharge applied. Full analysed can only be completed once the nature and loading conditions are known.

6.7.15 Alternatively, a piled foundation solution is the least risk option. Load is transferred down the piles to the more competent strata, i.e. the Bracklesham Beds, at depth. Piles offer the advantage of overcoming the settlement concerns and with careful selection of construction materials, can fit in with the overall environment suitable to a nature reserve.

6.7.16 With the site groundwater levels and the underlying tidal river deposits, a driven pile solution is the best option. The choice of material; steel, timber or concrete, may be a function of availability, price and the contractor's preference. The length of piles required will depend on the final design loads.

6.7.17 Piling can provide a pathway for contaminant migration from the made ground to the underlying tidal deposits and Bracklesham Beds, and also act as a conduits for ground gases to the surface. A piling risk assessment must be submitted to the Environment Agency for approval before piling works commence. In terms of the ground gases, a solution would be to have the visitors centre on stilts. This would have both the visual appeal of an old wooden pier and allow for venting of gases.

6.7.18 General guidance on the ultimate capacity of piles is presented below based on Tomlinson's analysis for frictional resistance. The analyses are limited to presentation of indicative values for an arbitrary driven pile of square concrete pile of dimension 300mm.

6.7.19 For the purpose of the simple analysis presented in Table 6.4, the contribution of the upper three layers to the skin friction is constant. The variation will be in the shaft resistance in the Bracklesham Beds which will be a function of the pile length.

6.7.20 For the purposes of design, the undrained strength of the Lower Bracklesham Beds (>15m) has been restricted to maximum of 100kPa for skin friction and the adhesion (α) to 0.5, thus limiting the αC_u to 50kPa. A maximum 20 metre pile has been allowed with a shear strength of 150kPa for end bearing.

6.7.21 The best case and worst case scenario in terms of ground conditions has been considered, represented by BH01 and BH05, respectively. It has been assumed that the made ground and the Tidal River Deposits will provide negative shaft friction or drag down.

Table 6:5 Design Table 300mm Pile - Best Case - BH01 (adhesion factor of 0.5)

Strata	Description	Thickness	Properties	Ultimate Capacity
Made Ground	Shaft Friction	4.7m	αC_u = 13 kPa	-76kN
Tidal Deposits	Negative Shaft Fiction	0.0m	αC_u = 15 kPa	- 0kN
Bracklesham Beds	Shaft Friction	7.0m	αC_u = 30 kPa	252kN
Bracklesham Beds	Shaft Friction	8.3m	αC_u = 50 kPa	498kN

Table 6:6 Design Table 300mm Pile – Worst Case - BH05 (adhesion factor of 0.5)

Strata	Description	Thickness	Properties	Ultimate Capacity
Made Ground	Shaft Friction	6.5m	αC_u = 13 kPa	-101kN
Tidal Deposits	Negative Shaft Fiction	5.0m	αC_u = 15 kPa	- 90kN
Bracklesham Beds	Shaft Friction	7.0m	αC_u = 30 kPa	252kN
Bracklesham Beds	Shaft Friction	1.5m	αC_u = 50 kPa	90kN

6.7.22 The ultimate pile capacity of a 20 metre pile ranges between a best case of 675kN and a worst case of 150kN. A conservative factor of safety of 2.5 is recommended given the nature of these soils yielding a safe pile capacity based on a 20m long pile ranging between 270kN (best case – BH1) and 60kN (worst case – BH5).

6.7.23 The final design length of a pile will be dependant on the final design loading of the proposed structure.

6.7.24 Based on a geotechnical assessment of the anticipated ground conditions at each of the six potential visitors centre locations, Table 6.6 below presents a summary of the ground conditions along with a preliminary assessment of suitability in terms of foundation design and construction.

Table 6:6 Summary Ground conditions at each of the six potential visitors centre locations

Location	Proven thickness of waste (W) and alluvial deposits (AD)	Summary Ground Conditions	Geotechnical Suitability for ground conditions for construction of new Visitor Centre.
BH01	4.7m (W), 0m (AD)	Alluvial Deposits are absent from the sequence in this exploratory hole (although they are recorded in the base of TP08 to the north). The made ground directly overlies the firm Clay of the Bracklesham Beds	Favourable - Best Option
BH02	6.0m (W), 0.5m (AD)	6.5m of soft materials proven to base of borehole, although thickness of alluvial deposits not confirmed. Also, high concentrations of landfill gases in this area	Unfavourable
BH03	3.0m (W), 5m (AD)	Total 8m of soft materials.	Unfavourable
BH04	3.5m (W), 1.0m (AD)	Base of alluvial deposits not proven (shallow borehole). Given thickness of alluvial deposits in BH03 and the similar position of BH04 close to Ferry Channel for BH04, thick alluvial deposits are expected.	Unfavourable
BH05	6.5m (W), 5m (AD)	11.5m of soft materials.	Unfavourable
BH06	1.5m (W), 1.1m (AD)	Thickness of alluvial deposits not proved (shallow borehole) but given thin layer of waste, this could be a good option. Further investigation to assess thickness of alluvial deposits would be required before pursuing this option	Favourable - Possible

6.8 Concrete Classification

6.8.1 Both a shallow raft foundation or piled foundation solution would need to accommodate the made ground at the surface and as such, the concrete classification for that strata should be adopted as this has the highest design sulphate class.

6.8.2 With reference to BRE Special Digest 1:2005 ‘Concrete in Aggressive Ground’ the design sulphate class of the made ground is DS-4 with a corresponding ACEC class of AC-4.

6.8.3 In applying this conservative approach, it is considered that this design sulphate class will allow for any potential oxidation of pyrite within the Bracklesham Beds during foundation construction.

6.9 Pavement foundations

6.9.1 California Bearing Ratios (CBR) within the made ground should be assumed to be less than 3% to overcome any variations close to ground level. Therefore a capping layer will need to be incorporated into a flexible pavement design where the pavement is bearing on the made ground.

6.9.2 The structural capping layer and subsequent pavement foundations should be rolled and compacted in lifts not exceeding 250mm to 95% of its Maximum Dry Density (BS 1377 Part 4 – Modified Proctor).

6.9.3 If material, is imported from the adjacent land to be used as a capping layer across the landfill a CBR of less than 3% should be assumed. The design CBR value of 1.5% has been determined for the Tidal River Deposits (Table 7.1). Prior to placement of any deposits from the adjacent site, both the Tidal River Deposits and London Clay will need to be dried so that an adequate compaction can be achieved (refer to Chapter 7). The drying process will raise the CBR and it is recommended that once the placed material has been compacted, in-situ testing using a TRL Dynamic Cone Penetrometer is undertaken to determine the construction CBR immediately prior to pavement construction. In essence, the effectiveness of the drying process will affect the CBR value achieved. The compacted materials should be protected from wetting prior to pavement construction.

6.10 Excavation Stability

6.10.1 Excavations of near surface materials can be handled by back acting excavators, however given the nature of the made ground and the proximity of the groundwater, sidewalls may require bracing if left open for extended periods.

6.10.2 Ingress of groundwater into shallow excavations was encountered during the investigation and was described as a fast inflow. Groundwater control measures would be required in excavations.

6.11 Re-use of Arisings

6.11.1 Material excavated from the landfill cannot be reused on site, the details of which have bee discussed in paragraph 6.7.5.

6.11.2 Reuse of the underlying Tidal River Deposits may be possible although this material will need to be treated before re-use. The natural moisture content of the soils is significantly greater than the optimum moisture content required for compaction and re-use. Therefore drying of the soils will be required before reuse.

6.12 Radon Gas

6.12.1 Assessment, in accordance with BR211 “Radon: guidance on protective measures for new dwellings” (1999) and the NRPB Radon Atlas of England and Wales, confirms that no radon protection measures are required for the site.

7 Geotechnical Assessment – Adjacent Land

7.1 Introduction

7.1.1 The primary focus of the geotechnical appraisal of the adjacent land is to understand the potential for excavation of the soils for reuse as a capping material cross the landfill, with a view that the ground levels will be sufficiently reduced such that a wetland area can be developed within the adjacent land.

7.1.2 This section will determine the suitability of soils within the adjacent land for reuse as a capping layer by examining the geotechnical parameters of the soils layers present in terms of moisture/density/compaction relationships. These parameters will govern how well the material can be placed and the options for soil improvement.

