

**Langstone FCERM Scheme
Appendix K – GI Report**

Langstone Flood and Coastal Erosion Risk Management Scheme Detailed Design

Ground Investigation Report

Havant Borough Council

Project number: 60656877

18 October 20212

Quality information

Prepared by	Checked by	Verified by	Approved by
Bridgette Maphosa Senior Engineering Geologist	Claire Johnson Senior Engineering Geologist	Steven Harris Associate Engineering Geologist	Jonathon Short Associate Director
Lydia Rouillard Graduate Ground Engineer	Luke Dalton Senior Engineering Geologist		
Sasha Layton Principal Geo- environmental Consultant	Phil Hough Regional Director		

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Prepared for:

Havant Borough Council

Prepared by:

AECOM Limited
Midpoint, Alencon Link
Basingstoke
Hampshire RG21 7PP
United Kingdom

T: +44(0)1256 310200
aecom.com

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The methodology adopted and the sources of information used by AECOM in providing its services are outlined in this Report. The work described in this Report was undertaken between **13 September 2021** and **21 January 2021** and is based on the conditions encountered and the information available during the said period. The scope of this Report and the services are accordingly factually limited by these circumstances. AECOM disclaim any undertaking or obligation to advise any person of any change in any matter affecting the Report, which may come or be brought to AECOM's attention after the date of the Report.

The exploratory holes carried out during the fieldwork, which investigate only a small volume of the ground in relation to the size of the site, can only provide a general indication of site conditions. The comments made and recommendations given in this Report are based on the ground conditions apparent at the site of the exploratory holes. There may be exceptional ground conditions elsewhere on the site which have not been disclosed by this investigation and which have therefore not been considered in this Report.

The comments made on groundwater conditions are based on observations made during site work and the limited monitoring programme. It should be noted that groundwater levels might vary owing to seasonal or other effects.

The investigation itself was designed as an exploratory, as defined by BS10175:2011 Investigation of Potentially Contaminated Sites: Code of Practice (BSI) (25 to 50m centres for exploratory phase investigations). As an exploratory/ main investigation, the results may not provide sufficient data to make detailed estimates of the quantities involved in any remediation work, if required.

The opinions expressed in this Report concerning any contamination found and the risks arising there from are based on current good practice simple statistical assessment and comparison with available soil guideline values, AECOM generic assessment criteria and other guidance values.

It should be noted that the effects of ground and water borne contamination on the environment are constantly under review, and authoritative guidance values are potentially subject to change. The conclusions presented herein are based on the guidance values available at the time this Report was prepared, however, no liability by AECOM can be accepted for the retrospective effects of any changes or amendments to these values.

Reference to historical Ordnance Survey (OS) maps and/or data provides invaluable information regarding the land use history of a site. However, it should be noted that historical evidence will be incomplete for the period pre-dating the first edition and between the release of successive maps and/or data.

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1. Introduction

1.1 Background

AECOM has been commissioned by Havant Borough Council (HBC), the coastal erosion and flood Risk Management Authority (RMA), to assist in designing and implementing the Langstone Flood and Coastal Erosion Risk Management (FCERM) Scheme. The scheme, which will introduce new or upgraded defences, is required to provide improved protection against tidal flooding to the village of Langstone.

AECOM was previously commissioned by HBC, via Coastal Partners - formerly the Eastern Solent Coastal Partnership (ESCP), to undertake an option appraisal study, identify leading options, develop outline designs, and draft an outline business case for the scheme to support the application for Grant in Aid (GiA) funding.

The work to date provides the strategic and economic justification for the scheme, as well as outline design level detail on defence types, alignment, crest levels, geometry, flood equipment and access requirements for the proposed defences.

The objective of the current scope is to build upon the outline design of the leading options to create the best fit detailed design solution for the Langstone FCERM scheme together with a construction scope of works.

AECOM carried out a ground Investigation (September 2018) at Langstone to feed into the outline design for the scheme. Although a previous (Phase 1) ground investigation was undertaken, the survey was proportionate for the outline design stage and further ground investigation has been carried out by Structural Soils Ltd on behalf of AECOM (September 2021) to support the development of the detailed design of the scheme.

The additional GI satisfies the requirements of Eurocode 7 (EC 7) in relation to spacing and depth of the exploratory holes where suitable and safe access could be achieved. Environmental constraints limited the ground investigation techniques that could be adopted at some locations. Additional holes were specified where there was lack of suitable information from previous GIs, where previous exploratory holes were too shallow or provided limited test data or where other site issues had an impact in obtaining satisfactory information to enable design and following advice from early contractor involvement.

This ground investigation report (GIR) has been written in accordance with Eurocode 7 and BS9530 to support the detailed design stage of the Langstone FCERM Scheme.

1.2 Proposed Scheme

The Langstone flood and coastal erosion risk management (FCERM) Scheme (the Scheme) will deliver structures around the west and east shoreline of Langstone. The scheme will replace, refurbish or enhance the deteriorating assets and provide a present day 0.5% Annual Exceedance Probability (AEP) for the area.

Modelling has shown a present day 0.5% Annual Exceedance Probability (AEP) (1 in 200 years) flood event would affect 73 residential properties and 4 business premises. The scheme also safeguards access to and from Hayling Island up to the design standard event.

Although the preferred option freeze for detailed design is still awaiting confirmation (due 11th February 2022), the following table sets out the likely defence types that will comprise the scheme:

Further details on the design are in outline drawing presented in **Error! Reference source not found.** Appendix A.

Table 1-1 Indicative defences types likely to comprise the scheme by frontage (subject to confirmation)

ODU sub-unit	Preferred defence measure
Frontage 1a	Earth embankment along the Billy line footpath / cycleway.
Frontage 1b	Earth embankment in the field, refurbished seawall in front of properties.
Frontage 2	Earth embankment along the footpath.
Frontage 3	Dwarf wall adjacent to the road, raised car park at The Ship Inn, New floodwall around the Ship Inn patio (potentially glass topped) and adjacent garden, flood gate for access.
Frontage 4	Reinforced existing walls, new floodwalls and flood gates.
Frontage 5	New floodwall in front of quay wall (potentially glass topped), flood gates, setback floodwall along footpath and earth embankment tying into high ground in the field behind.
Frontage 6	Rock armour revetment at the end of the spit.

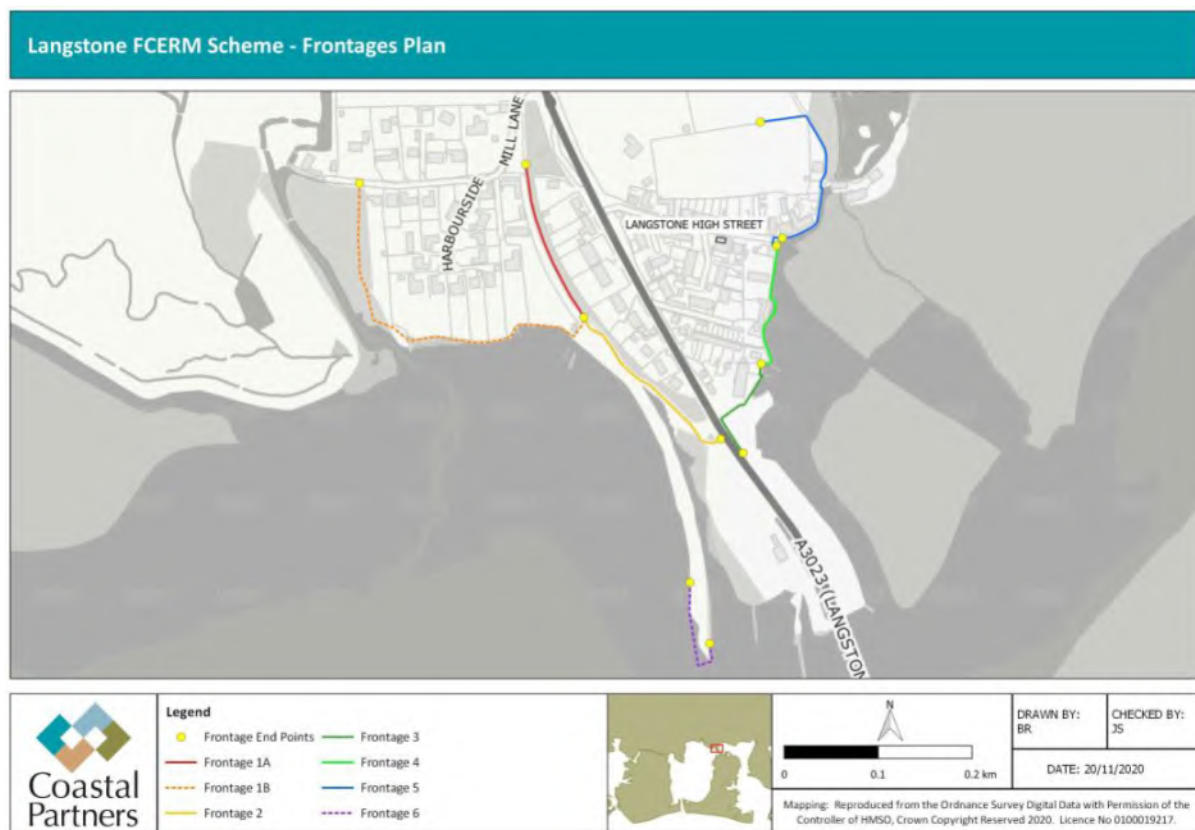


Figure 1-1. Langstone FCERM Scheme Frontages

1.3 Geotechnical Category of Project

This project is considered to be Geotechnical Category 2.

2. Sources of Information

The sources of information used in the preparation of this report comprise those listed below. Refer to Section 9 for a full reference list.

- BGS 1:50,000 geology series, sheet 316, Fareham 1998
- British Geological Survey (BGS) Geology of Britain borehole logs (www.bgs.ac.uk) accessed December 2021
- CIRIA C574 Engineering in Chalk, CIRIA, 2002
- Explosive Ordnance (EO) Threat Assessment (EOTA) - Langstone, Havant: Centred on Mill Lane and Langstone Road. PLANIT UXB Limited February 2018
- Langstone FCERM Scheme Detailed Design - Ground Investigation Works, Summary Method Statement and Habitat Regulations Assessment. AECOM August 2021
- Langstone FCERM Scheme, Environmental Scoping Report. Coastal Partners November 2020
- Langstone FCERMS – Factual Ground Investigation Report. WYG November 2018
- Langstone FCERMS - Option Development Unit Ground Models Technical Note. AECOM December 2018
- Langstone Flood and Coastal Erosion Management Scheme Detailed Design, Ground Investigation Scope and Rationale Technical Note. AECOM June 2021
- Langstone Flood and Coastal Erosion Management Scheme Detailed Design - Ground Investigation Specification. AECOM July 2021
- Langstone Flood and Coastal Erosion Management Scheme Factual Report on Ground Investigation Structural Soils December 2021
- Langstone Flood and Coastal Erosion Risk Management Scheme V2 – Detailed Design – Scope of Work. Coastal Partners – November 2020
- Langstone Flood and Coastal Erosion Risk Management Scheme, Cultural Heritage Desk-based Assessment. AECOM November 2018
- Langstone Flood and Coastal Erosion Risk Management Scheme, Pre-Construction Information. AECOM April 2020
- Langstone Flood and Coastal Erosion Risk Management Scheme, Preferred Option Report. AECOM April 2019
- Langstone Flood and Coastal Erosion Risk Management, Scheme Outline Design and Decision Criteria Report. AECOM, November 2019
- Langstone Topography Survey. Coastal Partners 2020
- Logging the Chalk, Rory N. Mortimore, 2014.
- Outline Design Drawings. AECOM 2019
- Southmoor WEM - Geotechnical Investigation Report with Outline Design. AECOM July 2017 (BH02 and TP04)

3. The Site

3.1 Location and Description

Langstone is within the jurisdiction of Havant Borough Council, located in Hampshire immediately north of Hayling Island and approximately 7km east of Portsmouth.

“The site” as used in this document refers to the foreshore area around the village of Langstone along the flood defences, and terrestrial areas with associated footpaths and roads.

The site is located within Langstone, a village in the Borough of Havant, Hampshire. The National Grid Reference to the centre of the site is SU 71877 04705. The Scheme frontage is adjacent to Langstone Harbour to the west and Chichester Harbour in the east. The location of the Scheme is presented in Appendix A.

The northern and eastern portion of the site extends from the area proximal to The Royal Oak pub on Langstone High Street, following the foreshore south to The Ship Inn public car park.

The western portion of the site is located along the foreshore to the west of Langstone Road, extending south along the foreshore embankment and north towards Mill Lane.

3.2 Topography

Topographical survey data (Coastal Partners, 2020) indicates that the western side of the site at the field off Mill Lane to be ranging between 2.2mAOD to 3.2mAOD. The cycle path is largely ranging between 3.3mAOD and 3.6mAOD. The land slopes down gently along the foreshore both on the eastern and western side of the site. Elevation ranges from 3.2mAOD to 0.6mAOD. Higher elevations along the foreshore are characterised by shingle deposits above Mean High Water.

On the eastern side of the site, elevation is indicated to be ranging between 2.5mAOD to 3.0mAOD at the Ship Inn Car Park. The sea wall is at elevation ranging between 2.3mAOD to 3.4mAOD. Similar to the western side, the foreshore slopes down gently from 2.2mAOD to 1.4mAOD moving into the harbour. Terrestrial elevation on the eastern side of the site ranges from 2.7mAOD to 3.1mAOD.

3.3 Historical Land Use

Historical mapping as part of the Envirocheck Report was not procured for this project. The historical land use summarised below is based on the historical review carried out as part of the Cultural Desk Based Assessment (AECOM, 2018). Further details on historical land use can be found in the afore mentioned report.

Prior to the start of WW2 in 1932, the site was a sparsely populated village (Langstone) with a well-established street layout which defined the future development of the area. Several properties were spread across the area including two public houses, a disused Mill along Mill Lane, and Coastguard Cottages overlooking Emsworth Harbour.

It is stated in the Cultural Desk Based Assessment (AECOM, 2018) that a quay was established with a couple of crossing points to Hayling Island – Langstone Bridge (Swing) to the west and Hayling Bridge (Swing) to the east. The AECOM, 2018 report states that the Highest Point to which the tides flow extends right up to Mill Lane. This means that during the air raids of WW2, a large part of the land to the west of the site (terrestrial) known as Southmoor was likely underwater due to sitting at a lower elevation than Mill Lane.

The site area remained relatively unchanged throughout the War years and through to no later than 1975 after which there was significant development of the area to the east of Langstone Road with many new buildings in evidence. The crossings to Hayling Island have changed considerably as the former Langstone swing bridge has been closed and the former Hayling Bridge has been modernised and renamed Langstone Bridge. By no later than 2002, development of the site area to the west of Langstone Road and especially to the south of Mill Lane had occurred and a few more houses appear further south towards the bridge. No significant development is evident onshore across the site. The site remains laid out in this way to the present day.

3.4 Utilities

Utilities information was obtained in September 2021 by Structural Soils from Landmark Information Group. The utilities information is presented in **Error! Reference source not found.** and summarised according to Frontage number below.

Table 3-1 identifies utilities that are in or near the frontages and describes their type and location.

Table 3-1 Summary of utilities across the site

Frontage	Utility company	Description	Location
Frontage 1B	n/a – no utilities located in sub-unit frontage		
	Southern Water	900mm concrete surface water pipe and 150mm surface water pipe	Through the private gardens behind the seawall a pipe runs north to south and exits through the seawall. In the east end of the sub-unit a pipe runs from north to south terminating at an outfall.
Frontage 6	Scottish and Southern Electricity Networks	2no. sets of high voltage 33kV cables	These are located near the southern end of the spit, travelling west to east, to the north of the indicative location of sub-unit 2a.
Frontage 1A and 2	Portsmouth Water	450mm fibre reinforced concrete main	In the northern half of the sub-unit a pipe runs alongside the eastern edge of the footpath, offset varies approximately 2-4m. Towards the southern end of the sub-unit the pipe passes below the footpath to the southwestern side and continues towards the sailing club property.
	Southern Water	900mm concrete surface water pipe	In the northern half of the sub-unit a pipe runs alongside the western edge of the footpath, offset varies approximately 1.5-7m. The pipe then travels towards the sea through an outfall (in sub-unit 1b).
	Openreach	One cable.	Located at the eastern end of the sub-unit, where the footpath meets the road pavement.
Frontage 3	SGN	Medium pressure polyethylene gas main	Southwest side of car park, continues south down the east side of road embankment before bridge.
	Southern Water	450mm concrete surface water pipe	Runs along southwest side of car park, outfalls through wall.
Frontage 3	n/a – no utilities located in sub-unit frontage		
Frontage 4	Scottish and Southern Electricity Networks	Low voltage underground mains cable	Runs from Langstone High Street along the Footpath to south of Green Cottage where it terminates in a pot end joint.
	Openreach	Two cables.	One cable runs from Langstone High Street in front of the footpath terminating at Green Cottage. The other cable is shown aligned behind the footpath in private property.
Frontage 4	Southern Water	225mm vitrified clay/cast iron surface water pipe	Runs west-east along High Street terminating at an outfall on the foreshore. Perpendicular to frontage.
	Openreach	One cable.	Cable runs perpendicular with the frontage alignment across road. Approximately 3m west of timber gate.
	Scottish and Southern Electricity Networks	Low voltage underground mains cable	Cable runs perpendicular with the frontage alignment across road. Approximately 5m west of timber gate.
Frontage 5	Scottish and Southern Electricity Networks	Low voltage underground mains cable	Runs along all sub-unit, located in footpath.
	Openreach	One cable.	Runs along all sub-unit, located in footpath for southern half and shown in foreshore on northern half.

Frontage	Utility company	Description	Location
	Portsmouth Water	4" PVC main	Runs along most of sub-unit, located in footpath. Terminates just before northern end of sub-unit.
	SGN	Low pressure polyethylene gas main	Runs along most of sub-unit, located in footpath. Just before northern end of sub-unit turns perpendicular to frontage towards Old Mill building.
Frontage 5	n/a – no utilities located in sub-unit frontage		

3.5 Unexploded Ordnance

An Explosive Ordnance Threat Assessment (EOTA) was carried out in February 2018 for the Phase 1 ground investigation by PLANIT UXB Limited.

The assessment findings indicate the unexploded bomb (UXB) threat level at the Site to be medium. Due to the threat level, site investigation works were supported by an unexploded ordnance (UXO) survey as appropriate. On-site UXO support for all investigation works involved the presence of an appropriately trained and experienced UXO Technician. No ferrous objects that could possibly be UXO were identified prior to commencement of the intrusive works as stated in the Factual Report provided in Appendix C **Error! Reference source not found.**

3.6 Published Geology

The superficial and solid geology of the site has been established by reference to published maps, and online resources comprising:

- BGS geology mapping (1:50,000 scale, sheet 316 Fareham), 1998
- The BGS online map viewer

3.6.1 Generalised Ground Profile

Table 3-2 summarises the ground profile of the site based upon the BGS geological mapping and the BGS GeoIndex Database.

Table 3-2 Summary of inferred ground profile from BGS geological mapping and BGS GeoIndex Database.

Strata Name	BGS Description	Occurrence
Made Ground		
Made Ground	Not given	Beneath South margin of site (3B), likely to be present across site due to historical development
Superficial Deposits		
Alluvium	Clay, silt, sand and gravel	East and western margins of the Site
Aeolian "Brickearth"	Fine sandy silt locally contaminated with gravel	Beneath the Site
River Terrace Deposits	Undifferentiated - Sand, silt and clay	Beneath the Site
Raised Marine Deposits	Silt and silty sand	West of the Site
Beach and Tidal Flat Deposits	Silt and clay with sand and gravel	Beneath the Site
Bedrock		
White Chalk Subgroup	Undifferentiated	Beneath the Site

3.7 Historical Ground Investigation

A ground investigation was undertaken in 2018 by WYG. A summary of the results of this GI are presented in Table 3-3. The investigation comprised the following:

- 2 No. Cable percussive boreholes to a depth of 10m bgl
- 1 No. Cable percussive borehole to a depth of 20m bgl
- Installation of a 50mm groundwater monitoring pipe within BH03 to a depth of 10.00m bgl
- 27 No. Hand excavated trial pits to expose existing sea defences or a maximum depth of 1.20m bgl
- 5 No. Dynamic (formerly known as Windowless) sampled boreholes to a depth of 10.0m bgl or refusal
- 10 No. Exploratory concrete core samples from the existing sea defence walls
- On-site inspection and logging of samples
- In-situ testing in boreholes including standard penetration tests and hand vane shear tests
- Chemical and geotechnical sampling in exploratory holes; and
- Laboratory geotechnical testing of soils and rock and chemical testing.

Table 3-3 Summary of Historical GI at Langstone 2018

Stratum	Strata thickness (m)		Description (m)
	Minimum	Maximum	
Made Ground	0.05	3.1	Brown sandy brick and flint gravel with other subordinate made ground components
Alluvium	0.1	1.6	Soft brown/grey slightly gravelly clay
River Terrace Deposits	0.3	1.3	Brown very sandy sub-rounded to rounded fine to coarse sandstone gravel and frequent sandstone cobbles and boulders. Coarse grained deposits typically comprised yellowish brown sandy subrounded to rounded fine to coarse flint gravel
Beach Deposits*	0.05	1.3	Yellowish brown sandy fine to coarse flint gravel
Portsdown Chalk Formation**	>10		Structureless chalk composed of soft to firm cream gravely silt. Gravel composed of angular to subrounded medium to coarse chalk and flint. Grades Dm to Dc

* Encountered immediately beneath the foreshore

**The BGS mapping indicates the underlying chalk as undifferentiated formations. The previous GI by WYG notes due to the location of the site, smaller scale BGS mapping and descriptions by Mortimer (2016) the chalk strata present is Portsdown Chalk. The chalk is likely to have been recovered as structureless because of the ground investigation methods used.

4. Ground Investigation

4.1 General

To provide site specific geotechnical data to develop the ground model sufficiently to assist with detailed design of the scheme, a ground investigation (GI) was specified by AECOM and undertaken by Structural Soils Ltd (SSL). The final factual report from the GI is attached as Appendix C.

Site supervision was undertaken by an Engineering Geologist from AECOM. An environmental watching brief was maintained by ecologists from Coastal Partners and an archaeological watching brief by an archaeologist from Wessex Archaeology.

An exploratory hole location plan is presented in Appendix D **Error! Reference source not found..**

4.2 Fieldwork

The GI field work comprised the following:

Terrestrial Above mean high water springs (MHWS)

- 3 No. cable percussion boreholes between 8m and 15m depth (BH101, BH104 and BH105)
- 6 No Dynamic Sample boreholes (DS102, DS103 to DS107 and DS110)
- 2 No. Machine Dug Trial Pits to a maximum depth of 3 m along the spit (MDTP 102 and MDTP103)
- 6 No. Hand Dug Trial Pits (HDTP102, HDTP106 to HDTP110)

Some of the HDTPs were excavated in private gardens to investigate existing foundations. For more information refer to the Factual Report, Appendix C.

Intertidal Below MHWS

- 3 No. cable percussion boreholes between 8m and 15m depth (BH102, BH103 and BH106)
- 2 No. dynamic sample boreholes up to 5 m depth (DS101 and DS109)
- 4 No. Hand Dug Trial Pits (HDTP103, HDTP104, HDTP105 and HDTP111)

All Exploratory Locations

- Standard Penetration Tests (SPTs)
- Hand shear vanes were carried out in cohesive soils in hand dug pits and inspection pits.
- 9 No. groundwater installations
- 3 No. rounds of groundwater level monitoring from existing borehole installation (BH03) and new installations
- 1 No. round of groundwater sampling from new installations
- 3 No. rounds of ground-gas monitoring in existing and new installations
- Surveying of all exploratory hole positions (Northing / Easting) and levels in metres above ordnance datum (m AOD)
- Logging of all exploratory holes in accordance with BS 5930:2015+A1:2020 and CIRIA C574
- Recording of groundwater strikes and general groundwater conditions encountered during the ground investigation works
- Obtaining of samples for geotechnical and environmental testing.

DS108 was not carried out due to access constraints, this was replaced by a hand dug trial pit (HDTP111) with follow on Macprobe.

The 3 machine dug trial pits located at the spit did not reach specified depth due to water ingress and trial pit side instability. A Dynamic Sample (DS110) was carried out to supplement the ground condition information at this location. DS110 did not progress below 2m due to the presence of boulders and cobbles. The rig was moved a metre to the south and re-drilled. This borehole also failed to reach the specified depth due to fast water ingress causing the hole to continuously cave in, and presence of boulders.

HDTP101 was not carried out due to landowner restrictions.

BH104 was relocated a few metres towards the existing flood wall due to the presence of a 12" gas main.

4.3 Laboratory Testing

Laboratory testing was scheduled by AECOM. Both Geotechnical and Contamination laboratory testing was completed at the Contractors in-house laboratories Eurofins Chemtest which are accredited by UKAS to ISO17025. The laboratory testing included the following:

Geotechnical Laboratory Testing

- 89 No. Determinations of natural moisture content
- 52 No. Determinations of Atterberg Limits (Plasticity)
- 59 No. Particle size distribution (PSD) by wet sieve and pipette as appropriate
- 10 No. Single stage unconsolidated undrained triaxial compression tests without the measurement of pore pressure.
- 7 No. One dimensional consolidation testing
- 32 No. Sulphate and pH for assessment of the potential for chemical attack of buried concrete pyrite absent (Suite C)
- 1 No. Sulphate and pH for assessment of the potential for chemical attack of buried concrete pyrite present (Suite D).
- 8 No. Organic matter
- 2 No. Dry density and Saturation moisture content of chalk

Geoenvironmental Laboratory Testing

- 40 No. AECOM Suite E
- 13 No. AECOM Suite G
- 6 No. Organo-tin Compounds
- 12 Volatile organic compounds (VOC)
- 9 No. Semi volatile organic compounds (SVOC) and tentatively identified compounds (TICs)
- 3 Polychlorinated bipheynls (PCBS)
- 21 Asbestos presence screens
- 11 Cyanide (free)
- 11 Cyanide (total)

5. Ground and Groundwater Conditions

For ease of description of encountered stratigraphy, the site has been divided into sections where geology is likely to be similar along the frontage, see Appendix E. The sections may contain one or more Option Development Units (ODU) and an overlap of some of the exploratory holes, a summary of the numbered sections and corresponding exploratory holes is shown in Table 5-1.

