Crown Quay Lane: Hydrogeological Risk Assessment

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Prepared for

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1 Introduction

1.1 Instruction

Stantec UK Ltd (Stantec) has been instructed by Keltbray Ltd (Keltbray) to prepare an Environmental Permit (EP) application for deposit of waste for recovery operations at Crown Quay Lane, Sittingbourne, Kent, ME10 3ST (the Site).

Keltbray will be the "Operator" under the EP and its role as Contractor to the Developer of the Site, Bellway Homes Ltd (Bellway).

This report presents the Hydrogeological Risk Assessment (HRA) which supports the application. The HRA is based on the data and information detailed in the Environmental Setting and Site Design (ESSD) report (Stantec, 2022).

1.2 Background

The Site is located within a 'mixed use' area, with large industrial units immediately bounding the Site. Further south of the Site is Sittingbourne Railway Station, with Sittingbourne High Street and Town Centre being located approximately 650 m southwest of the Site. Milton Creek, part of the Swale Estuary, is located adjacent to the Site and to the north and northeast of the Site. The general Site location is indicated in Figure 1.1. The Site is accessed via an entrance point off Crown Quay Lane.

The Site is proposed to be developed into an area of 107 residential properties with associated infrastructure. The Site is centred on approximate National Grid Reference TQ 90821 64060. Further detail regarding the Site setting and local land use is provided in the ESSD Report.

Prior to development proceeding, remediation works will be undertaken on the Made Ground at the Site as previous investigations have shown that there are currently risks to Controlled Waters from this material. The risk assessment and remediation strategy required to address this issue are being undertaken under the planning regime as detailed in the ESSD report.

The development will be undertaken following construction of a platform to raise the ground and protect it from flooding. This will be undertaken as a Deposit for Recovery (DfR) activity using a combination of waste materials currently available at the Site and via the importation of additional waste materials. It is understood that approximately 14,000 m^3 of waste materials are available on-site and a further 12,000 m^3 require to be imported to complete the development platform.

On-Site wastes have been processed, recovering suitable soil material for re-use on the Site. Subsequent sampling and analysis of the soil component of the material showed the soil was suitable for reuse on a site with a residential end-use and would not pose a risk to controlled waters. Keltbray produced a Completion Report, documenting the removal of asbestos and contravening materials from the stockpiled material (Keltbray Remediation Limited, 2017)). This material will be subject to stabilisation to render it chemically and geotechnically suitable for placement. Stabilisation trials have been undertaken by CE Geochem Ltd (Geochem, 2022), included here as Appendix A.

Prior to the placement of waste in the Site, the top 1 m of Made Ground will be excavated leaving a remaining depth of around 2 m of Made Ground. The stabilised material and imported waste will be placed in engineered layers providing a development platform and raising the site level to approximately 1 m above existing level. Imported wastes will be placed around the perimeter of the Site adjacent to Milton Creek and stabilised material towards the centre, as shown on Figure 1.2. It should also be noted that imported wastes will also be placed on top of the stabilised material to achieve the required formation level.

Figure 1.1 Site location

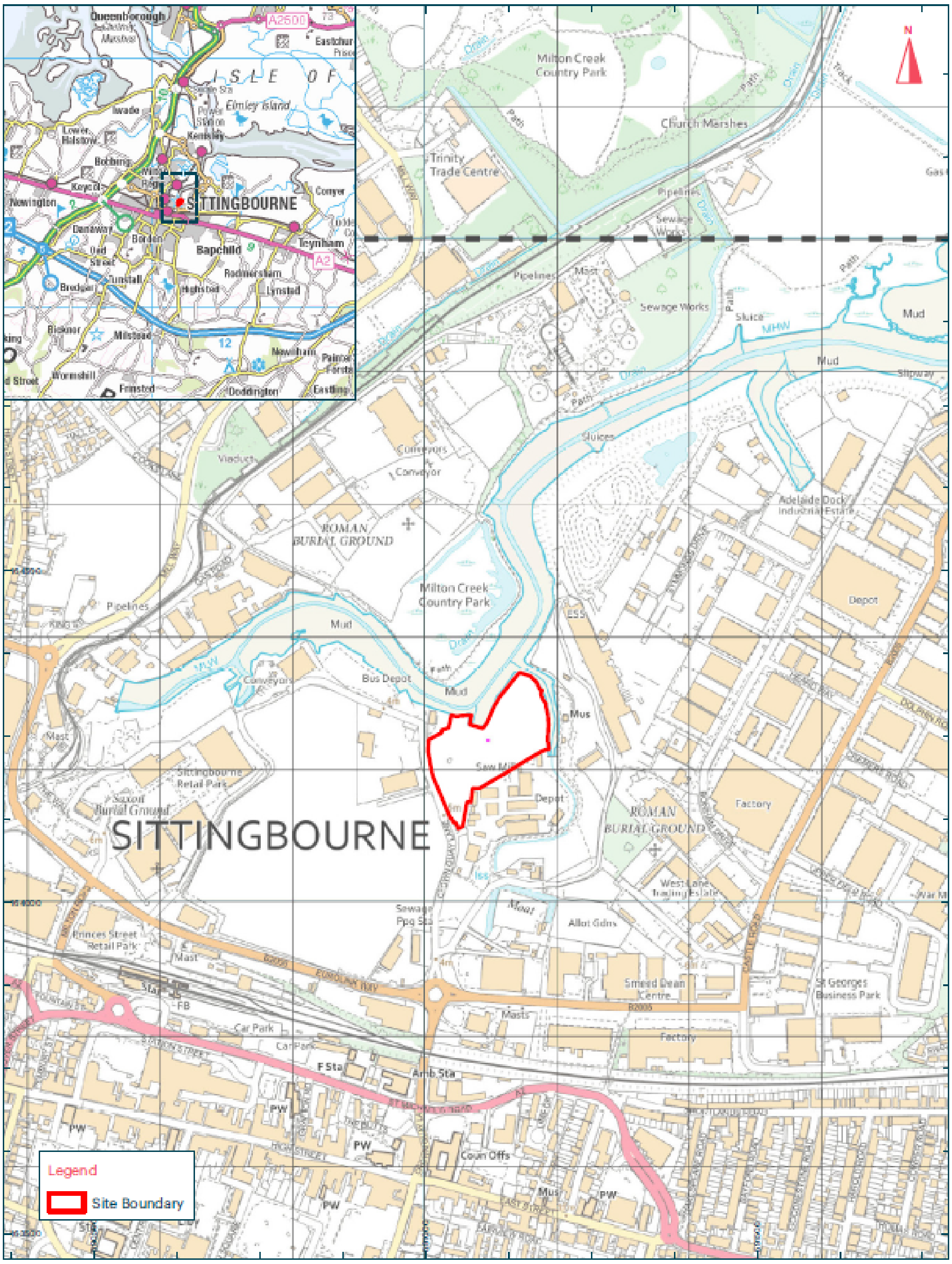
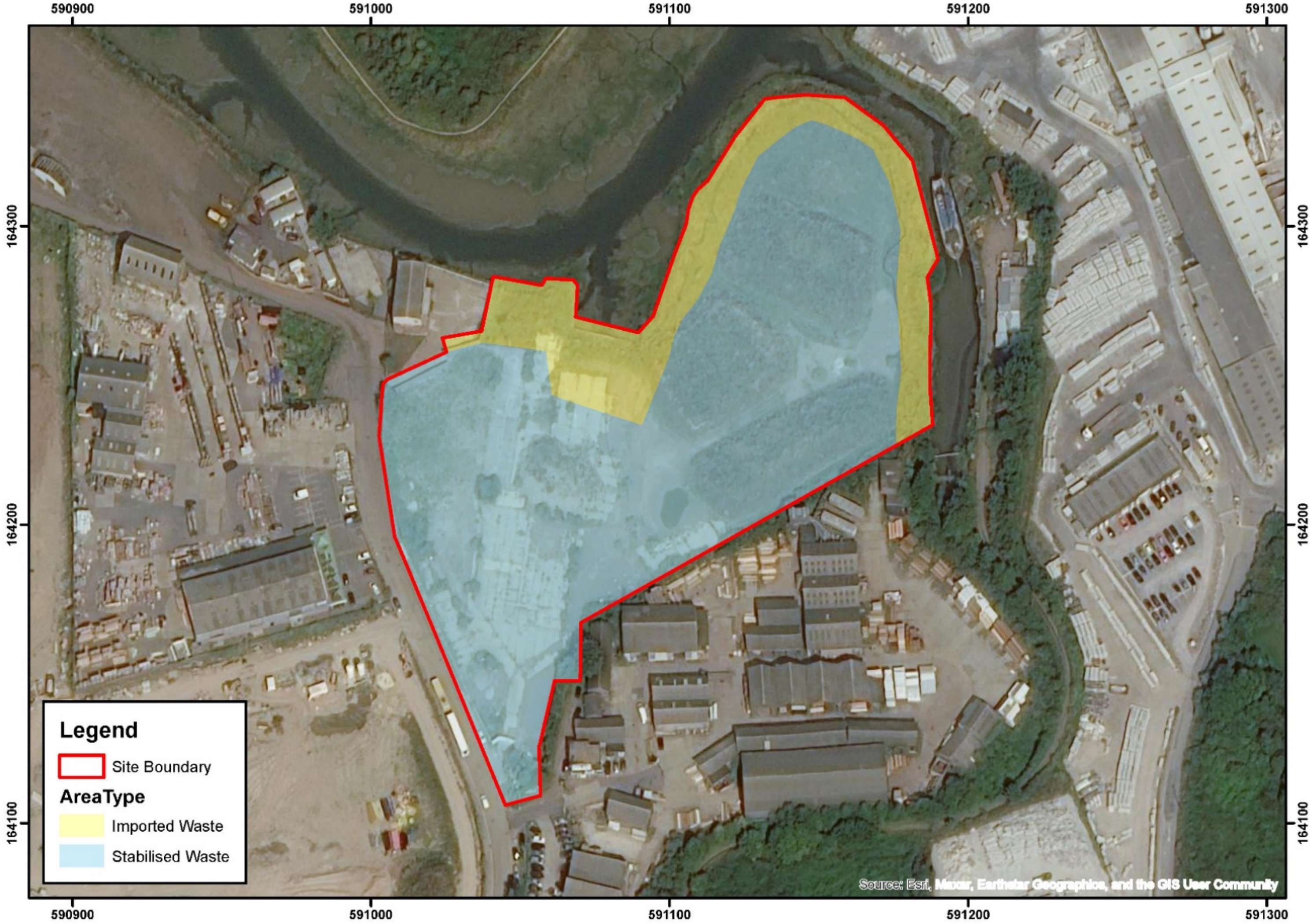


Figure 1.2 Areas proposed for placement of waste materials currently available at the Site and via the importation of additional waste materials



Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community

2 Baseline Conditions

2.1 Site Setting

A summary of the Site context is presented below in Table 2.1.

Table 2.1 Site Setting

Site address	Land East Of Crown Quay Lane Sittingbourne Kent ME10 3ST	
NGR	TQ 90821 64060	
Site location	The Site is located within the residential town of Sittingbourne, Kent and is located approximately 650 m northeast of the town centre and high street. Existing access to the Site is via Crown Quay Lane, which runs along the eastern boundary of the Site.	
Topography	The majority of the land is relatively flat, with ground elevations in the order of between 4.4 mAOD (metres Above Ordnance Datum) to 4.8 mAOD. There are slopes located along the northern and eastern boundaries, where the ground levels decrease to a low of approximately 1.3 mAOD. Three stockpiles of inert waste are located on the Site, which are proposed to be used in the recovery activity. The topography of the Site is shown on the Topographical Survey Sheet 1, Drawing No. CM/181000 (Appendix D of ESSD Report).	
Current land use	The Site has been used for a range of land uses, including printing works, concrete production / cement works, bulk liquid storage, backfilling marshland, and docks. The most recent use of the Site was as a waste transfer site for construction and demolition waste.	
Surrounding land use	North	The site abuts mudflats to the north, which form part of Milton Creek. Milton Creek is designated as part of the Swale Estuary Marine Conservation Zone (MCZ) and Milton Creek Local Wildlife Site (LWS). Milton Creek Country Park is located further north, approximately 70 m from the Site. To the northwest of the Site lies Bayford Meadows Kart Circuit, approximately 140 m from the Site. Biffa Sittingbourne (household waste transfer facility) is located approximately 770 m north of the Site.
	East	A concrete producer (Supreme Concrete) is located off Crown Quay Lane to the immediate east of the Site. Industrial units making up

		Eurolink Industrial Estate are located further to the east. A small tributary of the Swale is located immediately east of the Site.
	South	A timber supplier (Odds Timber) is located immediately south of the Site, with other industrial units located further south. The B2006 is located approximately 230 m south of the Site, with Sittingbourne Train Station being located approximately 470 m southwest of the Site.
	West	A builders' merchant (Jewson Sittingbourne) is located to the west of the Site, adjacent to Crown Quay Lane. An area of disused land (allocated for residential development) is also located to the west of the Site.

2.2 Geology

2.2.1 Bedrock geology

The majority of the bedrock geology at the Site is classified as "Seaford Chalk Formation – Chalk" (Figure 2.1). The sedimentary bedrock formed approximately 84 to 90 million years ago in the Cretaceous Period. The local environment was previously dominated by warm seas. These sedimentary rocks are shallow marine in origin. According to the borehole and trial pit logs (Appendix B), between 1.5 and 9.5 m at the top of the Chalk comprises structureless chalk, comprising silts and gravels.

Bedrock geology in the north-eastern corner of the Site is the "Thanet Formation – Sand, Silt and Clay" sedimentary bedrock formed approximately 56 to 59 million years ago in the Palaeogene Period. These sedimentary rocks are shallow marine in origin. This classification has been obtained from the British Geological Survey Geology Map.

