GROUND INVESTIGATION REPORT

Southfield Brook Flood Alleviation Scheme

Prepared for

Cheltenham Borough Council

Date: February 2016

CH2M Hill
Burderop Park
Swindon
SN4 0QD

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Acronyms and Abbreviations

AONB	Area of Outstanding Natural Beauty
BGS	British Geological Survey
CBC	Cheltenham Borough Council
CCGI	CC Ground Investigations Ltd
DEFRA	Department for Environment, Food and Rural Affairs
EA	Environment Agency
GIR	Ground Investigation Report
MDD	Maximum Dry Density
OS	Ordnance Survey
PRFA	Preliminary Flood Risk Assessment
SPT	Standard Penetration Test
SWPM	Surface Water Management Plan

Executive Summary

The Cheltenham Surface Water Management Plan (SWMP) (2011), produced by Halcrow Group Limited, identified Southfield Manor Park and Sandy Lane as areas that are highly vulnerable to surface water flooding. Approximately 20 to 30 properties were known to have experienced flooding during the July 2007 flooding incident, which was estimated to have an annual probability of 1 in 125 years.

CH2M HILL has been instructed by Cheltenham Borough Council (CBC) to design and oversee the construction of flood relief works in the Southfield Brook area. The proposed works to alleviate flooding to properties in Southfield Manor Park and Sandy Lane include two low contour bunds and the upgrading of an existing channel to manage exceedance flow and utilise existing storage.

A ground investigation was undertaken by CC Ground Investigations Ltd (CC GI) in July 2015, comprising four window sample holes to depths of between 5mbgl and 6mbgl. The ground was found to comprise Made Ground, Clay, Cheltenham Sand and Gravel and Charmouth Mudstone. Although competent bedrock was not proven during the ground investigation, clay within the Charmouth Mudstone Formation was found to tend towards extremely weak mudstone.

This report is the Ground Investigation Report (GIR) for the scheme. The GIR comprises a presentation and geotechnical evaluation of all available geotechnical information pertaining to the scheme, detailing the assumptions made in the interpretation of the ground investigation and test results.

A previous technical note dated February 2015 summarised the geotechnical desk study findings. This has been incorporated into this report and the technical note is superseded.

Introduction

1.1 Project description

The Cheltenham Surface Water Management Plan (SWMP) (Halcrow, 2011), identified Southfield Manor Park and Sandy Lane as areas of Cheltenham that are highly vulnerable to surface water flooding. Approximately 20 to 30 properties are known to have flooded during July 2007, an event which was estimated to have an annual exceedance probability of 1.1% (90 year return period).

CH2M HILL has been instructed by Cheltenham Borough Council (CBC) to design and oversee the construction of flood relief works in the Southfield Brook area to mitigate the risk of future flooding to the Southfield Manor Park and Sandy Lane areas.

1.2 Site location

The Southfield Brook Flood Relief Works study area (OS grid reference SO 956 194) is located in the vicinity of Southfield Manor, approximately 3.5km south of Cheltenham town centre (**Error! Reference source not found.**) and in a predominantly residential area. The Southfield Brook catchment is situated adjacent to, and within, an area designated as an Area of Outstanding Natural Beauty (AONB).

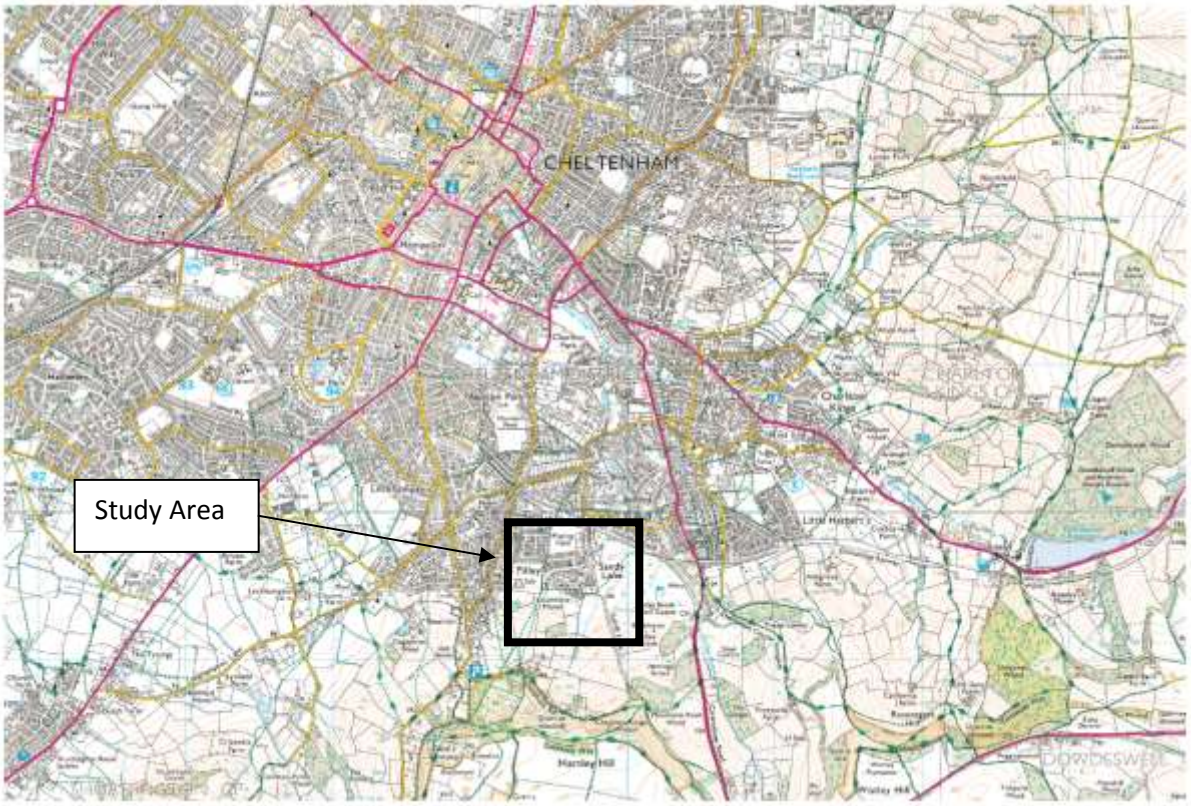

Figure 1-1 - Location Plan of Southfield Brook study area

1.3 Proposed works

The proposed works include two low height flood bunds and the upgrading of an existing channel to manage exceedance flow and utilise existing storage. The works will be at two localities – Location A and Location B (**Error! Reference source not found.**). The proposed measures seek to attenuate overland flow from the Cotswold escarpment up to the 1 in 100 year rainfall event, then gradually release the flow into the existing surface water network. Further details on the bunds' construction are shown on Drawing 204628.001 (Appendix A).

The earth bund at Location A will be constructed to the east of Southfield Manor, following the boundary of Southfield Manor and the access road. The bund has a maximum height of approximately 1.75m and side slopes no steeper than 1V:4H.

A smaller second bund is to be constructed to the west of Southfield Manor (Location B), using material excavated from the widening of the existing channel at this location. The bund will be approximately 0.5m to 0.6m above local ground level at its crest, and will follow the contours of the ground. A filter drain will also be installed at the western (upstream) end of the bund.