Table 5-1 Summary of referenced GI phases and corresponding exploratory holes

Ground Investigation Phase					
Section	Frontage	2021 Phase 2	2018 Phase 1	Southmoor GI	Historical BGS Boreholes
	1	1B	BH105, DS106, DS107	TP04 BH02	SU70SW16 SU70SW17
	2	1A and 2	BH103, DS103 HDTP103, HDTP104 HDTP105, HDTP111	WS03, TP22, TP23 TP24, TP25, TP28	SU70SW/18, SU70SW/18
	3	2	D104, DS105	WS03	
	4	3	BH104, DS101, DS102, HDTP110	BH03, TP15, TP16, TP17, TP18, TP19, TP20, TP20	
	5	4 and 5	BH102, BH103, DS109, HDTP102, HDTP107, HDTP108, HDTP109	TP01, TP02, TP03, TP04, TP05, TP06, TP07, TP08, TP10, TP11, TP12 TP13, TP14, TP31, BH01, BH02	
	6	5	BH101, BH102, HDTP106		
	7	6	MDTP102, MDTP103, DS110	WS02, WS05,	SU70SW20

5.1 Section 1 – Frontage 1B (Ch0A to Ch390A)

This section is on the western side of the site and the following exploratory holes have been used to derive the ground model:

- BGS historical exploratory records, SU70SW16 and SW70SW17
- Southmoor GI exploratory holes: BH02 and TP04
- 2021 GI exploratory holes: DS106, DS107 and BH105

The ground model along Section 1 comprises Made Ground over superficial deposits of Alluvium and River Terrace Deposits and Chalk bedrock. A summary of the stratigraphy encountered along Section 1 is presented in Table 5-2.

Table 5-2 Summary of stratigraphy encountered along Section 1- Frontage 1B

Stratum	Surface Level encountered (m AOD)	Depth to top of stratum (m)	Thickness of stratum (m)
Made Ground	1.50 – 2.97	0.00	0.15 – 0.60
Alluvium	1.04 – 2.37	0.15 – 0.60	1.10 – 4.40
River Terrace Deposits	-0.02 – -1.03	1.52 – 4.0	1.90 – >3.05
Chalk	-0.27 – -2.82	2.50 – 5.80	>5.95*

*Not fully penetrated

The following generalised sequence of strata was encountered.

5.1.1 Made Ground

Material interpreted as Made Ground was encountered in all the previously mentioned exploratory holes. This material was encountered at ground level with a range in thickness from 0.15m to 0.60m. Made Ground is described as firm to stiff or stiff slightly sandy slightly gravelly clay, firm light grey slightly gravelly clay or slightly gravelly clayey fine to coarse sand locally with coarse flint, brick, rare metal pipe fragments, charcoal, brick and ceramic fragments.

5.1.2 Alluvium

Material interpreted to be Alluvium was encountered underlying the Made Ground in all the exploratory holes with the exception of BH02. Alluvium was encountered at 0.15mbgl to 0.60 mbgl (.04AOD to 2.37m AOD). The Alluvium was described as largely firm brown mottled grey, orangish brown slightly gravelly to gravelly clay. In the BGS boreholes SU70SW16 and SU70SW17 this is described as firm brown sandy clay locally with tree remains.

5.1.3 River Terrace Deposits

Strata interpreted as River Terrace Deposits (RTD) was encountered within 3 (DS106, BH105 and SU70SW16,) of the exploratory holes underlying the Alluvium. The River Terrace Deposits were encountered at 1.52mbgl to 4.0mbgl (-0.02mAOD to -1.03mAOD) with a thickness ranging between 1.79m and >3.05m. Where encountered, this layer is described as loose brown mottled black and off-white, grey sandy slightly clayey angular to subrounded fine to coarse gravel of flint and/or chalk.

5.1.4 Chalk

Chalk was encountered in all the exploratory holes with the exception of SU70SW16 which terminated in the RTD. This stratum was encountered at -0.27 mAOD to -3.06 mAOD with a maximum penetration depth of >5.95m in BH02. Chalk is described as structureless composed of off-white gravelly silt classed as CIRIA Grade Dm but may at lower depths be structured chalk recovered as structureless chalk due to the ground investigation methods used. This was composed of slightly silty with subangular to subrounded gravel and cobbles of weak to moderately weak medium to high density clasts.

5.2 Section 2 – Frontage 2 (Ch180 to Ch373)

This section is on the western side of the site and the following exploratory holes have been used to derive the ground model:

- BGS historical exploratory records: SU70SW18 and SU70SW19
- Phase 1 GI exploratory holes: TP22 to TP25, TP28, WS03 and WS04
- 2021 exploratory holes: HDTP103 to HDTP105, HDTP111, DS103, BH106

The ground model along Section 2 comprises Made Ground and/or Beach Deposits over Alluvium and Chalk bedrock. A summary of the stratigraphy encountered along Section 2 is presented in Table 5-3.

Table 5-3 Summary of stratigraphy encountered along Section 2- Frontage 2

Stratum	Surface Level encountered (m AOD)	Depth to top of stratum (m)	Thickness of stratum (m)
Beach Deposits	0.49 - 3.31	0.00	0.15 - 1.30
Made Ground	1.23 - 3.16	0.0 - 1.30	0.30 - 2.74
Alluvium	0.15 – 1.71	0.15 - 0.80	0.90 - 4.50
Chalk	-2.79 - 1.06	1.50 – 5.00	> 8.45*

*Not fully penetrated in any location

5.2.1 Made Ground

Made Ground was encountered at surface in HDTP111, SU70SW18, TP22, TP28, SU70SW19, DS103, WS03 with the exception of WS04 and TP28 where it was encountered underlying Beach Deposits. Where underlying the Beach Deposits, the Made Ground was encountered at 0.90mbgl (TP28) and 1.30mbgl (WS04).

Where encountered the Made Ground was variable in thickness ranging from 0.30m to 2.74m. The variable descriptions of Made Ground are detailed below:

- In HDTP111 - Salt marsh grass over very soft brown slightly sandy gravelly clay with occasional plastic fragments, labels and crisp packets. Gravel is angular to subrounded fine to coarse flint and chalk. Sand is fine to coarse.
- In WS03 - Brown to dark brown very clayey slightly sandy fine to coarse gravel or silty slightly sandy subrounded to subangular coarse flint gravel and firm brown gravelly clay. Gravel is subrounded to subangular medium to coarse flint and brick fragments.
- In WS04: Dark brown and greyish brown slightly sandy clayey angular to rounded fine to coarse brick flint and concrete gravel.
- In DS103 - Possible Made Ground: Grass over brown slightly sandy gravelly clay with a low cobble content. Sand is fine to coarse. Gravel is angular to rounded fine to coarse flint and chalk. Cobbles are subrounded flint (up to 750 x 500 x 450 mm).
- In TP28 - Light brown, white sandy subrounded fine to medium chalk and flint quartz gravel.

5.2.2 Beach Deposits

Strata interpreted as Beach Deposits were encountered in 6 of the 15 exploratory holes along Section 2. Where encountered, the exploratory holes were along the foreshore and some further into the beach from land. Where not encountered, particularly in the HDTP, it maybe be likely due to the excavation terminating before they are encountered. The Beach Deposits were encountered at surface with thickness ranging from 0.15m to 1.30m. This layer was described as yellowish-brown fine to coarse or brown sandy rounded to subrounded flint gravel with frequent shell fragments.

5.2.3 Alluvium

Alluvium was encountered in 5 of the 15 exploratory holes along the Section 2 alignment. Where encountered this layer was either at surface (SU70SW18 and TP25) or underlying Beach Deposits at 0.30mbgl to 0.80mbgl (SU70SW19, TP22, TP24, HDTP103, HDTP104 and BH106) or underlying Made Ground at 1.80mbgl and 0.50mbgl (WS03 and DS103). The Alluvium was interpreted to range in thickness between 0.3m (TP23) and 4.50m (DS103).

This layer is described as soft to firm light brown mottled orangish brown slightly gravelly clay or firm brown silty clay. Gravel is rounded fine to coarse flint. DS103 recorded Alluvium as very soft to soft light bluish grey, orangish brown grey mottled slightly gravelly clay interbedded with soft light and dark clay or slightly sandy gravelly clay with numerous shell fragments.

5.2.4 Chalk

Six exploratory holes penetrated into the Chalk. This layer was encountered at 1.50mbgl to 5.00mbgl, total thickness was not proven. It is assumed to be greater than 8.45m thick which was recorded in BH106.

This material was described as soft structureless Chalk composed of silty angular to subangular coarse gravel with low cobble content. Clasts are very weak low-density cream and is classed as CIRIA Grade Dc. In BH106 this layer is described as off-white gravelly silt. Clasts are weak medium density off-white subangular fine to coarse with rare flint, and is classed as CIRIA Grade Dm.

5.3 Section 3 - Frontage 1A and 2 (Ch0 to Ch373)

The following exploratory holes have been used to inform the stratigraphy along this section, these are listed below:

- Phase 1 GI exploratory holes: WS03
- 2021 GI exploratory holes: DS104 and DS105.

Each exploratory hole encountered dissimilar stratigraphy. A summary of the encountered stratigraphy is presented in Table 5-4.

Table 5-4 Summary of stratigraphy encountered along Section 3 - Frontage 1A and 2

Stratum	Surface Level encountered (m AOD)	Depth to top of stratum (m)	Thickness of stratum (m)
Made Ground	3.16 – 3.19	0.00	1.20 – 1.80
River Terrace Deposits	3.19	0.00	1.55*
Alluvium	1.64 – 1.99	1.20 - 155	0.30 - 3.90
Chalk	0.74 – 1.06	2.10 - 2.45	>3.10*

*Not fully penetrated

5.3.1 Made Ground

Made Ground was encountered at ground level to a depth of 1.20mbgl (DS105) and 1.80mbgl (WS03). The Made Ground was described as the following:

- Slightly sandy slightly gravelly clay or firm light greyish brown, orangish brown and dark brown slightly gravelly clay locally with a low cobble content. Sand is fine to coarse; gravel is angular to subrounded fine to coarse flint and cobbles are angular to subangular concrete and flint (160 x 120 x 70mm). This is interlayered with orangish brown slightly clayey slightly gravelly fine to coarse sand. Gravel is angular to subangular fine to coarse flint.
- Brown to dark brown very clayey slightly sandy fine to coarse gravel of angular to rounded flint and brick fragments. Sand is fine.

5.3.2 River Terrace Deposits

At DS104 superficial deposits are recorded at ground level to 1.55mbgl. This is described as slightly clayey gravelly fine to coarse sand with a low cobble content. Gravel is angular to rounded fine to coarse flint and chalk. Cobbles are angular to subangular of chalk.

5.3.3 Alluvium

Strata interpreted as Alluvium was originally logged as possible Made Ground. In WS03, this material is described as soft black slightly gravelly clay. Gravel of fine rounded to well-rounded flint. In DS105 this material is described as firm light greyish brown, orangish brown and dark brown slightly gravelly clay. Gravel is angular to subrounded fine to coarse flint and chalk locally with hydrocarbon odour.

The Alluvium was encountered at 1.36mbgl (WS03), 1.55mbgl (DS104) and 1.20mbgl (DS105) with a thickness of 0.3m (WS03), 3.90 (DS104) and 1.25m (DS105).

5.3.4 Chalk

Chalk bedrock was encountered in DS105 and WS03 at 2.45 mbgl and 2.10 mbgl respectively. Chalk was not encountered in DS104 at termination which suggested it is at a greater depth in comparison with the adjacent exploratory holes. This layer is described as structureless chalk composed of light grey mottled light yellowish brown slightly sandy slightly gravelly silt. Clasts are off-white very weak medium density angular to subangular fine to coarse. Occasional very small to small nodular flints.

5.4 Section 4 – Frontage 3 (Ch373 to Ch 450)

The following exploratory holes have been used to inform the stratigraphy along this section, these are listed below:

- Phase 1 GI exploratory holes: TP15, TP16, TP17, TP18, TP19, TP20, TP21 and BH03
- 2021 GI exploratory holes: BH104, HDTP110, DS101 and DS102.

Each exploratory hole encountered dissimilar stratigraphy. A summary of the encountered stratigraphy is presented in Table 5-5.

Table 5-5 Summary of stratigraphy encountered along Section 4 - Frontage 3

Stratum	Surface Level encountered (m AOD)	Depth to top of stratum (m)	Thickness of stratum (m)
Made Ground	1.39 - 2.87	0.00	0.15 - 2.70
Alluvium	-0.02 - 2.13	0.15 – 2.70	0.80 - 4.61
River Terrace Deposits	-0.30	1.00	>0.30*
Chalk	-2.77 - 1.99	1.99 - 5.45	>19.2*

*Not fully penetrated

5.4.1 Made Ground

Made Ground was encountered from ground level to a maximum depth of 2.70m bgl in all exploratory holes except TP20 along Section 4. Where cohesive, this layer was described as soft to firm brown locally mottled brownish grey slightly sandy to sandy slightly gravelly to very gravelly clay. Sand is fine to coarse. Gravel is angular to subangular fine to coarse flint and rare brick fragments, occasional wood fragments, tile, concrete and chalk.

Where granular, the Made Ground is described as brown becoming dark brown slightly clayey gravelly fine to coarse sand or brown slightly sandy clayey angular to subangular fine to coarse gravel of flint, tile, chalk and rare brick fragments. Sand is fine to coarse.

In trial pits located at the foundations of existing flood defence walls, the Made Ground encountered was described as asphalt (0.1m thick in TP15), over soft yellowish brown to brownish slightly sandy gravelly clay, dark greyish brown subangular fine to coarse flint gravel or bluish grey clayey gravelly sand underlain by, grey mottled yellow slightly sandy gravelly clay. Gravel was recorded as angular to rounded fine to coarse flint, brick and concrete fragments.

5.4.2 Alluvium

Alluvium was encountered in eight of the exploratory holes (BH104, HDTP110, DS101, DS102, WS01, TP7, TP19 and TP20). In addition, the River Terrace Deposits encountered in TP20 have been interpreted as Alluvium. Where encountered, Alluvium was underlying the Made Ground at 0.15 to 2.70mbgl, with a range in thickness between 0.80m and 4.61m.

5.4.3 Chalk

Four exploratory holes along Section 4 encountered Chalk (BH104, DS101, DS102 and TP21) between 1.99 and 5.45mbgl, the base of the Chalk was not encountered. The upper section of Chalk was described as structureless composed of grey gravelly silt. Clasts are very weak to weak medium density off-white subangular to subrounded fine to coarse with occasional black flint and classed as CIRIA Grade Dm. Chalk grade is recorded to have changed with depth and was recorded as structureless chalk composed of slightly silty, subangular to subrounded gravel and cobbles and classed as CIRIA grade Dc. Clasts are weak to moderately weak, medium to high density, off-white. Matrix is off-white. Grade Dm chalk ranges in thickness from approximately 1.6m to 3.5m.

5.5 Section 5 – Frontage 4 and 5 (Ch450 to Ch750)

The following exploratory holes were carried out along Section 5:

- Phase 1 GI boreholes: TP01-TP08, TP10-TP16, TP30, TP31
- 2021 GI exploratory holes: HDTP102, HDTP107, HDTP108, HDTP109, DS109, BH102, BH103

A summary of the encountered stratigraphy is presented in Table 5-6.

Table 5-6 Summary of encountered stratigraphy along Section 5 - Frontage 4 and 5

Stratum	Surface Level encountered (m AOD)	Depth to top of stratum (m)	Thickness of stratum (m)
Beach Deposits	1.60 - 2.74	0.00-0.30	0.05 - 0.30
Made Ground	0.05 - 3.05	0.00 - 0.10	0.10 – 1.62
Alluvium	0.55 - 2.44	0.10 - 1.62	0.25 - 3.35*
River Terrace Deposits	1.38 - 2.44	0.22 - 0.30	>0.20*

*Not fully penetrated

5.5.1 Beach Deposits

Beach Deposits were encountered at surface in three exploratory holes (BH103, TP2 and TP5) overlying the Made Ground and one exploratory hole beneath the Made Ground (BH103). The Beach Deposits are recorded to be 0.05m to 0.30m in thickness and described as brown very sandy subrounded to subangular and rounded medium to coarse flint gravel locally with abundant shell fragments up to 10mm long.

5.5.2 Made Ground

Made Ground was encountered in all the exploratory holes with the exception of TP01 along Section 5, either at surface or underlying Beach Deposits (TP2 and TP5) at 0.05mbgl and 0.10mbgl respectively). Made Ground is recorded to be 0.10m to 1.62m thick and variable in composition. This layer is described as follows:

- Black very sandy subrounded to subangular fine to coarse flint brick and iron slag gravel with occasional flint cobbles (TP05 located at the beach).
- Paving slab over concrete or masonry slab over loosely cemented grey concrete (BH03, HDTP102, TP01, TP03, TP06 and TP07). These are located at the Ship in Car Park and along the sea wall.
- Brown fine to coarse sandy silty clayey fine to coarse gravel of angular fine to coarse shell fragments and brick.
- Soft, firm brown and greyish brown slightly sandy slightly gravelly clay or slightly gravelly silty clay. Gravel is angular to rounded fine to coarse brick chalk shell fragments and flint.
- Largely underlying pavement or masonry - Yellowish brown, brown gravelly fine to coarse sand. Gravel is rounded fine to coarse flint and brick fragments.

5.5.3 Alluvium

Strata interpreted as Alluvium was encountered in 8 exploratory holes (TP07, TP31, HDTP108, HDTP109, WS01, DS109, BH102 and BH103) underlying the Made Ground. Where encountered it was recorded at 0.10mbgl to 1.62mbgl with a thickness range between 0.25m and 3.35m where fully penetrated.

Alluvium was described as soft yellowish brown, greyish brown and brown slightly gravelly clay rarely locally interbedded with (0.1m thick) greyish brown sandy rounded fine to coarse flint gravel. Gravel is rounded fine to coarse flint. This layer was locally (BH103) underlain by soft brown mottled grey slightly gravelly silt. Gravel is subangular to subrounded fine to coarse of flint and chalk.

5.5.4 River Terrace Deposits

Strata interpreted as River Terrace Deposits were encountered in two exploratory hole logs (TP2 and TP5). Where encountered, the River Terrace Deposits were underlying the Made Ground at 0.22mbgl to 0.30mbgl with a thickness > 0.20m.

The River Terrace Deposits were described as firm brown silty/clayey sandy gravel of medium rounded chalk or brown slightly clayey/silty fine to coarse sandy fine to coarse gravel. Sand is fine to coarse.

5.5.5 Chalk

Chalk was encountered in six exploratory holes (BH01, BH02, BH103, BH102, WS01 and DS109) underlying the Made Ground or Alluvium at 0.35mbgl to 4.45mbgl.

Chalk was described as soft structureless chalk composed of grey gravelly silt with occasional orange staining, CIRIA Grade Dm. Clasts are very weak low density and medium density off-white subangular to subrounded fine with occasional flint and occasional rootlets. Locally (BH01 and DS109) chalk was recovered as structureless chalk, CIRIA Grade Dc, composed of slightly silty sandy angular to subangular fine to coarse gravel with medium cobble content. Clasts are very weak low and medium density cream.

5.6 Section 6 – Frontage 5 (Ch730 to Ch862)

The following exploratory holes were carried out along Section 6

- 2021 GI exploratory holes: BH101, BH102, HDTP106

A summary of the encountered stratigraphy is presented in Table 5-7.

Table 5-7 Summary of encountered stratigraphy along Section 6 - Frontage 5

Stratum	Surface Level encountered (m AOD)	Depth to top of stratum (m)	Thickness of stratum (m)
Made Ground	1.77 - 3.10	0.00	0.50
Alluvium	1.27 - 2.60	0.00 - 0.50	0.90 - 1.90
Chalk	0.37 - 0.70	1.40 - 2.40	> 13.05*

*Not fully penetrated

5.6.1 Made Ground

Made Ground was encountered in BH101 and BH102 at surface with a depth of 0.50m. This layer was described in BH102 as dark brown sandy very clayey angular to subrounded fine to coarse gravel of flint and brick fragments. Sand is fine to coarse.

In BH101 the Made Ground was described as firm and very stiff brown to dark brown slightly sandy slightly gravelly silt with occasional roots. Sand is fine to coarse. Gravel is angular to subangular fine to coarse flint and rare brick fragments.

5.6.2 Alluvium

Alluvium was encountered in all the exploratory holes along Section 6 either underlying the Made Ground at 0.5mbgl or at surface (HDTP106). Thickness of the Alluvium ranged from 0.90m to 1.90m where proven. The Alluvium was described as soft and firm brown locally mottled grey and light brown slightly gravelly clay locally with a low cobble content and rare rootlets. Gravel is angular to subrounded fine to coarse flint and chalk. Cobbles are subrounded flint up to 110mm long.

5.6.3 Chalk

Chalk was encountered in BH101 and BH102 underlying the Alluvium at 1.40mbgl and 2.40mbgl and is expected to be greater than 13m in thickness.

Chalk was described as structureless composed of light grey slightly gravelly silt. Clasts are very weak to weak medium density off-white subangular to subrounded fine with occasional black flint, CIRIA Grade Dm. In BH101 at 12mbgl chalk was recovered as structureless chalk composed of slightly silty, subangular to subrounded gravel and cobbles, CIRIA Grade Dc. Clasts are weak to moderately weak, medium to high density, off-white locally yellowish orange with rare black specks and rare flints. Matrix is off-white to yellow.

Layers of grey slightly sandy slightly silty angular to subangular fine to coarse gravel of flint and occasional chalk are recorded in BH101. These range in thickness between 1.0m and 1.5m. These are likely to be flint gravel washed out from the chalk during coring or flint beds.

5.7 Section 7 – Frontage 6 (Ch0 to

The following exploratory holes were carried out along Section 7, these are listed below:

- BGS historical borehole records, SU70SW20
- Phase 1 GI boreholes: WS02 and WS05
- 2021 GI exploratory holes: MDTP101 to MDTP103 and DS110

Table 5-8 Summary of encountered stratigraphy along Section 7 - Frontage 6

Stratum	Surface Level encountered (m AOD)	Depth to top of stratum (m)	Thickness of stratum (m)
Made Ground	0.05 - 3.10	0.00	0.05 - > 3.45*
Beach Deposits	0.38 – 1.92	0.05 - 3.10	0.50 - > 2.35*
Alluvium	-0.12 - 0.68	1.15 - -3.60	> 2.74*

*Not fully penetrated

5.7.1 Made Ground

Made Ground was encountered at ground level to a maximum depth of 3.45m in MDTP103. Thickness of the Made Ground ranges from 0.05m (DS110) to >3.45m. The limited thickness in DS110 is probably related to the location of the exploratory holes further into the beach. The thick Made Ground is probably related to the location of the historical railway line. This layer is described as multicoloured (black, brown, yellow, orange and red) sandy subangular to rounded fine to coarse gravel of flint, brick and chalk over greyish yellow slightly gravelly fine to coarse sand. Gravel is subangular to rounded fine to coarse flint, brick and chalk. In MDTP103 the multicoloured gravel is underlain by firm brown locally mottled bluish grey and red slightly sandy slightly gravelly clay with a medium cobble content of flint, chalk and brick.

5.7.2 Beach Deposits

Beach Deposits were encountered underlying Made Ground at 3.10mbgl in WS02 and at 0.05mbgl in DS110. In WS02 this layer is described as brown coarse sandy fine and medium subangular to subrounded gravel of flint. In DS110 this layer is described as loose yellowish grey slightly gravelly fine to coarse sand. Gravel is subangular to rounded fine to coarse flint and quartzite.

5.7.3 Alluvium

Strata interpreted as Alluvium was encountered in four exploratory holes (WS02, MDTP101, MDTP102 and SU70SW20) underlying Made Ground or Beach Deposits (WS02). This layer was described as soft, firm dark grey, black mottled brown clay locally with 2mm thick veinlets of evaporite at the base, with frequent fragments of decomposing wood and strong sulphurous odour. The Alluvium is expected to be greater than 2.74m in thickness.