2.2.2 Superficial geology

The superficial deposit geology at the Site is classified as "Alluvium – clay, silt, sand and peat" (Figure 2.2). The superficial deposits formed up to 2 million years ago in the Quaternary Period. The local environment was previously dominated by river conditions. These sedimentary deposits are fluvial in origin. They are detrital, ranging from coarse to fine grained and form beds and lenses of deposits. Immediately north of the site are tidal flat and beach deposits. This classification has been obtained from the British Geological Survey Geology Map.

According to the borehole and trial pit logs (Appendix B) the Alluvium has a thickness of between 2.6 and 3.9 m and comprises silty and sandy clays with occasional gravelly clay.

2.2.3 Made ground

The Site has been subject to various intrusive investigations, as detailed in the ESSD report. The investigations undertaken between 2013 and 2018 have identified a variable thickness of Made Ground beneath the Site, extending to depths of between 2.8 and 7.4 m below ground level (mbGL). The deepest extents of Made Ground relate to the wharf and tidal mud flats areas in the northwest of the Site that have been previously infilled.

According to LEAP Environmental (2019), the Made Ground comprises clay and sand containing a variable thickness of flint, brick, chalk, ash, concrete, and clinker. Alluvial and organic odours were recorded within the Made Ground soils.

Figure 2.1 Bedrock Geology

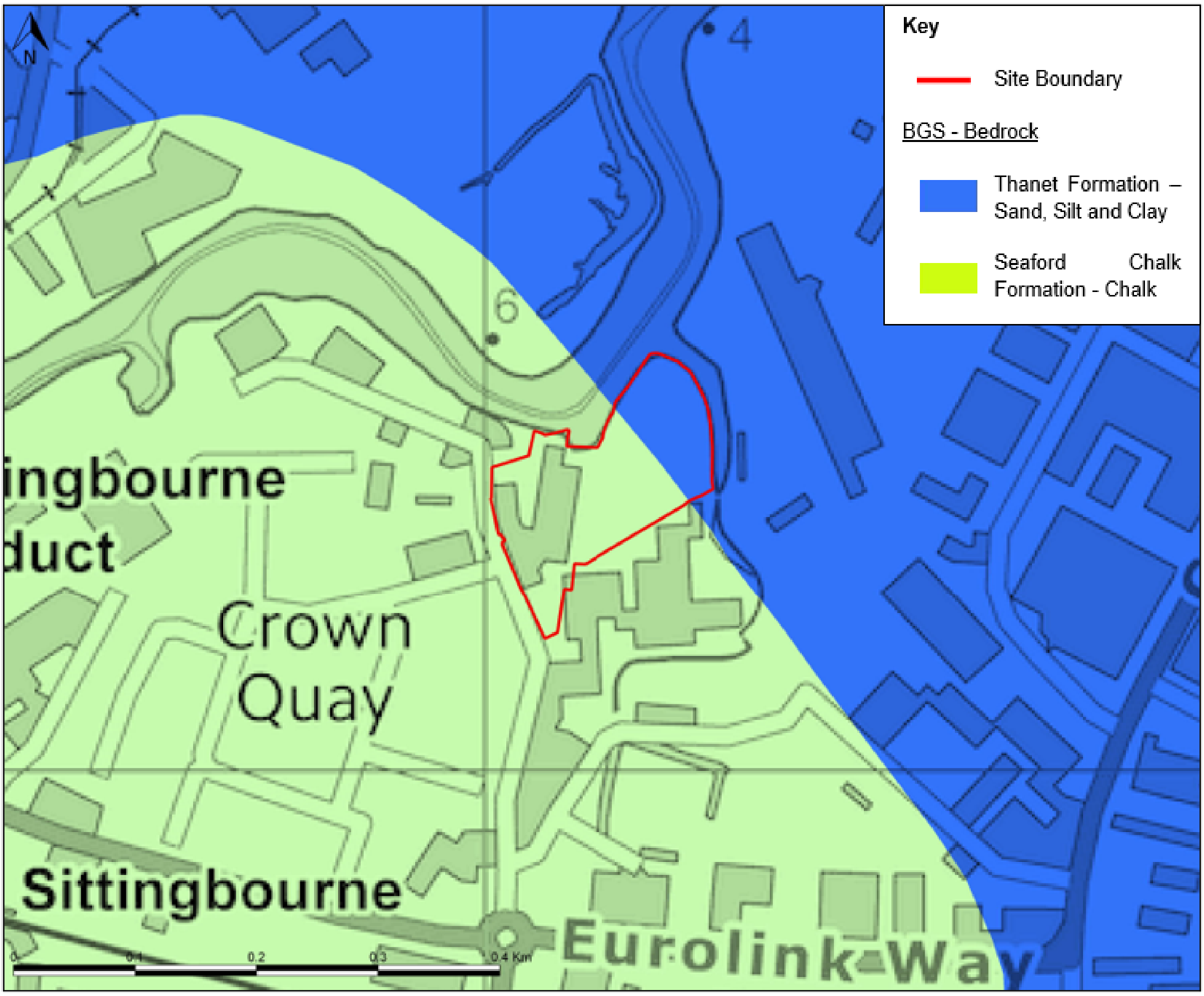
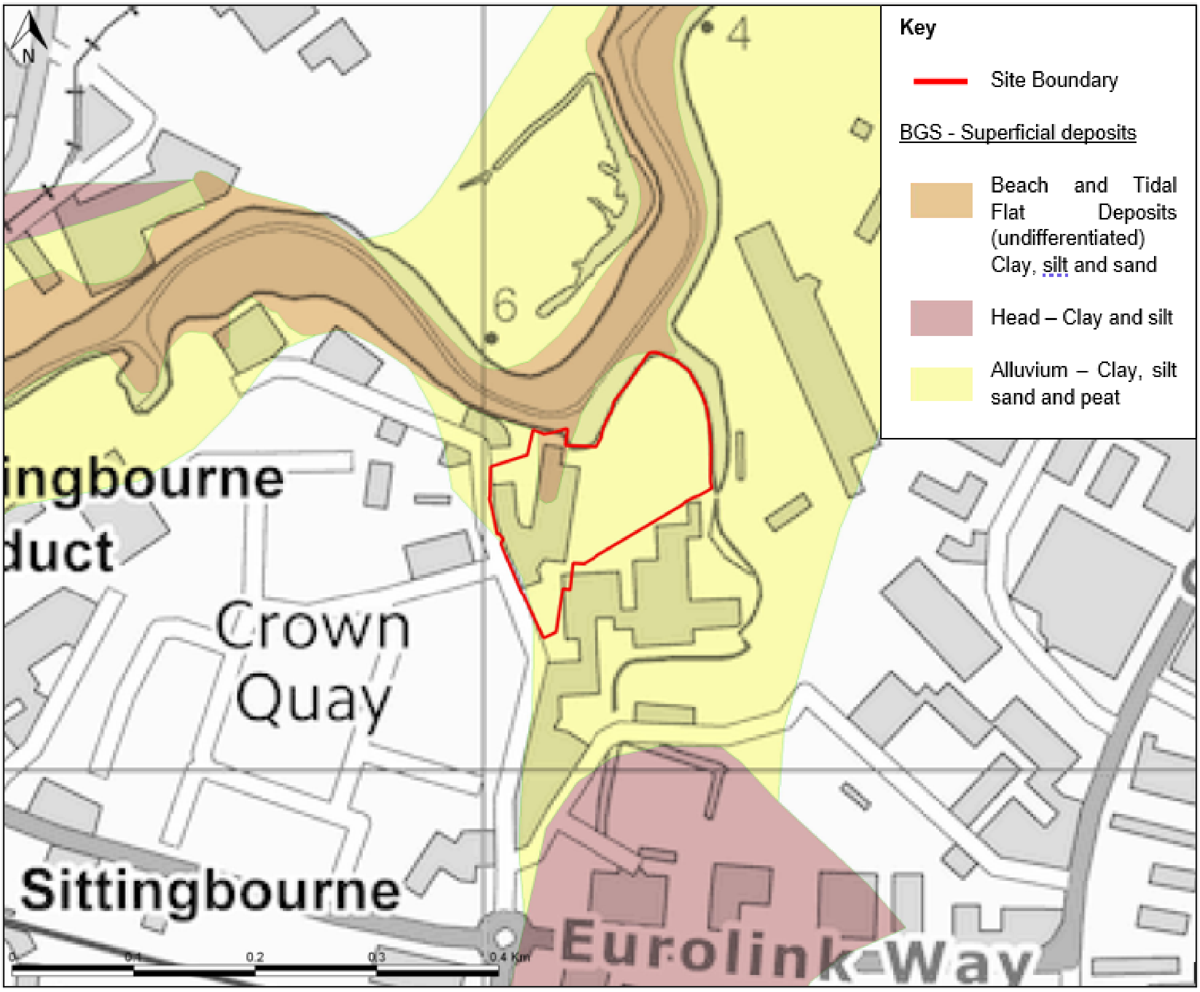


Figure 2.2 Superficial Geology



2.3 Hydrology

2.3.1 Rainfall

According to the UK Centre for Ecology and Hydrology, long term annual average rainfall (SAAR6190) at the Site is 600 mm. The baseflow index (Bfihost) is 0.72 implying that a significant proportion of incident rainfall runs off at the Site rather than infiltrating to groundwater. This is consistent with the recorded geology in the vicinity of the Site which comprises low permeability alluvial deposits.

2.3.2 Surface water features

The dominant surface watercourse in the vicinity of the Site is Milton Creek, located 10m north and northeast of the Site. This flows into the Swale Estuary 2.5 km northeast of the Site. A smaller tributary of the Milton Brook flows south to north around the eastern side of the Site.

A small waterbody is located 500 m northeast of the Site adjacent to Milton Creek.

2.3.3 Licensed surface water abstractions

Data provided by the EA in May 2022 indicated that there are no licensed surface water abstractions within 1 km of the Site.

2.3.4 Surface water quality

Surface water quality monitoring has not been undertaken at the Site. Following a data request in May 2022, the EA did not supply any surface water quality monitoring data for the Site or the surrounding area.

2.3.5 Discharge consents

According to the EA's Public Register, there are twelve active discharge consents within 1 km of the Site. Information regarding each discharge consent, including the reference, holder, site address and grid reference is included in Table 2.2.

Table 2.2 Active discharge consents with 1km of the Site

Discharge Consent ref.	Holder	Site Address	Site Grid Reference
SO/K02078/004	Southern Water Services Limited	K02078, Surf. Water Sewer Sittingbourne, Surf. Water Sewer Sittingbourne, Junction Of East St. & Crown Quay, Sittingbourne, Kent, ME10 3HT	TQ9110064050
SO/A00443/005	Southern Water Services Limited	A00443, Millway Sittingbourne Cso, Millway, Sittingbourne, Kent, ME10 2QB	TQ9057064460
SO/AU6862/001	UK Paper	AU6862, Release Point W1, Release Point W1, Sittingbourne Paper Mill, Sittingbourne, Kent, ME10 3ET	TQ9048064300
SO/P06791R/001	PR - Trinity Ltd	P06791R, Unit 6/3, Unit 6/3, Trinity Trading Estate, Sittingbourne, Kent	TQ9077064771
SO/W00518/010	Southern Water Services Limited	W00518, Sittingbourne Wwtw, Gas Road, Church Marshes, Sittingbourne, Kent, ME10 2QE	TQ9107864856
SO/P05085/001	Asda Stores Ltd	P05085, Dales Foodstore, Dales Foodstore, Mill Way, Sittingbourne, Kent	TQ9084064850
SO/P05086/001	Asda Stores Ltd	P05086, Dales Foodstore, Dales Foodstore, Mill Way, Sittingbourne, Kent	TQ9101064900
SO/A00444/004	Southern Water Services Limited	A00444, St Pauls Street Sittingbourne Cso, St. Paul's Street, Sittingbourne, Kent, ME10 2LA	TQ9035064400

SO/P05084/001	Asda Stores Ltd	P05084, Dales Foodstore, Dales Foodstore, Mill Way, Sittingbourne, Kent	TQ9110064950
SO/AU7184/001	UK Paper	AU7184, Release Point W1, Release Point W1, New Thames Mill, Kemsley, Sittingbourne, Kent, ME10 2SG	TQ9030064100
SO/A00441/004	Southern Water Services Limited	A00441, East St Sittingbourne Cso, East Street, Sittingbourne, Kent, ME10 4RX	TQ9138063480
SO/P07462/001	FCC Recycling (UK) Limited	P07462, Church Marshes Waste Transfer Stn, Church Marshes Waste Transfer St, Gas Road, Milton, Sittingbourne, Kent	TQ9145065100

2.4 Hydrogeology

2.4.1 Stabilised waste

It is proposed to stabilise this material using cement (CEMI) stabilisation. Stabilisation trials have been undertaken by Geochem as detailed in Geochem (2022) (Appendix A). Stabilised samples have been made up using 1%, 3% and 5% CEMI. Testing has been undertaken in triplicate giving a total of 9 sets of results.

The stabilised waste samples have been subjected to permeability testing via falling head tests in a laboratory tri-axial cell with a confining pressure of 50 kPa. There is a clear relationship between the percentage of CEMI applied and permeability with the higher proportion of CEMI resulting in the lowest permeability material. It is noted that all tests yielded permeabilities below 1×10^{-7} m/s. Whilst this is not a design parameter, it is the maximum permeability required for geological barriers in engineered inert landfills.

The stabilised samples have also been subjected to diffusive flux leaching assessments, allowing the derivation of determinand specific effective diffusion coefficients.