7.1.3 The tidal river deposits are present below a thin topsoil layer over the whole site except where made ground was encountered in TP17. The tidal river deposits are between 0.4 and 2.6m in thickness. These are underlain by Eocene London Clay

7.2 Tidal River Deposits

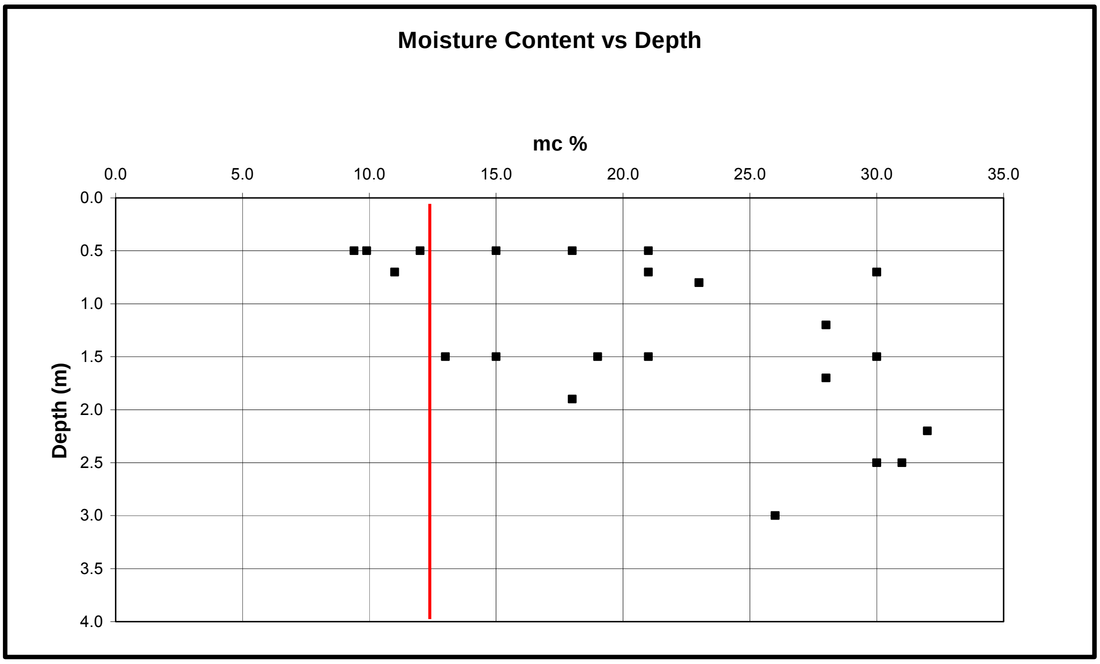
7.2.1 The key geotechnical parameters for the tidal river deposits on the adjacent land are summarised in Table 7.1 below.

Table 7:1 Geotechnical Parameters Tidal River Deposits

	Min	Max	Mean	No. of Tests	Design Values
Natural Moisture Content (%)	9	32	21	22	**25**
Optimum Moisture Content (%)	9	12	10	4	**12**
CBR	0.6	3.5	1.7	4	**1.5**
Liquid Limit (%)	24	74	47	12	**45**
Plasticity Index (%)	11	50	29	12	**30**
Granular Content	24	80	43	14	**40**

7.2.2 These deposits are all at or near the groundwater table which accounts for the high moisture contents. The moisture content versus depth is plotted in Figure 7.1. As a guide, the red line in Figure 7.1 indicates the design optimum moisture content for compaction.

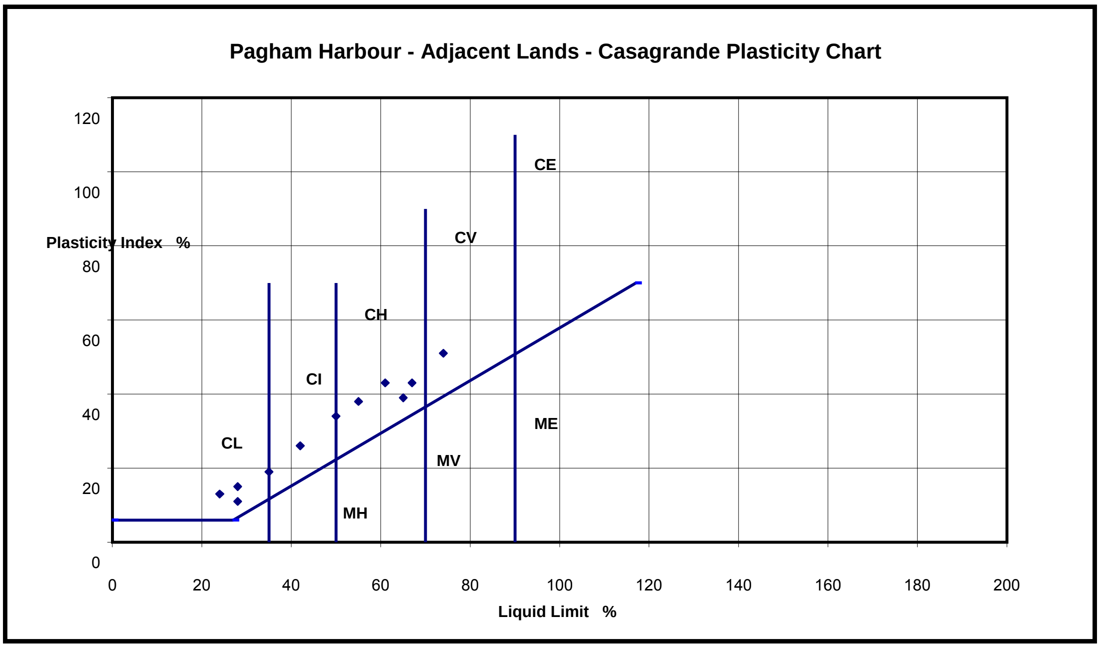
Figure 7:1 Moisture Content v Depth – Tidal Deposits



7.2.3 The natural moisture content of the tidal river deposits is greater than the optimum moisture content required to achieve the maximum dry density during compaction.

7.2.4 These tidal river deposits have widely varying granular content and this is reflected in the Atterberg Limits results where the Plasticity Indices range from 11 to 50, averaging 30. The results are presented in the Casagrande Chart below in Figure 7.2.

Figure 7:2 Casagrande Chart – Tidal River Deposits



7.2.5 Given the plasticity and the high moisture contents, the tidal deposits as they lie in situ would be difficult to place and compact elsewhere on site. Pre-treatment of the material will be required before reuse. The material will need to be dried to the optimum moisture content i.e. 12%.

7.3 London Clay (Eocene)

7.3.1 The relevant geotechnical parameters for the London Clay are summarised in Table 7.2 below.

Table 7:2 Geotechnical Parameters London Clay

	Min	Max	Mean	No. of Tests	Design Values
Natural Moisture Content (%)	22	31	26	6	**25**
Optimum Moisture Content	12	15	13	3	**14**
Liquid Limit (%)	42	63	50	4	**50**
Plasticity Index (%)	19	41	31	4	**30**

7.3.2 The deposits of London Clay are generally found below two metres bgl. In terms of re-use of material, the London Clay is similar in nature to the Tidal River Deposits.

7.3.3 The natural moisture content of the London Clay is greater than the optimum moisture content required to achieve the maximum dry density during compaction. Therefore pre-treatment of this material will be required before reuse. The material will need to be dried to the optimum moisture content i.e. 14%.

7.4 Pre-treatment (drying) and Compaction

7.4.1 Much of the drying process may happen during the excavation and placement process. With regard to the Tidal River Deposits, the material will be placed above its current level which is at or close to the groundwater table and given the granular content of these deposits which averages 40%, it is considered this granular portion within Tidal River Deposits would allow some drainage within the soil.

7.4.2 With regard to the London Clay, this should not be left to dry excessively otherwise the clay will become too hard and friable to be able to compact effectively.

7.4.3 It is recommended that excavation and placement of soils is undertaken during the summer months during which minimum rainfall and maximum temperatures are anticipated. During inclement weather, the placed soils should be protected from excessive wetting. The soils should be allowed to dry before compaction commences.

7.4.4 Both the Tidal River Deposits and the London Clay, once dried sufficiently, should thus be able to form an effective environmental capping layer for the landfill.

7.4.5 The deposits should be rolled and compacted in lifts not exceeding 250mm to 90% of its Maximum Dry Density (BS 1377 Part 4 – Standard Proctor).

7.5 Pavement Foundation

7.5.1 If material is imported from the adjacent land to be used as a capping layer across the landfill a CBR of less than 3% should be assumed for preliminary pavement foundation design. The design CBR value of 1.5% has been determined for the Tidal River Deposits. It is noteworthy however, that the CBR tests were completed at moisture contents well above the optimum. A CBR of less than 3% would suggest the requirement for a capping layer in a flexible pavement design.

7.5.2 However, prior to placement on the landfill, both the Tidal River Deposits and London Clay will need to be dried so that an adequate compaction can be achieved. This drying process will raise the CBR and it is recommended that once the placed material has been compacted, in-situ testing, using a TRL Dynamic Cone Penetrometer is under is undertaken immediately prior to pavement construction to determine the final pavement design. The compacted materials should be protected from wetting prior to pavement construction.