5.8 Groundwater

Groundwater strikes and seepages observed during excavation/advance of boreholes was recorded on the exploratory hole logs. Groundwater strikes are tabulated in Table 5-9

Table 5-9 Groundwater observations during the current ground investigation

Location	Stratum	Seepage / Strike / Perched	Depth of Strike (m bgl)	Level Struck (m OD)	Depth after 20 Min (m bgl)	Level after 20 Min (m OD)
BH101	Structureless chalk (CIRIA Grade Dm)	Seepage	3.5	-0.4		Not recorded
BH102	Structureless chalk (CIRIA Grade Dm)	Seepage	2.5	-0.73		Not recorded
BH103	Made Ground (sandy clayey gravel)	seepage	0.3	1.39		Not recorded
BH104	Structureless chalk (CIRIA Grade Dm)	Strike	6.0	-3.32	4.7	-2.02
BH105	Head Deposits (slightly sandy slightly gravelly clay)	Seepage	1.0	1.44		Not recorded
BH106	Structureless chalk (CIRIA Grade Dm)	Strike	3.0	-1.85	2.7	-1.55
HDTP103	Beach Deposits (sandy slightly clayey gravel)	Strike	0.12	0.71		Nor recorded
HDTP104	Beach and Tidal Deposits (slightly gravelly slightly sandy silt)	Strike	0.7	-0.21		Not recorded
HPTP105	Beach Deposit (slightly sandy slightly silty gravel)	Strike	0.4	1.13		Not recorded
HDTP106	Alluvium (slightly gravelly slightly sandy clay)	Seepage	0.6	1.74		Not recorded
HDTP110	Made Ground (yellow gravelly clayey sand with occasional cobbles)	Seepage	0.9	1.94		Not recorded
HDTP111	Made Ground (slightly sandy slightly gravelly clay)	Strike	1.0	1.06		Not recorded
MDTP101	Made Ground (slightly clayey fine to coarse sand)	Seepage	1.0	0.88		Not recorded
MDTP102	Made Ground (very sandy slightly clayey fine to coarse gravel)	Strike	1.3	0.92		Not recorded
MDTP103	Made Ground (very sandy slightly clayey fine to coarse gravel)	Seepage	1.5	1.74		Not recorded
DS101	Alluvium (sandy clayey gravel)	Seepage	0.75	1.22		Not recorded
DS102	Alluvium (slightly sandy gravelly clay)	Seepage	0.6	1.68		Not recorded
DS104	Alluvium (slightly sandy slightly gravelly clay)	Strike	2.6	0.59		Not recorded
DS106	Made Ground (slightly sandy slightly gravelly clay)	Seepage	1.2	1.77		Not recorded
DS107	Alluvium (slightly gravelly clay)	Seepage	1.3	1.23		Not recorded
DS109	Made Ground (slightly sandy slightly gravelly silty clay)	Seepage	1.0	0.65		Not recorded

Dual standpipes were installed in BH101, BH104 and BH105. Single standpipes were installed at relatively shallow depths in dynamic sample holes DS103 through DS107. Refer to logs in Appendix C for installation details.

The standpipes were monitored during the fieldwork period and three subsequent monitoring visits carried out on 08 October 2021, 14 October 2021, 25 October 2021 and on 20 January 2022 before decommissioning the boreholes. BH03 was not monitored on the last event as a car was parked on the location. The results of the monitoring are presented in Figure 5-1. The dashed lines represent installations into Chalk. The solid lines represent installations into superficial deposits. Variation in groundwater levels between monitoring dates occurs in BH101, BH104 shallow and BH105 deep standpipes installed within the Chalk. BH104 shallow is likely a reflection of tidal changes as it is located along the foreshore (Ship Inn Car Park). Without rainfall data to correlate the groundwater measurement with, the cause of the fluctuations is uncertain.

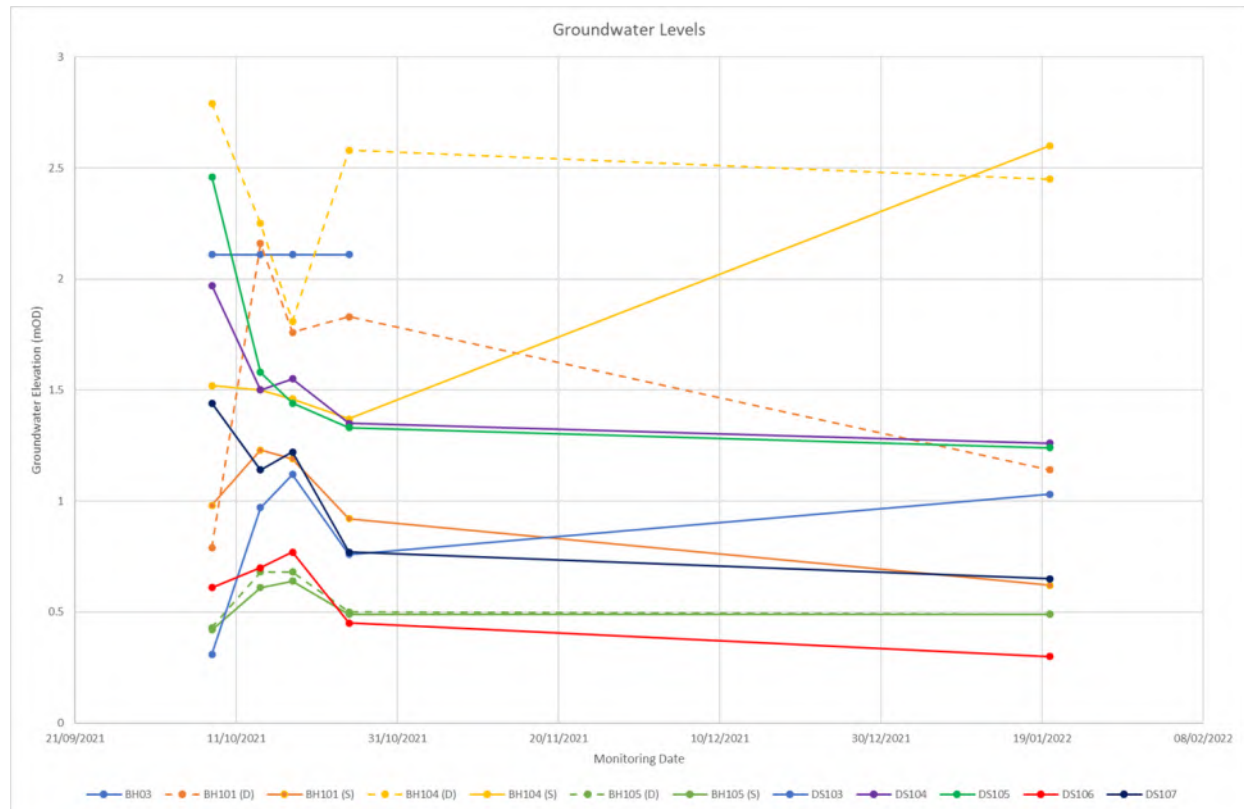


Figure 5-1 Groundwater levels (mOD) recorded during and after ground investigation

6. Ground Conditions and Material Properties

The assessment of engineering design parameters for the strata encountered are based upon the exploratory hole logs, engineering descriptions of the strata, in situ test data and the results of laboratory tests presented in the following sections and subsections. The majority of this data was obtained during in the most recent ground investigation, but data from the two earlier phases of ground investigation have also been utilised.

Where parameters are used in engineering analysis, they should be critically evaluated to ensure that the appropriate parameter or range of parameters is used.

6.1 Made Ground

Made Ground encountered during the geotechnical investigation was subject to the following in-situ and laboratory testing:

- In situ hand penetrometer measurements to determine soil compressive strength
- In situ hand vane testing to determine in-situ shear strength of cohesive soils
- Standard penetration tests (SPT)
- Determination of natural moisture content
- Determination of particle size distribution by wet sieving
- Determination of Atterberg Limits
- One dimensional consolidation test

6.1.1 Classification Tests

A total of 18 No. Atterberg Limit tests were carried out on cohesive Made Ground, these are summarised in Table 6-1. Natural moisture content (nmc) results ranged from 11% to 76% and average 24%. Liquid Limit (LL) results ranged from 26% to 80% and average 48%. Plastic Limit results ranged from 18% to 36% and averages 23%. Plasticity Index results ranged from 8% to 59% and average 26%. The samples with high liquid limits were retrieved from Frontages 2 (HPTP111), Frontage 3 (BH104), and Frontage 4 (HDTP102). These higher liquid limit values may be related to higher organic content within these areas

To assess the volume change potential of the Alluvium, the modified plasticity index (I_p) was calculated from recorded plasticity indices (I_p) according to the following formula:

$$I_p = I_p * \left(\% < \frac{425\mu m}{100\%} \right)$$

Table 6-1 Atterberg Limit and Moisture Content result summary for Made Ground

Statistic	Natural Moisture content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Passing 425 (%)	Modified Plasticity Index (%)
Minimum	11	26	18	8	32	4
Maximum	76	80	36	59	100	40
Average	24	48	23	26	64	17

The results of natural moisture content and Atterberg Limit testing on Made Ground are presented in Figure 6-1. Of the 18 samples tested and compared, 9 samples have lower moisture content than plastic limit. The remaining 9 samples have a lower plastic limit than moisture content.

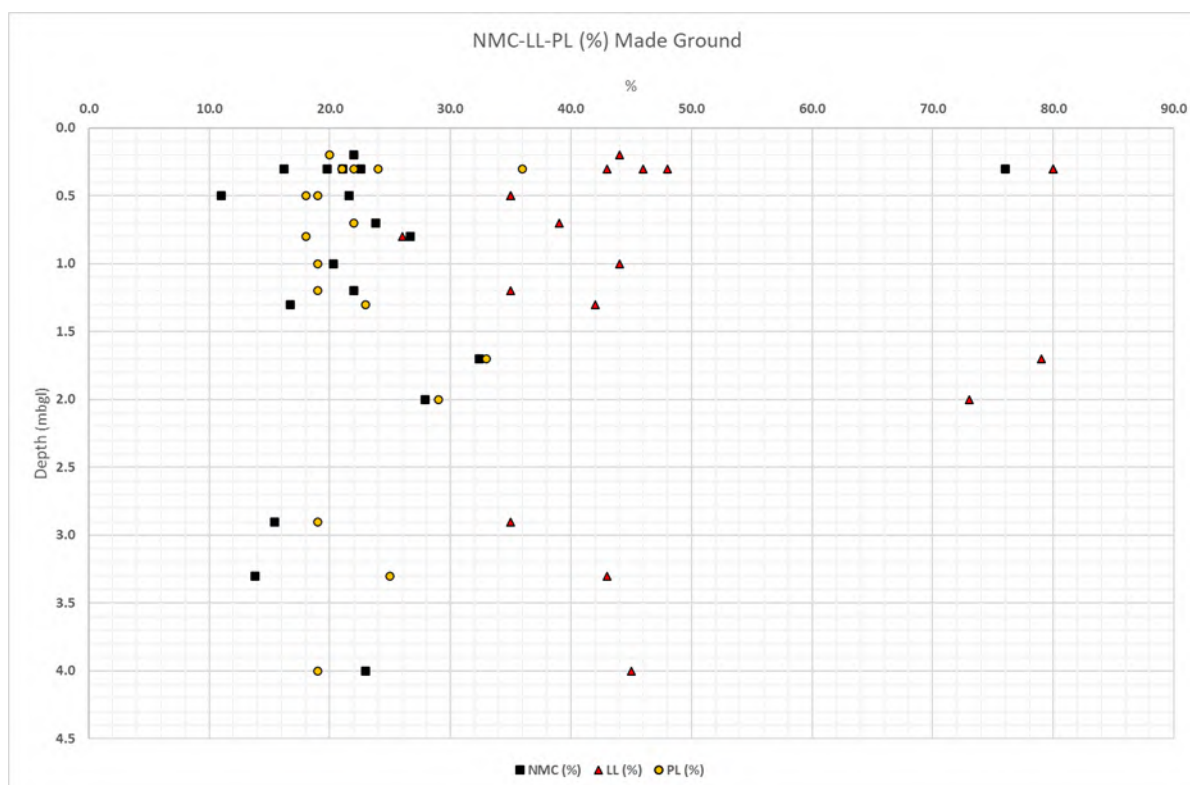


Figure 6-1 Made Ground - Moisture Content and Atterberg Limits vs Depth

Figure 6-2 shows the Atterberg limit results for Made Ground plotted on the Casagrande A-Line plot and shows the material to mainly be classed as intermediate plasticity clay with low volume change potential in accordance with BRE Digest 240. Three samples tested were classed as high plasticity clay and medium to high volume change potential (these samples were retrieved from MDTP102 at 1.7m, HDTP111 at 0.3m and BH104 at 2.0m).

One sample is a low plasticity clay (DS109 at 0.8m) and one sample is an intermediate plasticity silt (DS101 at 0.3m).

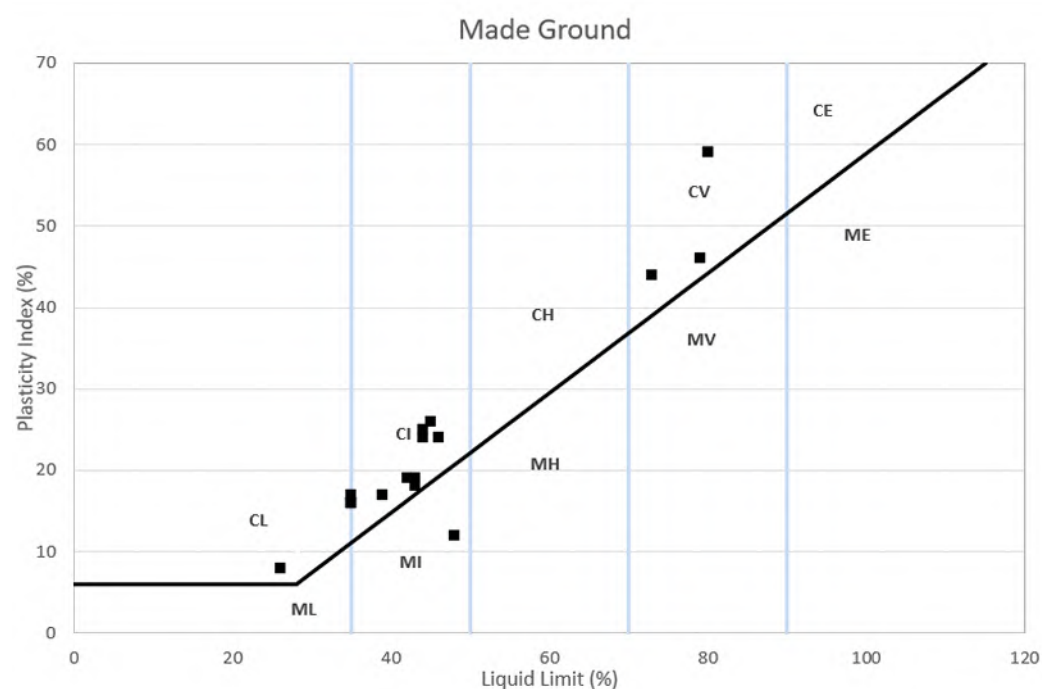


Figure 6-2 Atterberg limit results for Made Ground plotted on the Casagrande A-line

Particle size distribution was carried out on 38 No. samples obtained from the Made Ground. A summary of the results is presented in Table 6-2 and on Figure 6-2, the results show that the Made Ground comprises of a range of all particle sizes.

Table 6-2 Summary of Particle Size Distribution Testing for Made Ground

Statistic	% cobbles/boulders	% gravel	% sand	% silt	% clay
Minimum	0	0	5	7	3
Maximum	6	83	93	60	29
Average	1	38	22	27	14

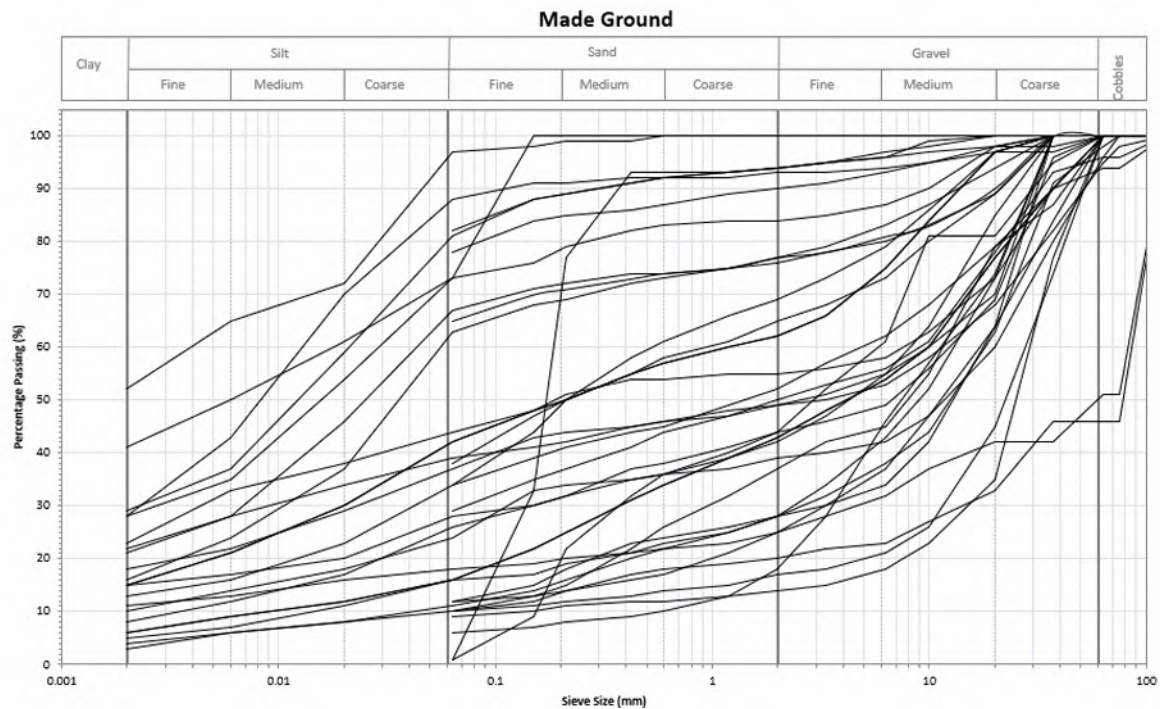


Figure 6-3 Particle Size distribution of Made Ground

6.1.2 Organic Matter

3 No. organic matter content tests were carried out on the Made Ground with the results ranging between 0.30% and 2.0%. In terms of BS5930 the materials tested are considered inorganic (less than 2% organic material of dry mass).

6.1.3 Bulk Unit Weight

Given the variable nature of the Made Ground the bulk unit weight is considered likely to vary significantly depending in the composition of the material and the relative density.

Based on soil descriptions and typical values for similar soils presented in BS8002 Figure 1, a bulk unit weight of between 17 and 21kN/m³ is inferred for granular Made Ground. Based on this, a bulk unit weight of 19kN/m³ can be adopted for granular Made Ground.

By the same method a bulk unit weight of between 14 and 20kN/m³ is inferred for cohesive Made Ground. Based on this, a bulk unit weight of 17kN/m³ can be adopted for cohesive Made Ground.

6.1.4 Strength

The undrained shear strength (C_u) of the cohesive Made Ground has been derived by the following methods:

- Hand shear vane results
- Hand penetrometer results
- Correlations based on SPT results (Stroud 1989)

A total of 8 No. hand penetrometers were taken on the Made Ground and the results ranged from 20kPa to >225kPa. It is important to note that granular inclusions within the Made Ground may have resulted in artificially high results.

A total of 61 No. hand shear vanes were undertaken in the Made Ground with the shear strength ranging from 10 to 120 kPa.

10 No. SPT tests were carried out on the Made Ground. To derive geotechnical parameters from SPT tests, the N value recorded during the test has been corrected using the energy ratio of the SPT hammer to give an N_{60} value using the following formula:

$$N_{60} = N * \left(\frac{E_R}{60} \right)$$

The results of the corrected test values plotted against depth are shown in Figure 6-4. The N_{60} values range in the Made Ground range between 6 and 73. The outlier value of 73 is likely due to a cobble or gravel impeding the advance of the SPT and resulting in an artificially high result. As such this value has been excluded from calculations of averages. An average N_{60} value of 19 has been calculated.

The corrected N_{60} values of between 6 and 73 for the granular material were further corrected for overburden pressure ($(N_1)_{60}$) according to the following formula:

$$(N_1)_{60} = N_{60} * CN$$

When corrected for overburden, the $(N_1)_{60}$ values were computed as between 9 and 108. As above the 108 value has been excluded from the determination of an average $(N_1)_{60}$ of 28.

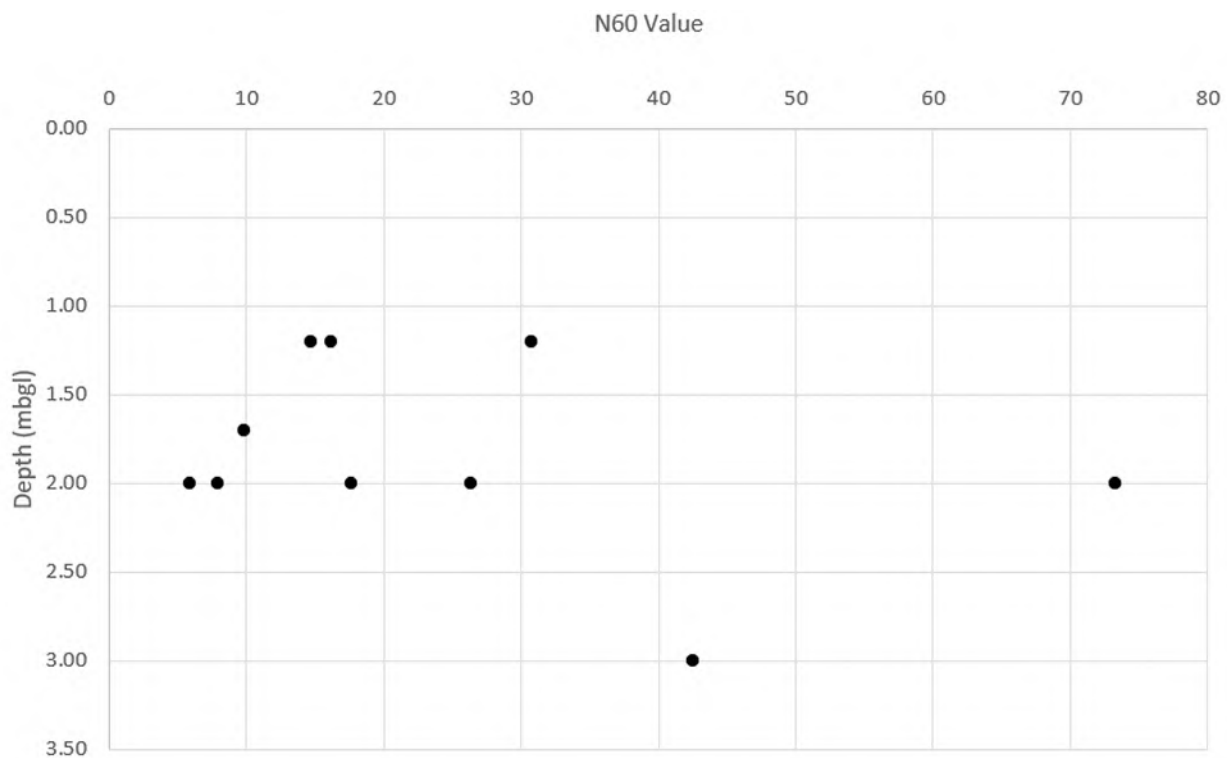


Figure 6-4 N60 Values vs Depth in Made Ground

The Stroud correlation for SPT N values is:

$$C_u = f_1 * N_{60}$$

where,

f_1 = empirical value that depends upon the plasticity of the material. Based on the obtained Plasticity Indices (8% to 59%), an f_1 value of 5 was adopted.

The results of the derivations are shown in Figure 6-5. The derived undrained shear strengths of the Made Ground are highly variable, generally ranging between 29kPa to 88kPa with an outlier value of 213kPa. when correlated from SPT 'N' value using Stroud (1989). The outlier is most likely due to the SPT being impeded by a cobble inclusion resulting in an artificially high blow count for the test, as such this value should be discounted. This variability is expected due to the variable nature of the Made Ground.

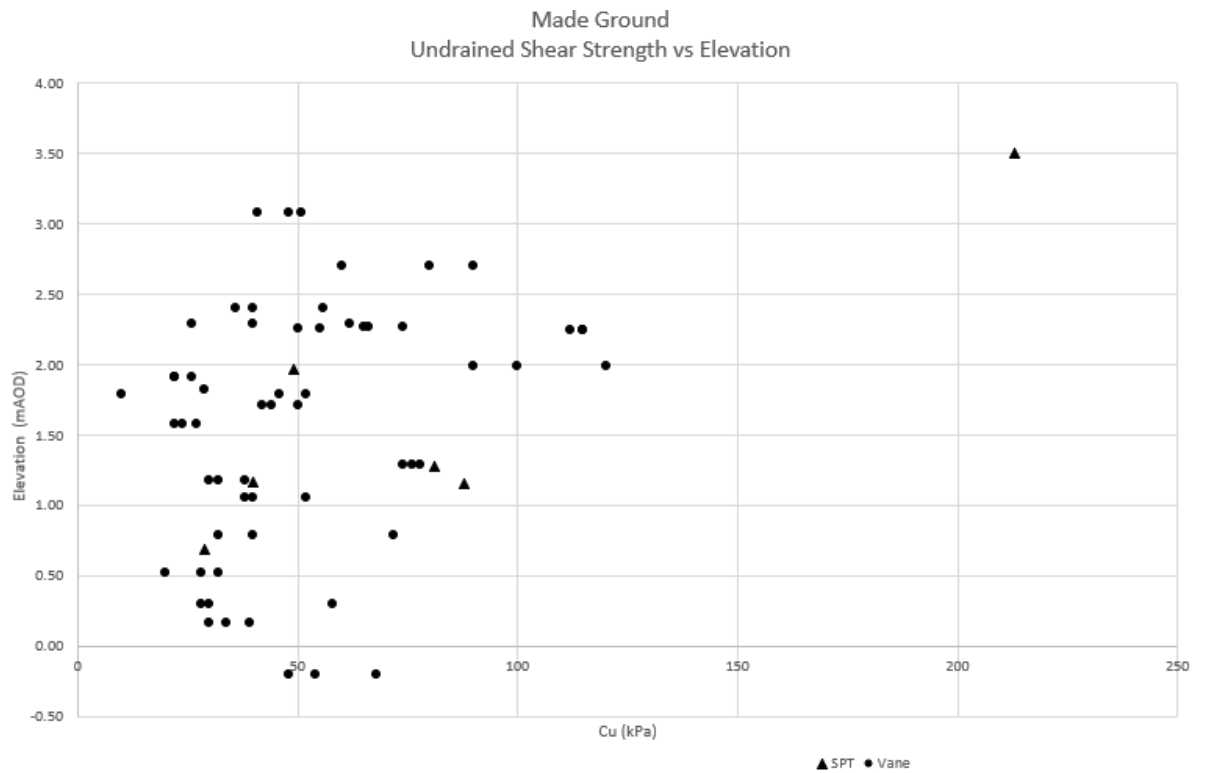


Figure 6-5 Derived undrained shear strength vs elevation in Made Ground

An estimation of the angle of shearing resistance in granular Made Ground has been estimated from SPT (N_1)₆₀ results after Peck et al (1959). The correlation from SPT values returned friction angles ranging between 35° and 40° with an outlier value of 48°. As mentioned above, this outlier is most likely due to the SPT being impeded by a cobble inclusion within the Made Ground resulting in an artificially high blow count for the test, as such this value should be discounted.