2.4.2 Groundwater classifications

The Chalk is defined as a Principal Aquifer. Principal Aquifers are defined by the Environment Agency (EA) as “layers of rock or drift deposits that have high intergranular and/or fracture permeability. This means they usually provide a high level of water storage. They may support water supply and/or river base flow on a strategic scale”. It is noted that the top 1.5 to 9.5 m of the Chalk comprises structureless chalk which will not be effective in transmitting water and may act as a barrier to the vertical movement of water between the structured chalk and Made Ground.

The Thanet Sands in the vicinity of the Site are defined as a Secondary A Aquifer. Secondary A aquifers comprise permeable layers that can support local water supplies and may form an important source of base flow to rivers.

Alluvial deposits in the vicinity of the Site are defined as a Secondary Undifferentiated Aquifer. Secondary undifferentiated aquifers are defined where it is not possible to apply either a

Secondary A or B definition because of the variable characteristics of the rock type. These aquifers were often formally defined as non-aquifer under previous definitions.

2.4.3 Groundwater abstractions

2.4.3.1 Source protection zones

The Site is for the most part located within Groundwater Source Protection Zone 1 (SPZ1). The northeastern corner part of the site is located within Groundwater Source Protection Zone 2 (SPZ2). The SPZ1 and SPZ2 are understood to be associated with abstractions from the Chalk bedrock aquifer, which is hydraulically separated from the Made Ground and development platform at the Site by the Alluvium.

2.4.3.2 Licensed groundwater abstractions

As detailed on Table 2.3, there are two groundwater abstractions within 1 km of the Site and one at an unspecified distance, but within the 4 km search radius provided to the EA in May 2022. It is noted that the groundwater abstractions are from the Chalk and will be isolated from any Site contamination by the Alluvium.

Table 2.3 Licenced abstractions with 1 km

Operator	Licence	Distance, direction	Source	Purpose	Name
D. S. Smith Paper Ltd	9/40/02/0021/GR	0.9km WSW	Swale Chalk	Industrial, Commercial and Public Services	Kemsey Mill
Bennett Opie (MFG) Ltd	9/40/02/0022/GR	0.99km W	Swale Chalk	Industrial, Commercial and Public Services	Point 1 at Bennett Opie Premises
Southern Water Services Ltd	9/40/02/0237/G	Unspecified	Swale Chalk	Water Supply	Borehole at Highstead

2.4.3.3 Private abstractions

The nearest recorded private groundwater abstractions to the Site have been identified 466 m northeast (paper and printing process works), 897 m west (food and drink process water) and 1,363 m east (drinking water) of the Site.

2.4.4 Groundwater levels and flow

Previous investigations of the Site have determined that the shallow groundwater within the Made Ground flows generally to the north, towards the Milton Creek. Groundwater monitoring and sampling was undertaken in 2019 to confirm any tidal effects on the shallow groundwater and changes to contaminant levels. Recorded groundwater levels varied between 2.03 mAOD (WS105) and 3.88 mAOD (WS202). No groundwater was recorded in boreholes WS204 and

WS205 throughout the duration of the monitoring. (LEAP Environmental (2019) give an unsaturated zone thickness under the Site of between 1.35 and 2.25 m.

The shallow groundwater has been shown to be tidally influenced to a limited extent in the northern and eastern areas of the Site and therefore is considered to be in hydraulic continuity with the surface water of Milton Creek as demonstrated by LEAP Environmental (LEAP Environmental, 2019).

BH2, BH3 and BH4 have the well screen installed across the Made Ground, Alluvium and Chalk and could, therefore be providing a short circuit for contamination between the Made Ground / waste stockpiles and the Chalk. The borehole logs show that groundwater was struck upon penetrating the Chalk. Thus, the water levels recorded in these wells are probably representative of the Chalk, but they may not provide reliable estimates of the Chalk groundwater piezometric levels.

LEAP Environmental (LEAP Environmental, 2019) has interpreted the deep Chalk groundwater as generally flowing west, towards the groundwater abstractions. Groundwater levels within the deep boreholes installed in the Chalk aquifer ranged between 1.40 mAOD (BH2) and 1.77 mAOD (BH4), indicating that the Chalk groundwater is confined by the Alluvium and / or Made Ground.

Based on the available data, there is no clear evidence on vertical hydraulic gradients. In November 2020, the level at WS106 (Made Ground) was 2.20 mAOD and the level at BH4 (Chalk) was 2.24 mAOD, implying an upwards hydraulic gradient. However, there are no other adjacent wells that monitor the Made Ground and Chalk with water level data on similar dates.

2.4.5 Aquifer properties

There are no site-specific aquifer properties data available at the Site.

Given the lithological composition of the Made Ground, and based on the hydraulic conductivity range for silt, sandy silts and clayey sands with various percentages of gravel, brick and chalk given in Fetter (2001) it is estimated that the hydraulic conductivity at the Site ranges between 0.1 to 10 m/d.

The Alluvium lithology suggests a hydraulic conductivity in the range of 0.0001 to 0.01 m/d might be typical.

The hydraulic conductivity of the structureless Chalk could be quite low and a range of 0.0001 to 0.01 m/d is estimated. The matrix hydraulic conductivity of the structured Chalk is likely to be low with the majority of flow occurring within fissures. Thus, the bulk hydraulic conductivity will depend on the frequency, size and connectedness of the fissures. Chalk bulk hydraulic conductivities of between 1 and 10 m/d are typical in this type of environment.

2.4.6 Groundwater quality

Made Ground beneath the Site has been recognised to be impacted with lead, benzo(a)pyrene and petroleum hydrocarbon contamination and localised asbestos contamination. Further details of the risk assessment undertaken can be found in LEAP Environmental (2019). A remediation plan is being developed under the planning regime to mitigate against this.

2.4.7 Designated sites

The closest designated site is the Swale Estuary, which is a Site of Special Scientific Interest (SSSI) 1.7 km northeast of the Site. There are no other designated sites within the vicinity of the Site.

3 Conceptual model

3.1 Overview

A Conceptual Site Model (CSM) for the Site is presented here, based on the Site information contained in the preceding sections and in the ESSD report.

The CSM identifies the potential sources of contamination, receptor(s) of concern and pathway segments that may link them. These are discussed in the following sections.

3.2 Water balance

An essential part of every CSM is the water balance that describes how water moves through the system. The water balance is illustrated on Figure 3.1.

Rainwater will fall onto the ground surface, where a proportion will infiltrate the soil zone and the balance will run off. Infiltration to the soil zone will be subject to evaporation and use by plants (transpiration). These two processes are often jointly referred to as evapotranspiration.

Of the remaining water, the lower hydraulic conductivity of the stabilised waste is such that the proportion of water that will infiltrate it is negligible and all the water is considered to run off to the margins of the stabilised waste. Reference to Figure 1.2 shows that along the western and southern margins of the Site, this runoff will infiltrate the ground adjacent to the Site. Along the northern and eastern margins, imported restoration materials will be placed. The amount of infiltration to the imported restoration material will depend on the hydraulic conductivity of that material. Given that the imported material will largely comprise cohesive material (as granular material will be recovered via recycling), the imported material is likely to have a similarly low hydraulic conductivity as the stabilised waste and infiltration to it will therefore be similarly limited. Surface runoff will therefore infiltrate the ground at the Site perimeter or be captured by Site surface water drainage system.

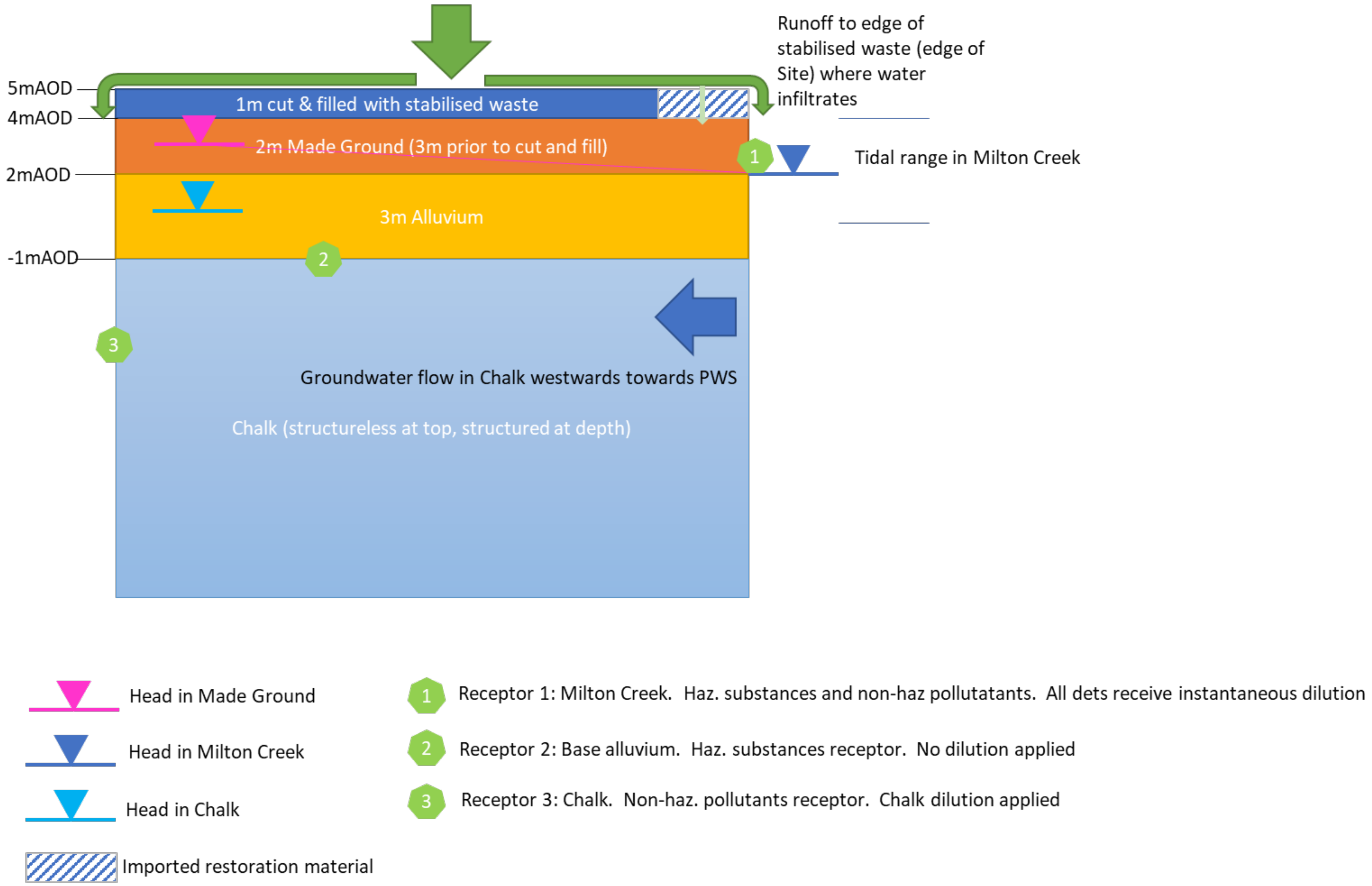
Due to the limited movement of water through the stabilised waste, the primary mechanism for contaminants to migrate from the stabilised waste into the surrounding strata is via diffusion. Upon reaching the exterior edge of the stabilised waste, contaminants will be subject to dilution by infiltrating water as described above. Given the unknown infiltration rate through the imported material and the fact that the imported material may contain contaminants at similar concentrations as the stabilised waste, stabilised waste dilution is only applied along the segment of the Site boundary where the stabilised waste is adjacent to that boundary i.e., along the western and southern sides.

Contaminants may similarly diffuse out of the imported material and / or be flushed out via limited infiltration into the underlying Made Ground.

Contaminants will then migrate downwards, to the watertable, which is present within the Made Ground. An unsaturated zone of around 1 m is present within the Made Ground.

Within the saturated Made Ground contaminant transport will occur horizontally down the hydraulic gradient towards Milton Creek and vertically, through the Alluvium (and structureless chalk), towards the Chalk. The proportion of horizontal and vertical contaminant migration will largely be controlled by the relative hydraulic conductivities of the Made Ground and Alluvium.

Figure 3.1 Conceptual Site Model



Contaminants that migrate horizontally towards Milton Creek will discharge into the Creek where they will be subject to dilution.

Contaminants that migrate vertically will do so through the Alluvium and any structureless chalk into the structured chalk, where they will be subject to dilution in the receiving Chalk groundwater.

On the basis of the CSM described here and shown on Figure 3.1, the relative flows in the Made Ground, Alluvium, Chalk and Milton Creek can be estimated and relevant Dilution Factors derived.

The stabilised waste water balance is based on the following:

$$Q_{inf} = Q_{mg} + Q_{al} \qquad \text{Equation 1}$$

where:

Q_{inf} is the infiltrating flux from rainwater infiltration at the perimeter of the stabilised waste (m^3/s),

Q_{mg} is the horizontal flux in the Made Ground (m^3/s) and

Q_{al} is the vertical flux through the Alluvium to the Chalk (m^3/s).

$$Q_{MG} = \frac{h_{mg}-h_{mc}}{d_{mg}} K_{mg} \left(\frac{h_{mg}+h_{mc}}{2} - B_{mg}\right) P_{mg} \qquad \text{Equation 2}$$

where:

h_{mg} is the head in the Made Ground (mAOD),

h_{mc} is the head at Milton Creek (mAOD),

d_{mg} is the distance from middle of Site to Milton Creek (m),

K_{mg} is the hydraulic conductivity of the Made Ground,

B_{mg} is the basal elevation of the Made Ground (mAOD) and

P_{mg} is the perimeter of the Site adjacent to Milton Creek (m)

$$Q_{al} = \frac{h_{mg}-h_{ck}}{t_{al}} K_{al} A \qquad \text{Equation 3}$$

where:

h_{ck} is the head in the Chalk (mAOD),

t_{al} is the thickness of the Alluvium (m),

K_{al} is the hydraulic conductivity of the Alluvium and

A is the stabilised waste area.