7.6 Groundwater

7.6.1 Groundwater seepage was encountered in WS1, WS3, WS4, WS5 and WS6, within or close to the base of the Tidal River Deposits. The depth to groundwater strike (no rise in level after twenty minutes occurred) ranged from 1.74m OD in the north of the site (WS1) to 1.06m OD in the south-east (WS5). Dampness was encountered at 2.5m depth (0.92m OD) in TP19, also within the Tidal River Deposits. No groundwater was encountered in the remaining trial pits.

7.6.2 No groundwater monitoring points were installed on this site.

7.6.3 Given the cohesive nature of the soils on site, it is anticipated that the permeability of the soils will be low and that groundwater will not have an adverse effect on the stability of shallow excavations.

7.7 Excavations

7.7.1 Removal of the surface materials can be handled by back acting excavators and given the variable granular nature of the Tidal River Deposits and their high in-situ moisture content sidewalls may require bracing if left open for extended periods. Alternately, the sides of the excavations may be battered back to a shallow angle of repose to prevent collapse.

7.8 Concrete Classification

7.8.1 With reference to BRE Special Digest 1:2005 ‘Concrete in Aggressive Ground’ the design sulphate class of DS-4 with a corresponding ACEC class of AC-4 as been recommended for buried concrete within the landfill site.

7.8.2 It is considered that this design sulphate class will allow for any potential oxidation of pyrite within the London Clay which may be laid as a capping layer over the landfill.

7.9 Pyrite Oxidation in London Clay

7.9.1 Once the Tidal River Deposits and London Clay has been excavated for use on the landfill, the remaining in-situ London Clay will have been sufficiently disturbed and exposed to the extent that the contained pyrite will oxidise. The resultant sulphate ions lead to the generation of acidic water.

7.9.2 If purchase of the adjacent land to create a wetland habitat is deemed likely, further assessment of the potential for oxidation of pyrite within the London Clay is recommended.

8 Tier 1 Human Health Assessment

8.1 Introduction

8.1.1 A Tier 1 human health assessment has been undertaken for both the Landfill Site and Adjacent Land in accordance with CLR (DEFRA) guidance and comprises the following:

- selection of appropriate screening values for human health Tier 1 assessment;
- assessment of contamination distribution and comparison of site data to screening values using mean and maximum value test (in accordance with CLR7);
- assessment of risks to receptors;
- determination of requirements for further investigation or remediation.

8.1.2 In the context of current UK Government guidance Planning and Pollution Control Guidance PPG23 and the Model Procedures for the Management of Land Contamination (CLR11), risks should be assessed using a “Source-Pathway-Receptor” assessment approach. Such an approach recognises that risks from site-based contaminants can only exist where all three components are present (constituting a complete pollutant linkage).

8.1.3 The risk assessment process will determine the Relevant Pollutant Linkages i.e., those where an unacceptable risk to human health or the environment has been identified based on the site’s proposed development plans. Remedial options will be designed to appropriately reduce or control these risks.

8.2 Assessment for Adjacent Land

8.2.1 The chemical and geotechnical assessment on the adjacent land was undertaken to assess the suitability of this material for use as capping on all or part of the landfill site.

8.2.2 The chosen screening value is residential without private gardens, the same as that for the landfill site. This is considered to be a conservative standard screening value given the proposed use of this material as a cap for the landfill site.

8.2.3 The ground investigation findings showed that with the exception of made ground in TP17, the results from across the adjacent land site were consistent, and therefore the soil results from the adjacent land have been assessed as one dataset.

8.2.4 Details of the analysis suite are provided in paragraph 3.4.3. With the exception of one concentration of arsenic, of 26mg/kg against a screening value of 20mg/kg, all results and 95% upper confidence levels (where calculated) including that for arsenic was below the respective screening values.

8.2.5 No further consideration is necessary.

8.3 Assessment for Landfill Site - Current and Future Site Use

8.3.1 This human health risk assessment considers the site for use as Public Open Space, as the public visiting the site use the visitor centre, car park, and designated footpaths to walk around the site.

8.3.2 The proposed development of the site to include a new visitor centre and car park together with areas of the site accessible to site visitors is similar to the existing site use. The classification of Public Open Space is therefore also acceptable for the proposed site. Refer to Revised Conceptual Site Model in Appendix 7.

8.4 Selection of Soil Screening Values

8.4.1 The chosen soil screening values for this Tier 1 assessment are published CLEA SGV's or Generic Assessment Criteria (GAC's) from Nathanial et al, 2007 for residential properties without gardens, where the receptor is a female child 0-6 years old on site all day every day of the year. This is considered to be a highly conservative choice of standard screening value given the proposed use.

8.5 Averaging Areas

8.5.1 The waste material is a heterogeneous mixture of waste and associated soil matrix, and all soil samples collected from the landfill site are from the waste material at various depths. The site is taken as a single averaging area since both the historic use and the proposed uses are approximately the same over the full area. The risk assessment assumes that exposure could be to the waste throughout the depth of the landfill, not just from the near surface. All results are therefore considered as one dataset.

8.6 Source-Pathway-Receptor Linkage

8.6.1 The public visiting the site are the main receptor considered for this assessment, and the source of contamination is the waste within the landfill site. Identified pathways are dermal (skin) contact, inhalation of volatile components and ingestion of soil. This assessment assumes that the public will be allowed access to all parts of the site in its current state, without any capping or other remedial measure.

8.7 Mean and Maximum Value Tests

8.7.1 Contaminant concentrations vary across a site. As a result, the mean concentration determined from a limited number of samples will have uncertainty associated with it, and will not necessarily equal the true mean concentration at the site. The mean value test requires the calculation of the 95% upper confidence level of the mean measured concentration, which is then compared against the chosen screening value. To be statistically representative, a minimum number of samples need to be used to calculate the 95% upper confidence level of the measured mean. In this case, the minimum number of samples used for assessment of a particular contaminant is 6.

8.7.2 In the data sets for some contaminants, individual concentrations at some locations may be significantly higher than those across the rest of the site. It is necessary to determine whether these significantly higher concentrations fall within the maximum of the range of values that can be expected from the sample population, or whether they are indicative of an area of higher contamination.

8.7.3 The maximum value test is used to determine whether significantly elevated concentrations statistically form part of the rest of the dataset, or whether they represent a different material and are hence "outliers". Where outliers are identified, it is necessary to determine whether additional investigation might be warranted in the vicinity to better understand the extent and nature of the contamination in that area.

8.7.4 Prior to undertaking the maximum and mean value tests, the dataset was screened to remove all concentrations that were recorded as below the limit of detection. The maximum value test was then undertaken on the remaining results, and unless otherwise stated any identified outliers were recorded and removed from the dataset before the mean value test was undertaken.

8.8 Results of the Tier 1 Assessment

8.8.1 Details of the analysis suite are provided in section 3.4.3.

8.8.2 No asbestos fibres were detected in any of the samples.

8.8.3 The following determinants were found to exceed relevant screening values These recorded one or more outliers, single concentrations or 95% upper confidence level concentrations of the mean above the respective screening values:

- Arsenic
- Lead
- Nickel
- Benzo(a)pyrene
- Chrysene
- Benzo(a)anthracene

8.8.4 The results and calculated 95% upper confidence level values for all other determinants were below the screening values.

8.8.5 Exceedance tables showing the determinants, screening values, concentrations less than the limit of detection, individual exceedances, 95% upper confidence level concentrations and results of the maximum value test are presented in Appendix 4.

8.8.6 All depths listed in this section are in metres below ground level (m bgl).

Arsenic

8.8.7 The calculated 95% upper confidence level for arsenic (excluding the single identified outlier) is 20.7mg/kg, marginally in excess of the screening value (20mg/kg). The 95% upper confidence level for arsenic including the outlier value is 39.3mg/kg.

8.8.8 Six elevated arsenic concentrations were identified above the screening value of 20mg/kg (see exceedance tables in Appendix 4 for details).

8.8.9 There is no obvious correlation between the significantly elevated concentration present in BH02 (identified as an outlier) and the material observed within the landfill at that depth, and this concentration should therefore be considered as representative of the variation within the landfill material as a whole. i.e., a similar outlier could occur anywhere else in the landfill.

Lead

8.8.10 There are moderate to high concentrations of lead across the site, and the 95% upper confidence level of 525mg/kg exceeds the screening value of 450mg/kg. No outliers were identified. Five individual exceedances above the screening value are present across the site (see exceedance tables in Appendix 4 for details).