For cohesive Made Ground, the Santamarina et al. (2003) correlation was used to estimate the effective constant volume angle of shearing resistance (ϕ'_{cv}) based on the plasticity indices (I_p) of Made Ground according to the following formula:

$$\phi'_{cv} = 42^\circ - 12.5 \log_{10}(I_p)$$

Generally, Plasticity Index results for the Made Ground ranged from 8% to 26% with the correlated ϕ'_{cv} results ranging from 24° to 30°. However, four samples show higher Plasticity Index results in the range 44% to 59% with lower correlated ϕ'_{cv} results ranging from 20° to 21°

6.1.5 Stiffness

For cohesive Made Ground, the following correlation (Jamiolkowski et al, 1979) was used to derive the undrained Young's Modulus for a large strain level (i.e., 0.1%)

$$E_u = 300c_u$$

Based on an average undrained shear strength of 83kPa and lower quartile of 42kPa (as derived by the SPT data), an undrained Young's Modulus of 25MPa and 13MPa is obtained.

Assuming linear elasticity, the drained Young's Modulus can be estimated for the cohesive Made Ground according to the following formula, resulting in a Young's Modulus of 11MPa and 21MPa:

$$E' = E_u * \left(\frac{2(1 + \nu')}{3} \right) = 0.83 * E_u$$

where,

ν' = drained Poisson's ratio (assumed 0.25).

Due to this variability in composition material stiffness can vary laterally and with depth across relatively short distances. The derived values should therefore be utilised with caution during any design.

The Stroud (1989) correlation was used to derive the drained Young's Modulus of the granular Made Ground according to the following formula:

$$E' = N_{60} * 1 \text{ MPa}$$

Based on an average N_{60} value of 36 and lower quartile of 24, undrained Young's Modulus of 36MPa and 24MPa can be considered.

6.2 Beach Deposits / Tidal Flat Deposits

Beach Deposits encountered during the geotechnical investigation were subject to the following in-situ and laboratory testing:

- In situ hand penetrometer measurements to determine soil compressive strength
- In situ hand vane testing to determine in-situ shear strength of cohesive soils
- Standard penetration tests (SPT)
- Determination of natural moisture content
- Determination of particle size distribution by wet sieving
- Determination of Atterberg Limits

6.2.1 Classification Tests

Particle size distribution testing was carried out on 5 no. samples obtained from the Beach Deposits, a summary of the results is presented in Table 6-3 and Figure 6-6. The PSD results appear to indicate two distinct materials, a gravel dominated beach deposit (Frontage 1B) and a sand dominated beach deposit (near the boundary between Frontage 1 and Frontage 2, as well as Frontage 6).

Table 6-3 Particle size distribution of Beach Deposits

Statistic	% cobbles/ boulders	% gravel	% sand	% silt	% clay
Minimum	0.0	20.0	3.0	3.0	2.0
Maximum	0.0	92.0	79.0	5.0	3.0
Average	0.0	56.5	39.8	4.0	2.5

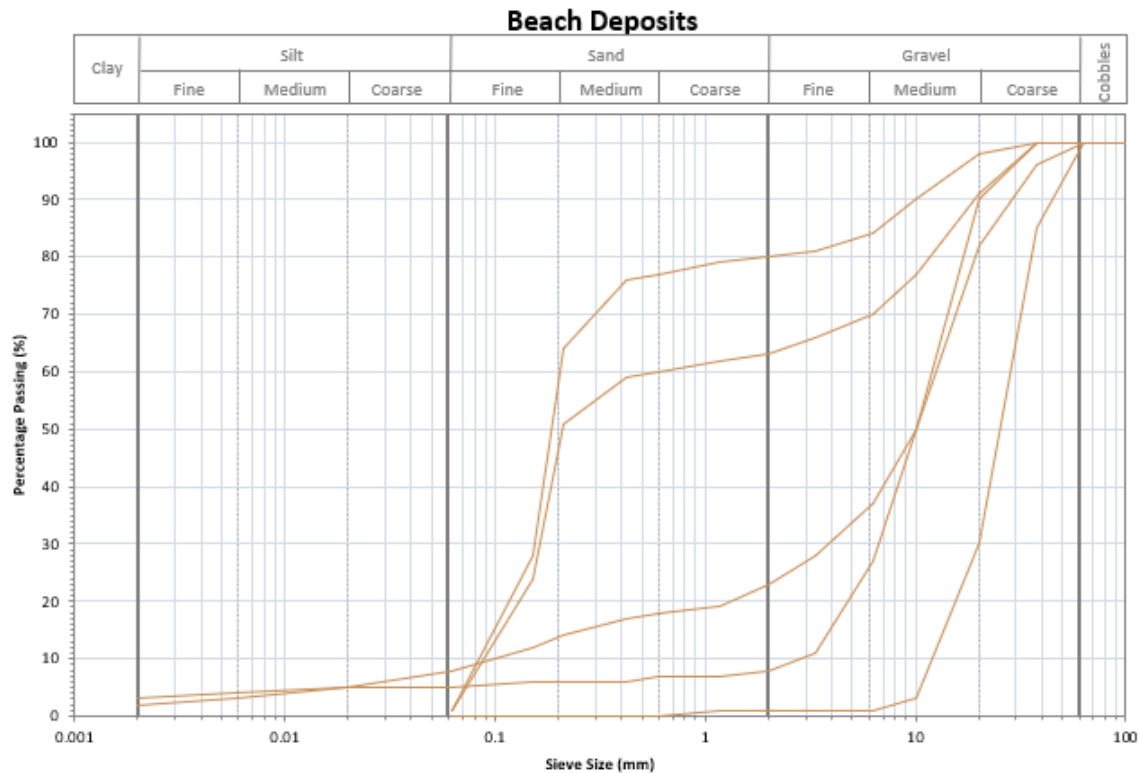


Figure 6-6 Particle Size Distribution of Beach Deposits

2 No. Atterberg Limit tests were carried out on cohesive Beach Deposits. Natural moisture content (NMC) results were reported as 23% and 73%, higher than the reported Plastic Limits of 20% and 35%, respectively. Liquid Limit (LL) results were reported as 32% and 80%. Plasticity Index results were reported as 12% and 45%. The materials are considered low and high plasticity.

The modified plasticity index (I_P) has been calculated at 7% and 44%, which are classed as low and high-volume change potential, respectively in accordance with NHBC guidance.

6.2.2 Bulk Unit Weight

Based on the soil descriptions and typical values for similar soils presented in BS8002 Figure 1 a bulk unit weight of between 14 and 21kNm³ is inferred for Beach Deposits. Based on this, a bulk unit weight of 17kNm³ can be adopted for beach deposits.

6.2.3 Strength

The undrained shear strength (*C_u*) of the cohesive Beach Deposits has been derived by correlations based on SPT results (Stroud 1989).

18 No. SPT tests were carried out on the Beach Deposits. To derive geotechnical parameters from SPT tests, the *N* value recorded during the test has been corrected using the energy ratio of the SPT hammer to give an *N*₆₀ value using the following formula:

$$N_{60} = N * \left(\frac{E_R}{60} \right)$$

The results of the corrected test values plotted against depth are shown in Figure 6-7. The *N*₆₀ values in the Beach Deposits range between 5 and 25 with an average of 15.

The corrected *N*₆₀ values were further corrected for overburden pressure (*N*₁)₆₀ for granular soils according to the following formula:

$$(N_1)_{60} = N_{60} * CN$$

When corrected for overburden, the (*N*₁)₆₀ values were computed as between 5 and 30.

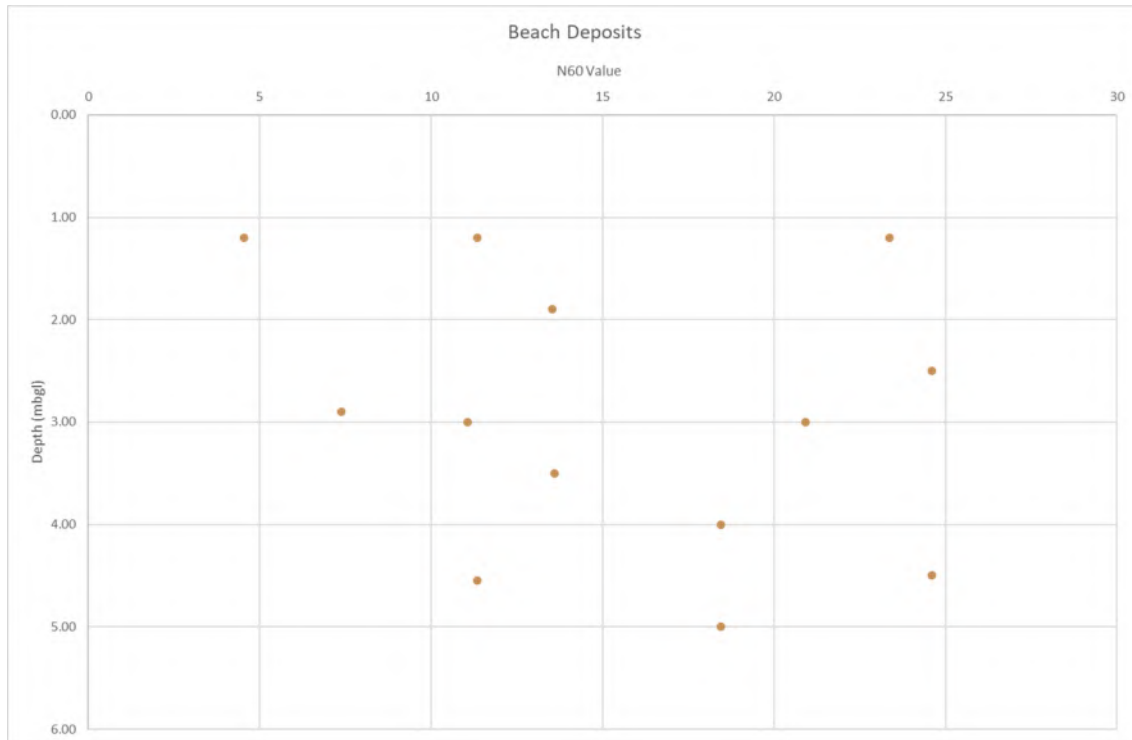


Figure 6-7 Plot of N60 values vs depth for Beach Deposits

An estimation of the angle of shearing resistance in non-cohesive/granular Beach Deposits has been estimated from corrected $(N_1)_{60}$ after Peck et al (1974). The correlation from SPT values returned friction angles ranging between 27° and 35°.

6.2.4 Stiffness

The Stroud (1989) correlation was used to derive the drained Young's modulus of the granular Beach Deposits according to the following formula:

$$E' = N_{60} * 1 \text{ MPa}$$

Based on an average N_{60} value of 14 and a lower quartile of 10, drained Young's Modulus of 14MPa and 10MPa can be considered.

6.3 Alluvium

Alluvium encountered during the geotechnical investigation were subject to the following in-situ and laboratory testing:

- In situ hand vane testing to determine in-situ shear strength of cohesive soils
- In situ hand penetrometer testing
- Standard penetration tests (SPT)
- Determination of natural moisture content
- Determination of particle size distribution by wet sieving
- Determination of Atterberg Limits
- Single stage unconsolidated undrained triaxial testing (without measurement of pore pressure)

6.3.1 Classification Tests

35 No. Atterberg Limit tests were carried out on samples of Alluvium. The results indicated a natural moisture content range from 13% to 77% with an average of 23%. Liquid Limit (LL) results range from 26% to 78% and average of 42%. Plastic Limit results range from 17% to 39% and average of 20%. Plasticity Index results range

from 9% to 47% and average 20%. The variation in LL could be related to variable amounts of organic material within the unit, higher percentages of organic material can result in higher LL.

Ten of the test results show that the moisture content is lower than the plastic limit, whilst the remaining twenty-five test results have lower plastic limit than moisture content.

The results of natural moisture content and Atterberg Limit testing on Alluvium are presented in Figure 6-8.

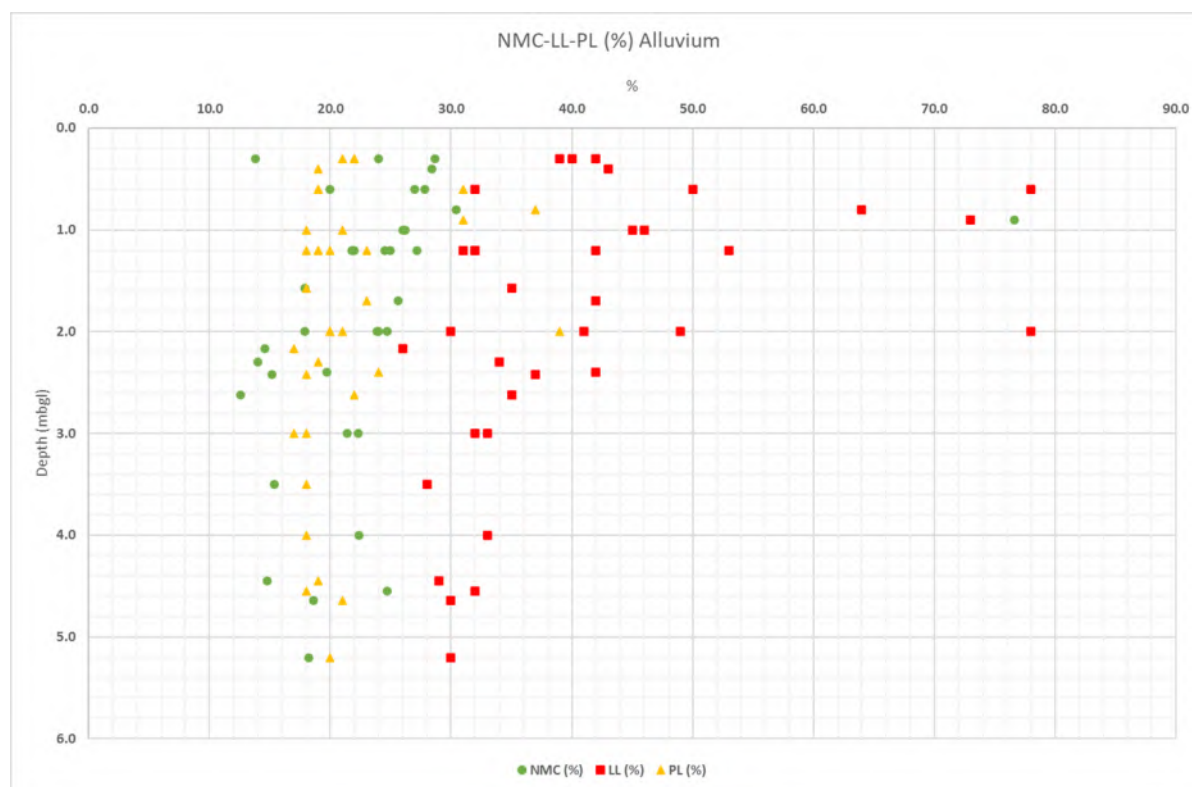


Figure 6-8 Moisture Content and Atterberg Limits vs Depth - Alluvium

Figure 6-9 shows the Atterberg limit results for Alluvium plotted on the Casagrande A-Line plot. The plot shows the material to mainly be classed as low to intermediate plasticity clay. Five samples tested were classed as high to very high plasticity clay/ silt. A summary of the Atterberg Limit and moisture content are given in Table 6-4.

Table 6-4 Atterberg Limit and Moisture Content result summary for Alluvium

Statistic	Natural Moisture Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Passing 425 (%)	Modified Plasticity Index (%)
Minimum	13	26	17	9	31	4
Maximum	77	78	39	47	100	38
Average	23	42	21	20	77	16

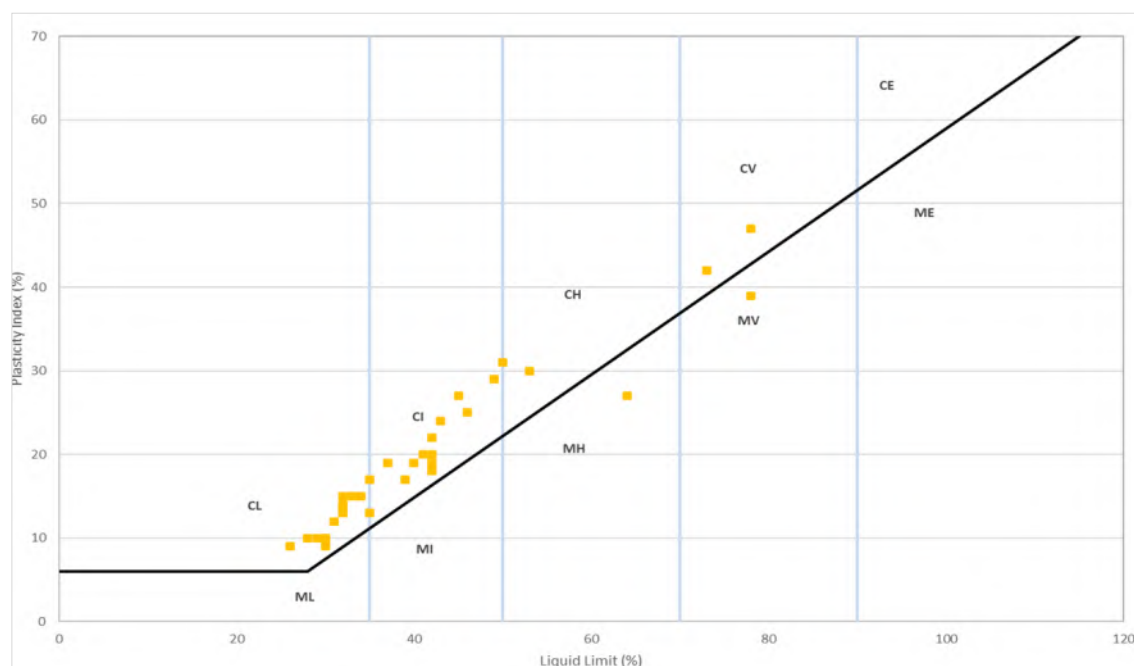


Figure 6-9 Atterberg limit results for alluvium plotted on the Casagrande A-line

In order to assess the volume change potential of the Alluvium, the modified plasticity index (I'_p) was calculated from recorded plasticity indices (I_p) according to the following formula:

$$I'_p = I_p * \left(\% < \frac{425\mu m}{100\%} \right)$$

Modified plasticity indices of between 4 and 38 were obtained, indicating a no to medium volume change potential in accordance with BRE Digest 240.

Particle size distribution was carried out on 33 no. samples obtained from the Alluvium: a summary of the results is presented in Table 6-5 and on Figure 6-10. The results show that the Alluvium comprises of a range of all particle sizes.

Table 6-5 Summary of Particle Size Distribution Testing for Alluvium

Statistic	% cobbles/ boulders	% gravel	% sand	% silt	% clay
Minimum	0	0	2	1	1
Maximum	4	96	37	72	47
Average	0	25	13	43	19

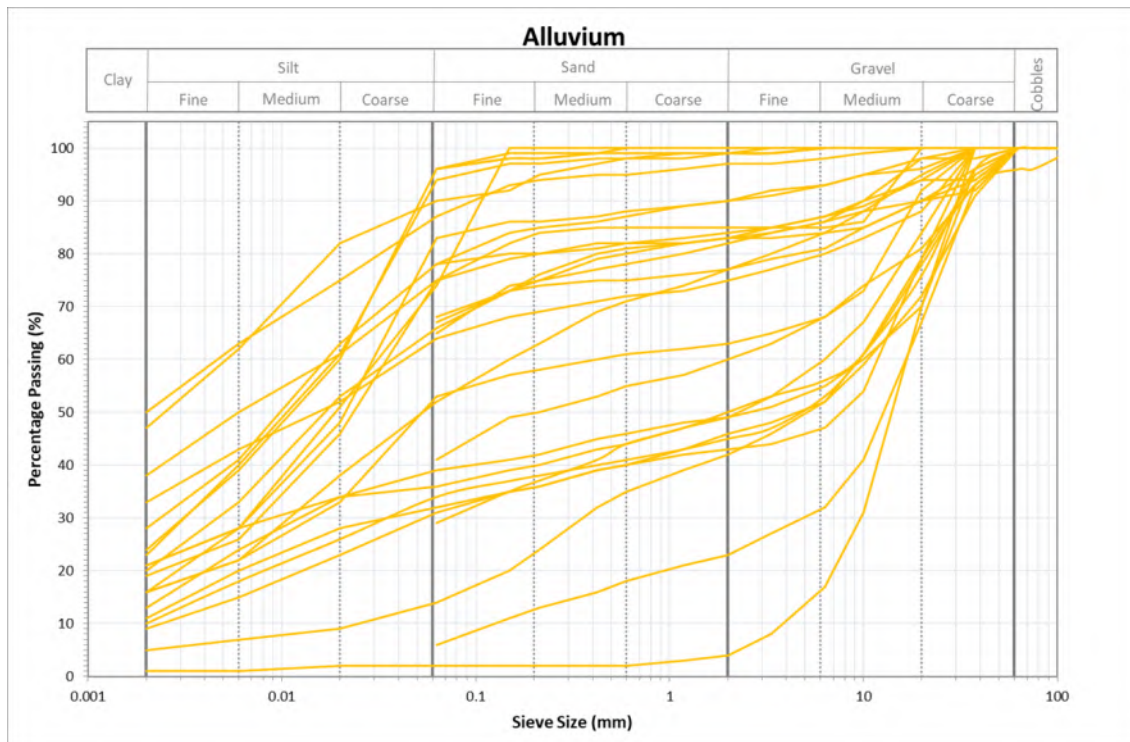


Figure 6-10 Particle Size Distribution graph of Alluvium

6.3.1 Organic Matter

5 No. organic matter content tests were carried out on the Alluvium with the results ranging between 0.20% and 5.60%. In terms of BS5930 the materials tested are considered inorganic (less than 2% organic material of dry mass) slightly organic (2% to 6% organic material of dry mass). Typically, the samples retrieved from nearer the shoreline have higher organic contents than those retrieved further inland.

6.3.2 Bulk Unit Weight

Based on material descriptions and in accordance with Figure 1 and Figure 2 of BS 8002:2015, dry unit weight and saturated unit weights ranging between 15kN/m³ and 21kN/m³ have been derived for Alluvium.

6.3.3 Strength

The undrained shear strength of (C_u) of the cohesive Alluvium has been derived by the following methods:

- 9 No. triaxial tests
- Correlation based on hand shear vane results
- Correlations based on SPT results (Stroud 1989)

One hand penetrometer test was carried out on the Alluvium giving a reading of 88kPa. 30 No. hand shear vanes were carried out on the Alluvium with the results ranging from 16kPa to 75kPa.

A total of 29 No. Standard Penetration Tests (SPTs) were carried out in the Alluvium, and uncorrected SPT blow counts (N) between 4 and 24 were reported.

To derive geotechnical parameters from the SPT tests, the N values were corrected to a standard hammer energy of 60% (N_{60}) according to the following formula:

$$N_{60} = N * \left(\frac{E_R}{60} \right)$$

where,

E_R = hammer energy ratio

The corrected N_{60} values ranged between 5 and 30 with an average value of 14 and a lower quartile of 10 showing an increase in N_{60} with depth. These values are plotted below in Figure 6-11.

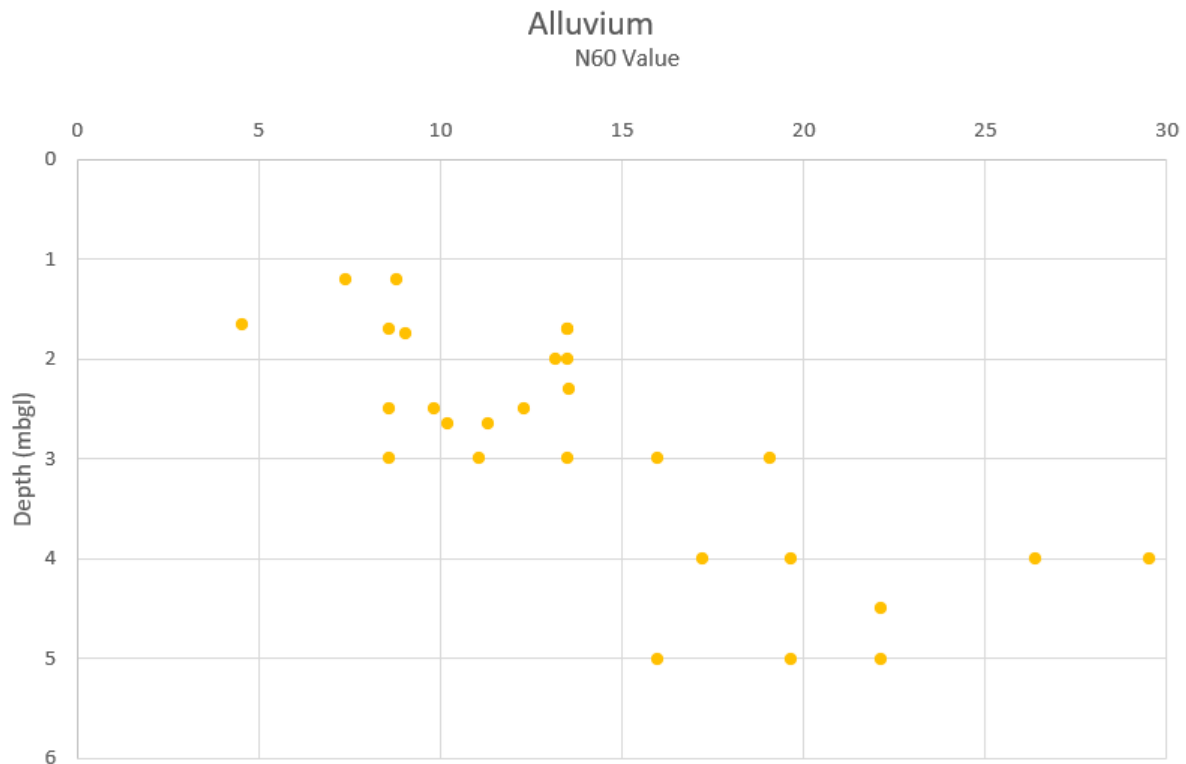


Figure 6-11 SPT N60 Values vs Depth in Alluvium

The Stroud correlation is:

$$C_u = f_1 * N_{60}$$

where,

f_1 = empirical value that depends upon the plasticity of the material.