Equations 2 and 3 can be substituted into Equation 1 and solved for the head in the Made Ground. The horizontal and vertical volumetric fluxes to Milton Creek and the Chalk can then be estimated.

Milton Creek is tidal, and dilution will occur as water flows out towards the estuary on the ebbing tide. The volume of water passing the Site can be estimated from the tidal range and Creek area upstream of the Site. An ebb tide runs for 6 hours allowing the tidal flow to be estimated.

Groundwater flow in the Chalk is estimated from Darcy's law, the width of the Site perpendicular to groundwater flow and an assumed saturated thickness where fissure flow occurs.

Dilution is calculated as follows

$D_{mc} = \frac{Q_{mg}+Q_{mc}}{Q_{mg}}$ (Equation 4) and $D_{ck} = \frac{Q_{al}+Q_{ck}}{Q_{al}}$ (Equation 5)

where:

D_{mc} is the dilution at Milton Creek and D_{ck} is the dilution in the Chalk.

The water balance spreadsheet is provided as Appendix C, input parameters are given in Table 3.1 and Dilution Factors are given in Table 3.2.

Table 3.1 Water balance input parameters

Parameter	Value	Unit	Justification
Effective rainfall	166	mm/a	Effective rainfall adjusted in model to provide a Made Ground head of approximately 3 mAOD, to match with Site observation.
Stabilised waste area	17,418	m^2	Measured from GIS
Made Ground head at Milton Creek	2	mAOD	Site observation
Travel distance in Made Ground	140	m	Approximate distance from mid-point of Site to Milton Creek beyond north-eastern extent of Site
Made Ground hydraulic conductivity	$1x10^{-5}$	m/s	Approximately 1 m/d. Mid-point of range estimated in Section 2.4.5
Elevation of base of Made Ground	2	mAOD	Measured from borehole logs
Perimeter length along Milton Creek	268	m	Measured from GIS
Alluvium thickness	3	m	Measured from borehole logs
Alluvium hydraulic conductivity	$1x10^{-8}$	m/s	Approximately 0.001 m/d. Mid-point of range estimated in Section 2.4.5
Head in Chalk	1.6	mAOD	Site observation
Chalk hydraulic gradient	$1x10^{-3}$	-	Estimated
Chalk hydraulic conductivity	$5.79x10^{-5}$	m/s	5 m/d. Mid-point of range estimated in Section 2.4.5

Parameter	Value	Unit	Justification
Chalk width perpendicular to groundwater flow	220	m	Measured in GIS from north-east tip to south-west tip of Site
Chalk saturated thickness	50	m	Groundwater flow restricted to top 50 m where fissured zone likely to be present
Milton Creek tidal range	2.2	m	Based on neap tides, 23 May 2022 tide-forecast.com
Milton Creek area upstream of Site	23,408	m^2	Typical area at mid-tide measured from GIS
Time period for tidal flow	518400	s	Tidal flow for 6 hrs

Table 3.2 Dilution factors

Receptor	Dilution Factor
Milton Creek	10,160
Chalk	8.77

3.3 Sources of contamination

Two contaminant sources have been identified; the stabilised wastes that have been stockpiled at the Site and the wastes to be imported to make up the volume required to build the development platform. Figure 1.2 shows the areas where it is proposed to place the stabilised waste and imported waste.

3.3.1 Stabilised waste

As detailed in Section 1.2, the waste material present at the Site has been processed and material suitable for re-use in the development platform has been recovered. A Completion Report (Keltbray, 2017) is available describing the recovery of this material.

It is proposed to stabilise this material using CEMI stabilisation. Stabilisation trials have been undertaken by Geochem as detailed in Geochem (2022) (Appendix A).

Concentrations in the stabilised waste have been estimated from the leachability results presented in Geochem (2022).

3.3.2 Wastes to be imported

The balance of material required to build the development platform will be imported. Only material that is classified as 17 Waste Code 17 05 04 (soil and stones from construction and demolition activities) and 19 12 12 (other wastes from the mechanical treatment of wastes) will be accepted to the Site, as detailed in the Waste Acceptance Procedure that forms part of the ESSD. Wastes will be from a single source. This material will be non-hazardous and meet the Waste Acceptance Criteria defined in 2003/33/EC for acceptance at inert landfills.

3.4 Pathways

The following potential contaminant pathways have been identified.

- Horizontal migration via Made Ground to Milton Creek. Within this pathway, contaminants may be subject to attenuation. Upon reaching Milton Creek they will be subject to instantaneous dilution.
- Vertical migration via Made Ground and Alluvium to Chalk. Within the Made Ground and Alluvium, contaminants may be subject to attenuation. Upon reaching the Chalk, they will be subject to dilution within the receiving Chalk groundwater.

3.5 Receptors

Two receptors have been identified.

- Milton Creek. Contaminant discharge to Milton Creek will be subject to instantaneous dilution such that concentrations are unlikely to be discernible within a very short distance from the discharge point.
- Chalk. For hazardous substances, the compliance point is taken to be the top of the Chalk and no dilution within Chalk groundwater can be accounted for. Thus, the only mechanism to reduce hazardous substance concentrations is via attenuation within the Made Ground and Alluvium. For non-hazardous pollutants, the compliance point is taken to be the Chalk and dilution within the receiving Chalk groundwater can be accounted for. We note that no account is taken here of the structureless chalk which may actually act as quite an effective barrier to contaminant migration to the underlying structured chalk where groundwater flow occurs.

4 Hydrogeological risk assessment

4.1 Overview

In this section a hydrogeological risk assessment (HRA) is presented which demonstrates the degree of risk posed to controlled waters from the use of the on-site stabilised waste and imported materials to construct the development platform. The HRA is based on the CSM defined in Section 3.

4.2 Stabilised waste

4.2.1 Diffusive flux modelling

Geochem (2022) (Appendix A) details experimentally derived effective diffusion coefficients and source term leaching test concentrations. Using these and converting mass to a concentration by using infiltration at the edge of the stabilised waste material, Geochem's modelling derived contaminant concentrations at the base of the stabilised waste. No further unsaturated or saturated zone processes have been considered.

Geochem (2022) has assessed the following contaminants: chloride, sulphate, calcium, sodium, arsenic, barium, cadmium, chromium, copper, mercury, molybdenum, nickel, lead, antimony, selenium, zinc, total aromatic hydrocarbons, total petroleum hydrocarbons, naphthalene, acenaphthylene, acenaphthene, fluorene, total of 16 polyaromatic hydrocarbons (PAH) and total phenols.

For the Milton Creek receptor, predicted concentrations have been diluted using the dilution factor given in Table 3.2 prior to being assessed against Environmental Assessment Limits (EAL).

For the Chalk receptor, non-hazardous pollutants have been scaled according to the dilution factor given in Table 3.2 prior to being assessed against EALs. Hazardous substances have been compared directly to their EALs without dilution.

Geochem (2022) has used the following EALs:

- Milton Creek: Environmental Quality Standards (EQS) and
- Chalk: UKTAG (2016) limits of quantification for hazardous substances and Drinking Water Standard (DWS) concentrations for non-hazardous pollutants.

The Geochem (2022) model assesses risk at the identified receptor between 1.5 months following remediation and 10 years.

On the basis of the modelling undertaken, Geochem (2022) reports that, with the exception of chromium, phenol, mercury and lead at the Chalk receptor, all modelled determinands are below the relevant EAL at both receptors.

Geochem (2022) notes that chromium exceeds the EAL because the entire predicted chromium flux has been assessed against the EAL for hexavalent chromium, which is a hazardous substance. In practice a substantial proportion of the chromium will be present in other, non-hazardous, forms. Mercury and phenol were not detected in the source term. Exceedances for these parameters are predicted due to the fact that the laboratory level of detection (LOD) is higher than the EAL. Lead is similar with only the 5% CEMI mix designs generating detectable leachate concentrations. The exceedances occur due to the LOD being higher than the EAL. The Geochem assessment is therefore conservative.

It is noted that a similar performance is achieved for all three (1%, 3% and 5% CEMI) mixes and thus the findings of this HRA are not dependent on the CEMI mix adopted for the Site.

The maximum concentrations across the different CEMI mixes at 0.12 years (approx.1.5 months) for the four determinands that showed exceedances are detailed in Table 4.1. This time was selected as the time period for construction of the development platform and associated stabilisation works.

Table 4.1 Concentrations at 0.12 years for determinands that exceed EALs in Geochem (2022) modelling

Determinand	Unsaturated zone concentration (mg/l)
Chromium	0.011
Phenol	0.003
Mercury	0.00004
Lead	0.0005

4.2.2 Hydrogeological modelling

The four determinands detailed in Table 4.1 have been taken forward into a hydrogeological model in order to assess attenuation within the alluvium deposits. The hydrogeological model is based on the same water balance as described in Section 3.2 and has been undertaken using Stantec's (formally ESI) modelling software RAM (ESI, 2008). A copy of the model is included in Appendix C.

The RAM software package, together with a number of groundwater risk assessment tools, has been benchmarked by ESI for the Environment Agency (ESI, 2001). Additionally, the equations used in RAM have been verified by comparison between direct evaluation of an analytical solution and the semi-analytic transform approach applied for more complex pathways, and by comparison with published solutions used for verification as part of the nuclear waste industry code comparison exercise INTRACOIN (Robinson and Hodgkinson, 1986).

In the RAM model the only pathway segment that is considered is transport within the Alluvium. No account is taken of groundwater dilution for phenol as dilution has already been accounted for in the Geochem (2022) model for this non-hazardous pollutant. No account is taken of groundwater dilution for any of the hazardous substances: chromium, mercury, or lead.

In addition to the water balance parameters defined in Table 3.1, the additional input parameters required for the RAM model are presented in Table 4.2.

Table 4.2 Additional RAM model parameters

Parameter	Value	Unit	Justification
Source thickness	1	m	CSM (Section 3)
Source volume	17,418	m^3	Product of area and thickness

Parameter	Value	Unit	Justification
Source field capacity	0.1	-	Adjusted to achieve source term decline that matches Geochem source term model
Alluvium porosity	0.01	-	Assumption based on lithologies described on logs
Cr sorption coefficient in Alluvium	2,200	l/kg	Mid-point of range given in LandSim manual.
Phenol sorption coefficient in Alluvium	0.22	l/kg	ConSim value for unspecified material, pH7, fraction of organic carbon 1%.
Phenol half life	100	Days	No data available for half life in anaerobic conditions as likely to be experienced in Alluvium. ConSim gives aerobic half life between 1.7 and 2.78 days. Selected a value two orders of magnitude higher for anaerobic conditions.
Hg sorption coefficient in Alluvium	2,143	l/kg	Mid-point of range given in LandSim manual.
Pb sorption coefficient in Alluvium	135,014	l/kg	Mid-point of range given in LandSim manual.

Longitudinal dispersion is considered by the model. A longitudinal dispersion length of 0.1 the travel distance was specified.

Metals do not degrade during transport, so no half life is simulated in the model.

The declining source option was specified in the model. RAM considers exponential source term decline as given by

$$C(t) = C_0 e^{-kt} \qquad \text{Equation 4}$$

and

$$k = \frac{Q_{decline}}{V_{source} \times W_{field\ capacity}} \qquad \text{Equation 5}$$

where:

C(t) is the concentration at time t (s),

C_0 is the initial concentration (when the contaminant concentration is at its maximum) (mg/l),

t is time (s),

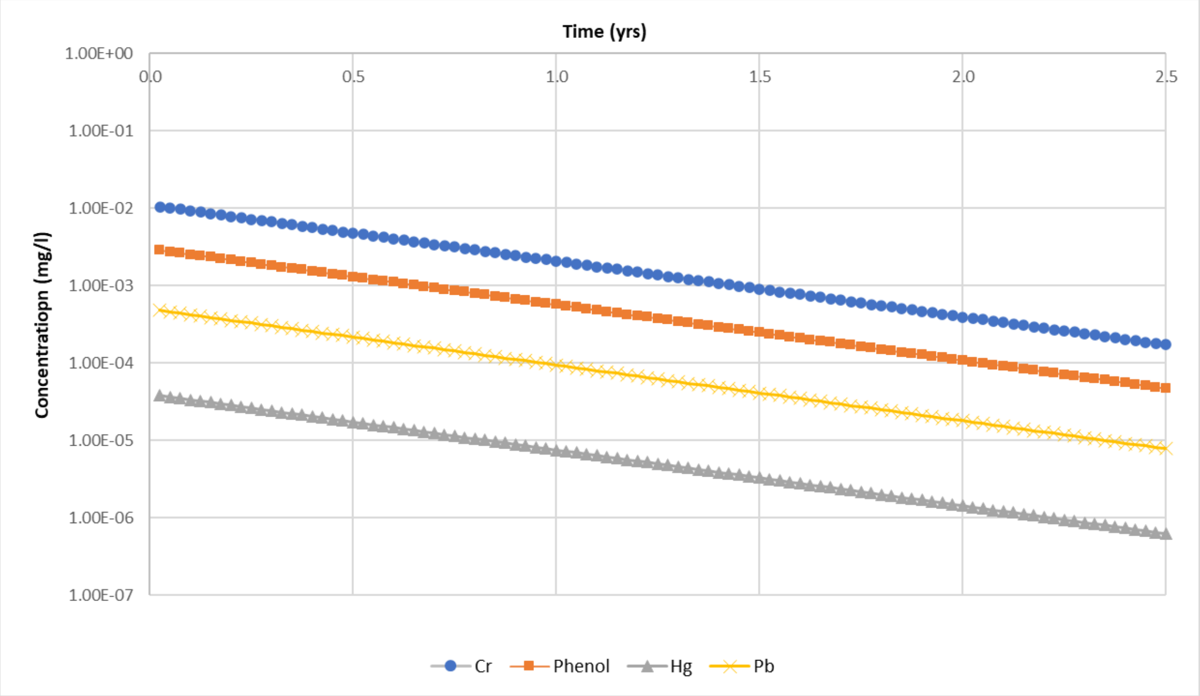
$Q_{decline}$ is the total flux of water out of the Site,

V_{source} is the source volume and

$W_{field\ capacity}$ is the source field capacity

In the model, $W_{field\ capacity}$ was adjusted to derive a value for *k* which provided a consistent rate of decline as modelled by Geochem. A value of 0.1 was found to provide the closest match. Figure 4.1 shows that by 2 years, chromium declines to 4.0×10^{-4} mg/l, phenol to 1.1×10^{-4} mg/l, mercury to 1.4×10^{-6} mg/l and lead to 1.8×10^{-5} mg/l, which are slightly higher than the concentrations given by Geochem (2022) at this timescale, indicating that the source term decline in the hydrogeological model is slower than the Geochem model.