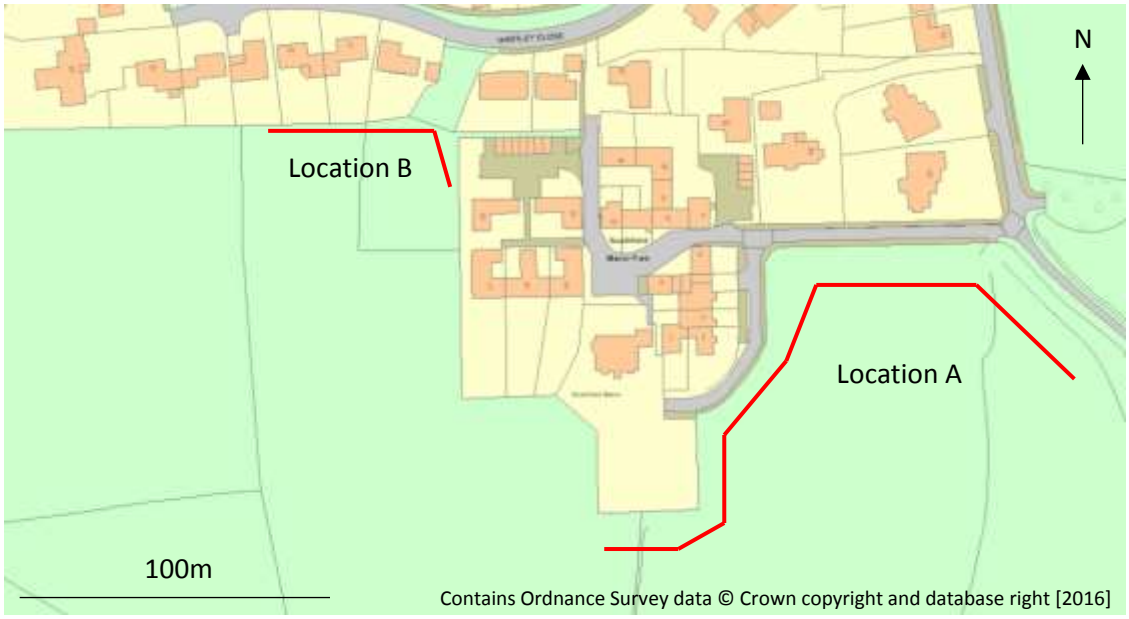

Figure 1-2 - Location Plan of development sites

1.4 Scope and objective of this report

The objectives of this Ground Investigation Report (GIR) are to:

- Present the findings of a ground investigation undertaken by CC Ground Investigations Ltd in July 2015;
- Provide an interpretation of the ground investigation and all geotechnical information pertaining to the scheme, in accordance with the requirement of Eurocode 7 (EC7); and
- Provide geotechnical design guidance and recommendations.

It is intended that the recommendations for the characteristics of the bund material contained within this report will assist an appropriately experienced earthworks contractor to source suitable borrow material. Notwithstanding this, we would recommend that the proposed borrow material is approved by the engineer prior to construction.

A previous technical note (CH2M HILL, 2015a) summarised the findings from a scheme-specific geotechnical desk study, and these findings have been incorporated into this report. The Envirocheck report acquired during the desk study is provided in Appendix B of this report.

The CCGI ground investigation factual report (CCGI, 2015) is included in Appendix C.

1.5 Geotechnical category of project

Based on the guidance provided in BS EN 1997, Part 1 (BSi, 2010), and the ground conditions identified in Section **Error! Reference source not found.** of this report, the earthworks required for this scheme are deemed to correspond to Geotechnical Category 2. This category includes conventional types of geotechnical structures, earthworks and activities, with no exceptional geotechnical risks, unusual or difficult ground conditions or loading conditions. The geotechnical

investigations, design and analyses for the scheme have therefore been undertaken in accordance with the requirements of this category.

Site Details and Hydrology

2.1 Site details

The study area is nominally bound to the west by Highland Road, to the north by Hartley Close, to the east by Sandy Lane and to the south by fields rising gradually to the toe of the Cotswold Escarpment. Key features and potential flood receptors include residential property on Hartley Close, Highland Road, Sandy Lane and Southfield Manor Park, and the associated highways.

The topography of the study area was determined from the 1:50,000 Ordnance Survey (OS) map (www.ordnancesurvey.com) and a topographic survey of the sites (Geomap, 2013). These indicate that the locations for the proposed bunds are relatively flat and dip gently towards the north, with elevations of approximately 110mOD (Location A) and 107mOD (Location B). The toe of the Cotswold Escarpment is located approximately 100m to the south of the site, with these steeper slopes rising up to approximately 270mOD approximately 1km to the south of the site.

A site walkover was completed by an engineering geologist from CH2M HILL on 10 February 2015. The weather was cold and overcast, and the ground generally muddy underfoot. Descriptions of the two locations are provided below.

2.1.1 Location A

Location A was observed from the central field in which the bund is proposed (Figure 2-1). Access was made through the gate on Sandy Lane with permission of the landowner. The site is bounded by Sandy Lane to the east and the Manor Park access road to the north, separated by a fence and small ditch. The fields are bounded by fences to the south and west.

Figure 2-1: Central field in which Location A is situated. Looking towards the west

The proposed flood bund is located over three adjacent fields, each divided by a small stream or drainage ditch lined by trees and mixed hedges. The streams flow towards the north and are culverted beneath Southfield Manor and Sandy Lane. The fields are laid to grass with horses grazing at the time of the survey. The ground was noted to be hummocky in places.

Vehicular access to the eastern and central fields is through the gates on Sandy Lane. A gate on the western side of the central field allows access to the western field and Location B.

2.1.2 Location B

Location B was viewed from the public footpath which runs adjacent to the proposed site. The site is bounded by Manor Park to the east and the gardens of properties of Hartley Close to the north. The fields are bounded by mixed hedgerows to the south and west.

The proposed bund is located over an area of rough ground and a field, currently divided by a fence. The field is laid to grass with horses grazing at the time of the survey. The area of rough ground consists of tall grasses and brambles with scattered trees. The land is relatively flat adjacent to the path and rises towards the south and the Cotswold escarpment (Figure 2-2).

Figure 2-2: Site of Location B, situated in an area of rough ground and adjoining field. Looking south

The existing ditch runs adjacent to the public footpath and is separated by a fence and tall grasses. Towards the eastern edge where the ditch will meet the proposed bund, the ditch is very overgrown with brambles.

Vehicular access to the site is via the gate on Sandy Lane and through the fields in which Location A is situated.

2.2 Hydrology

Southfield Brook flows approximately south to north across the site directly to the south of Southfield Manor. The watercourse is culverted beneath the manor and neighbouring residential

properties, re-emerging to the east of Sandy Lane where it continues northwards until converging with Lilley Brook just south west of Charlton Close. Lilley Brook continues to its confluence with the River Chelt just upstream of Cox's Meadow.

The principle flood risk within the Southfield Brook areas is from overland flows as a result of the topography of the land which rises steeply towards the Cotswolds AONB. The catchment area of Cheltenham is underlain by impermeable clay and is very responsive to rainfall leading to rapid surface runoff. The catchment is flashy even when soil is not saturated.

Runoff from the escarpment is directed to the study area by the relief of the land. A large volume of runoff is collected by the Southfield Brook. Two smaller tributaries of the Southfield Brook collect additional surface runoff from the escarpment; one watercourse runs along the western boundary of Lilley Brook Golf Course, and the other runs approximately 50m to the east of the main Southfield Brook channel. These watercourses converge into a ditch along the eastern edge of Sandy Lane before discharging into Southfield Brook.

During a flood event, the Brook cannot retain the flows in channel. Consequently the excess continues overland towards the residential properties

Existing Information

The following sources of information were consulted as part of the geotechnical desk study (CH2M 2015a) to provide a preliminary understanding of the site. This helped assess the expected ground conditions and potential geotechnical risks affecting the proposed works, and hence the requirement for further scheme-specific ground investigation.

3.1 Historical maps

Twenty historical maps at scales of 1:10,560, 1:10,000 1:2500 and 1:1250 were provided with the Envirocheck Report (Appendix B). The development of the study area, based on a review of these maps, is summarised in Table 3-1.

Table 3-1. Summary of Significant Changes

Survey Dates and Map Scale	Significant Features
1883 – 1885 1:10,560 1887 1:2,500	The proposed sites of Location A and B occupy three fields immediately adjacent to the buildings of Southfield, with a broadly similar layout to present day. A row of deciduous trees running approximately north-south separates the two fields south of Southfield and Location A. A small watercourse is shown towards the eastern side of Location A, running in a north-south direction. A well is shown to the south of Location B. The surrounding area is predominantly open land with a number of small tracks marked. Pilley Brick Field buildings are shown to the west of Location B, separated from Location B by a civil or parish boundary. Banbury and Cheltenham Railway is located to the north in a roughly northwest-southeast direction.
1903 1:10,560 1903 1:2,500	Lane to the east of Location A is now named Sandy Lane. Line of trees to south of Southfield no longer shown. A distinct area of deciduous woodland is marked in a field to the south of Southfield. A footpath is shown to the west, roughly following the municipal borough boundary in a north-south direction. A clay pit is shown to the west and the Pilley Brick Field is renamed Pilford Brick Works.
1924 1:10,560 1923 1:2,500	Area of woodland to south of Southfield extended towards the west. Line of trees identified to the south of Location A on 1884-1885 and 1887 plans now shown as water course. Southfield Brook is shown to the north of Southfield, running in a north-easterly direction. Watercourse which crossed eastern edge of Location A in previous plans no longer shown. Pilford Brick Works buildings and clay pit replaced by Southfield Villas development. Small area of possible hardstanding located at eastern end of Location B, immediately adjacent to Southfield Manor buildings.
1938 1:10,560	No changes within site boundary. Continued residential development to west and north of site.
1954 1:10,000 1953 1:1250	Buildings of Southfield now labelled Southfield Manor, Southfield Farm Cottages and Southfield Lodge. Area of woodland to south of Location A reduced in size but extended area to west still present. New woodland marked immediately to the north of Southfield and along Southfield Brook. Watercourse crossing the eastern side of Location A once again marked, with area of marsh to south. Open land to east of Location A now shown as a golf course, and tracks reduced to just one public footpath crossing in a northeast-south west direction. A number of houses are shown further along Sandy Lane to the north. Railway to the north no longer labelled.
1966 – 1968 1:10,000	No changes within site boundary. Railway to north disused.
1971 – 1978 1:10,000 1969 – 1978 1:1,250 1971 1:2,500 1974 1:1,250	Large Sandy Lane residential development to north of Southfield Manor and immediately north of Location A. Sports ground marked to west of Location B. Original woodland south of Location A no longer shown. Track and possible outbuildings located at eastern end of Location B, immediately adjacent to Southfield Manor buildings.