Based on the obtained Plasticity Indices (9% and 47%), an f_1 value of 5 was used for derivation of undrained shear strength of the Alluvium. The derived undrained shear strength values ranged between 37kPa and 148kPa with an average of 71kPa and lower quartile of 48kPa. In-situ hand vane testing returned undrained shear strength values between 16kPa to 60kPa.

The above results plotted against elevation are presented in Figure 6-12. The results show that generally the undrained strength increases with depth. From about 20kPa at 1mAOD to about 100kPa at -3mAOD.

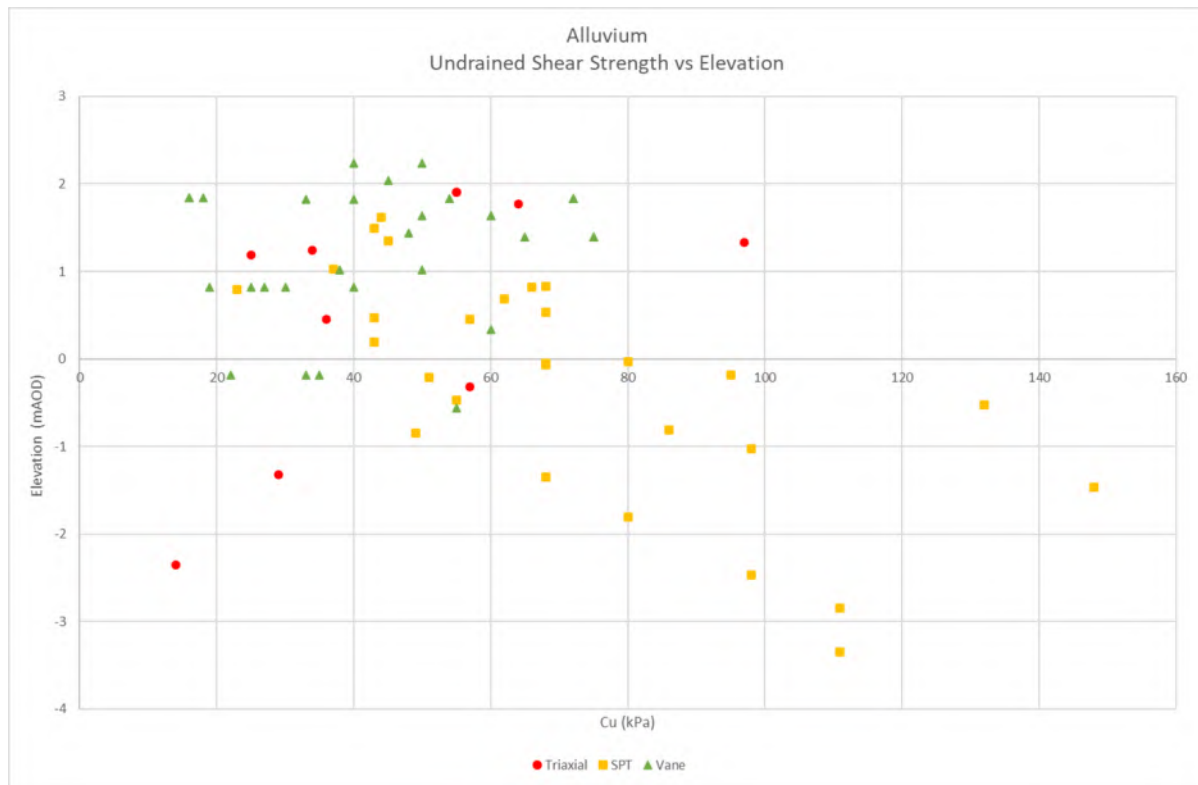


Figure 6-12 Undrained shear strength of alluvium plotted against depth

An estimation of the angle of shearing resistance in granular Alluvium has been estimated from one SPT result after Peck et al (1974). The correlation from SPT values returned a friction angle of 31°.

For cohesive Beach Deposits, the Santamarina et al. (2003) correlation was used to estimate the effective constant volume angle of shearing resistance (ϕ'_{cv}) based on the plasticity indices (I_p) of the Alluvium according to the following formula:

$$\phi'_{cv} = 42^\circ - 12.5 \log_{10}(I_p)$$

A lower-bound effective constant volume drained angle of shearing resistance (ϕ'_{cv}) of 21° was derived based on an upper-bound plasticity index of 47% for the Alluvium. The Plasticity Index results for the Alluvium range between 9% and 47% with the correlated ϕ'_{cv} results of between 21° and 30°. The average correlated ϕ'_{cv} is 26°.

6.3.4 Stiffness

The Jamiolkowski et al (1979) correlation was used to derive the undrained Young's modulus (E_u) of the Alluvium. The values estimated for stiffness should be used with caution as they are based on two correlations.

For cohesive Alluvium, the following correlation (Jamiolkowski et al, 1979) can be used to derive the undrained Young's Modulus for a large strain level (i.e. 0.1%):

$$E_u = 300cu$$

Based on an average undrained shear strength of 71kPa and a lower quartile of 48kPa, undrained Young's Modulus of 21MPa and 14MPa can be considered.

Assuming linear elasticity, the drained Young's modulus can be estimated according to the following formula, resulting in an average value of 18MPa and a lower quartile of 12MPa:

$$E' = E_u * \left(\frac{2(1 + \nu')}{3} \right) = 0.83 * E_u$$

where,

ν' = drained Poisson's ratio (assumed 0.25).

6.3.5 Compressibility

2 No. one-dimensional consolidation tests were undertaken on the Alluvium. The coefficient of volume compressibility measured during the oedometer testing is presented in Figure 6-6 and Figure 6-13. Figure 6-13 presents a plot of coefficient of volume change (m_v) versus effective stress for each oedometer test.

Table 6-6 One-Dimensional Consolidation Results - Alluvium

Hole ID	Test Depth (m)	Stress (kPa)	Void Ratio	Coefficient of Volume Compressibility (m_v) (m^3/MN)
BH105	1.20	30	0.589	1.4
		60	0.521	0.4
		90	0.503	0.27
		120	0.490	0.24
		30	0.481	-
DS105	2.00	30	0.579	1.6
		60	0.503	0.34
		90	0.487	0.24
		120	0.477	0.2
		30	0.468	-

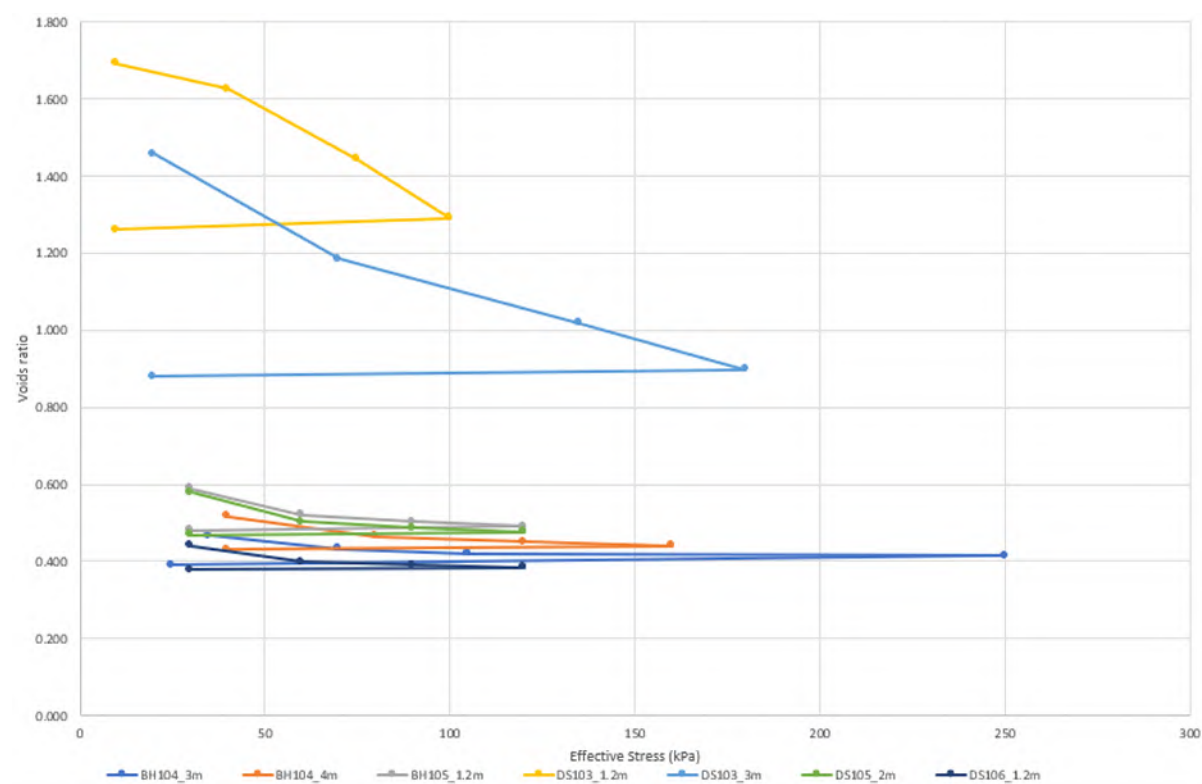


Figure 6-13 Void Ratio vs Effective Stress from Compressibility Tests

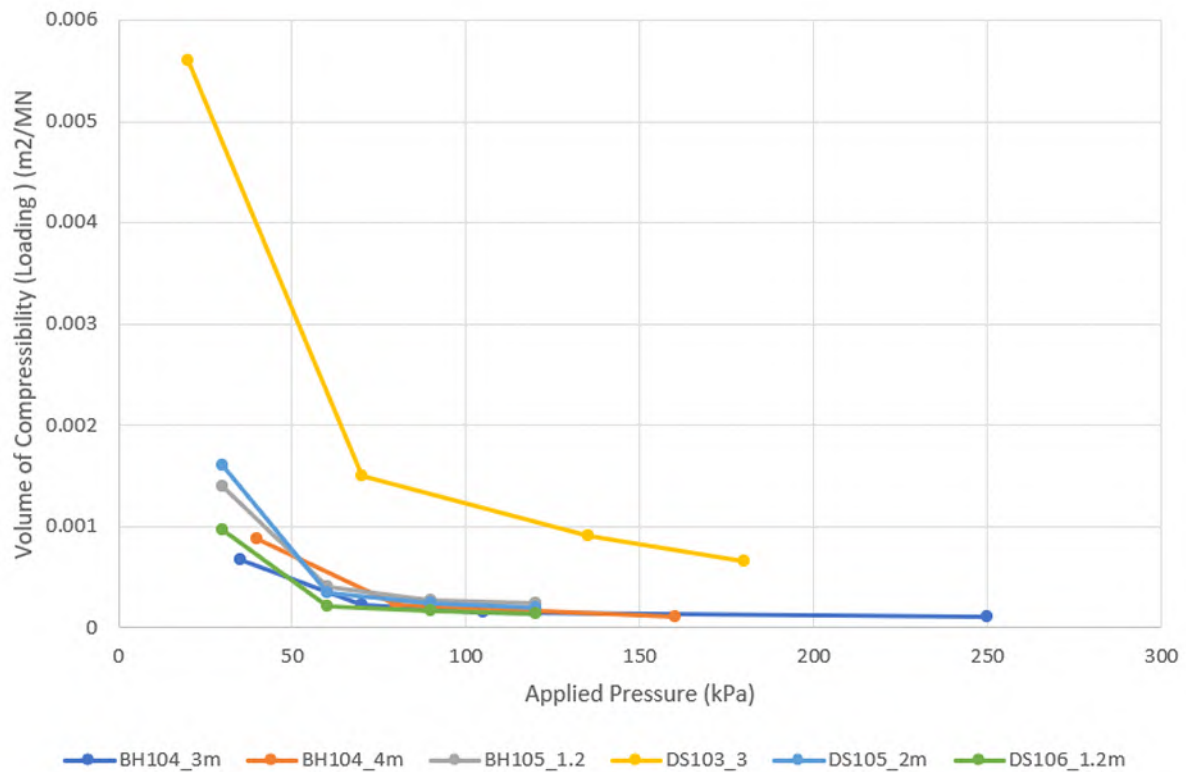


Figure 6-14 Coefficient of Volume Change vs. Effective Stress for Alluvium

6.4 River Terrace Deposits

No laboratory testing was carried out on the River Terrace Deposits encountered due to this unit being encountered in a limited number of boreholes. In situ testing carried out during the ground investigation included standard penetration tests.

6.4.1 Bulk Unit Weight

A dry unit weight ranging between 17kN/m³ and 21kN/m³ and a saturated unit weight ranging between 19kN/m³ and 22kN/m³ have been derived for the River Terrace Deposits based on the material description (loose to medium dense gravels and sand) and in accordance with Figure 1 and Figure 2 of BS 8002:2015 respectively.

6.4.2 Strength

A total of 3 No. Standard Penetration Tests (SPTs) were carried out in the River Terrace Deposits, and uncorrected SPT blow counts (N) between 9 and 21 were reported.

To derive geotechnical parameters from the SPT tests, the N values were corrected to a standard hammer energy of 60% (N_{60}) according to the following formula:

$$N_{60} = N * \left(\frac{E_R}{60} \right)$$

where,

E_R = hammer energy ratio

The corrected N_{60} values ranged between 11 and 24 with an average value of 18 and a lower quartile of 15.

The corrected N_{60} values were further corrected for overburden pressure ($(N_1)_{60}$) according to the following formula:

$$(N_1)_{60} = N_{60} * CN$$

When corrected for overburden, the $(N_1)_{60}$ values were computed as 14 to 27.

The angle of shearing resistance in granular River Terrace Deposits has been estimated from the $(N_1)_{60}$ after Peck et al (1974). The correlation from the $(N_1)_{60}$ values returned friction angles ranging between 30° and 34°. Due to limited number of data points these values should be utilised with caution during design.

6.4.3 Stiffness

The Stroud (1989) correlation was used to derive the drained Young's modulus of the granular River Terrace Deposits according to the following formula:

$$E' = N_{60} * 1MPa$$

A drained Young's modulus of 18MPa was derived for the granular River Terrace Deposits based on the average N_{60} from three SPT values available within this unit.

6.5 Structureless Chalk

Chalk was encountered during the geotechnical investigation and was subjected to the following in-situ and laboratory testing:

- In situ hand vane testing to determine in-situ shear strength of destructured chalk
- Standard penetration tests (SPT)
- Determination of natural moisture content
- Determination of particle size distribution by wet sieving
- Determination of Atterberg Limits
- Chalk Intact Dry Density Testing

It should be noted that due to the sampling methods employed (cable percussion and dynamic sampling) the chalk may have been recovered as structureless where it may be structured in the ground.

6.5.1 Insitu tests

9 No. hand shear vane tests were carried out on samples of structureless chalk with the results ranging between 24kPa and 42kPa.

6.5.2 Standard Penetration Tests

A total of 93 No. Standard Penetration Tests (SPTs) were carried out in the chalk, and uncorrected SPT blow counts (N) between 2 and 50 were reported. It is important to note that the occurrence of flint within chalk can result in artificially high blow counts during the advance of the SPT.

To derive geotechnical parameters from the SPT tests, the N values were corrected to a standard hammer energy of 60% (N_{60}) according to the following formula:

$$N_{60} = N * \left(\frac{E_R}{60} \right)$$

where,

E_R = hammer energy ratio

The corrected N_{60} values ranged between 2 and 53 with an average value of 16 and a lower quartile of 11. The corrected N_{60} values are plotted in Figure 6-15. There appears to be a linear correlation of increasing N_{60} value with depth below ground.

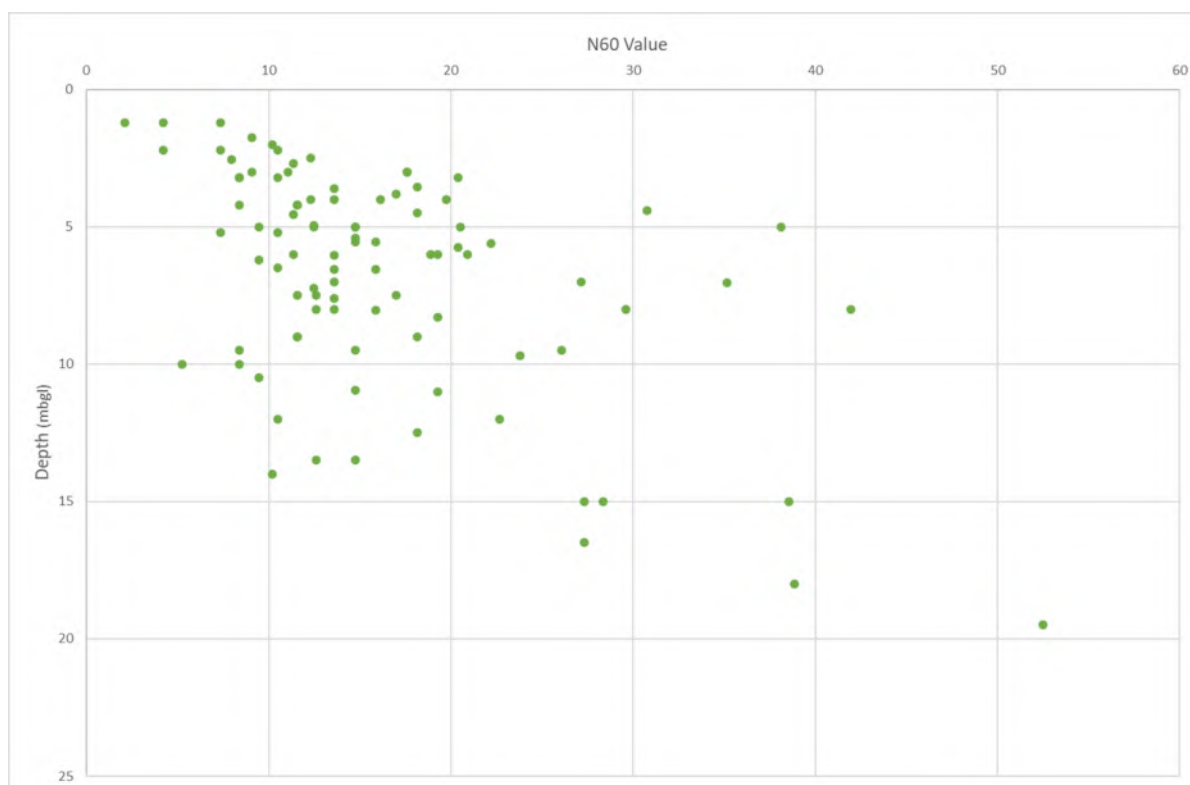


Figure 6-15 SPT N60 Values vs Depth in Chalk

6.5.3 Classification Tests

Three Atterberg Limit tests were carried out on recovered samples of chalk. The results are summarised in Table 6-7.

Table 6-7 Summary of Atterberg Limits on Chalk

Borehole No.	Depth (m)	Moisture Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Amount passing 425µm
BH105	7.0	16.4	30.0	20.0	10.0	34.0
BH105	8.5	18.2	30.0	21.0	9.0	31.0
WS03	1.0	14.0	53.0	16.0	37.0	100.0

It should be noted that the Atterberg Limit testing on the two samples from BH105 are on less than 35% of the recovered sample and as such may not be fully representative. The results indicate the material to be a low plasticity silt/ clay (BH105) and a high plasticity clay (WS03).

Table 6-8 summarises the intact dry density test results carried out on the two Chalk samples of sufficient size to undertake the test.

Table 6-8 Intact dry density of Chalk

Borehole No.	Depth (m)	Saturation Moisture Content (%)	Bulk Density (kg/m³)	Dry Density (kg/m³)
BH102	4.5	23	2.03	1.67
BH106	5.0	25	1.99	1.60

Based on the above, the Chalk is classified as ‘Medium density’, according to the density scale given in Table 3.2 of CIRIA C574 (Engineering in Chalk, 2002). This classification agrees with the logged descriptions of the Chalk at these positions and depths and generally at the exploratory holes logged.

6.5.4 Bulk Unit Weight

Intact dry density and saturated moisture content tests were carried out on two samples of Chalk, and bulk unit weights ranging from 19.9kN/m³ to 20.3kN/m³ were recorded. A bulk unit weight of 20kN/m³ is recommended for the Chalk based on the results of the intact dry density and saturated moisture content tests.

6.5.5 Stiffness

According to CIRIA C574, the following stiffness parameters are published for the Chalk:

Grade Dm Chalk

Secant modulus (E_s) 6MPa

Grade Dc Chalk

Secant modulus (E_s) 200MPa (short term)

75MPa (long term)

6.6 Soil and Groundwater Chemistry

A range of soil sulphate and pH testing was undertaken to assess the Aggressive Chemical Environment for Concrete (ACEC) Grade and the Design Sulphate (DS) Class for each stratum. The assessments were undertaken separately for each stratum in accordance with BRE Special Digest 1 (2005). No stratum was assessed as being pyritic; therefore, an assessment of Total Potential Sulphates (TPS) was not undertaken.

Table 6-9 Summary of ACEC Classification

Geology	No. of Tests	Sulphate as SO ₄ (mg/l)	pH	Characteristic Sulphate as SO ₄ (mg/l)	Characteristic pH	ACEC Class	Design Sulphate Class
Made Ground	12	10 - 465	7.84 – 10.80	400	7.8	AC-1	DS-1
Alluvium	18	10 – 910	7.28 – 10.18	720	7.8	AC-2	DS-2
Beach Deposits	3	18 - 130	8.95 – 9.44	130	8.95	AC-1	DS-1
Groundwater	4	23 - 2710	7.04 – 7.14	2700	7.04	AC-3	DS-3

The presence of Alluvium is extensive across the site with four exploratory holes recording either an organic or sulphuric odour (BH104, MDTP101, DS101, DS102). The assessment of the pH and sulphate testing indicates that the site has a Design Sulphate Class of DS-3 and an ACEC Class of AC-3 based on the groundwater samples.

Given the variation in sulphate with groundwater samples, in particular the outlier result of 2710mg/l on a sample retrieved from DS103, consideration could be given to carrying out additional ground water sampling and testing to verify these results and potentially reduce the design classes.

7. Contamination Assessment

This section of the report presents an interpretation of the laboratory results for soil and groundwater samples, as well as ground gas monitoring, to evaluate potential risks to human health, controlled waters and infrastructure. The data used is presented in the 2021 Structural Soils Factual Report (Appendix C **Error! Reference source not found.**). The exploratory hole location plan is presented in Appendix D **Error! Reference source not found.** and exploratory hole logs and chemical results are included in the Factual Report (Appendix C). The tabulated chemical results screened against the generic Evaluation Criteria (EC) are presented in Appendix F

The key objective of the geo-environmental investigation was to provide a quantified measure of baseline soil and groundwater quality and ground gas conditions along the proposed coastal defence alignment and to provide information on the chemical composition of the soils to support any disposal of soils arising, should this be required.

Current good practice recommends that the determination of hazards due to contaminated land is based on the principle of risk assessment, as outlined in the Environment Agency's online guidance for the management of land contamination; Land contamination: risk management (LCRM).

The risk assessment process for the environmental contaminants is based on a source-pathway-receptor analysis. These terms can be defined as follows:

- **Source:** a contaminant or pollutant that is in, on or under the land and that has the potential to cause harm or pollution;
- **Pathway:** a route by which a receptor is or could be affected by a contaminant; and
- **Receptor:** something that could be adversely affected by a contaminant, for example a person, controlled waters, an organism, an ecosystem, or Part 2A receptors such as buildings, crops or animals.

For a risk to be present there must be a viable contaminant linkage, i.e. a mechanism whereby a source impacts on a sensitive receptor via a pathway.

An initial Conceptual Site Model (CSM) for the Site has not previously been developed. Therefore, an initial CSM for the Site is presented below, with a view to assessing the potential risks during construction and upon completion of the proposed Scheme. This was used as the basis for the design of the geo-environmental elements of the ground investigation.

7.1 Initial Conceptual Site Model

The following potential sources, pathways and receptors have been identified that are relevant to the Site and proposed development.

7.1.1 Sources

The history of the Site is discussed in more detail in Section 3.3. The information below has been taken from Havant Borough Council Langstone FCERM Scheme Environmental Scoping Report, dated November 2020 and the AECOM Cultural Heritage Desk Based Assessment, Langstone Flood and Coastal Erosion Risk Management Scheme, 2018. An area of potential contaminative use is generally located within the southern section of the Scheme, within the area, and surrounding area, of the Sailing Club and south of Langstone High Street. This includes the southern area of AECOM Section 2 (Frontage 2), Section 4 (Frontage 3) and Section 7 (Frontage 6).

Potential contamination sources include:

- **Former railway, sidings and coal wharf.** Potential contaminants include: Inorganic and organic contaminants, in particular sulphates and poly-cyclic aromatic hydrocarbons (PAH) which may be present in the location of the former coal wharf (now Langstone Sailing Club's boat yard);
- **Boathouses, sailing clubs, slipways, quays and a coastguard station.** Organic and inorganic contaminants (including organo-tin compounds and asbestos) may be present at these locations, due to boat maintenance activities;
- **Reclaimed land in area of former coal wharf / Langstone Sailing Club's boat yard** - metals, inorganics, hydrocarbons; and

- **Corn mill** - metals, inorganics, hydrocarbons, asbestos.