Figure 4.1 Source term decline



EALs are taken from Table 7.2 of Geochem (2022) as detailed in Table 4.3.

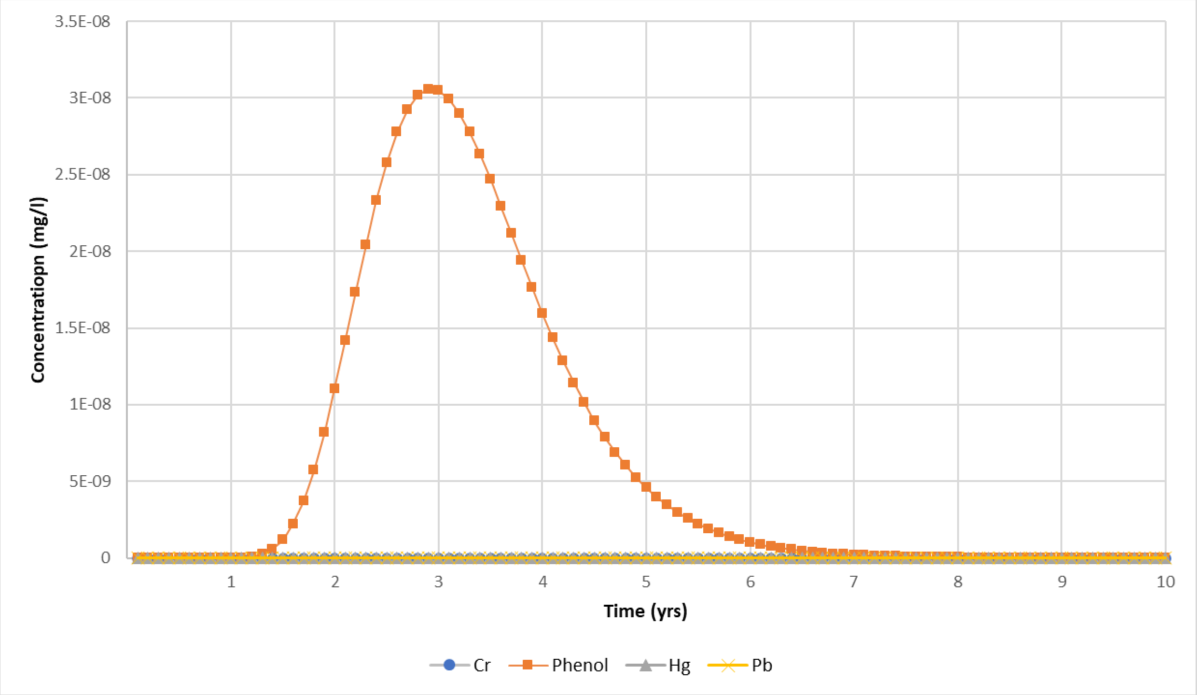
Table 4.3 EALs used in hydrogeological model

Determinand	EAL (mg/l)
Chromium	0.001
Phenol	0.0005
Mercury	0.00002
Lead	0.0002

4.2.3 Hydrogeological model results

Figure 4.2 shows the simulated breakthrough to the base of the Alluvium for the simulated determinands. The only determinand that breaks through within 1,000 years is phenol as the metals are highly sorbed to the alluvium. Peak phenol concentration is $3.1x10^{-8}$ mg/l, which is significantly below the EAL of $5x10^{-4}$ mg/l.

Figure 4.2 RAM model results



4.3 Imported materials

Strict waste acceptance procedures will be followed to ensure that the imported materials are non-hazardous, suitable for disposal at an inert landfill and well characterised. The depth of placement of imported materials is approximately 1 m, in order to construct the development platform. Given the placement of the material towards the northern and eastern edges of the Site, there will be an unsaturated zone of between approximately 1 and 2 m beneath the placed material which will allow attenuation of any residual contamination within the imported material.

The presence of Made Ground and Alluvium between the placed material and the Chalk will provide additional protection to the Chalk groundwater and it is considered very unlikely that there will be any significant impact on Chalk groundwater from residual contamination within the placed material.

Milton Creek is tidal, and a large dilution factor has been calculated as described in Section 3.2. Thus, it is extremely unlikely that there would be a discernible discharge of residual contamination from the placed material to this receptor.

5 Summary and Recommendations

Bellway is proposing to develop the Site for 107 residential properties with associated infrastructure. Prior to development proceeding, remediation works will be undertaken on the Made Ground at the Site as previous investigations have shown that there are currently risks to Controlled Waters from this material. The risk assessment and remediation strategy required to address this issue are being undertaken under the planning regime.

The development will be undertaken following construction of a platform to raise the ground and protect it from flooding. Prior to the placement of waste in the Site, the top 1 m of Made Ground will be excavated leaving a remaining depth of around 2 m of Made Ground. Available on-Site material and imported waste will be placed in engineered layers providing a development platform and raising the site level to approximately 1 m above existing level. This will be undertaken as a Deposit for Recovery (DfR) activity.

On-Site wastes have been processed, recovering suitable soil material for re-use on the Site. Subsequent sampling and analysis of the soil component of the material showed the soil was suitable for reuse on a site with a residential end-use and would not pose a risk to controlled waters. This material will be subject to stabilisation to render it chemically and geotechnically suitable for placement. Imported wastes will be placed around the north and northeast sides of the Site adjacent to Milton Creek and stabilised material towards the centre, west and south.

Stabilisation trials have been undertaken on samples of the material selected for re-use. Trials have been undertaken by Geochem. Following stabilisation, tank tests have been undertaken to determine the leaching rate of contaminants from the stabilised material into the surrounding ground. On the basis of the data collected from these tank tests, Geochem has undertaken diffusive flux modelling to estimate likely pore water concentrations in the surrounding ground. Determinands were selected for the modelling based on analysis of the leaching test data.

Milton Creek and the Chalk have been identified as receptors of concern for this assessment. A CSM has been developed that describes the source, pathway and receptor linkages. On the basis of water balance calculations, dilution factors have been estimated for the Milton Creek and Chalk receptors. Geochem has applied these dilution factors to the pore water concentrations to determine whether or not there is any significant environmental risk posed from these source-pathway-receptor linkages. Geochem reports that, with the exception of chromium, phenol, mercury and lead for the Chalk receptor, all modelled receptor concentrations are below the EALs even without considering contaminant attenuation.

These four determinands have been taken forward into a hydrogeological risk assessment model, to simulate attenuation processes within the Alluvium that isolates the Chalk from the contaminant source. This model shows that there is unlikely to be any environmental risk from these determinands to the Chalk receptor once Alluvium attenuation processes have been taken into account.

The imported material will be from a limited set of Waste Codes and will be from a single source. Site Waste Acceptance Procedures will be followed to ensure that only wastes that meet Waste Acceptance Criteria defined in 2003/33/EC are accepted to the Site. Taking into account the unsaturated zone that will extend below the base of the imported wastes, a qualitative risk assessment has been undertaken, which concludes that there is unlikely to be a risk to controlled waters from placement of the imported material.

6 References

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Appendices

Appendix A

CE Geochem stabilisation trials report

Crown Quay Lane

Laboratory Bench Scale Stabilisation Trials

Report A210806/02
July 2022

Prepared for

keltbray

Revision Schedule

Report
July 2022

Rev	Date	Status	Prepared by	Reviewed by	Approved by
1	07/2022	Draft	**Cameron Farr / Dr Jamie Cutting**	**Dr Joe Dean / Dr Vanessa Appleby**	**Dr Jamie Cutting**
2	07/2022	Draft	**Dr Jamie Cutting**	**Dr Joe Dean / Dr Vanessa Appleby**	**Dr Jamie Cutting**

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The methodology adopted and the sources of information used by CE Geochem in providing its services are outlined in the original Proposal [A210806]. The description of work packages described in this Proposal are based on the information available during the offer period. The scope of the original Proposal and offered services are accordingly factually limited by the availability of factual data and clarifications provided by the client to CE Geochem during the Proposal process.

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Table of Contents

1 Executive Summary

CE Geochem have been commissioned by Keltbray to undertake a suite of independent soil stabilisation trials to assess the geotechnical and geochemical performance of CEMI based mix designs for the reuse of stockpiled waste soils as part of a permit for recovery application in relation to the redevelopment of the Crown Quay Lane site, Sittingbourne.

Stabilisation trials were conducted on 3 No. test work samples, representative of waste soils currently laid to stockpile at the subject site. This study has included trial mix designs 1%, 3% and 5% CEMI.

This report details the findings from the following test work packages;

- Source term characterisation including BRE-SD1.
- Geotechnical classification testing for particle size distribution and natural moisture content analysis.
- Compaction studies to assess the relationship between moisture content and compaction density including determination of Optimum Moisture Content (OMC) and Maximum Dry density (MDD)
- Geotechnical performance testing by UCS strength gain curves, CBR, CBR swell and permeability analysis
- Geochemical performance investigated through semi-dynamic tank with the derivation of diffusive flux modelling parameters.
- Data Interpretation under the EA NEN 7375 Methodology
- Diffusive flux modelling with assessment against Annual Average Environmental Quality Standards (AA-EQS) for the identified surface water receptor on site, and groundwater compliance assessment; for hazardous pollutants against analytical detection limits without dilution, and for non-hazardous pollutants against Drinking Water Standards (DWS) with dilution in the underlying chalk aquifer

This study has demonstrated that soil stabilisation techniques may be regarded as suitable for improving the geotechnical performance of waste soils, with all trialled mix designs achieving >30% CBR following 7 days curing. The observed improvement in CBR response was found to be directly proportional to binder application rates with 5% CEMI additions achieving in excess of 100% CBR following 28 days maturation. CBR swell results confirmed no significant loss of strength in the fully soaked state following 28-day immersions with all 5% CEMI mix designs retaining >100% CBR with no indication of volumetric instability. From falling head permeability analysis, trialled mix designs were determined to exhibit hydraulic conductivities (k) between 1.4 x 10^{-8} m/s to 9.4 x 10^{-8} m/s. Permeabilities were found to be strongly correlated to binder application rates.

64 day semi-dynamic leaching assessments were undertaken to derive parameters for diffusive flux modelling under the Conceptual design Model (CDM) presented in section 7. Modelling outputs demonstrated satisfactory geochemical performance against surface water and ground water compliance targets for all potential contaminants of concern with the exception of short-term exceedances observed for chromium, modelled as a hazardous groundwater pollutant (assumed to be present as hexavalent chromium) that applies analytical limits of detection as the compliance target with no dilution within the underlying chalk aquifer. The duration of groundwater compliance target exceedances for chromium (1 ug/l) ranged from circa. 0.36 years (1% CEMI) to circa. 0.56 years (5% CEMI). Minor modelled exceedances for lead, phenol and mercury arise through the imposition of analytical detection limits on diffusive flux parameters.

It should be noted that he current CDM assumes direct instantaneous contaminant mass discharge into the receiving groundwater body, and ignores any potential retarded travel within the intervening alluvium.

Prior to the commencement of full-scale site operations, CE Geochem recommend that field trials be undertaken to demonstrate that the selected plant and earthworks methodologies are compatible with attaining any required end product specifications. As these operations are to be carried out under a deposit for recovery permit, we strongly recommend a suite of quality assurance testing is implemented in accordance with the Specification for Highways Works Series 600 for demonstrating geotechnical compliance. Geochemical compliance should be assessed using verification semi-dynamic tank testing. This approach should allow observed diffusivities to be compared to the effective diffusion coefficients (De) presented in this study, whereby site-specific De parameters are shown to be suitable for attainment of ground and surface water compliance.

2 Introduction

2.1 Project Appreciation

2.1.1 Keltbray have commissioned CE Geochem to undertake bench-scale stabilisation trials to assess the geochemical and geotechnical performance of hydraulically bound soils current laid to stockpile at the subject site.

2.1.2 Soil stabilisation is proposed for the geotechnical improvement of the stockpiled materials, whilst creating a hydraulically bound engineered fill for reinstatement. The stabilised matrix should potentially allow re-use of materials on site providing a base for foundations, car parking, piling mats and associated development platforms for any future installations, although CE Geochem aren't aware of any specific reuse requirements.

2.1.3 We understand that this mix design study will form part of the technical requirements for a deposit for recovery permit, whereby to satisfy reuse criteria, materials need to have been fully recovered following treatment.

2.1.4 This test work programme has been conducted on 3 No. test work composites identified as:

- SP01
- SP02
- SP03

2.1.5 All test work samples used within this investigation were sampled on site by others and delivered to CE Geochem laboratories as large, disturbed bulk samples. CE Geochem assume all test work samples are representative of the stockpiled materials present.