Table 3-1. Summary of Significant Changes

Survey Dates and Map Scale	Significant Features
1977 - 1990 1:1,250	Sandy Lane development extended south to the boundary with Southfield Manor and immediately north of Location B. Buildings of Southfield Manor divided into individual properties with gardens.
1978 1:10,000	No data
1983 1:1,250	
1990 1:1,250	
1991 – 1993 1:10,000	
1994 1:1,1250	No change within site boundary. Additional field boundaries shown south of Location A.
2006 1:10,000	Additional field boundaries south of Location B. Increased number of properties to the north of Location A. School shown to west of Location B within existing sports ground.
2014 1:10,000	No change within site boundary. School to west of Location B extended.

In summary, Location A is a greenfield site with no known history of previous development. Location B is mostly a greenfield site, although minor development associated with Southfield Manor (a track, possibly hardstanding and outbuildings) appears to have been present at the eastern end. The adjacent Sandy Lane development was built during the 1970s. The main buildings of Southfield Manor predate the earliest Ordnance Survey map of 1883.

3.2 Aerial photographs

An aerial photograph (dated 1947 - 1949) was provided with the Envirocheck Report (Appendix B). Historical aerial photos, dated 1945, 1999, 2005, 2006 and 2007 were also accessed via Google Earth (https://earth.google.co.uk/).

The aerial photographs dated 1945 and 1947-1949 reveal possible new development or reworking of the ground to the west of Southfield Manor. This corresponds with the area of rough ground identified at Location B during the site walkover. No features are shown on the historical OS maps from around this time, and therefore it is not clear what this development was.

3.3 Records of mines and mineral deposits

There is no record of mining within the vicinity of the site.

3.4 Archaeological investigations

An initial assessment to determine the requirement for an archaeological evaluation was undertaken by Gloucestershire County Council in February 2015. No potential archaeological issues were identified within the limits of the site and therefore no archaeological investigation or recording was deemed necessary.

3.5 Consultation with statutory bodies and agencies

The Envirocheck report (Appendix B) provides environmental information from bodies including the Environment Agency (EA), Natural England, Department for Environment, Food and Rural Affairs (DEFRA), British Geological Survey (BGS) and Local Authorities. The report contains site specific information on pollution incidents, groundwater vulnerability, aquifer designations, flood risk, landfill sites, hazardous substances, geological hazards, and sensitive land use which were all used for this report. The following salient points are noted from the report:

- The site lies within a Nitrate Vulnerable Zone.
- The site lies within an area of outstanding natural beauty and an environmentally sensitive area.
- The majority of the site is underlain by a minor aquifer (superficial aquifer designation of 'secondary aquifer – A'). This is within the Cheltenham Sand and Gravel Formation. Underlying bedrock is classed as 'unproductive strata'.
- In terms of ground water vulnerability, both locations are described as a 'non aquifer of negligibly permeable'. None of the sites are in Source Protection Zones 1 to 3 or in Zones of Special Interest.
- One pollution incident on controlled waters was recorded in the vicinity of Location A. This category 3 minor incident occurred in August 1996 as a result of land runoff of a miscellaneous pollutant.
- Approximately 250m north of the site, a Local Authority Recorded Landfill Site is noted. The local authority have recorded the site as now closed, but previously accepted soil and builders rubble. As the landfill is located down hydraulic gradient of the study area, contaminated ground is not expected within the site boundary.

3.6 Flood records

The Cheltenham SWMP and Preliminary Flood Risk Assessment (PRFA) both identify Southfield Manor Park, Hartley Close and adjacent Sandy Lane as a high flood risk area. This area has experienced frequent surface water flooding over many years and most recently during the extreme events of June and July 2007.

The Cheltenham SWMP stated that approximately 70 properties within the wider catchment of the Charlton Kings area (within which the study area occurs) were reported as flooded by residents during the 2007 flood event. The 2007 event is considered to have an annual exceedance probability of 1.1% (90 year return period).

The SWMP highlights that Sandy Lane and Southfield Manor Park experienced flooding during the summer 2007 flooding and this was confirmed by residents during a consultation event.

3.7 Utilities

Available service plans (dated 2015) indicate that a surface water drain runs in a north-south direction immediately to the south of Southfield Manor. The available plan suggests that this drain is located just to the west of the bund at Location A, however depending on the accuracy of the plan the drain may pass under the western extent of the bund.

A Virgin Media duct, low pressure gas main and BT underground cable run adjacent to the Southfield Manor access track. These are located on the extreme northern edge of the indicative site boundary and as such it is not expected that these services will be intercepted during construction.

No other services are identified beneath either Location A or Location B. However, given the proximity to residential housing of Southfield Manor, Hartley Close and Sandy Lane, there is a potential risk of unmarked services.

Up to date utility plans should be obtained ahead of construction works to check that no further utilities have been installed, or any changes made, since July 2015.

Conceptual Ground model

4.1 Geology

The geology of the study area is shown on the British Geological Survey (BGS) map sheet 235 (BGS, 1998), and described in the accompanying geological memoir (BGS, 2000). The BGS 'Onshore GeoIndex' (http://mapapps2.bgs.ac.uk/geoindex/home.html) and BGS Lexicon of rock units (http://www.bgs.ac.uk/lexicon/lexicon.cfm?pub=CHAM) were also consulted for further geological information. A summary of the geology based on these sources is provided below.

4.1.1 Solid geology

The study area is underlain by the Charmouth Mudstone Formation (formally named the Lower Lias Clay). The memoir describes it as being dominated by mudstone. The topmost part of the formation, consists of grey calcareous mudstones, with scattered clay ironstone nodules and the formation produces a brownish grey clay soil where it outcrops (BGS, 2000).

The BGS lexicon describes the mudstone as 'dark grey laminated shales, and dark, pale and bluish grey mudstones; locally concretionary and tabular limestone beds; abundant argillaceous limestone, phosphatic or ironstone (sideritic mudstone) nodules in some areas; organic-rich paper shales at some levels; finely sandy beds in lower part in some areas'.

4.1.2 Superficial Deposits

4.1.2.1 Cheltenham Sand and Gravel

BGS Sheet 235 indicates that both sites are underlain by superficial deposits comprising Cheltenham Sand and Gravel. These deposits overlie the Charmouth Mudstone Formation.

The BGS memoir states that the deposits comprise fine to medium grained generally unbedded quartz sand with seams of poorly sorted predominantly limestone gravel, especially in the lower part. The deposits are composite, the lower gravelly part is composed of gravel largely Middle Jurassic ooidal limestone, together with ironstone and derived fossils from the Lower Lias. The Cheltenham Gravels were probably derived from solifluction of the nearby Cotswold escarpment with some possible fluvial reworking at the foot. The overlying Cheltenham Sands were probably derived by aeolian processes from nearby river terrace deposits of the River Severn. It is likely that the material has been partially reworked by fluvial processes.

The Cheltenham Sand and Gravel is very variable in thickness. The BGS Lexicon of rock units notes that the deposits can reach a maximum thickness of around 15 metres although the BGS map indicates that the study area lies at the edge of these deposits and therefore they are only likely to be of limited thickness. Variability is due to channelling at the base, especially under Cheltenham. Except where dissected by streams, the surface of the deposits is of fairly low relief.