Figure 7-1 shows the approximate location of the potential sources of contamination detailed above.

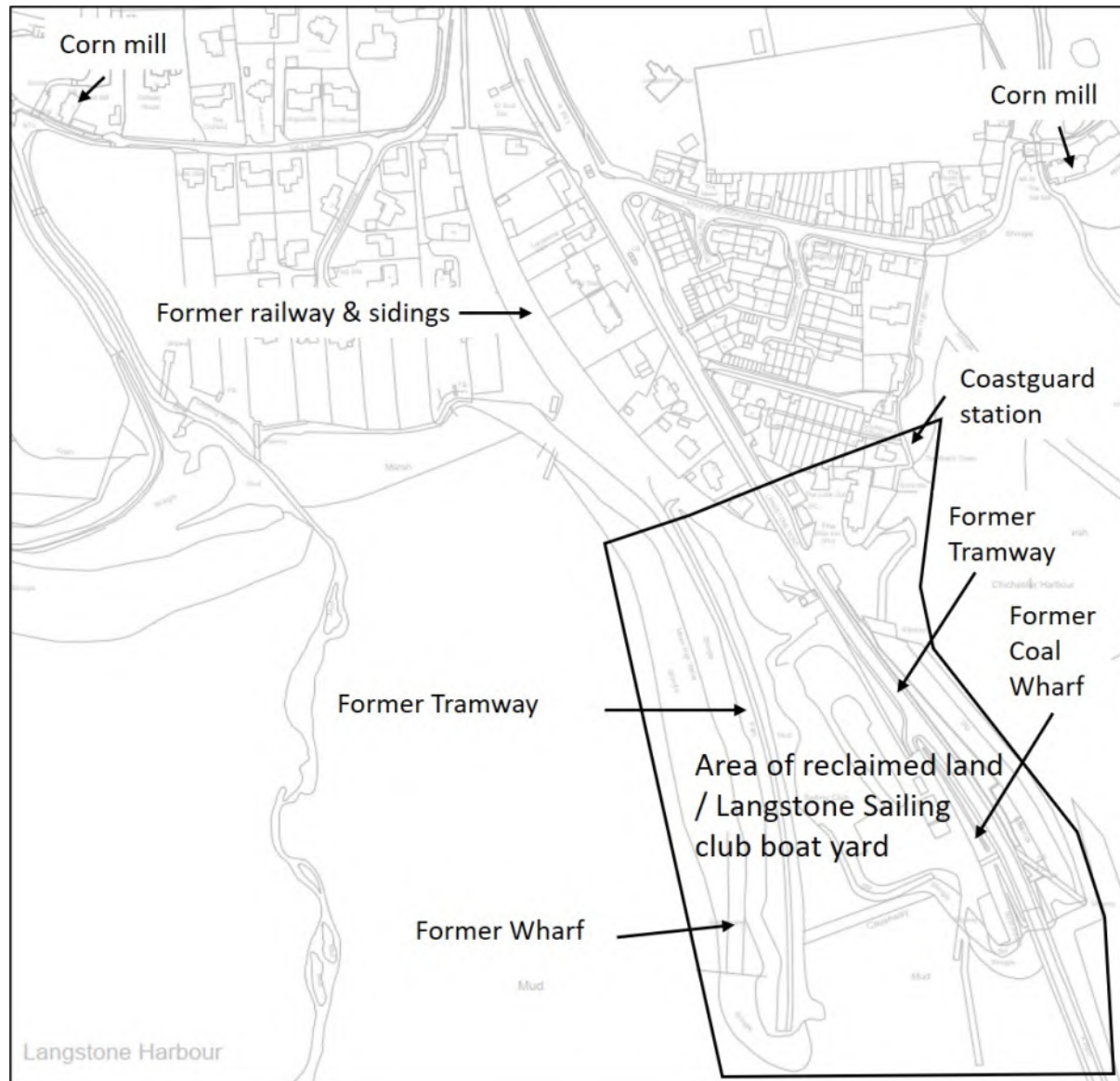


Figure 7-1 Potential sources of contamination

The ground investigation undertaken by WYG (see Section 3.7) included chemical analysis of soils. Soil samples were screened against generic assessment criteria (GAC) for a public open spaces (parks) end use¹. The results of the screening identified only dibenzo(a,h)anthracene (a PAH) within one location located in the vicinity of the Langstone Sailing Club (ODU 2B). The exceedance was marginal, 1.22 mg/kg compared to the GAC of 1.1 mg/kg. Based on the findings of this historical assessment, despite the contaminative sources detailed above, risk of contamination within the soils which could pose a risk to human health was concluded by WYG to be likely to be low.

No asbestos was detected within any of the soils tested for asbestos as part of the WYG investigation.

7.2 Potential Receptors

The potential receptors identified include:

- Human Health (Future users (public open space), construction and maintenance workers);

¹ Defra 2014 Category 4 Screening Level (C4SL), LQM/CIEH 2015: Suitable 4 Use Level (S4UL)

- Secondary A aquifer (River Terrace Deposits and alluvium);
- Secondary undifferentiated aquifer (Beach Deposits);
- Principal aquifer (Chalk);
- Langstone Harbour (surface water);
- Chichester Harbour (surface water);
- Lavant (Langbrook) Stream (surface water) – west boundary of the Scheme;
- Lymbourne Stream (surface water) – east boundary of the Scheme; and
- Coastal Defence Infrastructure.

The Site does not lie within a Source Protection Zone within regards to groundwater protection.

7.3 Potential Pathways

The potential pathways include:

- Human Health;
 - Direct contact, dermal absorption or ingestion of soil/waters;
 - Inhalation of soil particulates derived from soils;
 - Inhalation of asbestos fibres from ground disturbance;
 - Inhalation of soil vapour derived from soils/groundwater; and
 - Migration of hazardous gases/vapours via permeable strata into confined spaces (asphyxiation/explosion).
- Surface Water;
 - Spillage/loss/run off from surface direct to receiving water;
 - Lateral migration of impacted shallow groundwater (Secondary A aquifer) off-site towards surface water baseflow; and
 - Migration via underground drainage/ sewers (including granular backfilling materials).
- Groundwater;
 - Leaching of chemicals and vertical migration via permeable unsaturated strata to shallow (Secondary A/Secondary undifferentiated) aquifer); and
 - Vertical migration of impacted shallow groundwater to the deeper chalk Principal aquifer.
- Infrastructure;
 - Direct contact of buried concrete with contaminated soils (i.e. hydrocarbons) and aggressive ground conditions (pH and sulphate).
 - Direct contact of services and supply pipes with contaminated soils.
 - Migration of hazardous gases/vapours via permeable strata into enclosed spaces and service/utility trenches

7.4 Environmental Sampling and Testing

Chemical laboratory testing was undertaken on a range of soil and groundwater geo-environmental samples obtained during the ground investigation and the post-fieldwork groundwater monitoring. The GI was undertaken between 13th September and 4th October 2021. Gas and groundwater monitoring was undertaken on three occasions between the 8th and 25th October 2021. Development of the monitoring wells was undertaken on the first visit, with a round of full groundwater sampling being obtained on one occasion on the final monitoring visit. Further details on the samples obtained and the chemical analysis undertaken are presented in the following sections.

Whilst tests were scheduled based on the available information concerning the current/historical land use, it cannot be guaranteed that other contaminants are not present on site for which analyses have not been carried out or at

locations which were not sampled in the programme of exploratory holes. Method Detection Limits (MDL) for the chemical analysis undertaken are presented with the chemical laboratory results included in the factual report (Appendix C **Error! Reference source not found.**).

7.4.1 Soil Testing

A total of 46 No. soil samples from 25 exploratory locations were submitted for analysis to Envirolab Limited (Envirolab) laboratories for UKAS and MCERTS accredited (where applicable) environmental laboratory analysis. The analyses undertaken were for a variety of chemicals that were selected based on the current/historical land uses associated with the Site. The scheduled soil samples were obtained from a range of depths and geological material types, extending from between 0.2 and 6.2 m bgl.

The soil and soil leachate samples were obtained from the following lithologies.

Table 7-1 Lithology where soil samples obtained

Lithology	Number of soil samples	Number of soil leachate samples
Made Ground	24	6
Alluvium	11	4
Beach Deposits	4	0
Chalk	7	3

The following analysis was undertaken on these samples.

Table 7-2 Soil chemical testing suite and analysis

Chemical Analysis Conducted	Total No. of Samples Tested
Suite E: arsenic, barium beryllium, boron (water soluble), cadmium, copper, chromium, chromium (hexavalent)*, lead, mercury, nickel, selenium, vanadium, zinc, pH, Total Organic Carbon, Total Petroleum Hydrocarbons with aliphatic and aromatic split (TPH), benzene, toluene, ethylbenzene, xylene (BTEX) & methyl tert-butyl ether (MTBE), polycyclic aromatic hydrocarbons (PAH) (speciated)	40
Asbestos screen, ID	21
Asbestos quantification (if asbestos detected)	0
Organotin compounds	6
Semi volatile organic compounds (SVOC) Suite (exc. PAHs & inc. tentatively identified compounds (TICs))	9
Volatile organic compounds (VOC) suite	12
Poly-chlorinated biphenyls (PCBs)	3
Cyanide (free & total), ammoniacal nitrogen and phenol	11
Suite G – soil leachate: antimony, arsenic, barium, beryllium, boron, cadmium, chromium (total), chromium hexavalent, copper, lead, magnesium, mercury, molybdenum, nickel, selenium, chloride, zinc, potassium, alkalinity (carbonate as CaCO ₃), hardness as CaCO ₃ pH, total suspended solids sodium sulphate (soluble), free cyanide and total cyanide, phenol, PAH, nitrate, nitrite, ammoniacal nitrogen as N, dissolved organic carbon.	13

**Only analysed in 38 soil samples*

The results of the soil laboratory testing are discussed in Section 7.5. A total of 13 No. samples from six locations were scheduled for soil leachate analysis and these are discussed in Section 7.6

7.4.2 Groundwater Testing

Groundwater samples were obtained between the 14th and 25th October 2021, from nine groundwater monitoring installations (BH101, BH104, BH105 (shallow and deep), DS103, DS104, DS106 DS107 and BH03 drilled as part of the previous phase of works). Groundwater samples were submitted for UKAS accredited (where applicable) environmental laboratory analysis to Envirolab for various Chemicals of Potential Concern (CoPC). These CoPC were identified based on the current/historical land use associated with the site and these are listed in Table 7-4. The results of the three rounds of groundwater level monitoring are included along with the well development details and the physical parameters log for the sampling are included within the Structural Soils factual report (see Appendix C **Error! Reference source not found.**).

Groundwater samples were obtained from the following groundwater installations listed in Table 7-3.

Table 7-3 Monitoring wells where groundwater samples obtained

Exploratory Location	Top of Response Zone (mbgl)	Base of Response Zone (mbgl)	Geology
BH101	11	14	Chalk
BH104	7	10	Chalk
BH105	6	9	Chalk
DS103	1	3	Alluvium
DS104	1	3	Alluvium
DS105	1.5	2.5	Alluvium
DS106	1.6	3.6	Alluvium
DS107	1.5	5	Alluvium
BH03 (Previous Investigation)	2	10	Chalk

Source: Structural Soils Factual Report (Appendix C)

The following groundwater analysis was undertaken on the samples obtained from the nine monitoring wells (Table 7-4).

Table 7-4 Groundwater chemical testing suite and analysis

Suite of CoPC	Total No. of Samples Tested*
Groundwater Suite F: arsenic, antimony, barium, beryllium, boron, cadmium, chromium, hexavalent chromium, copper, lead, magnesium, mercury, molybdenum, nickel, selenium and zinc, chloride, potassium, alkalinity (carbonate as CaCO ₃), Ph, total suspended solids, sodium, sulphate (soluble), free cyanide and total cyanide, phenol, TPH, PAH, nitrate, nitrite, ammoniacal nitrogen as N, dissolved organic carbon.	9
VOC Suite	4
SVOC Suite (exc. PAHs & phenol but inc. tentatively identified compounds)	4
Poly-chlorinated biphenyls (7 congeners and WHO 12 congeners (dioxin like PCBs)	3

*Number count does not include duplicate and QA/QC samples obtained

The results of the groundwater laboratory testing are discussed in Section 6.6.

7.5 Human Health Generic Quantitative Risk Assessment

7.5.1 Methodology, Assumptions and Criteria Used

Where the initial CSM identified one or more complete pollutant linkage(s) with respect to human health, it is often necessary to clarify the risk posed by that pollutant linkage by comparison of reported concentrations with guideline values that represent acceptable concentrations. This includes assessing risks to human health at a generic level

termed 'Generic Quantitative Risk Assessment' (GQRA) or 'Tier 2' of 'Stage 1' in the Environment Agency's LCRM guidance. AECOM has adopted a prescribed methodology for assessing risks to human health at this GQRA stage.

Based on the proposed land use at the Site, the Evaluation Criteria (EC) for a public open space (park) end-use have been used as a conservative initial screen to assess the potential for risks to human health. While the open ground in this area is not a traditional park land, it is open land and transient exposure is anticipated; therefore commercial/industrial screening values are inappropriate. This approach is also consistent with that adopted within the previous screening assessment reporting undertaken as part of the Havant Borough Council Langstone FCERM Scheme Environmental Scoping Report, dated November 2020.

For this assessment, a sandy loam type with a 0.58 – 1.45% TOC content based on the geomean TOC of the samples recorded as 0.45% has been used.

In accordance with LCRM, AECOM has adopted the following hierarchy of published sources for Tier 2 EC for soil:

AECOM has screened the soil data against human health generic EC taken from various published sources from authoritative organisations including:

- Defra (2014) SP1010: Development of Category 4 Screening Levels for Assessment of Land Contamination - Policy Companion Document, December 2014;
- CL:AIRE (2021) Category 4 Screening Levels: Vinyl Chloride, Trichloroethene, Tetrachloroethene;
- Land Quality Management (LQM)/Chartered Institute of Environmental Health (CIEH) Suitable 4 Use Levels (2015);
- EIC/AGS/CL:AIRE EC;
- US Environmental Protection Agency, Regional Screening Levels, May 2020; and
- Dutch Soil Remediation Circular 2013 - Soil Intervention Values

The EC and the GQRA are not directly applicable to assessing the risk to construction/maintenance workers during ground works. The risk to groundworkers is therefore assessed separately.

It should be noted that screening against the EC is a conservative measure and concentration exceedances of the EC does not necessarily mean that remediation is required but rather that further assessment would be needed.

7.5.2 Comparison of Soil Results Against Human Health GAC

Screening of laboratory soil testing data indicates that all CoPC concentrations were below their respective EC protective of human health based on a public open space end use. The human health screening table can be found in Appendix F.

7.5.3 Asbestos Analysis and Assessment

A total of 21 soil samples were screened for asbestos. Asbestos was not identified in any of the samples.

The presence of asbestos in Made Ground is typically sporadic and unpredictable. Appropriate management and mitigation should be included during construction works to ensure safe working, public protection and provision of the correct stream of waste disposal in the event it is unexpectedly found. The assessment for asbestos must be undertaken in accordance with the 'CL:AIRE (2016) Control of Asbestos Regulations 2012 Interpretation for Managing and Working with Asbestos in Soil and Construction and Demolition Materials, Industry guidance, CAR-SOIL, CL:AIRE, London, 2016' (CAR-SOIL 2016) and associated industry guidance.

7.5.4 Construction Worker Assessment

It is considered, based on the proposed development / end use of the Site as coastal defences and the redevelopment / earthworks taking place, that a quantitative assessment should be made of the potential risks to human health for construction workers. The public open space EC used in Sections 7.5.1 to assess risks to human health are not considered appropriate as a reliable indicator of more acute risk to construction workers. These EC are based on different assumptions about viable exposure pathways, and the frequency, duration and rates of exposure.

The construction worker assessment details both acute and chronic exposure risk. Acute risk is associated with one-off or short-term exposure to relatively high contaminant concentrations (e.g. “hotspots”) occurs, whereas chronic exposure is associated with frequently repeated long-term exposure to more average concentrations.

Acute risks can be assessed by comparison to the acute EC (AEC) derived by the Society of Brownfield Risk Assessment (SoBRA) in 2020. These were derived for seven contaminants: arsenic, benzene, cadmium, free cyanide, phenol, trichloroethene (TCE) and vinyl chloride (VC). These were derived for two groups of receptors: members of the public and workers involved with excavations. Exposure scenarios considered for the latter are:

- Oral exposure – short-term exposure via direct contact with outdoor soil on the assumption that personal protective equipment (PPE) is not worn;
- Dermal exposure – short-term exposure via direct contact with outdoor soil on the assumption that PPE is not worn; and
- Inhalation exposure – short-term exposure via inhalation of dusts or vapours released from excavation activities without the use of PPE. Note that the exposure is assumed to occur for a worker at ground level at the top of the excavation. It does not apply to construction workers entering excavations.

No exceedances of the seven published SoBRA AEC were recorded.

The SoBRA 2020 AEC guidance, although only for seven substances, indicates that acute risks are unlikely to be of concern for most contaminants if concentrations do not exceed EC based on chronic exposure.

AECOM has derived its own construction worker EC values for chronic exposure, based on the assumptions made in the above SoBRA report and in accordance with UK Environment Agency (EA) guidance and the methodology set out within the Contaminated Land Exposure Assessment (CLEA) Model framework.

Construction worker EC have been derived for chronic exposure, as previously stated due to different assumptions about viable exposure pathways, and the frequency, duration and rates of exposure compared to the commercial / industrial EC assumed for non construction worker human receptors.

The soil chemical results were screened against the AECOM construction worker EC and a summary of the determinands which have been identified with exceedances above EC are shown in Table 7-5 below.

Table 7-5 Summary of determinands identifying exceedances above chronic construction worker EC

Determinand	Number of samples Exceeding GAC / Number of samples analysed	Construction Worker EC (mg/kg)	Min Concentration (mg/kg)	Max Concentration (mg/kg)
Lead	2/40	429	2.0	782

Exceedances of the chronic construction worker EC were identified for lead. However, these were isolated exceedances, with the majority of samples considerably below the chronic EC. The lead exceedances were identified within the following soils samples, with all concentrations recorded within the same order of magnitude as the chronic EC and thus are considered marginal exceedances:

- HDTP108 at 0.5m bgl (Made Ground) – 533 mg/kg Located within Frontage 4, east of Coastguard Cottages
- DS101 at 0.5m bgl (Made Ground) – 782 mg/kg. Located within Frontage 3, east of The Ship Inn

These are located within close proximity of each other in the southeast of the Site (Frontage 3 and Frontage 4),

A total of one sample recorded a high pH at 11.92 suggesting alkali conditions in soils in BH104.

The location of the lead construction worker exceedances and the alkali pH value are presented in Figure 7-2



Figure 7-2 Location of construction worker lead EC exceedances and location of alkali pH value

The EC used in this assessment were derived based on the assumption that personal protective equipment (PPE) is not worn and no methods of work are adopted to prevent or control exposure to soil. Therefore, they are considered conservative. However, where exceedances of the EC have been identified, it is recommended that the results of this risk assessment are considered in the planning of construction works in accordance with relevant statutory health and safety requirements.

7.5.5 Human Health GQRA Findings and Conclusions

Based on the results of the screening assessment of the AECOM 2021 chemical data no contaminants exceeded the EC for the proposed public open space end use. Therefore, the risk to future users is deemed negligible and thus acceptable with regard to contaminants identified within the CSM.

However, should contaminated soils be observed during construction development works, the assessment of risk may need to be reassessed.

No exceedances were identified of the acute construction worker EC. However, minor isolated exceedances of the chronic construction worker EC were identified for lead and a location of potentially corrosive pH value was recorded. Whilst the potential risks to construction workers is considered to be Low it is recommended that PPE is worn by all construction workers and that the planning of construction works is undertaken in accordance with relevant statutory health and safety requirements.

7.6 Controlled Waters Generic Quantitative Risk Assessment

7.6.1 Controlled Waters Assumptions and Criteria Used

Risks to controlled waters have been assessed using a tiered approach based on that described in the Environment Agency's Remedial Targets Methodology (RTM).

Soil leachate and groundwater data has been screened against controlled waters EC that are designed to be protective of surface water (Langstone Harbour, Chichester Harbour, Lavant (Langbrook) Stream and Lymbourne Stream and groundwater (Secondary A and (undifferentiated) aquifers associated with superficial deposits and Principal aquifer associated with the bedrock).

Controlled waters EC selected for soils and groundwater are primarily Environmental Quality Standards (EQS) for protection of the surface water and England & Wales Drinking Water Standards (DWS) for aquifer protection. However, these are not published for certain determinands and so, in the absence of an EQS or DWS, reference has been made to the following in order of preference:

EQS (coastal) criteria

- The Water Framework Directive (Standards and Classification) Directions (England and Wales) 2015 – Annual Average (AA)-Environmental Quality Standard (EQS) Transitional/Coastal;
- The Water Framework Directive (Standards and Classification) Directions (England and Wales) 2015 – Maximum Acceptable Concentration (MAC)-EQS Transitional/Coastal;
- The Water Framework Directive (Standards and Classification) Directions (England and Wales) 2015 – Saltwater Standards;
- SEPA, The Scotland River Basin District Standards Amendment Directions 2015 – AA – EQS inland;
- European Commission (EC) Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH). Predicted No Effect Concentrations (PNEC); and

DWS criteria

- Water, England & Wales - Water Supply (Water Quality) Regulations, 2016 No. 614;
- Guidelines for Drinking-water Quality (4th Edition inc. the First Addendum). World Health Organisation. 2017;
- World Health Organisation (WHO), 2008. Petroleum Products in Drinking Water. Background document for development of WHO Guidelines for Drinking-water Quality;
- United States Environmental Protection Agency (USEPA) Regional Screening Levels (tapwater), November 2019.

The Environment Agency Remedial Target's Methodology sets out a hierarchy of data relevant to controlled waters risk assessment, namely groundwater or surface water data, soil leachate data, and lastly soil data.

In the absence of soil leachate data, an assessment can be undertaken on the soil sample data to evaluate potential risks to controlled waters from reported contaminant concentrations in soil. This references calculated soil EC that represent theoretical soil concentrations that could partition at equilibrium to give a concentration in soil pore water equivalent to the applicable EC in the above list (as described in Section 5 of the RTM). As soil leachate data is available, this exercise has not been undertaken at this level of assessment as the actual soil leachate sample data provides a more accurate reflection of site conditions.

The site is not within a groundwater source protection zone. Therefore, the use of DWS criteria in this assessment is considered to be conservative. However, given the underlying aquifer is a Principal aquifer and SPZ are located to the north of the Site, it is prudent to assess the groundwater with regards potential potable water resources.

The controlled waters screening tables for leachate and groundwater can be found in Appendix F.

7.6.2 Risk to Surface Water

7.6.2.1 Comparison of Groundwater Results Against EQS EC

The screening of groundwater concentrations against the EQS EC criteria designed to be protective of surface water has identified exceedances. These are presented in Table 7.6 below. No groundwater exceedances were identified from groundwater obtained from DS106 (alluvium response zone).

Table 7.6 Groundwater exceedances against EQS EC

Determinand	EQS Transitional /Coastal*	BH101	BH03	BH104	BH105	DS103	DS104	DS105(S)	DS107
CHALK					ALLUVIUM				
AECOM Calc (Unionised as Ammonia as N) (mg/l)	0.021		0.0291	0.0306		0.0428			
Cyanide (total) (mg/l)	0.001							0.005	
Nickel (µg/l)	8.6				10				
Zinc (µg/l)	6.8	10	23	21	27		8		10

Determinand	EQS Transitional /Coastal*	BH101	BH03	BH104	BH105	DS103	DS104	DS105(S)	DS107
Fluoranthene (µg/l)	0.0063					0.02			

*WFD England/Wales. 2015 - Trans./Coastal / saltwater standards

0.0 = exceedance of EQS

7.6.2.2 Comparison of Leachate Results Against EQS EC

The screening of soil leachate concentrations against the EQS EC criteria designed to be protective of surface water has identified exceedances. These are presented below in Table 7.7 to Table 7.9.