2.1.6 The geotechnical test work programme discussed in this report includes:

- Compaction studies to determine Optimum Moisture Content - Maximum Dry Density (OMC-MDD) relationships
- Particle Size Distribution (PSD) analysis to assess textural consistency between test work samples.
- Strength Gain Curves over 28-day by Unconfined Compressive Strength (UCS)
- Determination of Californian Bearing Ratio (CBR) at 7 and 28 days curing
- Assessment of volumetric stability under immersion by CBR swell monitoring with CBR analysis in the fully soaked state
- Determination of mix design permeability by the falling head method using a triaxial cell arrangement at confining pressures of 50 kPa.

2.1.7 The geochemical test work programme discussed in this report includes:

- Geochemical source term characterisation including BRE-SD1 analysis in triplicate.

- Semi-dynamic diffusion based leaching assessments conducted in 3D configuration from hydraulically bound cylindrical monoliths. Semi-dynamic leaching assessments have employed an 8 fraction, 64-day sampling protocol, following a 28-day curing time.

- Interpretation of mass flux profiles from semi-dynamic tank testing to determine leaching mechanisms by EA NEN 7375 and derivation of effective diffusion coefficients by ASTM C1308 methodologies.

- Diffusive flux simulations using the experimentally derived, mix design specific, effective diffusion coefficients to parameterise contaminant mass flux rates with prediction of surface and groundwater concentrations based on the hydrogeological model provided by Stantec.

2.2 Nominated Third-Party Analytical Laboratory Accreditation and Quality Assurance

2.2.1 Chemtest is accredited to the ISO17025 International Standard *General Requirements for the Competence of Testing and Calibration Laboratories* (Lab Ref. 2183), for those tests that are so identified and listed on our current UKAS schedule. ISO17025 accreditation also demonstrates that our Quality Management System operates in accordance with the principles of ISO9001.

2.2.2 In addition to ISO17025, the laboratory is accredited to the EA MCERTS *Performance Standard for Laboratories Undertaking Chemical Testing of Soil* and MCERTS *Performance Standard for Organisations Undertaking Sampling and Chemical Testing of Water*. MCERTS accredited tests are also detailed on our UKAS schedule, available from the UKAS website.

2.2.3 Quality Control in the laboratory is ensured by a comprehensive system of internal and external QC measures. This includes the use of Certified Reference Materials (CRMs) in method validation and routine Analytical Quality Control (AQC) by means of in-house QC samples, independent AQC standards and blanks, as appropriate to the method and to satisfy the requirements of the accreditation held.

2.2.4 Inter-laboratory Proficiency Testing (PT) studies, notably the LGC CONTEST, LGC Aquacheck and DEFRA LEAP schemes, are participated in for a wide range of determinands and the resulting proficiency scores scrutinised by means of internal quality system procedures, in order to affirm fitness for purpose of the relevant tests.

2.2.5 Analytical results are controlled by means of AQC data subject to statistically derived limits and plotted on Shewhart control charts. These charts are reviewed regularly to monitor on-going method performance and are, where applicable, subject to the QC limits for bias and precision specified by the MCERTS standard.

3 Experimental Methodology

3.1 Preliminary Characterisation

3.1.1 3 No. circa. 150kg bulk test work samples were delivered to CEG Laboratories by Keltbray from the subject site to be used exclusively for the stabilisation trials discussed herein. CE Geochem understand that the test work materials delivered are representative of materials likely to be encountered on site during reuse of the stockpiled material. Test work samples are identified as follows:

- SP01 (6 No. Bulk Bags Circa 25kg)
- SP02 (6 No. Bulk Bags Circa 25kg)
- SP03 (6 No. Bulk Bags Circa 25kg)

3.1.2 The preparation of homogeneous test work samples is critical for any test work programme that requires comparison between independent samples / specimens. Preparation of a homogeneous test work sample for each location was undertaken using a forced action horizontal pan mixer to provide 3 No. homogenous test work sample splits. Each split sample was mixed for circa 5 minutes prior to sampling for PSD assessments, ensuring mixing didn’t modify the grading, followed by a further 25 minutes of mixing to ensure matrix homogeneity within the test work samples used in stabilisation trials.

3.1.3 Preliminary materials classification testing was conducted on the 3 No. test work sample to include:

- Particle Size Distribution (PSD) analysis was carried out by wet sieving to provide a grading classification in accordance BS 1377-2, Clause 9.2.
- Preliminary determinations for Natural Moisture Content (NMC) were performed in order to establish homogeneity of prepared samples. 3 No. of NMC tests were conducted on each sample due to the large mixing quantities to ensure homogeneity in accordance with BS EN 1377-2, Clause 3.2.
- Optimum Moisture Content Maximum Dry Density (OMC-MDD) relationships were determined by BS EN 1377-4, Clause 3.3 for light weight proctor compaction using a 2.5kg rammer for each of the 3 No. test work samples.
- Total Potential Sulphates (TPS) were determined in triplicate in order to assess the potential for sulphate induced heave by BRE-SD1 analytical suite including: Total Sulphur (TS), Water Soluble Sulphate (WSS) and Acid Soluble Sulphate (ASS).

3.2 Source Term Characterisation

3.2.1 Source term determinations were undertaken in triplicate from homogenised test work samples. Analytical composite samples were formed using 5 No. randomly selected 150g increment samples.

3.2.2 Source term analysis was undertaken by an independent UKAS accredited analytical laboratory operating under ISO 17025 for the following suite of determinands.

- Inorganics; As, Ba, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se, Zn
- Sodium, Chloride, Sulphate, Calcium
- Total Phenols
- Low Level PAHs
- CWG TPH

3.2.3 Statistical interpretations of source characterisation datasets are presented in section 4.

3.3 Specimen Manufacture

3.3.1 3 No. mix designs were trialled on each test work composite to assess both geotechnical and geochemical performance. Candidate mix designs are presented below within Table 3.1, with addition rates selected based on the idea to extrapolate the data series to ascertain the optimum binder application rate.

3.3.2 Specimens were manufactured at NMC as requested by Keltbray. Additional water was added to the mix designs to compensate for the addition of CEMI at a rate of 0.5 W/C based on mass.

Mix Design ID	Composite ID	Composition	Binder addition
Mix Design 1	SP01	MADE GROUND Light brown, gravely sandy silt with abundant organic rootlets.	1% CEMI
Mix Design 2	SP01		3% CEMI
Mix Design 3	SP01		5% CEMI
Mix Design 4	SP02	MADE GROUND Brown, gravely sandy silt with frequent organic rootlets.	1% CEMI
Mix Design 5	SP02		3% CEMI
Mix Design 6	SP02		5% CEMI
Mix Design 7	SP03	MADE GROUND Brown / Dark Brown, gravely sandy silt with abundant organic rootlets and grass.	1% CEMI
Mix Design 8	SP03		3% CEMI
Mix Design 9	SP03		5% CEMI

Table 3.1 Trialled mixes. Binder addition expressed as % dry wt.

3.3.3 All monoliths were produced using hydraulic binder content based on dry weight additions. Hanson CEMI 52.5N Ordinary Portlandite Cement (OPC) was used exclusively during the trials.

3.3.4 2 No. 100mm cylindrical monolithic specimens per mix design were produced for permeability testing and 3D semi-dynamic tank testing at an axial : diametric ratio of 1, in general accordance with BS 1377-4, for light weight proctor compaction.

3.3.5 3 No. 120 x 100mm cylindrical monolithic specimens per mix design were produced for Unconfined Compressive Strength (UCS) testing, in accordance with BS 1377-4, 2.5kg rammer compaction by a UKAS accredited laboratory.

3.3.6 1 No. 120mm x 150mm cylindrical hydraulically bound monolithic specimens per mix design were also manufactured in general accordance with BS 1377-4 with assessment at 7-day and 28-day. An additional specimen was manufactured for MD3, MD6 and MD9 for use in CBR Swell analysis with terminal CBR analysis in the fully soaked state following 28 days immersion.

3.3.7 All specimens were cured at 95%+ relative humidity at 20°C prior to subsequent testing.

3.4 Semi-dynamic Diffusion Based Tank Testing

3.4.1 Semi-dynamic diffusion-based tank testing was undertaken in 3D configuration in general accordance with EA NEN 7375 using a total cumulative leaching period of 64 days.

3.4.2 100mm hydraulically bound cylindrical monoliths were allowed to cure at 95%+ RH for 28 days prior to commencement of tank testing.

3.4.3 Gas tight glass tanks were employed throughout to avoid gaseous exchange with the atmosphere. In particular, this approach should reduce the potential for carbonation reactions responsible for the onset of calcite precipitation and lowering of leachant pH, which may compromise the stability of the stabilised soil matrix.

3.4.4 The leachant solution, 18.2 MΩ deionised water, was exchanged at cumulative time points t=, 0.25, 1, 2.25, 4, 9, 16, 36 and 64 days employing a monolith leachant volume: surface area ratio of circa. 46 L/m^2.

3.4.5 All calculations were undertaken as described in section 8 and Annex D of EA NEN 7375 for the determination of leaching mechanisms. Derivation of the effective diffusion coefficient is based on the semi-infinite medium approximation (ASTM C1308-08). All analytical data is presented in Appendix B and all calculations and numerical interpretations in Appendix C.

3.4.6 Semi-dynamic tank testing analytical suites comprised:

- Inorganic trace elements; As, Ba, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se, Zn
- Major ions; Sodium, Chloride, Sulphate, Calcium
- Phenol Index
- Low Level PAHs
- CWG TPH

3.5 Geotechnical Testing

3.5.1 Californian Bearing Ratio (CBR) swell monitoring was undertaken in general accordance with BS EN 13286-47, over 28-day immersion period following an initial 4-day cure.

3.5.2 For CBR swell specimens, CBR determinations were undertaken following 28 days immersion in the fully soaked state in accordance with BS EN 1377-4.

3.5.3 CBR testing was also conducted at 7-day and 28-day curing time for all mix designs in accordance with BS EN 1377-4.

3.5.4 Strength gain curves were generated for all mix designs over a 28-day curing period at time (t) = 7-days, 14-days, and 28-days. Strength gain assessments were completed by Unconfined Compressive Strength (UCS) using an electro-mechanical testing instrument under standard operating procedures in accordance with BS EN 13286-41, Part 41 by a UKAS accredited laboratory.

3.5.5 Permeability determinations were undertaken on 28-day specimens by falling head using triaxial cell arrangement in accordance with the K.H. Head Method (Manual of soil laboratory testing, Vol 2, 2011).

4 Source Term Characterisation

4.1.1 Statistical analysis of source characterisation datasets for the test work samples produced from stockpiled materials are presented in Tables 4.1 – 4.3, with certificates of analysis included in Appendix B.

4.1.2 Coefficient of Variation (CoV) statistics provide a measure of sample matrix homogeneity and are presented for all determinands in Table 4.1 – 4.3. Note that CoV analysis will be influenced where determinations are near limits of analytical detection due to influence on data quality, and by the rounding of analytical results to 2 significant figures (format supplied by sub-contracted analytical laboratory).

4.1.3 All readily measurable inorganic determinands such as arsenic, copper, lead, zinc etc., typically demonstrate relatively low CoV values (generally <20%) consistent with a well homogenised test work matrix. These observations provide confidence that test work homogenisation protocols were successful in producing acceptable test work matrices for the intended geochemical test work programme discussed herein.

4.1.4 For key inorganic determinands such as arsenic, copper, lead, zinc etc., there are consistent reported concentrations for all 3 of the stockpiled materials. The CoV between the stockpiled materials is <11.5% for all the aforementioned contaminants.

4.1.5 PAHs were detected across all stockpiled materials with SP01 and SP02 showing similar levels of contaminant source term mass. SP03 however, showed approximately double the source term mass of PAHs, reported a Normalised Upper Bound with 95 percentile confidence limits of (NUB_{95}) of 93 mg/kg compared to 53 mg/kg and 40 mg/kg from SP1, and SP2 respectively. CoV statistics for PAH compounds for SP02 and SP03 are all typically <20%, with SP01 materials all typically <40%.

4.1.6 TPH source term concentrations were typically reported between 180 mg/kg – 840 mg/kg across all test work samples with one outlier results from SP01-A recording 2400 mg/kg resulting in a 100% CoV for Total TPH in this test work sample. All CWG data suggest the majority of petroleum hydrocarbon contaminant mass resides in the lower mobility Aromatic C21-C35 fraction, common to all test work samples. There were no detections of aliphatic or aromatic compounds below C10 for any of the triplicate analyses conducted on test work matrices.