4.1.2.2 Landslip deposits

According to the BGS memoir, landslips have occurred widely throughout the district with the largest landslides recorded along the Cotswold escarpment. This situation is common in the district, because the Lias Group (which tends to be highly plastic) is overlain by permeable limestones. When the strength of the deposits forming a slope is insufficient to resist the gravitational shear stress, slipping results. Any such slope has potential for landslipping, but where these deposits are overlain by water-bearing strata, the probability of slipping increases considerably. Mudflows can eventually develop.

Landslip deposits are shown on the BGS map to the southeast and southwest of the site boundary, on the flanks of the Cotswold Escarpment. Hummocky ground potentially associated with historic landslips was noted within the southern half of the central field at Location A during the site walkover, and therefore landslip deposits may underlie the site. If present, these are likely to comprise reworked bedrock, glacial solifluction and head deposits.

4.2 Existing ground investigation records

A search of the BGS borehole database, available through the BGS Onshore Geoindex (http://mapapps2.bgs.ac.uk/geoindex/home.html), indicated that there is one existing borehole within the site boundary. Five further boreholes are located within 1km of the site. These boreholes were undertaken by Holst Soil Engineering on behalf of the South West Road Construction Unit in 1973 for the proposed A40 Improvements Works. Summary details from these borehole records are provided in Table 4-1.

Table 4-1. Summary of BGS Boreholes Selected for Locations A and B

Easting	Northing	Distance (m)	BGS Reference	Drilled Length (m)	Borehole Name	Borehole Summary
395760	219450	0 (at Location A)	SO91NE35	10.50	A40 IMPROVEMENT BH64	Stiff clay with occasional stones and weathered mudstone with occasional cement stone nodules
395270	219150	350	SO91NE36	10.00	A40 IMPROVEMENT BH66	Firm to stiff silty clay and weathered mudstone. Occasional ironstone nodules and silt partings
395330	218850	610	SO91NE22	20.00	A40 IMPROVEMENT 7	Weathered strong oolitic limestone to 6.8mbgl. Firm to stiff clay, silt and weathered silty mudstone
396450	219650	680	SO91NE34	10.00	A40 IMPROVEMENT BH63	Firm to stiff sandy or silty clay and weathered silty mudstone
394810	219170	690	SO91NW123	30.00	A40 IMPROVEMENT 65	Firm to stiff silty clay, strong siltstone and weathered mudstone. Weathered limestone band present at 2mbgl
395610	218760	710	SO91NE21	15.00	A40 IMPROVEMENT 6	Weathered oolitic limestone and silty clay with silt bands

All holes only encountered the Charmouth Mudstone Formation, which had weathered to a firm to stiff clay to a depth of two to three metres below ground level.

4.3 Hydrogeology

Groundwater is likely to be in hydraulic continuity with the River Chelt and the various water courses throughout the area, and is therefore expected to be close to the surface (<5mbgl) across the site.

The existing BGS borehole record BH64 (Table 4-1) encountered groundwater at 2.9m depth, and the water level stabilised at 2.4m depth.

4.4 Geo-environmental

Based on a review of the existing information and observations from the site walkover, no known geo-environmental hazards are expected at the site.

2015 Ground Investigation

5.1 Introduction

CC Ground Investigations Ltd (CC GI) carried out a ground investigation between 13th and 14th July 2015 under the instruction of CH2M Hill, on behalf of Cheltenham Borough Council. The ground investigation aimed to establish the following:

- The geology and groundwater conditions beneath the footprint of the proposed bund for the purpose of undertaking foundation design;
- The presence of potentially water-bearing sands and gravels which may result in unacceptable seepage volumes beneath the proposed bunds; and
- The presence of landslip deposits and any existing shear surfaces.

The factual report for the investigation is provided as Appendix C of this report, and this provides full details of the holes, *in situ* and laboratory testing. A summary of the investigation is provided in the subsections below, and discussion of the results is provided in Sections 6 and 7.

5.2 Fieldwork

The investigation consisted of four window sample holes referenced WS06 to WS09 to depths of between 5.0mbgl and 6.0mbgl. The locations of the exploratory holes and geological long section are shown on Drawings 204628.109 to 111.

5.3 In situ testing and sampling

In situ Standard Penetration Tests (SPTs) were carried out in accordance with BS EN ISO 22476-3:2005.

Hand shear vane tests were carried out in accordance with BS1377: Part 9:1990:4.4 and are presented on the exploratory hole logs in Appendix C.

Soil samples from the exploratory holes were logged by CCGI in general accordance with BS5930, Amendment 2 (2010). Undisturbed (U70) samples, small disturbed and bulk soil samples were recovered for subsequent geotechnical and geo-environmental laboratory testing.

No groundwater monitoring standpipes or piezometers were installed in the holes.

5.4 Laboratory investigation

The laboratory tests undertaken on recovered soil samples are summarised in Table 5-1

Table 5-1. Laboratory Test Summary

Test Type	Number of Tests	Remarks
Natural Moisture Content	12	The results are shown on the summary of soil classification tests.
Liquid and Plastic Limits	12	The results are shown on the plasticity chart and summary of soil classification tests.
Particle Size Distribution (Wet Sieving)	8	The fine fractions of 5 of these tests were further analysed using the hydrometer method.

Table 5-1. Laboratory Test Summary

Test Type	Number of Tests	Remarks
One Dimensional Consolidation	2	
Linear Shrinkage Test	2	
Quick Undrained Triaxial Test	4	
Consolidated undrained Triaxial Test of 3no 38mm Diameter Specimens with Porewater Pressure Measurement	2	
Dispersive Classification Category Determinations	1	Using the pinhole method. A single sample was returned as unsuitable for the test.
Shear Strength by Laboratory Vane (Set of 3)	3	
Shear Strength of 3no Specimens by Direct Shear	2	
BRE SD1 Chemical Testing Suite for Soil	5	Testing carried out by Chemical Testing Laboratories in accordance with BRE Special Digest 1.
Organic Matter Content	3	

Geo-environmental testing was also carried out on recovered soil samples in order to assess the presence of contamination. The testing suites included heavy metals, Total Petroleum Hydrocarbons (TPH) and speciated Polycyclic Aromatic Hydrocarbons (PAH).

Ground Conditions

6.1 Introduction

The following section presents the findings from the 2015 CC GI Ground Investigation. Table 6-1 summarises the ground and groundwater conditions encountered during the investigation.

Table 6-1 Summary of encountered ground and groundwater conditions

Hole	Made Ground (mbgl)	Clay (mbgl)	Cheltenham Sand and Gravel (mbgl)	Charmouth Mudstone Formation (mbgl)	Groundwater (mbgl)
WS06	0.0 to 0.1	0.1 to 1.7	1.7 to 2.55	2.55 to 6.0	5.2 (strike) 5.1 (standing)
WS07	0.0 to 1.0	1.0 to 1.65	-	1.65 to 6.0	Dry
WS08	0.0 to 0.4	-	0.4 to 1.35	1.35 to 5.0	3.75 (strike) 2.75 (standing)
WS09	0.0 to 0.3	0.3 to 1.75	1.75 to 2.95	2.95 to 5.0	4.1 (strike) 4.0 (standing)

6.2 Made ground

Made Ground was encountered in all exploratory holes to depths of between 0.1mbgl and 1.0mbgl, and was consistently described as soft friable sandy slightly gravelly CLAY with roots and rootlets. The gravel was described as sub-angular to rounded fine to coarse brick, limestone, shells and siltstone.

Locally at WS09, the clay was underlain by dark to light grey and black clayey sandy ashy gravel with occasional pockets of stiff clay and low cobble content. The gravel was found to consist of angular to sub-angular fine to coarse brick, clinker, limestone and siltstone.

6.3 Clay (head deposits)

In all but one exploratory hole, the Made Ground was found to overly a soft to firm brown or orange-brown locally mottled slightly sandy slightly gravelly clay to depths of between 1.65mbgl and 1.75bgl. Gravel was recorded as sub-angular to sub-rounded fine to medium of limestone and siltstone. The thickness of the clay ranged from 0.65m to 1.6m, and was absent in WS08.

6.4 Cheltenham Sand and Gravel

Cheltenham Sand and Gravel was identified at three of the four exploratory holes. In WS06 and WS09, the sands and gravels were found underlying the clay, while in WS08 the deposits were found immediately beneath the Made Ground. Cheltenham Sand and Gravel was encountered to depths of between 1.35mbgl and 2.95mbgl, with thicknesses ranging from 0.85m to 1.2m. The deposits were generally described as very loose to loose, becoming very dense is WS09, light brown and orange-brown clayey to very clayey sandy to very sandy gravel with rare roots and rootlets. Gravel is sub-angular to sub-rounded fine to coarse of limestone and siltstone.