Table 7.7 Made Ground soil leachate exceedances against EQS EC

Determinand	EQS Transitional /Coastal*	DS107 0.50 mbgl	BH101 0.4 to 0.8 mbgl	DS101 0.5 mbgl	HDTP111 0.5 mbgl	BH104 1 to 1.3 mbgl
Made Ground						
Ammoniacal nitrogen as N (mg/l)	0.021 (unionised)	0.31	-	2.48	0.37	0.65
Arsenic (µg/l)	25	-	-	45	-	-
Copper (µg/l)	3.76	40	20	83	11	24
Lead (µg/l)	1.3	168	34	7080	-	3
Nickel (µg/l)	8.6	15	12	203	-	12
Zinc (µg/l)	6.8	34	21	878	9	12
Anthracene (µg/l)	0.1	-	-	0.34	-	0.4
Benzo(a)pyrene (µg/l)	0.00017	-	-	2.63	-	0.07
Benzo(b)fluoranthene (µg/l)	0.017	-	-	3.03	-	0.07
Benzo(ghi)perylene (µg/l)	0.00082	-	-	1.59	-	0.04
Benzo(k)fluoranthene (µg/l)	0.017	-	-	1.23	-	0.04
Fluoranthene (µg/l)	0.0063	0.13	0.03	4.25	0.02	0.66

*WFD England/Wales. 2015 - Trans./Coastal / saltwater standards

0.0 = exceedance of EQS

Table 7.8 Alluvium soil leachate exceedances against EQS EC

Determinand	EQS Transitional /Coastal* (µg/l)	BH103 0.5 mbgl	BH102 0.5 mbgl	DS104 0.5 mbgl	BH104 2.8 mbgl
Alluvium					
Ammoniacal nitrogen as N (mg/l)	0.021	-	-	0.09	0.84
Copper (µg/l)	3.76	10	4	7	-
Lead (µg/l)	1.3	7	3	10	-
Zinc (µg/l)	6.8	-	-	17	-
Fluoranthene (µg/l)	0.0063	-	-	0.03	-

*WFD England/Wales. 2015 - Trans./Coastal / saltwater standards

0.0 = exceedance of EQS

Table 7.9 Chalk leachate exceedances against EQS EC

Determinand (µg/l)	EQS Transitional /Coastal* (µg/l)	BH101 2.7 to 3.1mbgl	BH103 2.6 to 3.0 mbgl	BH106 1.5 to 1.7mbgl
Chalk				
Ammoniacal nitrogen as N (mg/l)	0.021	0.1	-	-
Copper (µg/l)	3.76	-	5	26
Lead (µg/l)	1.3	-	2	120
Zinc (µg/l)	6.8	-	16	80
Anthracene (µg/l)	0.1	-	-	0.14
Benzo(a)pyrene (µg/l)	0.00017	-	-	0.09
Benzo(b)fluoranthene (µg/l)	0.017	-	-	0.08
Benzo(ghi)perylene (µg/l)	0.00082	-	-	0.03
Benzo(k)fluoranthene (µg/l)	0.017	-	-	0.04
Fluoranthene (µg/l)	0.0063	-	-	0.27

*WFD England/Wales, 2015 - Trans./Coastal / saltwater standards

0.0 = exceedance of EQS

7.6.2.3 Surface water risk discussion

Although arsenic, copper, lead and PAHs (anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(ghi)perylene and benzo(k)fluoranthene) were detected at concentrations in soil leachate at concentrations which exceeded their EQS EC, these were not subsequently detected with the groundwater at concentrations which may pose a risk to surface water. This includes the groundwater in the vicinity of DS101, east of the Look Out Public House, where recorded notable soil leachate concentrations of lead and PAHs in excess of their EQS EC were detected.

A soil leachate concentration of 7080 µg/l of lead was recorded from DS101 compared with the EQS EC of 1.3 µg/l. Made Ground including brick and mortar was located at this location but it was not notably different composition to Made Ground encountered at the rest of the Site. The greatest concentrations of lead within the soil were also noted to be within this area of the site (Section 4-Frontage 3 and Section 5 -Frontage 4), with concentrations above 100 mg/kg being recorded along this section of the site. The greatest concentration was from DS101 where a concentration of 782 mg/kg was recorded compared to background soil concentrations (UK Soil Observatory data) of 55 mg/kg. However, based on the groundwater results, although leachable and at higher concentration in soil compared to the rest of the Site, lead does not appear to be impacting the groundwater within this area or wider area of the site.

Nickel and zinc were also elevated in the soil leachate in the Made Ground at DS101 in comparison to the EQS EC (one to two orders of magnitude greater) and compared to other soil leachate sample concentrations within the Made Ground. As with lead, the elevated concentrations of these metals coincide with the higher concentrations of these contaminants within the soil, again generally confined to Section 4-Frontage 4 and Section 5- Frontage 4 of the site. The greatest soil concentrations were recorded higher than background soil concentrations for these contaminants, 211 mg/kg for zinc (HDPTP08) compared to 60.89 mg/kg and 72 mg/kg for nickel (HDPTP105) compared to 14.84 mg/kg. Although, HDPTP105 is located in the southwest of the site on the opposite side of the harbour. Average concentrations of zinc and nickel in the soils across the site are comparable to background concentrations.

Although exceedances of nickel and zinc were recorded in the groundwater, the concentrations are considered marginal as they were within the same order of magnitude as the EQS.

Nickel was an isolated exceedance, only being encountered greater than the EQS EC in BH105 in the deeper chalk aquifer.

Zinc exceedances within the groundwater were more widespread, exceeding the EQS EC of 6.8 µg/l in six of the nine sampled locations. The greatest concentrations were observed within the chalk aquifer monitoring wells. However, all are marginal, with a maximum concentration of 27 µg/l recorded (BH105).

Within the groundwater, PAHs (fluoranthene), cyanide and ammoniacal nitrogen (based on unionised ammonia as N) also exceeded the EQS EC protective of surface water in more than one groundwater sample obtained from the Site. These are all considered to be marginal exceedances as they were recorded to be within the same order of magnitude as their EQS EC.

Cyanide and fluoranthene were isolated exceedances, only detected at concentrations in the groundwater greater than the EQS EC within the alluvial deposits and within individual locations DS105(S) and DS103, respectively.

Soil leachate PAH exceedances (other than fluoranthene) from the Made Ground were generally confined to the southeast section of the Site (DS101 and BH104) (Frontage 1B). However, PAHs (other than fluoranthene) were also detected in BH106 (Frontage 1B section of the Site) within the Chalk. The chalk was at shallow depth, with no covering superficial deposits observed at this location.

On the basis of the general limited exceedances of EQS in groundwater compared to soil leachate, the magnitude of exceedances in relation to the EQS, the spatial distribution of the exceedances across the Site and expected attenuation, it is considered that the soil and groundwater quality beneath the Site is unlikely to pose a significant risk to surface water quality during or post construction works. However, it is noticeable that there is a potential for mobilisation of contaminants (metals and PAHs) during construction in the area of Section 4 (Frontage 3) and Section 5- (Frontage 4) and in particular around DS101 with soil and leachate concentrations generally being higher in this area compared to the rest of the site. This area of the site is possibly associated of reclaimed land during development of the area.

Although the risk is low, given the potential for mobilisation of contaminants into groundwater during construction works within the vicinity of Frontage 3 and Frontage 4, it would be prudent to undertaken groundwater chemical analysis prior to discharge into the surface water. Chemical analysis of the receiving water is also suggested prior to works and to be monitored during the works. As part of the CEMP mitigation for the potential for contaminated groundwater to be encountered should be included and any water control measures required during construction should include assessment of groundwater quality to ascertain appropriate discharge options and discharge consents. These options should be discussed with the Environment Agency and/or local water company to understand their requirements and ensure compliance and consent prior to any works being undertaken. The groundwater results obtained as part of this GIR may be sufficient. However, this will need to be confirmed by Regulators.

7.6.3 Risk to Groundwater Quality

7.6.3.1 Comparison of Groundwater Results Against DWS EC

The screening of groundwater concentrations against the DWS EC criteria designed to be protective of groundwater quality has identified exceedances. These are presented in Table 7.10 below. No groundwater exceedances were identified from groundwater obtained from DS105(S) and DS107 (alluvium response zone).

Table 7.10 Groundwater Exceedances against DWS EC

Determinand	DWS*	BH101	BH03	BH104	BH105	DS103	DS104	DS106
CHALK				ALLUVIUM				
Ammoniacal nitrogen as N (mg/l)	0.5		3.24	7.63		14.1		
AECOM calc - Ammonia as NH3 (mg/l)	1.5**		3.93	9.27		17.12		
AECOM calc - Ammonium as NH4 (mg/l)	0.5		4.17	9.81		18.13		
Chloride (mg/l)	250	2230	15400	11200	6060	17900	889	
Sulphate (mg/l)	250	311	1850	1490	705	2710		
Boron (dissolved) (µg/l)	1000		4480	3430		3770		
Sodium (dissolved) (mg/l)	200	983	7710	6880	2680	10500	491	285
Ali >C21-C35 (µg/l)	300***						7667	
Aro >C21-C35 (µg/l)	90***						109	

*WS Regs 2016 (Eng/Wal)

**WHO 2017 – Odour

***WHO Petroleum DWG 2008

0.0 = exceedance of DWS

7.6.3.2 Comparison of Soil Leachate Results Against DWS EC

The screening of soil leachate concentrations against the DWS EC criteria designed to be protective of groundwater quality has identified exceedances. These are presented in Table 7.11 to 7.12 below. No soil leachate exceedances were identified from BH105 (Made Ground), DS104 (Alluvium) and BH101 (Chalk) samples.

Table 7.11 Made Ground Soil Leachate Exceedances against DWS EC

Determinand	DWS*	DS107 0.50 mbgl	BH101 0.4 to 0.8 mbgl	DS101 0.5 mbgl	HDTP111 0.5 mbgl	BH104 1 to 1.3 mbgl
Made Ground						
Ammoniacal nitrogen as N (mg/l)	0.5			2.48		0.65
Chloride (mg/l)	250			1750	4400	671
Sulphate (mg/l)	250			636.53	697.9	
Antimony (µg/l)	5			148		
Arsenic (µg/l)	10			45		
Boron (µg/l)	1000			1520	1380	
Lead (µg/l)	10	168	34	7080		
Nickel (µg/l)	20			203		
Sodium	200			1030	2490	
Benzo(a)pyrene (µg/l)	0.01			2.63		0.07
Benzo(b)fluoranthene (µg/l)	0.1			3.03		
Benzo(ghi)perylene (µg/l)	0.1			1.59		
Benzo(k)fluoranthene (µg/l)	0.1			1.23		
Dibenzo(ah)anthracene (µg/l)	0.07**			0.35		
Fluoranthene (µg/l)	4***			4.25		
Indeno(123-cd)pyrene (µg/l)	0.1			1.72		
PAHs (sum of 4)(µg/l)	0.1			7.57		0.92

*WS Regs 2016 (Eng/Wal)

**AECOM DWG (WHO method)

***WHO DWG 2017

0.0 = exceedance of DWS

Table 7.12 Alluvium Soil Leachate Exceedances against DWS EC

Determinand	DWS*	BH103 0.5 mbgl	BH102 0.5 mbgl	BH104 2.8 mbgl
Alluvium				
Ammoniacal nitrogen as N (mg/l)	0.5			0.84
Chloride (mg/l)	250	1170	1120	1348.62
Sulphate (mg/l)	250			297.94
Sodium (mg/l)	200	769	772	778

*WS Regs 2016 (Eng/Wal)

0.0 = exceedance of DWS

Table 7.13 Chalk Soil Leachate Exceedances against DWS EC

Determinand	DWS*	BH103 2.6 to 3.0 mbgl	BH106 1.5 to 1.7mbgl
Chalk			
Chloride (mg/l)	250	1150	847
Antimony (µg/l)	5		9
Arsenic (µg/l)	10		12
Lead (µg/l)	10		120
Sodium (mg/l)	200	775	562
Benzo(a)pyrene (µg/l)	0.01		0.09
PAHs (sum of 4) (µg/l)	0.1		0.19

*WS Regs 2016 (Eng/Wal)

0.0 = *exceedance of DWS*

7.6.3.3 Groundwater Quality Risk Discussion

No metals (with the exception of sodium) or PAHs were detected at concentrations within the groundwater water which would impact on groundwater quality as were recorded less than the DWS.

Ammoniacal nitrogen, chloride, sulphate, boron and sodium were recorded to exceed the DWS EC protective of groundwater quality in more than one groundwater sample obtained from the Site. The concentrations of chloride, sulphate and sodium are likely to reflect sea water intrusion. It was also noted that the locations further inland recorded lower concentrations of chloride, sulphate and sodium compared to those close or on the shoreline.

The groundwater concentrations detected for the determinands detailed above were recorded to be within the same order of magnitude or 1 order of magnitude greater than their DWS EC. Therefore, these are all considered to be marginal exceedances given the context of the Site and surroundings, with the groundwater being tidally influenced and the Site not being located within an SPZ.

Hydrocarbons were detected in the groundwater within DS104 that exceeded DWS EC. There is no indication within the exploratory log / observations within the soil at this location to suggest a potential source. However, within DS105 to the north of DS104, a hydrocarbon odour was noted within the alluvial deposits. Although, the concentrations recorded for hydrocarbons from the soil samples obtained from DS105 do not indicate particularly elevated concentrations (total hydrocarbon concentration of 62 mg/kg). Therefore, the TPH concentrations observed within DS104 are considered to be an isolated location and not related to a known ongoing source.

With regards to soil leachate, as with the risk to surface water, the greatest soil leachate concentrations and the greatest number of different determinands exceeding the DWS EC at one location were from soils obtained from DS101 east of the Look Out Public House. The following determinands only exceeded the DWS EC from soil leachate samples obtained from DS101: boron, nickel, benzo(b)fluoranthene, benzo(ghi)perylene, benzo(k)fluoranthene, dibenzo(ah)anthracene, fluoranthene, indeno(123-cd)pyrene and PAH (sum of 4).

Ammoniacal nitrogen as N, antimony, arsenic, lead, chloride, sulphate, sodium, chloride, sodium, benzo(a)pyrene and PAH (sum of 4) also exceeded the DWS EC from soil leachate samples obtained from DS101, but these also exceeded in other isolated locations across the Site. No metals or PAHs were noted to exceed the DWS EC from soil leachate samples obtained within the alluvium.

Given only ammoniacal nitrogen, chloride, sulphate boron and sodium were identified within the groundwater at concentrations greater than the DWS EC and these can be partially explained by tidal influence, it is not considered that the soils at the Site are a potential source of unacceptable contamination which would result in potential harm to groundwater quality in the context of the Site and its surroundings and its potential use as a potable supply.

It is unlikely that the Principal chalk aquifer (or Secondary A aquifer) will be exploited as a potable water in the future within this area, given the tidal influence, and also noting that SPZ associated with the Principal Chalk aquifer are all further inland. Therefore, the exceedances in the groundwater or soil leachate are unlikely to result in unacceptable harm or damage to potable water resources during or post construction works.

7.7 Ground Gas Assessment

The generation or migration of ground gases from natural or landfill sources can pose a major hazard to structures if gases are able to accumulate within them. In terms of the proposed scheme, the major risks are that ground gases may accumulate within excavations, any enclosed structures such as drainage runs and manholes.

For this study, the borehole gas concentration and flow rate results for carbon dioxide (CO₂) and methane (CH₄) have been compared to guidance values given in the following documents:

- BS 8485:2015+A1:2019 “Code of practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings”; and
- CIRIA Report C665 (2007) “Assessing Risks Posed by Hazardous Ground Gases to Buildings”.

These guidelines have been developed to address ground gas risks to buildings. However, provides a baseline for comparison.

7.7.1 Ground Gas Monitoring Results

A total of three rounds of ground gas monitoring have been completed. These were undertaken between 8th and 25th October 2021. Based on the monitoring data from all three rounds the following assessment has been undertaken for the Site.

The range of gas concentrations, flow rates and atmospheric pressures recorded during the monitoring rounds are presented in Structural Soils Factual Report (Appendix C **Error! Reference source not found.**). Recorded barometric pressure ranged between 1014 mbar and 1031 mbar throughout the monitoring period. Atmospheric pressures were relatively stable on all monitoring visits, but monitoring was undertaken on both falling and rising atmospheric pressure.

Table 7-4 presents a summary of the maximum concentration and the maximum flow rate recorded at each borehole during the monitoring period.

It should also be noted due to the high-water table and tidal influence, the majority of the gas monitoring well response zones were flooded at time of monitoring. Therefore, the gas concentrations observed should be taken with caution.

Any future iterations of the development which incorporate buildings should include a more detailed assessment of ground gas in accordance with BS8485 to apply Characteristic Situation for the Site based on derived gas screening values.

Table 7.14 Summary of Ground Gas Monitoring Results

Well Installation	Response Zone	Max. CH ₄ (% v/v)	Max. CO ₂ (% v/v)	Min. O ₂ (% v/v)	Max. CO (ppm)	Max. H ₂ S (ppm)	Flow Rate (l/hr)
BH101(D)	Chalk	<0.1	0.1	16.8	2.0	<1.0	0.4
BH101(S)	Chalk	<0.1	0.1	9.3	<1.0	<1.0	0.5
BH104(D)*	Chalk	<0.1	0.1	6.4	3.0	<1.0	-0.4/0.4
BH104(S)*	Made Ground	<0.1	0.1	5.3	<0.1	<1.0	0.3
BH105(D)	Chalk	<0.1	0.3	20.5	2.0	<1.0	0.1 / -0.7
BH105(S)	Alluvium	<0.1	0.2	20.8	2.0	<1.0	0.3 / -0.1
BH3**	Chalk	<0.1	0.1	20.3	<1.0	<1.0	0.3
DS103	Alluvium	<0.1	0.3	19.7	1.0	1.0	0.3
DS104	Alluvium	<0.1	3.7	17.6	<1.0	<1.0	0.4
DS105***	Alluvium	<0.1	0.2	20.6	<1.0	<1.0	0.1
DS106	Alluvium	<0.1	0.1	20.4	<1.0	<1.0	0.3
DS107	Alluvium	<0.1	0.1	20.7	<1.0	<1.0	0.3

*Only two rounds able to be completed – due to parked vehicle on 2nd monitoring round

**Only one round able to be completed – due to parked vehicle on 1st and 3rd monitoring rounds

***Not monitored on 3rd monitoring round.

The response zones of monitoring wells, BH101(S), BH101(D), BH105(S), BH105(D), DS103, DS105, DS106, DS107 and DS104(D) were flooded on one occasion or more during the monitoring programme. This was due to high water table, coastal/tidal influence.

The gas monitoring results indicate that CH₄ was not detected at concentrations greater than 0.1% during the monitoring and the maximum CO₂ concentration recorded during the monitoring was 3.7 % v/v from DS104 within the alluvial deposits. The maximum flow rate recorded during the monitoring was -0.7l/hr at BH105(D) within the Chalk.

7.7.2 Ground Gas Assessment for Construction and Maintenance Workers

A potential risk to construction workers from the accumulation of ground gas could exist during the construction and maintenance phases. There is not considered to be a significant risk from ground gas during the operation phase as ground gas accumulation is only considered a risk in confined/enclosed spaces and this can be mitigated through design of appropriate in-ground protection measures.

During the construction phase, restricted access to confined spaces, including excavations should be implemented. Where work in confined spaces is unavoidable, a site-specific and task-specific risk assessment should be undertaken prior to commencement of works. Monitoring of confined spaces for potential ground gas accumulations should be undertaken by suitably trained personnel with the use of specialist PPE where necessary.

Maintenance workers that are required to enter excavations or confined spaces during the operation life of the scheme will be provided with sufficient information by the project team on the nature of each sub-area at the site, upon which to base site and task-specific risk assessments. Such maintenance work will also include measures as detailed in the construction phase to minimise the effects of the work to human health.

The assessment presented in the following sections focuses on occupational exposure risks.

7.7.2.1 Methane

The greatest hazards posed by methane are those of fire and explosion. The limits of flammability, i.e. the Lower Explosion Limit (LEL) and Upper Explosion Limit (UEL), are 5% v/v and 15% v/v respectively. Where methane concentrations are encountered between these two ranges there is the possibility of ignition/explosion. However, it is important to note that where methane is outside of this range, i.e. above, safety shouldn't be assumed as further dilution can occur bringing it back to within explosive limits.

Where monitored, none of the installations had concentrations of methane within the 5% to 15% v/v range. Maximum methane (% v/v) concentrations within each of the wells were recorded below the detection limit of the monitoring equipment on all occasions.

For methane, the threshold for toxicity by asphyxiation is considered to be 30% (v/v) (8 hour long term Occupational Exposure Limit (OEL). The results show that the concentrations of methane (% v/v) recorded, do not exceed this limit.

Ventilation in tunnels and confined spaces is required at concentrations greater than 0.25% (v/v). This should be monitored on site during construction activities. Where entry into excavations is unavoidable the activity should comply with confined space legislation.

7.7.2.2 Oxygen

The results show that oxygen concentrations ranged from 5.3% v/v to 20.8% v/v. Depleted oxygen (i.e. less than 18%) was detected in BH101(D), BH101(S), BH104(D)*, BH104(S) and DS103.

Table 7.15 summarises the physiological effects of an oxygen deficient atmosphere. Based on the oxygen data recorded at the site, it is concluded that there would be a potential risk to construction workers entering excavations or enclosed spaces at the site.

Table 7.15 Effects Reduced Oxygen Concentrations

Oxygen% (vol./vol.)	Physiological Effects
19 – 21	Normal range of concentration in the atmospheric air
17	Faster breathing, slight impairment of judgement
10 – 16	Initial signs of anoxia leading to emotional upsets, abnormal fatigue upon exertion
6 – 10	Nausea, vomiting, unconsciousness, collapse may occur
<6	Convulsions, gasping respirations, death

7.7.2.3 Carbon Dioxide

For carbon dioxide there is no risk of flammability; however, there is a risk of asphyxiation and as such there are toxicity levels of 0.5% (v/v) for an 8 hour long-term Occupation Exposure Limit (OEL) and 1.5% (v/v) for a 10 minute OEL. Only monitoring well DS104 recorded concentrations of CO₂ greater than these limits. Therefore, there may be a risk to construction workers entering confined spaces within this area of the Site.

A potential risk of asphyxiation would exist if concentrations exceeding the toxicity limits were identified within confined spaces. It is recommended that confined space legislation be adhered to where entry into excavations by site workers is unavoidable.

7.7.2.4 Hydrogen Sulphide

A long-term (8 hour) workplace exposure limit of 5ppm and a short-term (15 minute) workplace exposure limit of 10ppm are given for hydrogen sulphide.

Hydrogen sulphide concentrations were recorded at or below the detection limit of the monitoring equipment. Therefore, risk due to short term or prolonged exposure to hydrogen sulphide is unlikely to present an issue at this Site.

7.7.2.5 Carbon Monoxide

A long-term (8 hour) workplace exposure limit of 30ppm and a short-term (15 minute) workplace exposure limit of 200ppm are given for carbon monoxide.

Carbon monoxide concentrations were recorded at concentrations ranging from <1.0ppm (detection limit of monitoring equipment) to 3.0ppm. Therefore, risk due to short term or prolonged exposure to carbon monoxide is unlikely to present an issue at this Site.

7.8 Health and Environmental Risk Assessment

7.8.1 Risk Assessment Principles

Current good practice recommends that the determination of hazards due to contaminated land is based on the principle of risk assessment, as outlined in the Environment Agency in the Land Contamination: Risk Management.

For a risk to be present, there must be a viable pollutant linkage; i.e. a mechanism whereby a source impacts on a sensitive receptor via a pathway. The potential pollutant linkages that have been identified for the Site are presented in this section.

Assessment of risks associated with each of these pollutant linkages are discussed in the following sections.

Using criteria broadly based on those presented in EA, Chartered Institute of Environmental Health (CIEH) and National House Building Council (NHBC) R&D Publication 66 'Guidance for the Safe Development of Housing on Land Affected by Contamination' (2008), the magnitude of the risk associated with potential contamination at the Site has been assessed. To do this an estimate is made of:

- The magnitude of the potential consequence (i.e. severity); and
- The magnitude of probability (i.e. likelihood).

7.8.2 Severity of Risk

The severity of risk is classified according to the criteria in Table 7-16

Table 7-16 Severity of Geo-Environmental Risk

Severity	Definition and Examples
Severe	Highly elevated concentrations that are likely to result in “significant harm” to human health as defined by the EPA 1990, Part 2A, if exposure occurs. Equivalent to EA Category 1 pollution incident including persistent and/or extensive effects on water quality; leading to closure of a potable abstraction point; major impact on amenity value or major damage to agriculture or commerce, e.g. highly elevated concentrations of contaminants in groundwater close to a sensitive abstraction. Major damage to aquatic or other ecosystems, which is likely to result in a substantial adverse change in its functioning or harm to a species of special interest that endangers the long-term maintenance of the population, e.g. major fish kill from large spillage on Site. Catastrophic damage to crops, buildings or property, e.g. explosion to buildings.
Medium	Elevated concentrations which could result in “significant harm” to human health as defined by the EPA 1990, Part 2A if exposure occurs. Equivalent to EA Category 2 pollution incident including significant effect on water quality; notification required to abstractors; reduction in amenity value or significant damage to agriculture or commerce. Significant damage to aquatic or other ecosystems, which may result in a substantial adverse change in its functioning or harm to a species of special interest that may endanger the long-term maintenance of the population. Significant damage to crops, buildings or property e.g. damage to foundations rendering it unsafe or ingress of contaminants through plastic, potable water pipes.
Mild	Exposure to human health unlikely to lead to “significant harm”. Exposure could lead to slight short-term effects e.g. mild skin rash. Equivalent to EA Category 3 pollution incident including minimal or short-lived effect on water quality; marginal effect on amenity value, agriculture or commerce. Minor or short-lived damage to aquatic or other ecosystems, which is unlikely to result in a substantial adverse change in its functioning or harm to a species of special interest that would endanger the long-term maintenance of the population. Minor damage to crops, buildings or property e.g., spalling concrete.
Minor	No measurable effect on humans. Equivalent to insubstantial pollution incident with no observed effect on water quality or ecosystems. Repairable effects of damage to buildings, structures, and services, e.g., loss of plants in a landscaping scheme.

Adapted from EA, Chartered Institute of Environmental Health (CIEH) and National House Building Council (NHBC) R&D Publication 66 ‘Guidance for the Safe Development of Housing on Land Affected by Contamination’ (2008), Annex 4

7.8.3 Likelihood of Risk Occurrence

The probability of the risk occurring is classified according to the criteria in Table 7-17.

Table 7-17 Likelihood of Geo-environmental Occurrence

Likelihood	Explanation
High	Pollutant linkage may be present that appears very likely in the short-term and risk is almost certain to occur in the long term, or there is evidence of harm to the receptor.
Likely	Pollutant linkage may be present, and it is probable that the risk will occur over the long term.
Low	Pollutant linkage may be present and there is a possibility of the risk occurring, although there is no certainty that it will do so.
Unlikely	Pollutant linkage may be present but the circumstances under which harm would occur even in the long term are improbable.

Adapted from EA, Chartered Institute of Environmental Health (CIEH) and National House Building Council (NHBC) R&D Publication 66 'Guidance for the Safe Development of Housing on Land Affected by Contamination' (2008), Annex 4

7.8.4 Risk Based on Comparison of Likelihood and Severity

An overall evaluation of the level of risk is gained from a comparison of the severity and probability, as shown in Table 7-18.