Nickel

8.8.11 There is one elevated concentration that exceeds the 75mg/kg screening value: 110mg/kg in BH05 at 0.9m (sample 040), and this is identified as an outlier. The 95% upper confidence level (37mg/kg) is below the screening value.

Benzo(a)pyrene

8.8.12 There are mildly elevated concentrations of benzo(a)pyrene across the site, and the 95% upper confidence level of 3mg/kg exceeds the screening value of 1.3mg/kg. No outliers are identified in the maximum value test (see exceedance tables in Appendix 4 for details).

Chrysene

8.8.13 One elevated concentration of 8.7mg/kg was recorded in TP8 and 1.4m (sample 004) against the screening value of 8.09mg/kg. The 95% upper confidence level is 2.6mg/kg. No outliers were identified for Chrysene.

Naphthalene

8.8.14 One elevated concentration of 15mg/kg against the screening value of 7mg/kg was recorded in TP8 at 1.4m (sample 004). There were insufficient samples (three, including this exceedance) with concentrations above the limit of detection to allow the 95% upper confidence level to be calculated.

Benzo(b/k)fluoranthene

8.8.15 One elevated concentration of 20mg/kg was recorded in TP8 and 1.4m (sample 004), against the screening value of 14mg/kg. The 95% upper confidence level is 6mg/kg. No outliers were identified.

Other outliers

8.8.16 In adition to the outliers identified above, outliers were identified for chromium (three), anthracene (two), phenanthrene, fluoranthene, pyrene, and C16-C21 aromatic TPH (one).

8.9 Discussion - Landfill Site

8.9.1 The elevated concentrations of arsenic, lead, nickel, benzo(a)pyrene, chrysene and benzo(a)anthracene exceeding relevant human health screening criteria have are associated with the presence of waste materials identified throughout the soil profile within the landfilled area. There is therefore a potential risk to future site users arising from direct contact / ingestion of surface and near surface soils.

8.9.2 The lack of any detectable concentrations of any volatile compounds from the BTEX and fractionated TPH analysis indicates no significant vapour risks to the public and site staff from this site.

8.9.3 In the case of lead and benzo(a)pyrene the 95% upper confidence level exceeds the screening value and there are materials in the ground which at these concentrations could pose an unacceptable risk for the assessed end use. Three of the fifteen samples were below the limit of detection (0.1 mg/kg).

8.9.4 For arsenic, the 95% upper confidence level calculated both with and without the outlier value included does exceed the screening value. Most of the exceedances are only slightly above the screening value, but the one significant concentration of 160mg/kg in BH02 at 0.5m, in the same location as the greatest exceedance for lead. Given the heterogeneous nature of the waste material, and the lack of evidence to indicate the source for this significantly elevated concentration, the identified outlier is considered representative of the waste material as a whole. Any recommendations for lead and benzo(a)pyrene will likely be protective for these concentrations of arsenic as well.

8.9.5 With respect to chrysene, naphthalene and benzo(b/k)fluoranthene, these exceedances are recorded in the same location (1.4m bgl in TP8), and represent the only exceedance of the screening value for all three determinants. In the case of chrysene and benzo(b/k)fluoranthene, the 95% upper confidence level is below the screening value and no further consideration is considered necessary. In the case of naphthalene, the low concentrations identified across the site has meant that of the 18 samples tested, only three results were above the limit of detection, and the 95% upper confidence level w calculated. This individual elevated concentration is not considered further.

8.9.6 The singular exceedance of nickel at 0.9m in BH05 may represent a localised hotspot. However, given its presence in the same location as other exceedances for lead, benzo(a)pyrene and arsenic which do require further assessment, and given the 95% upper confidence level is below the screening value, no specific consideration is required.

8.9.7 In the case of the determinants which have one, two or three outliers but where no exceedances of the screening values are present, these outliers are considered most likely to represent the inherent variability within the landfill waste material and not specific areas of elevated concentrations. As the concentrations and 95% upper confidence level do not exceed the screening values, no specific consideration is required.

8.10 Discussion – Adjacent Land

8.10.1 Using BRE guidance 465 (2004) a capping thickness for the landfill site was calculated. The input values used were the 95% upper confidence level for benzo(a)pyrene and lead (the two determinants from the landfill site where the 95% upper confidence level exceeded the screening value), together with the concentrations of these determinants found in the soils on the adjacent land. The calculation assumed a 600mm thick mixing zone and the Target Guideline Value as the respective screening values.

8.10.2 The resulting cap thickness was calculated as 89mm for lead and 352mm for benzo(a)pyrene. This indicates that, based on the chosen screening values, the concentrations of benzo(a)pyrene found within the landfill are the driving factor in the requirement and thickness of a capping layer on the waste material, and that a capping thickness of at least 352mm would be required to reduce the risks to human health receptors to an acceptable level.

9 Ground Gas Risk Assessment (Landfill)

9.1 Introduction

9.1.1 A ground gas risk assessment has been undertaken in accordance with CIRIA Guidance C659 (now C665), "Assessing Risks Posed By Hazardous Ground Gases To Buildings" 2006 (2007), and comprises the following:

- Assessment of results;
- Conceptual Site Model;
- Calculation of Gas Screening Values for Methane and Carbon Dioxide;
- Assessment of risks from ground gas;
- Development Options

9.2 Assessment of Results

9.2.1 Concentrations of methane, carbon dioxide, oxygen, hydrogen sulphide and carbon monoxide were measured using a calibrated Geotechnical Instruments Gas Monitor GA2000. The atmospheric pressure was greater than 1000mbars in all rounds, with a positive (increasing) pressure trend during the first three rounds of monitoring and a falling pressure trend during the last round of monitoring.

9.2.2 A flow pod was used to measure flow rates, and initial and steady state results are available for the second two rounds of monitoring (30th January and 5th February 2008).

9.2.3 No volatile compounds were identified within the BTEX or fractionated TPH analysis undertaken on the soil samples from the landfill, and no gas monitoring for these compounds was considered necessary.

9.3 Conceptual Site Model

9.3.1 Degradation of waste material within this 30-40 year unlicensed unlined landfill is the source for elevated concentrations of methane and carbon dioxide within the landfill waste material across the site. The highest concentrations of methane and carbon dioxide recorded within the monitoring installations generally correlate with the recorded quantities of degradable materials (wood, paper and textiles) on the exploratory hole logs.

9.3.2 The main pathway for the movement of ground gases on the site is considered likely to be escape from the surface of the uncapped landfill into the atmosphere. Secondarily, migration will be through the landfill material in the unsaturated zone, which is of variable but generally low permeability comprising sandy clays and waste material. The level of perched groundwater within the landfill is not tidally influenced, and whilst levels remained generally consistent during the first two rounds of monitoring, the groundwater levels were higher during the second two monitoring rounds. The approximate unsaturated zone thickness within the response zone of the installations during the first two monitoring rounds was around 1m (0.5m in BH04 and 2m in BH07), allow gas to migrate through the upper parts of the landfill and accumulate within the plain top 1m of monitoring standpipe.

9.3.3 During the second two rounds of monitoring, the water level was on average 0.5m higher, reducing the depth of the response zone in the unsaturated strata to 0.5m or less in BH01, BH02, BH03, BH05 and BH06, to 1.5m in BH07 and eliminating the response zone in the unsaturated strata in BH04.

9.3.4 Ground gases (in particular carbon dioxide, which is denser than air) may also migrate around and offsite along services routes, in particular water and drainage services around the western part of the site.

9.3.5 If the drainage channel (Red Barn Ditch) that crosses the northern part is not underlain by waste material, then it may act as a barrier to the migration of ground gases between the landfilled areas to the north and south. However, the depth of the channel is not as deep as the base of the landfill recorded to the north and south, and there is the potential, although considered slight that waste material may be present beneath the channel. If this is the case, it will likely act as a pathway for ground gases to migrate between the areas to the north and south of the channel.

9.3.6 The current receptors on the site are the general public visiting the site and the visitor centre buildings. The absence of a cap will allow much of the ground gases generated to escape into the atmosphere, and the risks to human health for visitors walking along the designated footpaths across the site are considered low. In the case of the visitor centre, where the landfill is thinnest, degradable materials appear absent and the concentrations of methane and carbon dioxide are low.

9.3.7 The future receptor on site is the proposed visitor centre, for which there are six proposed locations (the locations of the borehole monitoring installations except BH07). Of the six locations, the area around BH03 (south-eastern corner of the site) and BH06 (existing visitor centre location) have the lowest recorded concentrations of landfill gases. In the remaining areas, with a greater thickness of landfill waste and greater quantity of degradable materials present, the concentrations of methane and carbon dioxide are higher, and risks to the proposed new building without protection measures is moderate to high.