6.5 Charmouth Mudstone Formation

The Charmouth Mudstone Formation was identified at all exploratory holes at depths of between 1.35mbgl and 2.95mbgl. The formation was described as firm indistinctly thinly laminated grey and brownish grey locally mottled slightly sandy silty clay, becoming stiff thinly laminated grey and bluish

grey slightly sandy silty clay with occasional shell and fossil fragments with depth. Locally, the strata tended towards extremely weak mudstone.

6.6 Groundwater and Chemistry

Groundwater was encountered in three of the four window sample holes, at depths ranging from 3.75mbgl to 5.19mbgl. Generally a rise of around 0.1m was recorded after 20 minutes, however in WS08 a rise of 1.0m was observed.

No groundwater monitoring was undertaken in the window sample holes.

Geotechnical Parameters

7.1 Introduction

The following section presents recommended characteristic geotechnical parameters for design purposes, based on a review of the site investigation data. A summary of these parameters is provided as Table 7-1.

7.2 Made ground

No in-situ or laboratory testing was undertaken on the Made Ground. Based on the field descriptions of the Made Ground as a soft sandy clay, and geotechnical parameters for similar strata presented in Look (2007), the following characteristic parameters are recommended:

- Unit weight: 17.0kN/m^3
- Effective strength: c' = 0kPa, ϕ' = 27
- Undrained shear strength: 40kPa

A permeability of 10^{-7} m/s is recommended based on published values for sandy clays (Carter and Bentley, 1991).

7.3 Clay (head deposits)

Two Particle Size Distribution (PSD) tests were undertaken on samples of clay from WS06 and WS07.The fines content of the material was found to be 89% and 83% respectively and the clay content was 40% and 37%.

Atterberg limit tests were carried out on five samples of clay. Test results indicated clays of intermediate to high plasticity, with a median plasticity index of 21% (Figure 7-1). The natural moisture content varied from 13% to 24%.

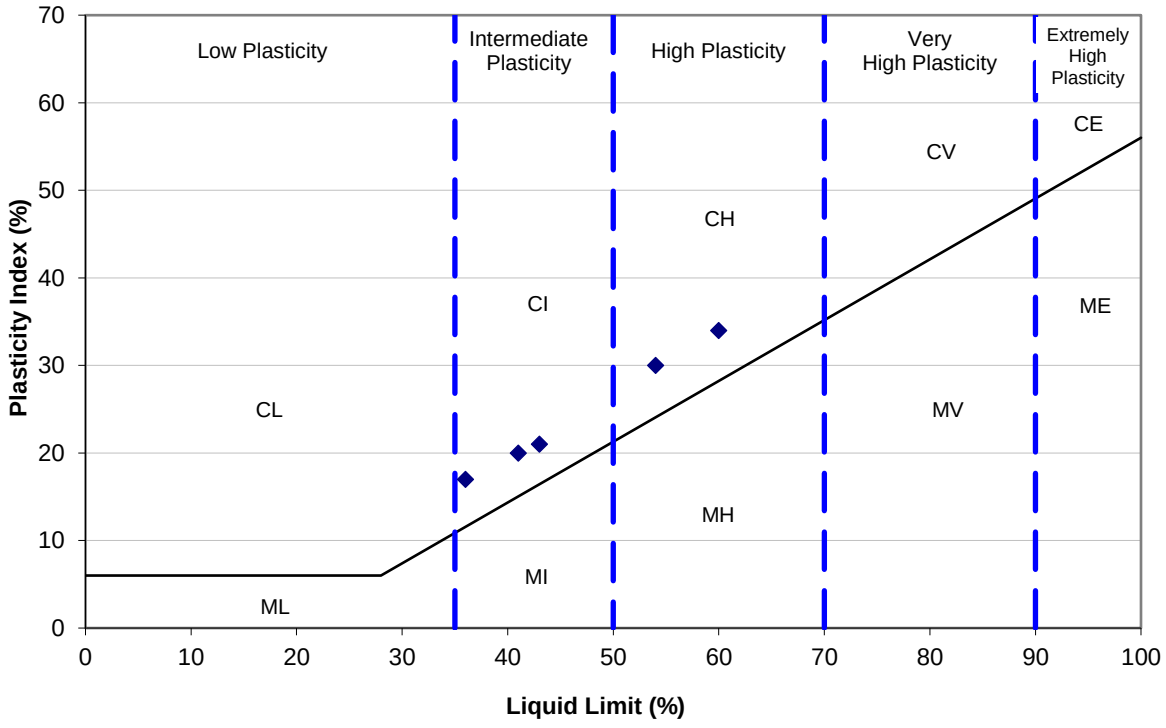

Figure 7-1: Plasticity chart for clay/head deposits

Three Standard Penetration Testing (SPT) were undertaken on the clay, with uncorrected SPT N values varying from 7 to 12. The results suggest that the deposits are soft to firm, which is consistent with the observations made during the ground investigation. On the basis of the material descriptions and relative densities indicated by the SPT data, a characteristic unit weight of 18.0kN/m^3 is recommended.

No strength testing was undertaken on samples of clay. The relationship with the median plasticity index provided in CIRIA Report 104 suggests an angle of 28°. This was adopted as the characteristic angle of shearing resistance. Correlation of SPT N values to undrained shear strength suggest values in the range 35kPa to 60kPa. A characteristic value of 40kPa is therefore recommended.

No permeability testing was undertaken during the ground investigation. The permeability of the clay has therefore been assessed by adopting the relationship based on plasticity index. Published values for high plasticity clays indicate a range from 10^{-10} m/s to 10^{-8} m/s (Carter and Bentley, 1991). A characteristic value of 10^{-8} m/s is therefore considered appropriate.

7.4 Cheltenham Sand and Gravel

Two PSD tests were undertaken on samples of Cheltenham Sand and Gravel. A sample from WS09 recorded a fines content of 9%. A sample from WS06 however, recovered from a depth of 1.75mbgl, recorded a fines content of 46% and clay content of 20%. This indicates a slightly sandy slightly gravelly clayey silt which is inconsistent with the description provided in the exploratory hole log and photographs of the core. It is believed that the high fines content is due to collapse from the clay strata immediately above the sample depth and is therefore not representative of the Cheltenham Sand and Gravel.

Three Uncorrected SPT N values varied from 4 to 68, indicating very loose to loose deposits in WS06 and WS08, and very dense deposits in WS09. This is consistent with the descriptions provided in the exploratory hole logs.

Shear box testing was undertaken on the same two samples as used for the PSD tests. Discarding the results from the sample recovered from WS06 which was considered unrepresentative of the strata, the results indicate a best fit effective shear strength of c’ = 7kPa, ϕ’ = 37°. Correlations with SPT N values (after Peck et al., 1974) suggest a median friction angle equal to 32°. A characteristic strength of c’ = 0kPa, ϕ’ = 34° is recommended (Figure 7-2).