	Determinand	Units	N	N<LOD	Min	Max	Ave	σ	NUB$_{95}$	CoV
INORGANICS	Chloride (Water Soluble)	g/l	3	0	0.03	0.13	0.06	0.059	0.16	95.2%
	Sulphate (2:1 Water Soluble) as SO4	g/l	3	0	0.43	0.65	0.52	0.12	0.72	23.1%
	Calcium (Total)	mg/kg	3	0	36000	61000	47000	13000	69000	27.7%
	Sodium (Total)	mg/kg	3	0	250	330	290	40	360	13.8%
	Arsenic	mg/kg	3	0	11	14	13	1.7	16	13.1%
	Barium	mg/kg	3	0	100	130	120	17	150	14.2%
	Cadmium	mg/kg	3	0	0.30	0.39	0.36	0.049	0.44	13.6%
	Chromium	mg/kg	3	0	23	33	29	5.1	38	17.6%
	Copper	mg/kg	3	0	53	98	73	23	110	31.5%
	Mercury	mg/kg	3	0	0.26	0.39	0.33	0.067	0.44	20.3%
	Molybdenum	mg/kg	3	3	2.0	2.0	2.0	0	2.0	0.0%
	Nickel	mg/kg	3	0	19	27	24	4.2	31	17.5%
	Lead	mg/kg	3	0	99	150	130	26	170	20.0%
	Antimony	mg/kg	3	0	2.3	5.8	3.5	2	6.9	57.1%
	Selenium	mg/kg	3	3	0.2	0.2	0.2	0	0.2	0.0%
	Zinc	mg/kg	3	0	120	160	150	23	190	15.3%
TPH	Aliphatic TPH >C5-C6	mg/kg	3	3	1	1	1	0	1	0.0%
	Aliphatic TPH >C6-C8	mg/kg	3	3	1	1	1	0	1	0.0%
	Aliphatic TPH >C8-C10	mg/kg	3	3	1	1	1	0	1	0.0%
	Aliphatic TPH >C10-C12	mg/kg	3	1	1	10	7	5.2	16	74.3%
	Aliphatic TPH >C12-C16	mg/kg	3	0	10	15	13	2.8	18	21.5%
	Aliphatic TPH >C16-C21	mg/kg	3	2	1	30	11	17	40	154.5%
	Aliphatic TPH >C21-C35	mg/kg	3	0	21	130	83	56	180	67.5%
	Aliphatic TPH >C35-C44	mg/kg	3	3	1	1	1	0	1	0.0%
	Total Aliphatic Hydrocarbons	mg/kg	3	0	30	150	110	69	230	62.7%
	Aromatic TPH >C5-C7	mg/kg	3	3	1	1	1	0	1	0.0%
	Aromatic TPH >C7-C8	mg/kg	3	3	1	1	1	0	1	0.0%
	Aromatic TPH >C8-C10	mg/kg	3	3	1	1	1	0	1	0.0%
	Aromatic TPH >C10-C12	mg/kg	3	2	1	6	3	3	7.8	111.1%
	Aromatic TPH >C12-C16	mg/kg	3	1	1	76	31	40	98	129.0%
	Aromatic TPH >C16-C21	mg/kg	3	0	10	450	160	250	580	156.3%
	Aromatic TPH >C21-C35	mg/kg	3	0	140	1700	840	790	2200	94.0%
	Aromatic TPH >C35-C44	mg/kg	3	3	1	1	1	0	1	0.0%
	Total Aromatic Hydrocarbons	mg/kg	3	0	150	2200	1000	1100	2900	110.0%
	Total Petroleum Hydrocarbons	mg/kg	3	0	180	2400	1100	1100	3000	100.0%
PAH	Naphthalene	mg/kg	3	0	0.22	0.29	0.26	0.035	0.32	13.5%
	Acenaphthylene	mg/kg	3	0	0.16	0.33	0.24	0.086	0.38	35.8%
	Acenaphthene	mg/kg	3	0	0.11	0.24	0.17	0.065	0.28	38.2%
	Fluorene	mg/kg	3	0	0.12	0.21	0.17	0.047	0.25	27.6%
	Phenanthrene	mg/kg	3	0	1.10	3.20	2.50	1.2	4.5	48.0%
	Anthracene	mg/kg	3	0	0.34	1.00	0.78	0.38	1.4	48.7%
	Fluoranthene	mg/kg	3	0	3.20	8.60	6.30	2.8	11	44.4%

	Pyrene	mg/kg	3	0	3.00	7.60	5.50	2.3	9.4	41.8%
	Benzo[a]anthracene	mg/kg	3	0	1.70	4.10	3.10	1.2	5.1	38.7%
	Chrysene	mg/kg	3	0	1.50	3.30	2.60	0.95	4.2	36.5%
	Benzo[b]fluoranthene	mg/kg	3	0	2.60	5.40	4.10	1.4	6.5	34.1%
	Benzo[k]fluoranthene	mg/kg	3	0	0.79	1.80	1.40	0.52	2.3	37.1%
	Benzo[a]pyrene	mg/kg	3	0	2.00	4.00	3.10	1	4.8	32.3%
	Indeno(1,2,3-c,d)Pyrene	mg/kg	3	0	1.90	3.30	2.70	0.72	3.9	26.7%
	Dibenz(a,h)Anthracene	mg/kg	3	0	0.29	0.56	0.43	0.14	0.67	32.6%
	Benzo[g,h,i]perylene	mg/kg	3	0	1.50	3.00	2.40	0.78	3.7	32.5%
	Total Of 16 PAH's	mg/kg	3	0	21.00	47.00	36.00	13	58	36.1%
	Total Phenols	mg/kg	3	3	0.10	0.10	0.10	0	0.1	0.0%

Table 4.1 Statistical interpretation for source term concentrations from SP01 test work sample (n=3). All statistical analysis presented to 2 significant figures. CoV analysis is presented as a percentage.

	Determinand	Units	N	N<LOD	Min	Max	Ave	σ	NUB$_{95}$	CoV
INORGANICS	Chloride (Water Soluble)	g/l	3	0	0.025	0.051	0.04	0.014	0.064	35.0%
	Sulphate (2:1 Water Soluble) as SO4	g/l	3	0	0.41	0.67	0.52	0.14	0.76	26.9%
	Calcium (Total)	mg/kg	3	0	43000	52000	47000	4600	55000	9.8%
	Sodium (Total)	mg/kg	3	0	350	370	360	10	380	2.8%
	Arsenic	mg/kg	3	0	14	16	15	1.2	17	8.0%
	Barium	mg/kg	3	0	120	140	130	10	150	7.7%
	Cadmium	mg/kg	3	0	0.34	0.42	0.37	0.042	0.44	11.4%
	Chromium	mg/kg	3	0	30	35	32	2.5	36	7.8%
	Copper	mg/kg	3	0	58	73	64	7.8	77	12.2%
	Mercury	mg/kg	3	0	0.33	0.64	0.44	0.17	0.73	38.6%
	Molybdenum	mg/kg	3	3	2	2	2	0	2	0.0%
	Nickel	mg/kg	3	0	25	26	26	0.58	27	2.2%
	Lead	mg/kg	3	0	120	140	130	12	150	9.2%
	Antimony	mg/kg	3	0	2.3	3.2	2.6	0.49	3.4	18.8%
	Selenium	mg/kg	3	3	0.2	0.2	0.2	0	0.2	0.0%
	Zinc	mg/kg	3	0	150	160	150	5.8	160	3.9%
TPH	Aliphatic TPH >C5-C6	mg/kg	3	3	1	1	1	0	1	0.0%
	Aliphatic TPH >C6-C8	mg/kg	3	3	1	1	1	0	1	0.0%
	Aliphatic TPH >C8-C10	mg/kg	3	3	1	1	1	0	1	0.0%
	Aliphatic TPH >C10-C12	mg/kg	3	0	9.5	11	10	0.78	11	7.8%
	Aliphatic TPH >C12-C16	mg/kg	3	0	6.1	20	14	7	26	50.0%
	Aliphatic TPH >C16-C21	mg/kg	3	3	1	1	1	0	1	0.0%
	Aliphatic TPH >C21-C35	mg/kg	3	0	41	90	65	25	110	38.5%
	Aliphatic TPH >C35-C44	mg/kg	3	3	1	1	1	0	1	0.0%
	Total Aliphatic Hydrocarbons	mg/kg	3	0	57	120	89	32	140	36.0%
	Aromatic TPH >C5-C7	mg/kg	3	3	1	1	1	0	1	0.0%
	Aromatic TPH >C7-C8	mg/kg	3	3	1	1	1	0	1	0.0%
	Aromatic TPH >C8-C10	mg/kg	3	3	1	1	1	0	1	0.0%
	Aromatic TPH >C10-C12	mg/kg	3	3	1	1	1	0	1	0.0%
	Aromatic TPH >C12-C16	mg/kg	3	0	6	39	18	18	48	100.0%
	Aromatic TPH >C16-C21	mg/kg	3	0	10	64	32	28	79	87.5%
	Aromatic TPH >C21-C35	mg/kg	3	0	140	330	240	95	400	39.6%
	Aromatic TPH >C35-C44	mg/kg	3	3	1	1	1	0	1	0.0%
	Total Aromatic Hydrocarbons	mg/kg	3	0	160	430	290	140	530	48.3%

	Determinand	Units	N	N<LOD	Min	Max	Ave	σ	NUB_{95}	CoV
	Total Petroleum Hydrocarbons	mg/kg	3	0	220	550	380	170	670	44.7%
PAH	Naphthalene	mg/kg	3	0	0.2	0.25	0.22	0.025	0.26	11.4%
	Acenaphthylene	mg/kg	3	0	0.23	0.3	0.26	0.035	0.32	13.5%
	Acenaphthene	mg/kg	3	0	0.12	0.14	0.13	0.01	0.15	7.7%
	Fluorene	mg/kg	3	0	0.16	0.2	0.18	0.021	0.22	11.7%
	Phenanthrene	mg/kg	3	0	1.6	2.4	2	0.4	2.7	20.0%
	Anthracene	mg/kg	3	0	0.59	0.84	0.72	0.13	0.94	18.1%
	Fluoranthene	mg/kg	3	0	4.5	5.8	5.3	0.7	6.5	13.2%
	Pyrene	mg/kg	3	0	4	5.1	4.6	0.57	5.6	12.4%
	Benzo[a]anthracene	mg/kg	3	0	2.3	3.2	2.8	0.47	3.6	16.8%
	Chrysene	mg/kg	3	0	2.1	2.7	2.4	0.31	2.9	12.9%
	Benzo[b]fluoranthene	mg/kg	3	0	3.2	4.6	3.8	0.71	5	18.7%
	Benzo[k]fluoranthene	mg/kg	3	0	1.1	1.6	1.3	0.29	1.8	22.3%
	Benzo[a]pyrene	mg/kg	3	0	2.7	3.8	3.2	0.55	4.1	17.2%
	Indeno(1,2,3-c,d)Pyrene	mg/kg	3	0	2.3	3	2.6	0.35	3.2	13.5%
	Dibenz(a,h)Anthracene	mg/kg	3	0	0.38	0.5	0.44	0.06	0.54	13.6%
	Benzo[g,h,i]perylene	mg/kg	3	0	2	2.5	2.2	0.29	2.7	13.2%
	Total Of 16 PAH's	mg/kg	3	0	27	37	32	5	40	15.6%
	Total Phenols	mg/kg	3	3	0.1	0.1	0.1	0	0.1	0.0%

Table 4.2 Statistical interpretation for source term concentrations from SP02 test work sample (n=3). All statistical analysis presented to 2 significant figures. CoV analysis is presented as a percentage.

	Determinand	Units	N	N<LOD	Min	Max	Ave	σ	NUB_{95}	CoV
INORGANICS	Chloride (Water Soluble)	g/l	3	0	0.023	0.048	0.031	0.014	0.055	45.2%
	Sulphate (2:1 Water Soluble) as SO4	g/l	3	0	0.45	0.6	0.53	0.075	0.66	14.2%
	Calcium (Total)	mg/kg	3	0	41000	52000	45000	5900	55000	13.1%
	Sodium (Total)	mg/kg	3	0	320	340	330	12	350	3.6%
	Arsenic	mg/kg	3	0	11	14	12	1.5	15	12.5%
	Barium	mg/kg	3	0	100	120	110	10	130	9.1%
	Cadmium	mg/kg	3	0	0.29	0.37	0.33	0.04	0.4	12.1%
	Chromium	mg/kg	3	0	22	32	27	5	35	18.5%
	Copper	mg/kg	3	0	58	62	60	2.1	64	3.5%
	Mercury	mg/kg	3	0	0.25	0.45	0.34	0.1	0.51	29.4%
	Molybdenum	mg/kg	3	3	2	2	2	0	2	0.0%
	Nickel	mg/kg	3	0	21	26	23	2.6	27	11.3%
	Lead	mg/kg	3	0	110	120	110	5.8	120	5.3%
	Antimony	mg/kg	3	0	2.1	2.9	2.6	0.42	3.3	16.2%
	Selenium	mg/kg	3	3	0.2	0.2	0.2	0	0.2	0.0%
	Zinc	mg/kg	3	0	130	150	140	10	160	7.1%
TPH	Aliphatic TPH >C5-C6	mg/kg	3	3	1	1	1	0	1	0.0%
	Aliphatic TPH >C6-C8	mg/kg	3	3	1	1	1	0	1	0.0%
	Aliphatic TPH >C8-C10	mg/kg	3	3	1	1	1	0	1	0.0%
	Aliphatic TPH >C10-C12	mg/kg	3	0	9	12	10	1.6	13	16.0%
	Aliphatic TPH >C12-C16	mg/kg	3	1	1	11	7.1	5.4	16	76.1%
	Aliphatic TPH >C16-C21	mg/kg	3	3	1	1	1	0	1	0.0%
	Aliphatic TPH >C21-C35	mg/kg	3	0	62	130	90	35	150	38.9%