9.3.8 Potential off-site receptors include the farmland to the north of the site (“Adjacent Land”) (not considered high risk due to current agricultural land-use with no obvious vegetation distress) and the buildings comprising the Saliota Nursery to the north-west. The depth of the landfill is less on the western side of the site, typically around 1.5m, with less degradable material recorded (BH6 and TP5) and low concentrations of methane and carbon dioxide as generally recorded in BH04 and BH06. In addition, the drainage channel running north-south at the boundary of the “Adjacent Land” and Saliota Nursery may minimise ground gas migration to the Nursery site from the eastern part of the landfill. The potential risks posed to the buildings on the Saliota Nursery site are considered moderate to low.

9.4 Calculation of Gas Screening Values

9.4.1 A Gas Screening Value is derived by multiplying the maximum gas concentration (%) by the maximum measured flow rate (l/h).

Table 9:1 Gas Screening Value for Methane

Monitoring Location	Highest measured CH4 concentration (%)	Flow Rate (l/h)	GSV	Risk Classification	Characteristic Situation
BH1	0.5	0.1	0.0005	Very low risk	1
BH2a	8.2	0.7	0.057	Very low risk	1
BH3	0.3	0.2	0.0006	Very low risk	1
BH4a	0.2	0.2	0.0004	Very low risk	1
BH5	4.2	0.8	0.034	Very low risk	1
BH6a	0.4	0.2	0.0008	Very low risk	1
BH7a	1.3	0.2	0.0026	Very low risk	1

Table 9:2 Gas Screening Value for Carbon Dioxide

Monitoring Location	Highest measured CO2 concentration (%)	Flow Rate (l/h)	GSV	Risk Classification	Characteristic Situation
BH1	15.1	0.1	0.015	Very low risk	1
BH2a	21.6	0.7	0.151	Low risk	2
BH3	3.4	0.2	0.0068	Very low risk	1
BH4a	16.0	0.2	0.032	Very low risk	1
BH5	19.7	0.8	0.158	Low risk	2
BH6a	7.2	0.2	0.014	Very low risk	1
BH7a	14.9	0.2	0.030	Very low risk	1

9.5 Assessment of Risk from Ground Gas

9.5.1 The results indicate that the maximum measured flow rates in BH02 and BH05 are the driving factor in the risk from ground gases for this site.

9.6 Development Options

9.6.1 Table 8.6 in the CIRIA 659 (C665) guidance provides indications of the protective measures required depending on the characteristic situations. The typical scope of protective measures for the development of office / commercial / industrial use in the highest risk areas (around BH02 and BH05) is recommended as a one of the following options:

- Reinforced concrete cast in-situ floor slab with at least 1200g damp proof membrane;
- Beam and block or pre- cast concrete slab and minimum 2000g damp proof membrane or reinforced gas membrane;
- Possibly underfloor venting or pressurisation in combination with a) and b), depending on design and use.

9.6.2 All joints and penetrations to be sealed.

9.6.3 These recommendations are considered appropriate for the new visitor centre building at all of the proposed visitor centre locations.

10 Tier 1 Controlled Waters Assessment

10.1 Methodology

10.1.1 A Tier 1 assessment has been undertaken as follows:

- Development of conceptual hydrogeological model;
- Selection of appropriate screening values for controlled waters Tier 1 assessment;
- Comparison of measured groundwater and landfill leachate results with defined screening values;
- Assessment of contaminant distribution;
- Assessment of risk to receptors; and
- Determination of requirements for further investigation or remediation.

10.2 Conceptual Hydrogeological Model

10.2.1 The geological strata at the site comprise made ground (landfill) overlying sandy clay deposits of Quaternary and Eocene age. The made ground is a sandy gravelly clay with frequent waste items, formed by the landfilled material, which is anticipated to have a moderate to high hydraulic conductivity. The underlying deposits are predominantly soft alluvial clays with some sand (Quaternary River Tidal Deposits) over layers of sandy clay and clayey sand (Eocene Bracklesham Beds). The Bracklesham Beds are classified as a minor aquifer, but at this location, based on the lithology encountered in boreholes, these strata can be considered to comprise a non-aquifer. The Quaternary River Tidal Deposits and Bracklesham Beds together form an aquitard which has the effect of hydraulically isolating the landfill.

10.2.2 The site is largely surrounded by surface water formed by the harbour and associated drainage channels, and Ferry Pool on the landward side of the site.

10.2.3 Data loggers were used to capture the changes in groundwater levels in six boreholes at 15 minute intervals for one week. The measured groundwater levels are plotted together with predicted tidal variation for this period on the chart in Appendix 6. They show tidal variation in the underlying natural strata, but no discernible variation in the landfill leachate.

10.2.4 The underlying groundwater in the natural strata (Quaternary River Terrace Deposits and Eocene Bracklesham Beds) shows a tidal range of approximately 0.3m in BH1, 0.15m in BH3 and.0.03m in BH5 (furthest from harbour). The groundwater levels in these boreholes indicate a hydraulic gradient of 0.002 toward the south.

10.2.5 The leachate within the landfill is not tidally influenced. This indicates that it is not well connected hydraulically to the underlying strata. The elevation of the landfill leachate in boreholes is typically between 1.25mOD and 2.25mOD, with the highest levels recorded on the eastern side of the site and an interpreted hydraulic gradient both southwards and westwards from this area. This may reflect groundwater flowing from the central part of the landfill towards the lowest areas where discharge at the surface or sub-surface may occur. The presence of the highest landfill leachate levels on the eastern side of the site adjacent to the former railway line, together with the absence of tidal fluctuation in these boreholes, indicates that there is no significant hydraulic connection between the perched landfill leachate and Pagham Harbour or the Red Barn Ditch.

10.2.6 The surface of the landfill is generally open with no capping material and frequent but not continuous plant cover.

10.2.7 The annual amount of precipitation (rainfall) for the site area is reported to be 714mm (Meteorological Office average annual rainfall (1961-1990), Bognor Regis weather station) and given the surface ground conditions, a relatively high proportion of infiltration of around 30% is considered likely. Precipitation will soak into the made ground, and infiltrate down through it leaching contaminants from the made ground.

10.2.8 The accumulating leachate is known to emerge at the ground surface along the northeastern side of the site and may flow away in service ducts. There is also likely to be some flow (although very slow) both vertically into the underlying strata and laterally into the Red Barn Ditch and the harbour. In all cases Pagham Harbour is the main receptor for any contamination migrating from the leachate.

10.2.9 Assessing the conceptual model from a source-pathway-receptor approach, the source of the contaminants present is the landfill material, the pathway is the leaching of these contaminants by infiltrating precipitation and migration first vertically through the base of the landfill and then laterally in the underlying strata, and the receptor is the estuarine water in Pagham Harbour. The groundwater below the site is not considered as a separate receptor as the sandy clays are of low hydraulic conductivity and form an aquitard, and the groundwater is saline and not suitable for use.

10.2.10 The water quality data provides further evidence about the hydrogeology and the hydraulic connections between the various water bodies. The electrical conductivity (EC) provides an indication of the relative degrees of seawater, landfill leachate and freshwater influence on the sampled waters. The EC of seawater is approximately 40,000 µS/cm. The EC of fresh clean groundwater is usually less than 1000 µS/cm and the EC of landfill leachate is highly variable, but typically between 2000 and 10000 µS/cm. Some observations regarding EC from samples at the site and their interpretation are listed below:

- The EC of the leachate from boreholes and trial pits in the central part of the landfill is typically between 2000 and 4500µS/cm.
- The groundwater sampled from below the landfill has EC in a similar range, although one sample from BH5 had a higher EC at 6400µS/cm. This could be a result of the influence of seawater or landfill leachate or both.

- The groundwater and leachate from boreholes BH3 and BH4 has EC of 13000-18000 µS/cm . These high values demonstrate seawater mixing.
- The EC of the leachate/perched water in BH6 is lower than the leachate at 1600 µS/cm which is indicative of a much lower strength of leachate/greater dilution of leachate with rainwater or groundwater.

10.2.11 Consideration of the relative proportions of chloride ion (indicative of seawater) and ammonium (indicative of leachate) suggests the following:

- the results show three principal end members with results falling between them representing mixtures of water – the three end members are landfill leachate, estuarine water and fresh surface waters;
- the landfill leachate is mainly characterised by high ammonium (~50-250 mg/l) and relatively low chloride (<500mg/l) concentrations;
- the estuarine/seawater is characterised by high chloride and relatively low ammonium;
- the surface water is generally characterised by low ammonium and low chloride, but with a range of concentrations of both reflecting varying degrees of mixing of fresh water with leachate;
- the samples from BH3 appears to represent a mixture between seawater and freshwater, although there may be a degree of influence from the landfill;
- the samples from BH4 appears to have a much greater influence from the landfill than the BH4 samples and represent a mixture between seawater and leachate;
- the results from SW1 and SW2 have highly variable chloride which reflects the tidal flux in and out of Red Barn Ditch;
- the samples from BH1 suggest that the leachate has affected the groundwater to a greater degree in this area than in the other areas where groundwater has been sampled. This may be because the River Tidal Deposits are absent in this area.