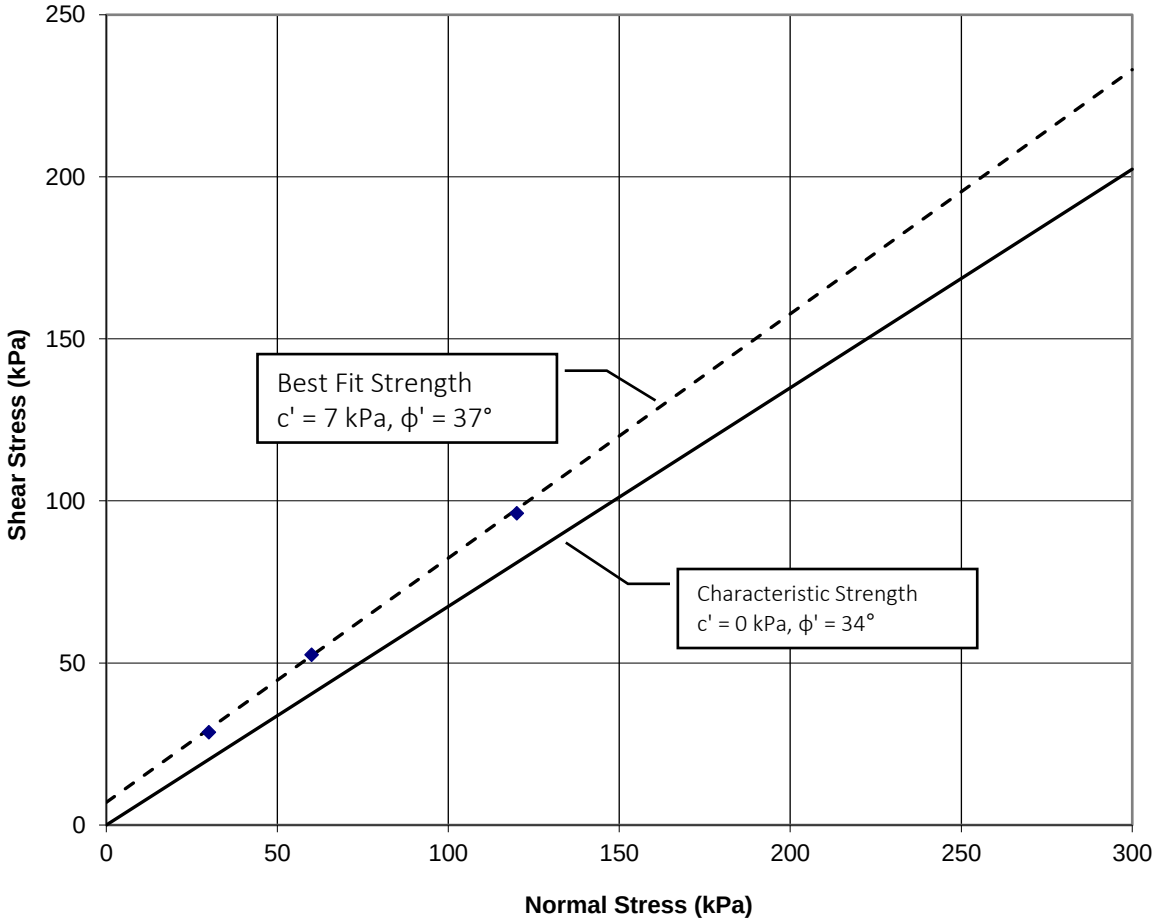

Figure 7-2: Effective shear strength (shear box) results for Cheltenham Sand and Gravel.

A bulk density of 1.96Mg/m^3 was determined during shear box testing. A unit weight of 19.2kN/m^3 is therefore recommended.

No permeability testing was undertaken during the ground investigation. The permeability of the Cheltenham Sand and Gravel has therefore been assessed by adopting the relationship proposed by Hazen based on grading curves, which indicates a permeability of around 10^{-5} m/s. Published values for clayey sandy gravels suggest a maximum permeability of 10^{-6} m/s. This is considered appropriate as a characteristic value for this strata.

7.5 Charmouth Mudstone Formation

PSD tests were undertaken on four samples of Charmouth Mudstone. The fines content of the material varied from 97% to 100% and the clay content from 42% to 44%.

Atterberg limit tests indicated high plasticity clays with a median plasticity index of 32%. The natural moisture content of samples varied from 18% to 27%.

Uncorrected SPT N values varied from 23 to 71 with a median of 29 for completed tests. The results suggest a general increase from stiff to hard consistency with depth (Figure 7-3). Of the nine tests undertaken, two were terminated at >50 blows.

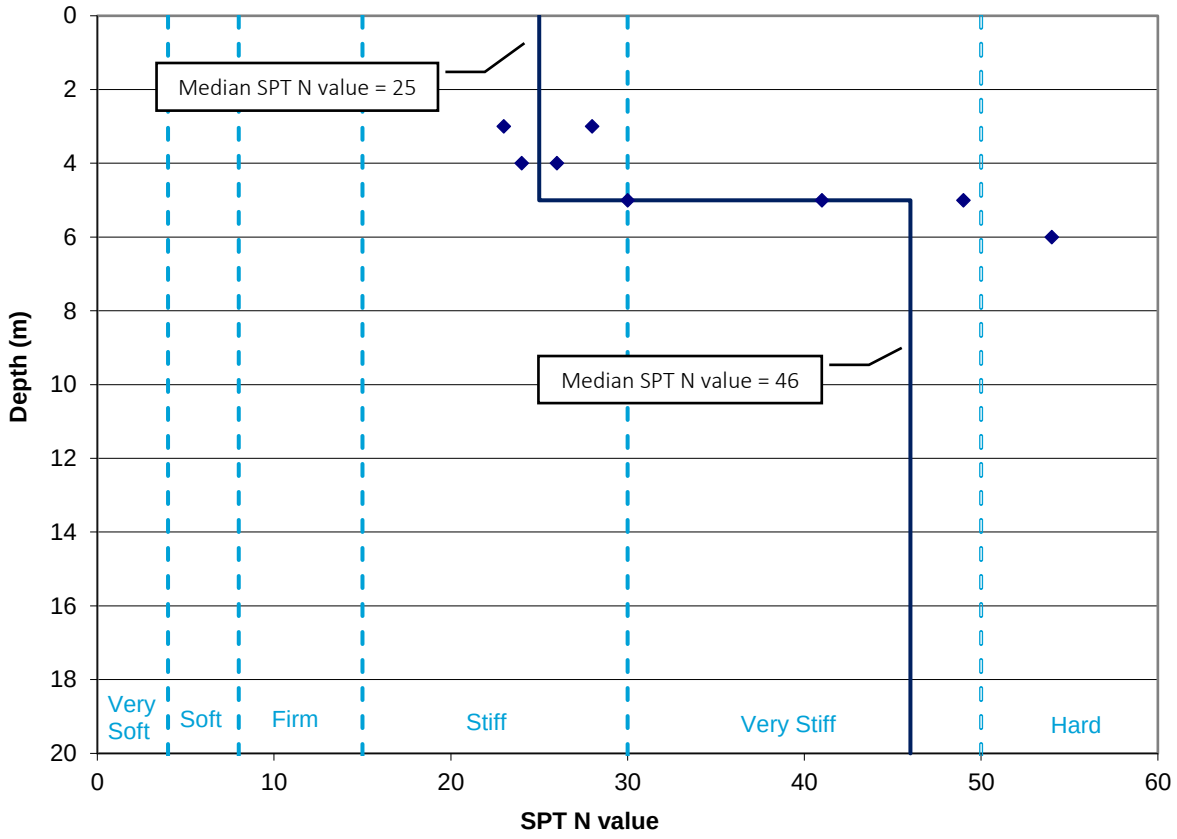

Figure 7-3: SPT N value with depth for the Charmouth Mudstone.

Triaxial testing with pore pressure measurement was carried out on two samples of Charmouth Mudstone. The tests recorded effective shear strengths of c’ = 3.1kPa, ϕ’ = 33.4°, and c’ = 15.5kPa, ϕ’ = 23.9°, giving an overall ‘best fit’ strength of c’ = 17kPa, ϕ’ = 23°. An effective shear strength of c’ = 0kPa, ϕ’ = 24° is therefore recommended (Figure 7-4)

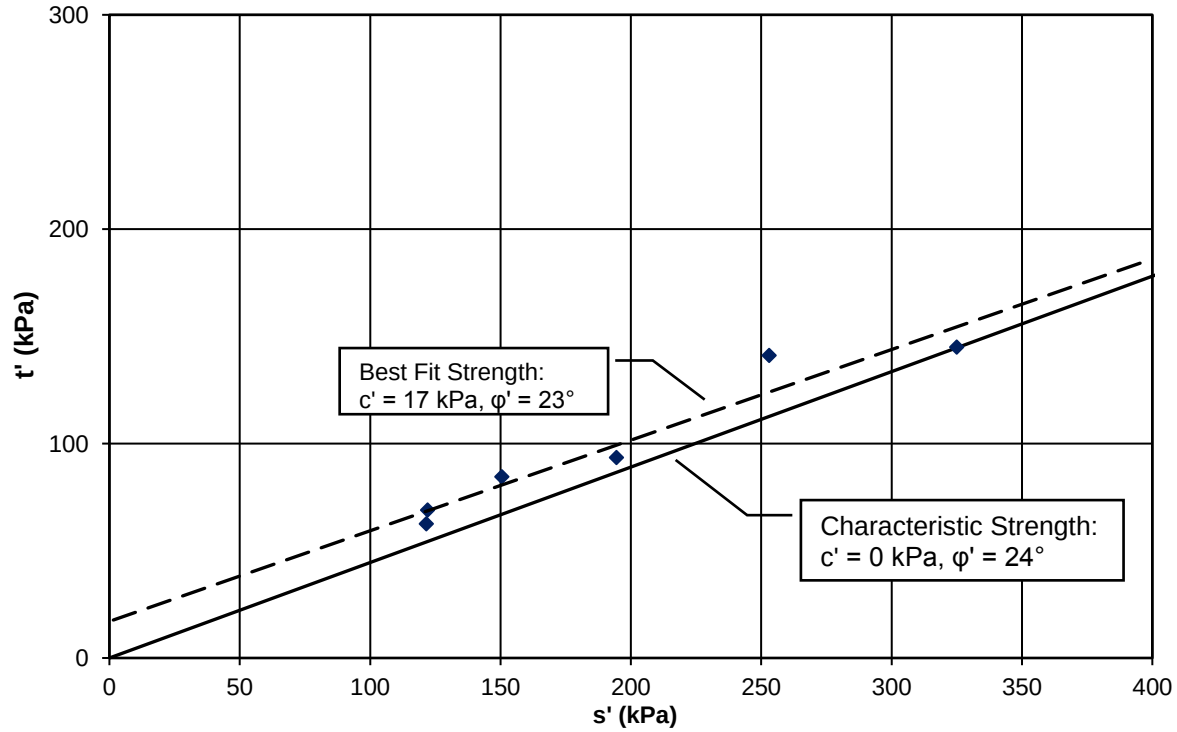

Figure 7-4: Effective strength (triaxial) results for the Charmouth Mudstone.