Table 7-18 Risk Based on Comparison of Likelihood and Severity

		Severity			
		High	Medium	Mild	Minor
Probability	High	Very high	High	Moderate	Moderate/low
	Likely	High	Moderate	Moderate/low	Low
	Low	Moderate	Moderate/low	Low	Very low
	Unlikely	Moderate/low	Low	Very low	Very low

Adapted from EA, Chartered Institute of Environmental Health (CIEH) and National House Building Council (NHBC) R&D Publication 66 'Guidance for the Safe Development of Housing on Land Affected by Contamination' (2008), Annex 4

7.8.5 LCRM Assessment of Risk

In 2019, the UK government issued new guidance on the evaluation and management of contaminated land, LCRM. Current contaminated land guidance in (LCRM) (Environment Agency, 2020) categorises risk at Stage 1 Tier 1 (i.e., PRA) as follows:

- Acceptable; and
- Unacceptable.

However, no framework for assessing the risk has been published to accompany the guidance, so the CIEH & NHBC R&D 66 assessment framework constitutes best practice in this regard. To align the risk rankings in Section 7.8.4 with the LCRM rankings and with the Part 2A definitions, the following matrix has been utilised. This conversion is demonstrated in Table 7-19 below:

Table 7-19 LCRM Risk

Risk (R&D 66)	LCRM Risk	
	Acceptable	Unacceptable
Very Low		
Low		
Moderate/Low		
Moderate		
High		
Very High		

* This risk category spans both acceptable and unacceptable. This is intentional as it is this risk band that tends to have the greatest level of uncertainty associated with it. Acceptability will be dependent on site-specific circumstances and level of confidence in the available evidence. For a risk to be unacceptable, the contaminant linkage should be associated with at least a “medium” severity as defined in Table A4.3 in Annex 4 of R&D66 and the probability should (in the majority of cases) be at least “likely” as defined in Table A4.4 of R&D66

These risk categories represent the level of risk as it is currently understood from the information available at this time.

7.8.6 Evaluation of Risk

In accordance with the risk assessment principles outlined above, an evaluation of the potential risks associated with the identified sources at the site to the various potential receptors is discussed and presented in Table 7-20 below. The level of risk is determined based on the current condition of the site (i.e., the effects of mitigation measures are not included). Mitigation is then proposed based on the significance of the risk. In some cases, a degree of mitigation is assumed as part of legislative requirements or standard construction practice. This is acknowledged where these assumptions are made.

Table 7-20 Evaluation of Geo-Environmental Risks

Receptor	Contaminant Linkage	Severity	Likelihood	Risk (R&D 66)	Risk (LCRM)	Discussion
Human Health <i>Future site users; surrounding land users (future and during construction)</i>	- Direct contact, dermal absorption or ingestion of soil. - Inhalation of soil particulates derived from soils - Inhalation of asbestos fibres from ground disturbance - Inhalation of soil vapour derived from soils / groundwater - Migration of hazardous gases/vapours via permeable strata into confined spaces (asphyxiation/ explosion)	Mild	Unlikely	Very Low	Likely to be acceptable	- No exceedances of evaluation criteria designed to be protective of human health based on a public open space end use were recorded as part of the human health GQRA assessment. Therefore, the risk is considered acceptable. - The potential risk to surrounding users is also considered to be low. - Best construction practices need to be in place to reduce exposure during construction works and hence potential risk. Measures to control the generation of soil derived dust should be outlined in the Construction Environmental Management Plan and be based on guidance in CIRIA C741 4th Edition 'Environmental Good Practice On Site' (2015). - Ground gas is not considered to pose a risk to future site users based on the ground gas concentrations encountered during the monitoring programme, combined with the transient exposure which is anticipated to occur for future users of the Site. Also, there is not anticipated to be any enclosed structures which the public will enter. - Asbestos was not encountered in Made Ground. Therefore, it is unlikely that exposure would occur during or post construction of the works.
Human Health <i>Construction / maintenance workers</i>	- Direct contact, dermal absorption or ingestion of soil. / waters - Inhalation of soil particulates derived from soils - Inhalation of asbestos fibres from ground disturbance - Inhalation of soil vapour derived from soils / groundwater	Mild	Likely	Moderate / Low	Likely to be acceptable	- A moderate low risk has been assigned to construction workers and maintenance workers due to the presence of lead concentrations within the area of the Ship Inn and east of Coastguard cottages (Section 4 and Section 5 -ODU 3B, 3F to 3H1). - High pH values within BH104 (north point of Sailing Club), has the potential to cause harm (corrosive). pH within the groundwater is neutral. Contaminants have been identified within the groundwater which could cause harm based on drinking water standards. - The results of the risk assessment should be considered in the planning of construction works in accordance with relevant statutory health and safety requirements.
	- Inhalation of asbestos fibres from ground disturbance - Migration of hazardous gases/vapours via permeable strata into confined spaces (asphyxiation/ explosion)	Medium	Low	Low	Likely to be acceptable	- Ground gas is not considered to pose a risk to construction worker users based on the ground gas concentrations encountered during the monitoring programme. However, depleted oxygen was detected within some exploratory locations which may pose a risk if confined space entry is required. Entry into excavations / confined spaces if required should be compliant with Confined Space Legislation. - Asbestos was not encountered in Made Ground within any samples tested. Therefore, it is unlikely that exposure would occur during of construction of the works. However, as Made Ground is present vigilance should be undertaken during excavations works and if asbestos is suspected, appropriate risk assessment and mitigation in accordance with CAR2012 should be undertaken prior to works continuing.

Receptor	Contaminant Linkage	Severity	Likelihood	Risk (R&D 66)	Risk (LCRM)	Discussion
Groundwater <i>Secondary A aquifer (River Terrace Deposits and alluvium);</i> <i>Secondary undifferentiated Aquifer (Beach Deposits);</i> <i>Principal Aquifer (Chalk);</i>	- Leaching of chemicals and vertical migration via permeable unsaturated strata to shallow (Secondary A / Secondary undifferentiated) aquifer) - Vertical migration of impacted shallow groundwater to the deeper chalk Principal aquifer	Mild	Likely	Low	Likely to be acceptable	- Ammoniacal nitrogen, chloride, sulphate boron and sodium were identified within the groundwater at concentrations greater than the DWS EC. These are likely to mainly reflect tidal influence / sea water intrusion, with the greater concentrations recorded along the shoreline. The concentrations recorded were within the same order of magnitude or 1 order of magnitude greater than their DWS EC. Therefore, these are all considered to be marginal exceedances given the context of the Site and surroundings. - Hydrocarbons were detected in the groundwater within DS104 that exceeded DWS EC. No known source in this area was identified. However, a hydrocarbon odour was noted within the alluvial deposits north of the Site, but soil concentrations of hydrocarbons were low (total hydrocarbon concentration of 62 mg/kg). Therefore, the TPH concentrations observed within groundwater at DS104 are considered to be an isolated location and not related to a known continuing source. - It is not considered that the soils at the Site are a potential source of unacceptable contamination which would result in potential harm to groundwater quality in the context of the Site and its surroundings. Although, numerous contaminants exceeded the DWS EC from soil leachate samples, including metals and PAHs (in particular DS101 east of the Look Out Public House where soil leachate concentrations were in the case of lead, 2 orders of magnitude greater than the DWS EC) no metals or PAHs were detected within the groundwater beneath the Site at concentrations which may pose a risk to groundwater quality. - It is unlikely that the Principal chalk aquifer (or Secondary A aquifer) will be exploited as a potable water in the future within this area, given the tidal influence, and noting that SPZ associated with the Principial Chalk aquifer are all further inland. Therefore, the exceedances in the groundwater or soil leachate detected are unlikely to result in harm or damage to potable water resources during or post construction works.
Surface Water <i>Langstone Harbour</i> <i>Chichester Harbour</i> <i>Lavant (Langbrook) Stream</i> <i>Lymbourne Stream</i>	- Spillage/loss/run off from surface direct to receiving water - Lateral migration of impacted shallow groundwater (Secondary A aquifer) off-site towards surface water baseflow - Migration via underground drainage/ sewers (including granular backfilling materials).	Medium	Low	Moderate / Low	Likely to be acceptable	- All groundwater concentrations detected were recorded to be within the same order of magnitude as their EQS EC. Therefore, they are all considered to be marginal exceedances. Those determinands which exceeded the EQS EC protective of surface water in more than one groundwater sample obtained from the Site included, metals (nickel and zinc), PAHs (fluoranthene), cyanide and ammoniacal nitrogen (based on unionised ammonia as N). - On the basis of the general limited exceedances of EQS in groundwater compared to soil leachate, the magnitude of exceedances in relation to the EQS, the spatial distribution of the exceedances across the Site and expected attenuation, it is considered that the soil and groundwater quality beneath the Site is unlikely to pose a significant risk to surface water quality during or post construction works. However, it is noticeable that there is a potential for mobilisation of contaminants (metals and PAHs) in the area of Section 4 and Section 5 and in particular around DS101 with soil and leachate concentrations generally being higher in this area compared to the rest of the site. This area of the site is possibly associated of reclaimed land during development of the area.

Receptor	Contaminant Linkage	Severity	Likelihood	Risk (R&D 66)	Risk (LCRM)	Discussion
						- With regards to soil leachate, although arsenic, copper, lead and PAHs were detected at concentrations which exceeded their EQS EC, these were not subsequently detected with the groundwater at concentrations which may pose a risk to surface water. This includes the groundwater in the vicinity of DS101, east of the Look Out Public House, where recorded notable soil leachate concentrations of lead and PAHs in excess of their EQS EC were detected. A soil leachate concentration of 7080 µg/l of lead was recorded compared with the EQS EC of 1.3 µg/l. Yet, this is not reflected within the groundwater within this area (BH103, BH104, as DS101 was not installed). - Although the risk is low and concentrations are low, given the potential for mobilisation of contaminants into groundwater during construction works within the vicinity of Frontage 3 and Frontage 4, it would be prudent to undertake groundwater chemical analysis prior to discharge into the surface water. Consent to discharge and or abstract water is likely to require consent from the Environment Agency. Chemical analysis of the receiving water is also suggested prior to works and to be monitored during the works. As part of the CEMP mitigation for the potential for contaminated groundwater to be encountered should be included and any water control measures required during construction should include assessment of groundwater quality to ascertain appropriate discharge options and discharge consents. These options should be discussed with the Environment Agency and/or local water company to understand their requirements and ensure compliance and consent prior to any works being undertaken. The groundwater results obtained as part of this GIR may be sufficient. However, this will need to be confirmed by Regulators
Coastal Defence Infrastructure	- Direct contact of buried concrete with contaminated soils (i.e., hydrocarbons) and aggressive ground conditions (pH and sulphate). - Direct contact of services and supply pipes with contaminated soils	Medium	Likely	Moderate	Potentially unacceptable	- High pH values within BH104 (north point of Sailing Club), has the potential to cause harm (corrosive conditions) - Sulphate - Engineering mitigation is likely to be required where concrete/infrastructure is required in the area of BH104. Further investigation may be prudent within the area to delineate if high pH in this area is more widespread or an isolated sample hot spot.
	Migration of hazardous gases/vapours via permeable strata into enclosed spaces and service/utility trenches	Mild	unlikely	Very Low	Likely to be acceptable	Ground gas is not considered to pose a risk to infrastructure due to the low / negligible concentrations of hazardous/explosive ground gas concentrations recorded. Due to the high-water table, most wells were flooded and thus the results should be used with caution. However, the ground model for the site does not indicate a ground gas source at the site or surrounding area.

8. Hazardous Waste Assessment

A preliminary waste classification has been undertaken on the soils sampled during the ground investigation. This assessment is indicative only, and only relevant in the event that the soils are excavated with a view to being disposed of off-site as waste during construction. For a material to be waste there must be an intention to discard such materials. If the material under consideration is not intended to be discarded as waste, then the following assessment does not apply; instead, risk-based criteria for re-use as part of the development should be adopted and consideration given to adopting a materials management plan and the Definition of Waste: Development Industry Code of Practice or it may be necessary to consider an exemption or permitting approach.

The samples have been classified in accordance with Technical Guidance WM3 (Version 1.2), published by the Environment Agency in October 2021. This should be considered an indicative assessment also because the classification of soils destined for disposal should be based on representative sampling of the soils specifically identified for disposal.

The following steps have been undertaken to classify the soils sampled:

- Setting of an initial European Waste Catalogue (EWC) code (transposed into UK legislation as the List of Wastes Regulations). This is based on our current understanding of the soils present at the site that may require disposal.
- Review of the chemical composition of the soils based on the Conceptual Site Model developed for the site, and the laboratory analysis completed on samples recovered from ground investigation.
- Comparison of reported concentrations of dangerous substances in the waste against threshold levels for hazardous and non-hazardous waste classifications; and
- Proposal of final classification.

The waste classification was carried out with support of HazWasteOnline™, which is a licensed online software package that provides an accurate and auditable tool for the classification of waste materials such as contaminated soils, filter cakes, sludge residues and wastes from organic processes. The software follows the WM3 guidance and European regulations and lets the user focus on what is in the waste that is driving the classification. This can help in designing treatment and disposal strategies.

8.1 European Waste Catalogue Code (List of Wastes Regulations)

Soils potentially requiring excavation and that may be considered for off-site disposal are considered to align with 'Construction and Demolition Wastes (Including Excavated Soil from Contaminated Sites)' which has waste code 17.

From this code, the sub-code 17 05 04 (soil and stones other than those mentioned in 17 05 03) and its hazardous mirror entry 17 05 03 (soil and stones containing dangerous substances) are selected as the most appropriate waste categories for further classification.

8.2 Determination of Waste Classification

HazWasteOnline™ uses the solid waste analysis from sample testing to classify materials as 'Hazardous' or 'Non-Hazardous' (in accordance with Environment Agency WM3 Technical Guidance). The tool also sometimes refers to a 'Potentially Hazardous' classification, which is unique to HazWasteOnline™. A 'Potentially Hazardous' classification is normally identified where a hazardous property could be present simply because a determinand is detected in a sample, i.e., there is no threshold other than its presence or absence. By identifying this as 'Potentially Hazardous' this enables the assessor to consider this further and, where appropriate, include further justification as to why the sample should be adopted as either 'Hazardous' or 'Non-Hazardous'.

For some analytes (primarily inorganics), the laboratory analysis does not identify the compound present in the waste but instead reports the individual species that make up that component, such as cations and anions. Environment Agency (2021) WM3 guidance states that if it is not possible to ascertain which substances might be present based on the process/activity that produced the waste, the most conservative classification should therefore be initially assumed for each component and the waste assessed accordingly.

In the UK, some laboratories report their analytical results for solids on a dry weight basis i.e., the concentration of the substance in the sample after any moisture has been driven off. If the moisture content is known, HazWasteOnline™ allows assessors to select an option to adjust the chemical concentrations to take account of moisture in the samples, which effectively dilutes the chemical concentration in the soil mass. Where metal (loids) are the primary contaminant the methodology can consider specific mineralogy which may affect toxicity and the outcome of the assessment.

8.3 Waste Classification and Assessment

The chemical parameters for the laboratory assessment were selected taking into account the CSM / past and current site use. The laboratory soil chemical data from the recent ground investigation has been considered in this preliminary and indicative assessment. The output generated from HazWasteOnline™ for the samples is presented in Appendix G and included a total of 40 environmental chemical samples segregated into Made Ground (18 samples) and Natural Deposits Alluvium (11 samples), Beach Deposits (4 samples), and 'Chalk' (7 samples).

8.3.1 Assumptions

As part of the assessment, AECOM has assumed the following (where applicable) for all groups of samples within the Made Ground and Natural Deposits:

Hazardous Property HP3(i) 'Flammable'

A 'potentially Hazardous' rating was triggered for the Hazardous Property HP3(i) 'Flammable' due to the presence of Total Petroleum Hydrocarbons or 2 4-isopropyltoluene above the laboratory method detection limit (MDL). This is due to there being no threshold other than presence or absence for flammable liquids.

A judgement was taken to overrule a 'Potentially Hazardous' classification on selected samples raised by the Hazardous Property HP3(i) 'Flammable' recorded for these chemicals. This was discounted as the samples analysed were a solid potential waste without a free draining liquid phase and with no evidence of visual or olfactory evidence or free product identified during the site investigation.

This adjustment removed the 'Potentially Hazardous' classification.

Barium (chromate)

The screening tool assumes, as a default worst case assumption, that barium would take the form of barium chromate. However, barium chromate is most commonly associated with limited use in yellow paints and specific industrial chemical processes and the CSM does not anticipate these sources to be present onsite.

This is reflected in the analysis as barium chromate is a compound of chromium VI and upon review of the data no chromium VI concentrations were reported above the MDL (1 mg/kg) and as all samples analysed are below the detection limit the potential presence of chromium VI and by extension barium chromate is considered unlikely. The default association has therefore been reduced to barium sulphide as the next most conservative form of barium.

This adjustment removed the 'Potentially Hazardous' classification for barium within all samples noted as 'Potentially Hazardous' for the chemical.

8.3.2 Results and Conclusion

Taking into account the assumptions above; 39 of the 40 samples were reported to be 'Non-Hazardous' and 1 sample was reported as "Hazardous".

The single "Hazardous" sample was from BH104 at 1mbgl. The sample was from the Made Ground strata and was described in the exploratory hole log as *"Soft to firm brown locally mottled brownish grey slightly sandy slightly gravelly Clay. Sand is fine to coarse. Gravel is angular to subangular fine to coarse flint and rare brick fragments and chalk"*.

The "Hazardous" classification for the samples was only raised by the pH value for the sample which was 11.92. This flagged as being "assumed to be irritant / corrosive because of pH value" with relation to the Hazardous Property 8 Corrosive 'waste which on application can cause skin corrosion'.

Three other samples taken from this borehole location one in the made ground (0.2mbgl), one in the alluvium (2.8mbgl) and one in the underlying Chalk (4.9mbgl) are classified as Non-Hazardous with pH recorded between

8.92 and 9.8. These remain slightly elevated relative to the other samples obtained from the other exploratory locations which are typically around pH 8.

While Chalk is noted to be present in this sample which can report a more alkaline pH, the pH recorded for the sample is considered to be outside of what would be anticipated for chalk alone. It was additionally noted that the soil leachate sampled within this sample also showed an elevated pH. However, groundwater across the Site was generally neutral.

8.3.3 Recommendations

Once the detailed design for the Site has been finalised and any cut and fill works have been identified (if applicable); in the event that soils are generated for waste disposal during construction, further testing and classification may be required based upon the actual soils excavated and segregated for disposal. Should the area of BH104 be included within material for off-site disposal or reuse, consideration for additional analysis to delineate the source of the elevated pH should be considered.

The initial WM3 hazardous waste classification does not replace waste acceptance analysis for off-site disposal. The WM3 hazardous waste assessment only identifies the material as 'Hazardous' or 'Non-Hazardous' under the classifications in WM3. Material classed as 'Non-Hazardous' may potentially be taken off site to a 'Non-Hazardous' landfill, but not an 'Inert' landfill without additional Waste Acceptance Criteria (WAC) analysis.

Materials sent off site as Non-Hazardous typically incur higher disposal costs than that of 'Inert' materials. Additional WAC analysis of material destined for off-site disposal could reduce the overall costs associated and provide a more environmentally responsible transfer of waste.

Any additional sampling undertaken should be representative of the material for off-site disposal and follow the guidance provided in Appendix G of WM3.

WAC analysis undertaken for materials designated for off-site disposal can provide an inert / Non-Hazardous / Hazardous classification for the material. However, it should be noted that landfills will likely have their own acceptance criteria in addition to WAC classification and may also require additional chemical analysis, leachate testing data.

9. Engineering Considerations

9.1 Unexploded Ordnance

Due to the medium threat level identified by an Explosive Ordnance Threat Assessment (EOTA) carried out by Planit and presented in a document referenced EOTA Havant 16/02/18 (Appendix H) a UXO threat management strategy is required to be in place prior to intrusive works. Intrusive works should be supported by an UXO specialist on methods of UXO clearance appropriate to construction activities to be undertaken in line with CIRIA C681 (2009).

9.2 Ground Permeability

For the proposed flood defence to provide an effective flood water barrier, the seepage through and beneath the defence must be minimal. The permeability of the flood defence structure is controlled by its construction, in an earth embankment, using controlled fill with low remoulded permeability. Seepage beneath the defence is controlled by the permeability of the natural strata and the potential for unacceptable flow volumes to the downstream side is a function of this permeability and the duration of the flood event.

Interpretation of the ground investigation results indicate that the permeability beneath the site will be controlled both laterally and vertically by the occurrence of the strata identified. The Alluvium which was encountered as a variably sandy and silty clay, is anticipated to have a low permeability. The River Terrace Deposits encountered were logged as slightly sandy slightly clayey angular to subangular fine to coarse gravels, no grading data was undertaken in these deposits. It is expected to have a higher permeability than the Alluvium although may still be controlled by the fine-grained material. The Chalk was identified as largely Grade Dm where the fine-grained matrix dominates which is indicative of low permeability.

9.3 Earthwork Slope Stability

Slope stability of the embankment cannot be fully assessed until the material from which it will be constructed is identified and its geotechnical properties known. However, if the embankment is constructed with side slopes of 1 vertical to 3 horizontal, and the fill material is controlled to have a minimum drained friction angle of 25° the slopes of the embankment are likely to remain stable under normal conditions. For preliminary purposes this may be taken as equivalent to a clay fill with a PI of 30% or less but this should be confirmed by laboratory testing to measure the drained strength of remoulded samples of the material. Compaction testing of the fill selected will also be required.

However, the stability of the embankment slopes during the transient and steady state seepage conditions during a flood event should be investigated during detailed design, along with the stability following draw down of the flood water when the porewater pressures within the fill will remain elevated.

Depending on space constraints, material availability, settlement tolerances and slope stability it may be possible to found shallow sided or steeper sided reinforced embankments onto the superficial deposits at ground level.

9.4 Earthwork Settlement and Bearing

Much of the proposed flood embankment will be constructed where Alluvium is the near surface stratum. The Alluvium was typically found to be soft to firm over its full encountered depth. Detailed calculations are beyond the scope of this report, but settlement of the embankment should be assessed at detailed design.

Some settlement of the embankment due to compression of the underlying soft strata is likely but may be tolerable if the embankment is monitored and “topped up” over its lifetime to maintain the required crest elevation.

9.5 Earthworks Constructability

To provide the required low permeability of the imported fill material used in the construction of the embankment, adequate compaction must be achieved. The compaction of the initial layers of material placed from existing ground level will be influenced by the response to the compaction loads of the foundation material. Where Alluvium will form the foundation to the embankment, which is likely to be over most of its length, the low undrained strength may result in the need for additional measures to ensure compaction results in densification of the fill material rather than deformation of the foundation and poor density of the completed fill. The use of a proprietary basal

reinforcement product or ground improvement beneath some or the entire embankment footprint could be considered to address this issue. Use of such a reinforcement material or ground improvement would also improve the stability of embankment slopes.

Given the shallow nature of the groundwater and the thickness of low strength soils, it is likely to be difficult to undertake a remove and replace exercise to improve the underlying ground conditions.

As a result of the soft ground and sensitive and protected habitats, consideration should be given to the access routes of wheeled plant during construction as trafficking of an unprepared surface is likely to result in degradation of the surface and the development of ruts.

9.6 Excavations

Based on the ground conditions encountered across the site, excavations required during the proposed development should not pose difficulties for conventional excavators and earth moving equipment. Excavations within Made Ground are likely to be stable in the short term unless very soft/loose or groundwater is present. Excavations into Beach Deposits, Alluvium and River Terrace Deposits are likely to be unstable, potentially even at shallow depths. It is recommended that allowance be made for lateral support and shuttering of excavations, as well as dewatering to control water ingress into excavations.

Excavations should be suitably shored or battered and inspected regularly by a competent person. No operatives should enter un-shored or otherwise unprotected excavations. A site-specific risk assessment should be carried out where man entry into excavations is required.

9.7 Sheet Pile Flood Walls

9.7.1 Required Depth

For stability, sheet piles installed to retain water standing above ground level, typically require an embedded length of approximately six times that of the retained water height. The retained flood water height and required depths of installation will determine if plastic sheet piles are suitable for use at the site.

9.7.2 Drivability

Assessment of sheet pile drivability is usually made with reference to SPT N values and CIRIA Report 143 guidance. The data available indicate that the RTD range from very loose to medium dense, and there appears to be no consistent trend of increase in density with depth. This suggests that where sheet piles are required there should not be issues with driving them into the ground. However, there are limited penetration test results available in the RTD to confirm the drivability of sheet piles.

Drivability of sheet piles into Chalk is controlled by the presence or lack of hard jointed chalk and presence of large flints that would act as obstructions. The ground investigations indicates that the flint at this site is largely limited to gravel to cobble size. The soft superficial soils and grade Dm chalk will permit driving of sheet piles but due to the low strength of the near surface soils the sheets are likely to need to be long to achieve lateral stability under flood conditions.

Due to the use of cable percussion drilling in the chalk, the recovery quality of the chalk was poor. The chalk descriptions should be used cautiously in the detailed design.

9.8 Existing Infrastructure

9.8.1 Presence of Existing Buried Utilities

Utilities information was obtained in September 2021 by Structural Soils from Landmark Information Group and is presented in more detail in Section 3.4.

The search identified the presence of surface water pipes from the private gardens draining into the foreshore and numerous key services buried beneath the footpath in this location.

In addition, a Scottish and Southern Electricity low voltage cable was identified located in the footpath from the High Street to near Green Cottage. This cable was uncovered during the Phase 1 ground investigation at 0.45m below ground level. It is recommended that during the detailed design stage the utility company is contacted about the approach to be taken to this cable and what form of future access is required. Potentially the cable could be left in place beneath the new flood wall, or a duct could be located along the base of the new flood wall, below the timber decking, to accommodate the relocated cable.

Utilities information was obtained in September 2021 by Structural Soils from Landmark Information Group.

9.9 Chemical Environment for Buried Concrete

Assessment of the results of the pH and sulphate testing indicates that the site has a Design Sulphate Class of DS-3 and an ACEC Class of AC-3.

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