10.2.12 The results suggest that the leachate is generally hydraulically isolated from the harbour and surrounding surface waters and that there is only limited hydraulic connection between the landfill and the underlying groundwater. There may be a limited influence on the landfill leachate quality from seawater. The surface waters sampled from the northeastern edge of the landfill are affected by landfill leachate but are diluted with surface water run-off. Typically the ratio of magnesium:calcium in the seawater samples from the site is approximately 1:2.5, whilst these samples have much lower ratios of less than 0.5:1. This indicates (contrary to initial interpretations in the Phase 1 report) that the influence of seawater on the landfill leachate is minor.

10.3 Identification of Screening Values for Tier 1 Assessment

10.3.1 The measured concentrations of potential contaminants of concern were screened against Environmental Quality Standard (EQS) for sea water, since the tidal waters of Pagham Harbour which are essentially marine in nature are the principal receptor for contaminated groundwater / leachate from the site. Where no sea water EQS is available, other standards were used for the screening, such as freshwater EQS or UK Drinking Water Standard. The screening values are presented with the full groundwater and surface water chemistry dataset in Appendix 6.

10.3.2 Nitrite values of several tens to several hundreds of milligrams per litre have been reported in some of the samples from site from the first round of monitoring the boreholes. In subsequent rounds of monitoring the results have mostly been below the limit of detection. In the surface water samples there is a similar pattern with very high concentrations on the first sampling round and very low subsequently. Nitrite normally occurs as an intermediate stage between nitrate and ammonium and its concentrations are generally much lower than the corresponding ammonium or nitrate concentrations. It has not been possible to establish from the testing laboratory why such high nitrite results have been recorded in the samples from the boreholes and consequently they are being ignored at this stage.

10.4 Surface water samples: screening

10.4.1 The surface water samples indicated the following exceedances:

- Red Barn Ditch: exceedances in copper and zinc observed upstream of the site and in decreasing concentrations through the site. While the decrease in these concentrations may indicate an upstream source for these chemicals, they are also observed in ponded surface water / leachate on the site, suggesting that leachate from the landfill may be having a minor impact on the Red Barn Ditch throughout its course through the site and with some dispersion upstream.
- Water sampled from ponded surface water / leachate along the northern boundary of the site had exceedances in nitrate and ammonium, copper and zinc.
- Standing water near the current visitor's centre had exceedances in copper and zinc only.
- No exceedances were observed in the sample from the Ferry Pool; or the adjacent drain.
- ammonium and zinc concentrations exceeded the screening value in one of the samples from the edge of the harbour.

10.5 Water samples from trial pits

10.5.1 Five water samples were taken from trial pits during excavation, from trial pits 1, 2, 5, 8 and 13. The sample from TP2 was tested for total petroleum hydrocarbons only. These samples revealed exceedances for chromium only, exceedances are tabulated below. Ammonium was not tested.

Table 9:1: Exceedances of screening values in water from trial pits

Analyte	Screening Value (mg/l)	TP1 (mg/l)	TP5 (mg/l)	TP8 (mg/l)	TP13 (mg/l)
Chromium	0.015	n.e.	0.045	0.022	0.035

n.e. = no exceedence of screening value

10.6 Leachate Test Screening

10.6.1 Leaching test and analysis was undertaken on three soil samples were taken from trial pits during excavation, from TP2, TP11 and TP15. The only exceedance above screening values was for ammonium in all samples, as tabulated below.

Table 9:2: Exceedances of screening values in leachate tests

Analyte	Screening Value (mg/l)	TP2 (mg/l)	TP11 (mg/l)	TP15 (mg/l)
Ammonium	1	19	19	20

10.7 Groundwater Screening

10.7.1 Groundwater samples were taken on two occasions in November 2007, and analysed for a range of chemicals. Screening revealed exceedances for nitrite and ammonium, arsenic, chromium, copper, nickel and zinc from the first round of sampling. Samples from installations within the made ground of the landfill were tested for TPH, which was not detected.

Table 9:3: Exceedances of screening values in groundwater samples (mg/l)

Analyte and Screening value		**BH1**		**BH2**		**BH3**		**BH4**		**BH5**		**BH6**		**BH7**	
Installation position		Natural		Made Ground		Natural		Made Ground		Natural		Made Ground		Made Ground	
Date		6/11	15/11	6/11	15/11	6/11	15/11	6/11	15/11	6/11	15/11	6/11	15/11	6/11	15/11
Nitrite	0.5	33	ne	60	ne	ne	Ne	ne	ne	ne	ne	25	Ne	59	Ne
Ammonia	1	63	70	150	170	1.5	0.6	67	62	3.9	4.8	51	52	150	160
Arsenic	0.025	Ne	ne	ne	ne	0.036	0.045	0.042	0.049	ne	0.031	ne	Ne	ne	0.028
Chromium	0.015	0.07	0.1	0.1	0.15	ne	Ne	0.059	0.061	0.018	ne	ne	0.041	0.11	0.17
Copper	0.005	0.0095	ne	0.0066	0.013	0.034	0.088	0.12	0.28	0.01	0.071	ne	Ne	ne	0.0079
Nickel	0.03	ne	ne	ne	ne	0.064	0.054	0.032	ne	ne	ne	ne	Ne	0.037	ne
Zinc	0.04	ne	ne	ne	ne	0.083	0.049	ne	ne	ne	ne	ne	Ne	ne	ne

ne = no exceedances of screening value

10.8 Assessment of risks to controlled waters

10.8.1 The screening indicates that the landfill leachate contains high concentrations of ammonium and elevated concentrations of chromium. Detail inspection of the other exceedances suggests that, whilst there are some concentrations marginally above the screening value there is no pattern indicating that they originate from the landfill. The exceedances of zinc, nickel and arsenic are marginal with the highest concentrations of copper and zinc originating from the natural ground in BH3. With respect to the exceedances recorded for copper, it is considered that the screening value represents the solubility limit of copper in estuarine waters and we would expect copper entering the harbour to precipitate down to this level.

10.8.2 The ratio of ammonium concentration between the leachate and the underlying groundwater is generally 30-50:1, indicating significant dilution of the infiltrating leachate by groundwater, probably flowing from the north. The sample from BH1 is not consistent with this observation, since at this location the ammonium concentration in the underlying strata is similar to that in the landfill. This suggests better hydraulic connection between the landfill leachate and underlying strata where the Tidal River Deposits are absent.

10.8.3 The lithology and hydraulic gradients suggest that the horizontal groundwater flow rate to Pagham Harbour, below the site is very low at a few tens of metres cubed per year. The ammonium ratio suggests that a very small proportion of this comprises landfill leachate. This is consistent with the low hydraulic conductivity of the River Tidal Deposits and the low vertical hydraulic gradients. The condition may be different in the northern part of the landfill, but the flux of leachate to surface waters is, nevertheless, very low.

10.8.4 The surface of the landfill is uncapped and therefore the rate of infiltration is expected to be high. This will result in a high rate of leachate accumulation. A small proportion is expected to flow to the underlying groundwater, another very small amount probably migrates directly through the railway embankment and sides of Red Barn Ditch and some ponds on the northern side of the landfill and either evaporates or under very wet conditions flows away. These losses probably do not account for all the gains and therefore some sub-surface losses are also expected, probably via services runs in the area of the visitors centre.

10.8.5 The leachate accumulating in the landfill is likely to flow to surrounding surface waters and ultimately reach Pagham Harbour where dilution by several orders of magnitude is anticipated.

10.8.6 In summary, the landfill leachate is characterised by high ammonium concentrations and some low concentrations of metals, specifically chromium. The flow of leachate to the surrounding environment is at a very low rate through the underlying groundwater and edges of the site. The harbour itself provides a very high degree of dilution for ammonium entering its waters and the potential for a significant effect on the ecology of the harbour or its water quality is negligible.

10.8.7 There is some concern about leachates which over-top the northern margin of the site and potential leachate losses via unidentified pathways such as service runs.

11 Summary and Conclusions

11.1 Ground Conditions

11.1.1 The ground investigation on the landfill has proved the thickness of the waste at the exploratory hole locations, from 1.5m thick in the west and south near the existing visitor centre and bird hide (where the ground level is lower) to between 5m and 6.5m thick in the central and eastern parts of the site. The waste material comprises a sandy gravelly clay with a mixture of household waste, including paper, textiles, plastics, tin cans and glass bottles together with car parts, tyres, metal, wood, brick and concrete.