Bulk densities determined during triaxial testing ranged from 1.89Mg/m^3 to 2.07Mg/m^3, with a median value of 2.01Mg/m^2. A bulk unit weight of 19.7kN/m^3 is therefore recommended.

In situ and laboratory hand vane test results ranged from 40kPa to 136kPa with a median of 78kPa. Triaxial testing indicated undrained shear strength in the range 107kPa to 136kPa. There was no clear correlation with depth. A characteristic undrained shear strength of 45kPa is therefore recommended (Figure 7-5).

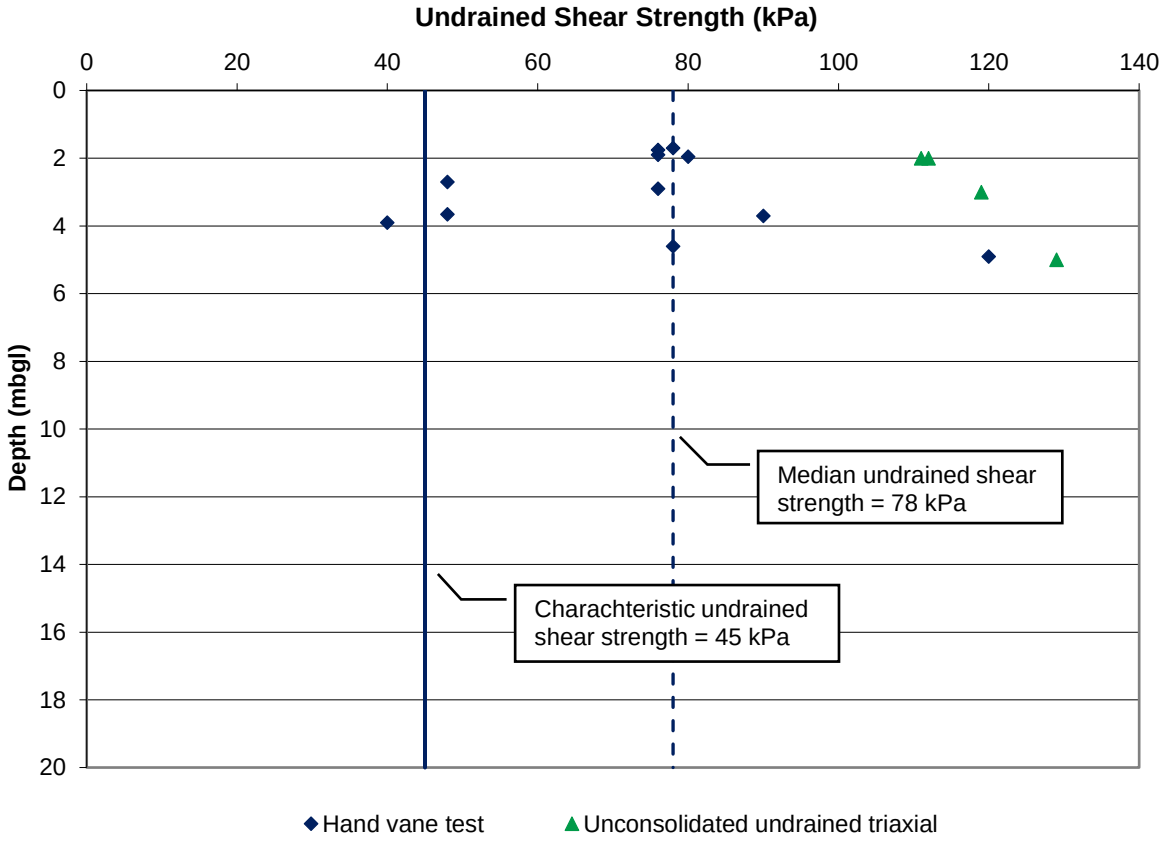

Figure 7-5: Undrained shear strength of Charmouth Mudstone

Two oedometer tests were undertaken on samples of Charmouth Mudstone to determine the coefficient of consolidation. Using the root time method, values of 7.4m^2/year and 11.6m^2/year were found for stress increments similar to those expected beneath the flood bund. The correlation with median liquid limit suggests a value of 4m^2/year (Carter and Bentley, 1991). The higher value of 11.6m^2/year is recommended as the characteristic value.

No permeability testing was undertaken during the ground investigation. Published values for high plasticity clays indicate a range from 10^{-10} m/s to 10^{-8} m/s. The relationship with the coefficient of consolidation suggests a value in the order of 10^{-7} m/s. A value of 10^{-8} m/s is therefore recommended.

7.6 Summary

Table 7-1 presents a summary of the recommended parameters.

Table 7-1 Characteristic Geotechnical Parameters

Material	Unit Weight (kN/m^3)	Undrained Shear Strength (kPa)	Effective shear strength: c' , ϕ' (kPa)	Permeability k (m/s)
Made Ground	17.0	40.0	0 , 27	10^{-7}
Clay/Head Deposits	18.0	40.0	0 , 28	10^{-8}
Cheltenham Sand and Gravel	19.2	N/A	0 , 34	10^{-6}
Charmouth Mudstone	19.7	45.0	0 , 24	10^{-8}

Assessment of Potential Contamination

8.1 Introduction

This section presents the findings of a contaminated land risk assessment for the site.

The Geotechnical Desk Study (CH2M HILL, 2015a) did not identify potential sources of contamination at the site. However, the ground investigation revealed the presence of Made Ground to a maximum depth of 1.0mbgl and therefore chemical analysis was undertaken on recovered samples.

8.2 Policy Overview

The Government's current approach to existing land that is contaminated is to encourage such land to be used safely and economically. In the case of Brownfield sites this results in restoring such land back into use. In accordance with these policy objectives a 'Suitable for Use' approach is adopted by regulators for addressing existing contamination. Site conditions are assessed in relation to the intended use of the site and, where required, involve appropriate restoration measures.

Any potential developer will need to satisfy the local authority that unacceptable risk from contamination will be successfully addressed through remediation, without undue environmental impact during and following the development.

Where collected lines of evidence can be concluded to indicate that contamination of land will not give rise to unacceptable risks and that there is no basis for further investigation nor related risk assessment activities, the development may be undertaken directly. Such a decision may relate to either the site itself or to the condition of the neighbouring land.

In terms of land contamination, risk assessment is carried out to determine whether the available lines of evidence of presence, concentration and distribution of substances may be concluded to give rise to unacceptable risks. The current commonly accepted approach to risk assessment is to examine information on various substances that may be considered to give rise to sources of contamination. The process is then to examine whether potential pathways provide the source with a link to defined receptors (which may be human, environmental or building).

All three elements together comprises a complete pollutant linkage and the approach is to establish whether the linkage gives rise to a risk that is considered to be unacceptable. If any one or more of the elements of the pollutant linkage (source, pathway or receptor) are absent, or may be subsequently removed, the pollutant linkage is then broken and the conditions at the site in respect of that combination are not then considered to pose a risk.

However, if linkages are indeed identified, the risk assessment process then seeks to establish the relevance of the linkage in terms of whether the risks that may arise with receptors are indeed considered as unacceptable.

8.3 Conceptual Site Model

The site is considered Public Open Space for the purposes of Human Health risk assessment.