11.1.2 The decomposition of degradable materials within this 30-40 year old landfill is producing significant concentrations of carbon dioxide and less so of methane, which is expected in landfills of this age, indicating that it is now in the anaerobic phase.

11.1.3 On the adjacent land, topsoil overlies Quaternary River Terrace Deposits (alluvial deposits), which in turn overlie firm sandy clays of the London Clay formation. A small quantity of made ground was identified in one location, otherwise the soils comprised natural strata.

11.2 Geotechnical Considerations

11.2.1 The made ground and River Tidal Deposits have similar geotechnical properties with an average SPT N Value of 6, widely variable moisture content averaging 40% and a safe bearing capacity of less than 60kPa. The combined maximum thickness of these two strata is 8m, and given the River Tidal Deposits are below the water table and act in a semi-fluid state (design moisture content approaches the design liquid limit) these strata will settle excessively upon loading. In addition, the variable made ground within the landfill will cause differential settlements and therefore traditional shallow foundations are considered inappropriate for this site.

11.2.2 The Bracklesham Beds are slightly sandy clays with less granular content than the overlying tidal deposits, with an associated higher plasticity index average of 45. The average undrained shear strength is between 50 and 60kPa, with a mean value of 55 kPa. A strength-depth relationship of 40+7.5D kPa beyond 6m bgl has been established.

11.2.3 Soil replacement, soil improvement, shallow raft and piled foundation solutions have been considered for the proposed visitor centre locations (BH01 to BH06). The final solution will be dependent upon the proposed design loads and size of structure footprint. The principal control influencing the future foundation design is the potential for settlement, and more particularly the differential settlement, within the made ground and Tidal River Deposits.

11.2.4 Whilst a piled foundation solution is considered to provide the least risk option by transferring the imposed load down the piles to the Bracklesham Beds at depth, a raft foundation solution may also be considered. Both options are viable, but final design and hence associated cost implications cannot be determined until the proposed structural loads are known.

11.2.5 A safe pile capacity of 150 kN has been estimated. As any pile will traverse the made ground, we adopt the concrete classification for that strata which is DS-4, AC-4 (BRE Special Digest 1:2005 'Concrete in Aggressive Ground'). Furthermore, piling provides a pathway for contaminants and ground gases and a piling risk assessment done to the Environment Agency Standards must be carried out before piling works commence.

11.2.6 California Bearing Ratios within the made ground should be taken as 3% to overcome any variations in the made ground. The material as such will require a capping layer within a flexible pavement foundation design. Any structural capping layer and subsequent pavement foundations should be rolled and compacted in lifts not exceeding 250mm to 95% of its Maximum Dry Density (BS 1377 Part 4 – Modified Proctor).

11.2.7 With respect to the Adjacent Land, in terms of re-use of material, the London Clay is similar in nature to the Tidal River Deposits. The natural moisture content of both deposits is greater than the optimum moisture content required to achieve the maximum dry density during compaction. Therefore pre-treatment of this material will be required before reuse. The material will need to be dried to the optimum moisture content.

11.2.8 Much of the drying process may happen during the excavation and placement process. It is recommended that excavation and placement of soils is undertaken during the summer months during which minimum rainfall and maximum temperatures are anticipated. With regard to the London Clay, this should not be left to dry excessively otherwise the clay will become too hard and friable to be able to compact effectively. During inclement weather, the placed soils should be protected from excessive wetting. The soils should be allowed to dry before compaction commences.

11.2.9 Both the Tidal River Deposits and the London Clay, once dried sufficiently, should thus be able to form an effective environmental capping layer for the landfill. The deposits should be rolled and compacted in lifts not exceeding 250mm to 90% of its Maximum Dry Density (BS 1377 Part 4 – Standard Proctor).

11.2.10 Where pavements are to be constructed on this newly laid capping layer, for design purposes a CBR of <3% should be assumed. However, the drying and compaction of the capping layer will raise the CBR of the material. It is therefore recommended that in-situ CBR testing is undertaken immediately prior to construction of any pavement to determine the final pavement design.

11.2.11 Any excavations in either the made ground or Tidal River Deposits on the landfill will encounter shallow groundwater. This, in addition to the very soft/very loose nature of the deposits, will make shallow excavations unstable and therefore provision should be made for temporary support of any excavations.

11.2.12 Once the Tidal River Deposits and London Clay has been excavated for use on the landfill, the remaining in-situ London Clay will have been sufficiently disturbed and exposed to the extent that the contained pyrite will oxidise. The resultant sulphate ions lead to the generation of acidic water.

11.2.13 If purchase of the adjacent land to create a wetland habitat is deemed likely, further assessment of the potential for oxidation of pyrite within the London Clay is recommended.

11.3 Chemical considerations

11.3.1 The Tier 1 Human Health Assessment for the landfill site was undertaken using screening values for residential landuse without plant uptake, as a conservative assessment of the site conditions for the proposed use as public open space. The assessment identified exceedances of some metals and PAH's within the waste material across the site. Of these, lead and benzo(a)pyrene are the two determinants which could be considered to pose a risk to human health, and for which some remedial measures should be considered.

11.3.2 The provision for a cap thickness of at least 350mm, calculated in accordance with BR465 (2004) is recommended for the site, in particular in areas where the public will be provided access. The calculation of the thickness for such a cap to be protective for human health is driven by the concentrations of benzo(a)pyrene identified within the made ground.

11.3.3 The soils from the adjacent land comprise natural strata, with the expcetion of one small area of made ground within TP17. Screening of the soil analysis results against the screening values show no exceedances, and the chemistry of the made ground in TP17 is no different to the results from the remainder of the site. The soils from the adjacent land are therefore considered chemically suitable for the intended use as a capping material for the landfill site.

11.4 Gas considerations

11.4.1 The landfill site is generating moderate concentrations of carbon dioxide (21.6% maximum) and to a lesser extent methane (8.2% maximum), and the distribution of the highest concentrations and flow rates (maximum 0.8l/hr) correlates with the recorded thickness of and presence of degradable materials within the waste.

11.4.2 The gas monitoring results have been assessed using the CIRIA Guidance C659, 2006 (C665, 2007) and the calculated gas screening values (GSV's) show that the main driver for risks from ground gases is the flow rate, which is highest in the areas of the deepest fill (BH02 and BH05).

11.4.3 The risks to human health of current users is considered low at present due to the lack of a capping layer across the waste material, and the generally low flow rates and moderate concentrations of carbon dioxide and methane. The lack of a capping layer is allowing the escape of ground gases to the atmosphere.

11.4.4 Although the site does not lie within an area where radon protection measures are required (BR211, 1999), passive gas protection measures for the new visitor centre will be necessary, in accordance with Characteristic Situation 2, identified in table 8.6 of C569, 2006 (C665, 2007).

11.4.5 Given the agricultural use of the adjacent land and the purpose of the initial investigation (to assess suitability of the top 1-2m as a capping material), no gas monitoring points were installed on the adjacent land.

11.5 Hydrogeological Considerations

11.5.1 The investigation incorporated the installation of seven groundwater monitoring installations across the site; four screened within the landfill and three screened within the underlying natural strata (Quaternary and Eocene deposits).

11.5.2 The underlying Eocene Bracklesham Beds are recorded as a minor aquifer, but at this location the lithology encountered in the boreholes indicate this unit to comprise a non-aquifer. In combination with the overlying Quaternary River Tidal Deposits, these natural strata have the effect of hydraulically isolating the perched water/leachate within the landfill.

11.5.3 This hydrogeological model is supported by the findings of a one-week period during which dataloggers were used to capture changes in groundwater levels in six of the boreholes. The results show tidal variation within the underlying natural strata, but no discernable variation in the landfill leachate.

11.5.4 Furthermore, the hydraulic gradient within the natural strata is indicated to be southwards, but the hydraulic gradient within landfill is shown to be westwards, away from the harbour. This supports the model showing the landfill leachate to be hydraulically separate from the groundwater within the natural strata beneath.

11.5.5 The site is largely surrounded by surface water formed by the harbour and associated drainage channels, and Ferry Pool on the landward side of the site.

11.5.6 Chemical analysis results for the surface waters, landfill leachate and groundwaters within the natural strata beneath the site indicate some exceedances for the surface waters and landfill leachate of ammonium and some metals. No exceedances for organics were identified in any of the samples.

11.5.7 The results suggest that the leachate is generally hydraulically isolated from the harbour and surrounding surface waters and that there is only limited hydraulic connection between the landfill and the underlying groundwater. There may be a limited influence on the landfill leachate quality from seawater. The surface waters sampled from the northeastern edge of the landfill are affected by landfill leachate but are diluted with surface water run-off. Typically the ratio of magnesium:calcium in the seawater samples from the site is approximately 1:2.5, whilst these samples have much lower ratios of less than 0.5:1. This indicates (contrary to initial interpretations in the Phase 1 report) that the influence of seawater on the landfill leachate is minor.

11.5.8 The lithology and hydraulic gradients suggest that the horizontal groundwater flow rate to Pagham Harbour, below the site is very low at a few tens of metres cubed per year. The ammonium ratio suggests that a very small proportion of this comprises landfill leachate. This is consistent with the low hydraulic conductivity of the River Tidal Deposits and the low vertical hydraulic gradients. The condition may be different in the northern part of the landfill, but the flux of leachate to surface waters is, nevertheless, very low.

11.5.9 The surface of the landfill is uncapped and therefore the rate of infiltration is expected to be high. This will result in a high rate of leachate accumulation. A small proportion is expected to flow to the underlying groundwater, another very small amount probably migrates directly through the railway embankment and sides of Red Barn Ditch and some ponds on the northern side of the landfill and either evaporates or under very wet conditions flows away. These losses probably do not account for all the gains and therefore some sub-surface losses are also expected, probably via services runs in the area of the visitors centre.

11.5.10 The leachate accumulating in the landfill is likely to flow to surrounding surface waters and ultimately reach Pagham Harbour where dilution by several orders of magnitude is anticipated.

11.5.11 In summary, the landfill leachate is characterised by high ammonium concentrations and some low concentrations of metals, specifically chromium. The flow of leachate to the surrounding environment is at a very low rate through the underlying groundwater and edges of the site. The harbour itself provides a very high degree of dilution for ammonium entering its waters and the potential for a significant effect on the ecology of the harbour or its water quality is negligible.

11.5.12 There is some concern about leachates which over-top the northern margin of the site and potential leachate losses via unidentified pathways such as service runs.

12 Recommendations

12.1 Further investigations

12.1.1 The ground investigations undertaken to date have been sufficient to meet the objectives of the investigation by:

- assessing the risks posed by the site to human health and controlled waters;
- establishing the requirements for remediation;
- assessing the requirements for foundations at potential sites for the proposed visitors centre;
- establishing the requirements for pavement construction (roads and car parks);
- establishing the suitability of the materials on the adjacent site for re-use.

12.1.2 In general, for the site, further chemical characterisation of the soils and groundwater contamination should not be required for the purposes of risk assessment for the redevelopment of the site, although there may be a requirement for further characterisation where materials on the site need to be excavated and either disposed of or replaced. This would need to be discussed and agreed with the Environment Agency and Local Authority Contaminated Land Officer as part of the remediation design process before remediation works were undertaken.

12.1.3 Certain specific actions are required to enable the site development plans to be finalised. These are discussed below.

Gas Monitoring

12.1.4 With reference to CIRIA Guidance C665 "Assessing risks posed by hazardous ground gases to buildings", the period of gas monitoring should be sufficient to record details of the gas concentrations and flow rates within the monitoring installations during high, falling and low pressure atmospheric pressure, and to be confident that the collected results are representative of the site.

12.1.5 Suggestions for the frequency and periods of monitoring are given within the guidance, but the actual period of monitoring should be reviewed and adjusted as results are collected. It is important that the full data set includes results from a range of different atmospheric and weather conditions.

12.1.6 It is recommended that a total of twelve gas monitoring visits are undertaken during a six month period (for a high gas generation potential from the landfill and a commercial end-use i.e., visitor centre building). If this monitoring commences in early 2008, the total number could be reduced to eight visits over four months, and the results combined with the existing data gathered during the ground investigation.

Investigation along Red Barn Ditch

12.1.7 Although it is likely that the Red Barn Ditch is situated on natural strata, there is a possibility that it is located fully or partly on waste. An intrusive investigation is required in the vicinity of Red Barn Ditch to determine the lateral and vertical extent of the waste material adjacent to and beneath the channel to assess whether any remedial works are required in the vicinity of the ditch.

Detailed geotechnical and geo-environmental investigation in the area of proposed structures, car parks and roads

12.1.8 Once the preferred location of the visitor centre is agreed, a detailed investigation will be required in the areas of the proposed structure, car parks and roads in order to facilitate including foundations, pavements and waste characterisation.

Piling Risk Assessment

12.1.9 As piling is the preferred foundation option from a geotechnical perspective, a Piling Risk Assessment in accordance with the Environment Agency Guidance "Piling into Contaminated Sites" will need to be undertaken and reviewed by the Environment Agency at an early stage. The purpose of this assessment is to identify the most appropriate method of piling for the site, to minimise the risks to controlled waters and human health.

Geotechnical/hydrological investigation and engineering and ecological design of proposed artificial wetlands and associated infrastructure

12.1.10 If the use of the Adjacent Land for the creation of a wetland and a source of capping material for the landfill is chosen, detailed geotechnical and hydrological investigations and engineering and ecological design will be required.

12.2 Remedial Options

12.2.1 Four remedial options for the site to allow the construction of a new visitor centre were posed in the Brief from SEEDA, and discussed in the Phase 1 Report based on the available desk study and surface water sampling information at that time.

12.2.2 The remedial options have now been revised taking into account the following additional information:

- findings from the intrusive investigation;
- the potential to convert the Adjacent Land into a wetland and use the excavated soils as a source for the capping material on the landfill.

12.2.3 Six proposed locations for the new visitor centre were provided within the SEEDA Brief and these remain unchanged for the purposes of this Remedial Option Assessment.

Option 1 – Do Nothing

12.2.4 This would entail leaving the waste, which is currently exposed at the surface across much of the site. The exposed waste poses a number of health and safety risks (slips and trips, cuts and abrasions, contact with contaminated materials, fall, etc). The waste and associated leachate is posing a limited risk to controlled waters and human health (via direct contact with contaminated soils) and potentially also the surrounding ecology both now and in the future. This option is not compatible with the proposal of building a new visitor centre.

Option 2 – Remediate Preferred Site Only

12.2.5 Similar to Option 1, remediating the preferred site only would not remove the health and safety risks on the remainder of the site or risks to controlled waters and human health. This option is not compatible with the proposal of building a new visitor centre.

Option 3 – Cap the entire site

12.2.6 A cap is required on the landfill area to:

- provide an even surface which is free from the physical hazards of the existing landfill surface;
- create a barrier between contaminants in the site soils and potential human contact;
- reduce infiltration to reduce the rate of leachate generation and the risk of leachate overtopping the landfill, particularly on the northern side.

12.2.7 The indicative thickness of this cap is 600mm (based on calculations for protection of human health), but the thickness can be increased if necessary (depending on planting thickness requirements) to accommodate a greater quantity of soils from the adjacent land.

12.2.8 Passive gas protection measures will be required for the visitor centre, in accordance with Characteristic Situation 1 as described in table 8.6 from C665, 2007.

12.2.9 A compacted clay layer at the base of the cap would assist in reducing infiltration.

Option 4 – Remediate the preferred site and wider area for habitat creation and landscaping

12.2.10 This could be achieved by a combination of:

- Capping of the waste to limit direct contact, provide a planting medium and limit rainfall infiltration;
- Leachate collection drain;
- Gas venting;
- Partial removal of waste to a licensed landfill;
- Screening of waste to separate inert material from more hazardous materials with removal of the more hazardous component;
- Reprofiling of the site (for example to create low lying areas within the inter-tidal zone) and to concentrate remaining waste within a more engineered area.

12.2.11 Reactive treatment, such as bioremediation or thermal treatment, are not considered appropriate due to the nature of the contamination as these will not remove the physical hazards relating to the waste.

Preferred Option

12.2.12 Either Option 3 or Option 4 would be acceptable for the site, depending on the preferences of the project team. Option 4 could be considerably more expensive than 3 depending on the amount of material to be treated and disposed of.

12.2.13 From the ground investigation findings, it may be possible to leave the wooded area in the south of the site uncapped, allowing the trees to be retained as part of the site. Management of run-off from the capped areas across the rest of the site would be required to minimise the quantity of surface water that enters the landfill in the uncapped area, thereby minimising the quantity of leachate being generated within the landfill.

12.2.14 A shallow leachate drain should be constructed on the north western side of the site to collect any any leachate that accumulates and prevent overtopping. The leachate could then be collected and pumped into the artificial wetland (on adjacent land) where ammonium would be expected to convert to nitrate and metals allowed to precipitate.

12.2.15 In either case (Option 3 or 4) some form of gas venting is likely to be required across the site, although details will depend on the results of a longer term period of monitoring. Passive gas protection measures for the building(s) will be required.

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