Whilst the desk study did not identify any potential sources of contamination, the ground investigation did encounter Made Ground. Samples of materials recovered from exploratory holes have been submitted for contaminant analysis (Table 8-1).

Table 8-1 Summary of Made Ground occurrence and sampling

Hole	Made Ground (mbgl)	Descriptions	Chemical Analysis Sample depths (mbgl)
WS06	0.0 to 0.1	Shallow layer of topsoil/Made Ground	0.2

Table 8-1 Summary of Made Ground occurrence and sampling

Hole	Made Ground (mbgl)	Descriptions	Chemical Analysis Sample depths (mbgl)
WS07	0.0 to 1.0	Visual/olfactory contamination not encountered.	0.5 and 1.0
WS08	0.0 to 0.4	Visual/olfactory contamination not encountered.	0.2
WS09	0.0 to 0.3	Visual/olfactory contamination not encountered although clinker is noted in the borehole log	0.2

The results are provided in the factual report (Appendix C) and the findings are summarised below.

To assess significant of soil contamination, concentrations of contaminants have initially been compared to the Suitable for Use Level (S4UL) for Public Open Space (near residential), (The LQM/CIEH S4ULs for Human Health Risk Assessment, LQM, 2015, licence number S4UL3168), and the relevant Environmental Quality Standards for surface waters. The S4UL represent levels which are considered safe for a given land use. Comparison to these levels are considered a conservative assessment, the majority of the soils are below water, and the proposed structure encourage very little contact with exposed soils, so in effect minimal risk to human health exists post construction due to a lack of a potential exposure. Lead concentrations have been compared to the C4SL for Public Open Space (SP1010 – Development of Category 4 Screening Levels for Assessment of Land Affected by Contamination, Contaminated Land: Applications in Real Environments - CL:AIRE (2014).

None of the samples of Made Ground exceed the Suitable for Use Level (S4UL) for Public Open Space (near residential) for any of the contaminants analysed. Based upon this, in terms of human health, no source of contamination is considered present.

8.4 Contamination Risk Assessment

Based upon the Desk Study and Ground Investigation it is considered that no credible source of contamination exists at the site.

For Human Health, concentrations of contaminants do not exceed the S4UL for Public Open Space.

Risk to ground and surface water are also considered minimal. Whilst low concentrations of some contaminants have been encountered, they are not considered to represent a significant source of contamination and are considered to present a low risk to surface water or groundwater. The proposed flood prevention bunds are unlikely to significantly change the current situation.

8.5 Waste Management

Whilst no significant source of contamination is considered to be present, should waste soils be generated and require disposal the Made Ground will require waste classification. From the results obtained, this classification is likely to be non-hazardous.

SECTION 9

Geotechnical Risk Register

This section presents the Geotechnical Risk Register for the scheme, together with details of other constructions related risks known at this time.

A qualitative approach has been used based on the procedures set out in Managing Geotechnical Risk (2001). Under a qualitative risk assessment, the degree of risk is the expected impact of damage, loss or harm for a given hazard under particular circumstances which is expressed as:

Degree of Risk = Likelihood (L) x Effect (C)

The likelihood and the scale of effect are determined using Table 13-1 and 13-2 respectively, which together then provide the degree of risk given in Table 13-3.

Table 8-1. Scales of Likelihood

Likelihood (L)	Scale
Improbable	1
Remote	2
Occasional	3
Probable	4
Frequent	5

Table 8-2. Scale of Effect

Consequence (C)	Scale
Insignificant	1
Marginal	2
Serious	3
Critical	4
Catastrophic	5

Table 8-3. Degrees of Risk

Degree of Risk	Risk Level	Recommended Response
1 to 5	Low Risk	Broadly acceptable if all reasonably practicable control measures are in place.
6 to 8	Medium Risk	Tolerable only if further mitigation is not reasonably practical and there is need to continue activity with identified controls.
9 to 15	High Risk	Apply further mitigation measures and/or alter method of work to reduce risk further.
16 to 25	Very High Risk	Unacceptable. Re-examine activities to provide lower risk.

The risk register is provided in Table 8-4.

Table 8-4. Geotechnical Risk Register

No.	Hazard	Consequence of Hazard	Risk Level Before Mitigation			Measures to Eliminate or Mitigate Risks	Risk Level After Mitigation		
			Likelihood	Consequence	Degree of Risk		Likelihood	Consequence	Degree of Risk
1	Unforeseen ground conditions	Foundation failure or deformation in excess of serviceability limits. Disruption to construction.	3	3	9	The ground conditions have been established from a desk study review supplemented by a ground investigation	2	3	6
2	Risk of flooding due to surface run off prior to bund construction	Flooding of site resulting in delay to program and damage to residential properties.	2	3	6	Contractor to be aware of weather conditions and Environment Agency adverse weather warnings. Contractor to plan temporary works to avoid working in adverse weather conditions. Residual risks for management by the contractor and site staff to be notified via Designer's Risk Assessment	2	2	4
3	Total and differential settlements in excess of those predicted, resulting in damage to the culvert.	Damage to culvert.	3	4	12	Review of available ground investigation information to undertake a settlement analysis	2	3	6
4	Contaminated ground	Risk to human health, water receptors, buried services and structures.	4	4	16	The potential contamination risk from past historical land use was assessed during the desk study review. This was supplemented by ground investigation and appropriate geo-environmental contamination testing.	2	4	8
5	Aggressivity of ground	Long term degradation of concrete foundations resulting in structure damage.	4	3	12	A site specific ground investigation with appropriate chemical testing has been undertaken to establish the aggressivity characteristics of the ground	1	3	3

Table 8-4. Geotechnical Risk Register

No.	Hazard	Consequence of Hazard	Risk Level Before Mitigation			Measures to Eliminate or Mitigate Risks	Risk Level After Mitigation		
			Likelihood	Consequence	Degree of Risk		Likelihood	Consequence	Degree of Risk
6	Permeability of the ground higher than anticipated	Possible erosion of fines and damage to embankment foundations through excessive seepage.	5	3	15	Permeability of granular materials has been determined from particle size distribution tests. Permeable materials will be excavated and replaced.	2	2	4
7	Variability in made ground	Potential for differential settlement due to inherent variability across site. Higher than anticipated permeability through granular materials.	3	3	9	Review of available ground investigation information to undertake a settlement analysis with known thicknesses of made ground. Requirement for excavation and replacement of granular materials communicated.	2	2	4
8	Service strikes	Potential for unmarked services resulting in delays to construction, risk of serious injury/death of construction workers and disruption service provision.	3	3	9	Liaison with utility providers prior to construction to obtain up to date plans	1	3	3

SECTION 10

References

BRE, 2005. Special Digest 1. Concrete in aggressive ground

British Geological Survey, 2000. Geology of Cirencester District, Memoir for 1:50,000 Geological Sheet 235.

British Geological Survey, 2015. Lexicon of Named Rock Units: http://www.bgs.ac.uk/lexicon [Accessed February 2015].

British Geological Survey, 2015. Onshore Geoindex: http://mapapps2.bgs.ac.uk/geoindex/home.html [Accessed February 2015].

British Standards Institute, 1990. Methods of test for Soils for civil engineering purposes, Part 9: In-situ tests [incorporating Amendments Nos. 1 and 2]. (BS 1377-9:1990).

British Standards Institute, 2004. Eurocode 7: Geotechnical design, Part 1: General rules [incorporating corrigendum, February 2009] (BS EN 1997-1:2004).

British Standards Institute, 2005. Geotechnical investigation and testing – field testing, Part 3: standard penetration test [incorporating corrigendum no. 1] (BS EN ISO 22476-3:2005).

Carter, M. and Bentley, S., 1991. Correlations of Soil Properties.

CC Ground Investigation Ltd, 2015. Factual Report for Southfield Brook Flood Alleviation Scheme. Report Number C4710.

CH2M Hill, 2015a. Southfield Brook Geotechnical Desk Study.

CH2M Hill, 2015b. Southfield Brook Design and Access Statement.

Geomap, 2013. Southfield Topographical Survey.

Halcrow, 2011. Cheltenham Surface Water Management Plan (SWMP). Produced for Gloucestershire County Council.

Landmark, 2015. Envirocheck Report Order Number 64164432. [Received February 2015].

Look, B. 2007. Handbook of Geotechnical Investigation and Design Tables.

Peck, R.B., Hanson, W.E. and Thornburn, T.H., 1974. Foundation Engineering, 2nd Edition.

Appendix A – Drawings

Appendix B – Envirocheck Report

Appendix C – CC Ground Investigation Ltd Factual Report