	Determinand	Units	N	N<LOD	Min	Max	Ave	σ	NUB$_{95}$	CoV
	Aliphatic TPH >C35-C44	mg/kg	3	3	1	1	1	0	1	0.0%
	Total Aliphatic Hydrocarbons	mg/kg	3	0	74	150	110	39	180	35.5%
	Aromatic TPH >C5-C7	mg/kg	3	3	1	1	1	0	1	0.0%
	Aromatic TPH >C7-C8	mg/kg	3	3	1	1	1	0	1	0.0%
	Aromatic TPH >C8-C10	mg/kg	3	3	1	1	1	0	1	0.0%
	Aromatic TPH >C10-C12	mg/kg	3	3	1	1	1	0	1	0.0%
	Aromatic TPH >C12-C16	mg/kg	3	3	1	1	1	0	1	0.0%
	Aromatic TPH >C16-C21	mg/kg	3	0	9	55	24	26	68	108.3%
	Aromatic TPH >C21-C35	mg/kg	3	0	220	540	340	170	630	50.0%
	Aromatic TPH >C35-C44	mg/kg	3	3	1	1	1	0	1	0.0%
	Total Aromatic Hydrocarbons	mg/kg	3	0	230	600	370	200	710	54.1%
	Total Petroleum Hydrocarbons	mg/kg	3	0	330	750	470	240	870	51.1%
PAH	Naphthalene	mg/kg	3	0	0.19	0.25	0.22	0.03	0.27	13.6%
	Acenaphthylene	mg/kg	3	0	0.32	0.4	0.36	0.04	0.43	11.1%
	Acenaphthene	mg/kg	3	0	0.28	0.44	0.39	0.092	0.55	23.6%
	Fluorene	mg/kg	3	0	0.25	0.55	0.42	0.15	0.67	35.7%
	Phenanthrene	mg/kg	3	0	6	8.6	7.1	1.3	9.3	18.3%
	Anthracene	mg/kg	3	0	1.8	2.8	2.2	0.55	3.1	25.0%
	Fluoranthene	mg/kg	3	0	10	15	13	2.5	17	19.2%
	Pyrene	mg/kg	3	0	8.6	13	11	2.2	15	20.0%
	Benzo[a]anthracene	mg/kg	3	0	4.8	7	6.1	1.1	8	18.0%
	Chrysene	mg/kg	3	0	3.7	5.3	4.7	0.85	6.1	18.1%
	Benzo[b]fluoranthene	mg/kg	3	0	5.9	8.7	7.5	1.4	9.9	18.7%
	Benzo[k]fluoranthene	mg/kg	3	0	2.1	2.9	2.6	0.44	3.3	16.9%
	Benzo[a]pyrene	mg/kg	3	0	5.1	8	6.6	1.5	9.1	22.7%
	Indeno(1,2,3-c,d)Pyrene	mg/kg	3	0	4	5.8	5	0.93	6.6	18.6%
	Dibenz(a,h)Anthracene	mg/kg	3	0	0.7	0.84	0.77	0.07	0.89	9.1%
	Benzo[g,h,i]perylene	mg/kg	3	0	3.1	4.6	3.9	0.75	5.2	19.2%
	Total Of 16 PAH's	mg/kg	3	0	58	84	71	13	93	18.3%
	Total Phenols	mg/kg	3	3	0.1	0.1	0.1	0	0.1	0.0%

Table 4.3 Statistical interpretation for source term concentrations from SP03 test work sample (n=3). All statistical analysis presented to 2 significant figures. CoV analysis is presented as a percentage.

5 Geotechnical Performance

5.1 Classification Testing

5.1.1 Particle size grading curves were carried out on the 3 No. test work samples in accordance with BS1377-2 clause 9.2 – wet sieving method.

5.1.2 Textural composition summaries, presented In Table 5.1 below, demonstrate that all three stockpiled materials have comparable textural characteristics. From the Particle Size Distribution data, comparison of all three test work samples provides a CoV below 20%, demonstrating consistency / homogeneity of source materials in stockpile.

Particle Size mm	Percentage Passing (%)		
	SP01	SP02	SP03
75	-	-	-
63	-	-	-
50	-	-	-
37.5	-	100	100
28	100	98	99
20	95	96	97
14	91	92	92
10	88	87	85
6.3	83	81	78
5	81	79	74
3.35	77	76	68
2	74	73	63
1.18	71	70	59
0.6	67	66	55
0.425	64	62	52
0.3	59	58	47
0.212	53	51	42
0.15	48	46	38
0.063	37	35	29

Sample Proportions	% Dry Mass		
	SP01	SP02	SP03
Very Course	0	0	0
Gravel	26	27	37
Sand	37	39	34
Fines <0.063mm	36	34	29

Table 5.1 Summary for PSD determinations for 5 No. test work samples undertaken during characterisation testing.

5.1.3 Natural Moisture Content (NMC) determinations were undertaken on materials with less than 10% retained on a 20% sieve in accordance with BS 1377-2. NMC determinations were undertaken in triplicate from 2 No. representative 2kg sub-samples recovered from the composited batch, and the third sample derived from the circa. 4.5kg PSD sample. NMC determinations are presented in Table 5.2 below.

Summary of Natural Moisture Content Determination				
Sample ID	**NMC A (%)**	**NMC B (%)**	**NMC C* (%)**	**NMC Average (%)**
SP01	16	16	13	15
SP02	12	12	13	12
SP03	14	15	13	14

Table 5.2 Summary of NMC determinations for the 3 No. test work samples undertaken during characterisation testing. *PSD sample used for moisture determination. *Note, moisture contents are reported to the nearest whole number in accordance with UKAS accreditations.*

5.1.4 Test certificates for PSD and NMC determinations are presented in Appendix A.

5.2 Optimum Moisture Content - Maximum Dry Density (OMC-MDD)

5.2.1 Compaction studies were undertaken to characterise OMC-MDD relationships for each of the 3 No. test work composites. Minimum 5 point, OMC-MDD determinations were conducted using a 2.5kg Rammer in accordance with BS 1377-4, Clause 3.3 (standard proctor), with OMC-MDD parameters presented in Table 5.3 below.

5.2.2 All 3 test work samples fell under the classification of grading zone 2 with OMC-MDD determinations undertaken in accordance with preparation procedure 2A for materials not susceptible to crushing.

Sample	Composition	NMC (%)	OMC (%)	MDD (Mg/m^3)	Moisture range (%)
SP01	MADE GROUND Light brown, gravely sandy silt with abundant organic rootlets.	15	17	1.76	12.0 - 20.0
SP02	MADE GROUND Brown, gravely sandy silt with frequent organic rootlets.	12	14	1.75	9.5 - 19.0
SP03	MADE GROUND Brown / Dark Brown, gravely sandy silt with abundant organic rootlets and grass.	14	15	1.81	8.5 - 18.0

Table 5.3 Summary for OMC-MDD determinations for test work samples.

5.2.3 All OMC-MDD results relate to test work samples in the absence of binders or alternative additives.

5.2.4 Stockpiled materials for SP01 and SP02 show very similar Maximum Dry Density (MDD) results, corresponding with the similarity in PSD. SP03 however, reported a slightly higher MDD, which CE Geochem tentatively ascribe to the marginally higher proportion of gravel present within this test work sample.

5.2.5 All 3 stockpiled materials however, provide similar Optimum Moisture Content (OMC) requirements ranging from 14 – 17%.

5.2.6 Certificates of analysis are presented in Appendix A.

5.3 CBR Analysis

5.3.1 CBR testing was conducted on 150mm diameter monoliths cured at 95%+ RH prior to CBR analysis following a 7-day and 28-day curing period, with the later used as an indicator for long-term performance (terminal strength). CBR analyses are presented in Table 5.4 for each of the candidate mix designs. Test certificates for CBR determinations are available in Appendix A.

5.3.2 CE Geochem are not aware of any specific site criteria for trialled mix designs. However, we would anticipate, given terminal strength was in excess of 40% CBR for the lowest binder application rate, with a reported maximum of >100% for the higher binder application rate, that all trialled mix designs would be compliant with the geotechnical specifications for any proposed capping and subbase construction layers (typically taken as 15% CBR for capping and 30% CBR for sub-base).

5.3.3 CBR determinations for 1% binder application rate, reported CBR values ranging from 33% - 40% CBR following the initial 7-day curing period. 28-day results for SP01 and SP03 demonstrated continued strength development with reported CBRs achieving 46% and 56% respectively. For these two stockpiles the 7-day CBR determinations demonstrated that 72% (SP01) and 70% (SP03) of the terminal strength had been achieved following the early stage curing period at 7 days. SP03 however showed no improvement in CBR strength following 7 days.

5.3.4 CBR determinations for 3% binder application rate, reported a significant improvement in CBR strength over 1% application rates, ranging from 73% - 83% CBR following the initial 7-day curing period. 28-day results for all 3 stockpiled material demonstrated continued strength development with reported CBRs achieving between 77% - 98%. Stockpiled materials SP01 and SP02 demonstrated that 95% of the terminal strength development was achieved following the 7-day curing period, whilst SP03 exhibited 79% early strength development.

5.3.5 5% binder application rate continued to show further improvement in CBR strength over the lower binder application rates trialled in this study, with 7 day results ranging from 85% - 140% CBR. Further strength development was reported for all the trialled mix designs, with 28-day results for all 3 stockpiled materials exceeding 130% CBR up to 160% for SP03. As aforementioned, CE Geochem consider that the terminal 28-day CBR values are likely to significantly exceed site specific criteria.

5.3.6 28-day CBR determinations have been presented in Figure 5.1 below and demonstrate excellent regression statistics for all three trialled stockpiled materials, with calculated valuations reported all above $R^2 = 0.9655$. The excellent regression statistics for the effect of the binder application rates on the CBR determinations could allow for the extrapolation of the datasets to calculate a minimum binder application rate (+ safety factor) to achieve any future onsite geotechnical criteria.

Sample ID	Composite ID	Target MC (%)	CEMI Application Rate (%)	7 Day CBR Index (%)	28 Day CBR Index (%)	Moisture Content (%)
Mix Design 1	SP01	(NMC) 15	1% CEMI	33	46	15
Mix Design 2	SP01	(NMC) 15	3% CEMI	83	87	15
Mix Design 3	SP01	(NMC) 15	5% CEMI	100	130	14
Mix Design 4	SP02	(NMC) 12	1% CEMI	40	40	13
Mix Design 5	SP02	(NMC) 12	3% CEMI	73	77	13
Mix Design 6	SP02	(NMC) 12	5% CEMI	85	150	13
Mix Design 7	SP03	(NMC) 14	1% CEMI	39	56	13
Mix Design 8	SP03	(NMC) 14	3% CEMI	77	98	13
Mix Design 9	SP03	(NMC) 14	5% CEMI	140	160	15

Table 5.4 CBR determinations for the 9 No. of trialled mix designs with terminal moisture contents.

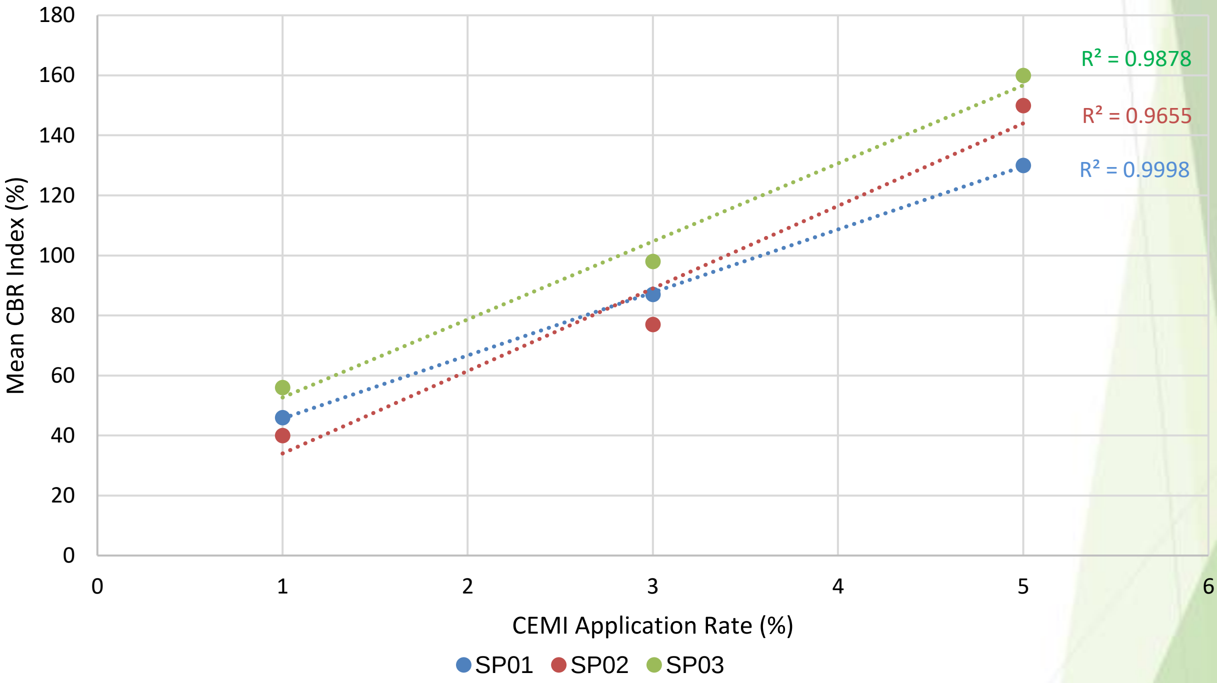


Figure 5.1 28-day CBR determinations for the 9 No. of trialled mix designs with calculated regression statistics.

5.4 Swell Monitoring and Soaked CBR Analysis

5.4.1 CBR Swell testing was undertaken specifically to monitor the potential for heave (including sulphate induced heave) that may arise from the interaction of hydraulic binder phases with sulphate bearing or producing components from the materials matrix.

5.4.2 No significant heave was observed for any specimen following 28-days immersion, with a maximum reported vertical deformation of 0.09mm for stockpiled materials SP02 and SP03. SP01 reported a maximum vertical heave of 0.02mm. CBR swell datasets are summarised in Table 5.5.

5.4.3 Terminal CBR index following 28-days immersion were tested in the fully soaked state. All specimens were manufactured with 5% CEMI addition rate, to assess the maximum potential heave, and achieved a terminal CBR index of >100%, with SP01 and SP02 achieving 110%, whilst SP03 achieved 150%.

5.4.4 All trialled specimens observed to increase slightly in moisture content during the immersion period, when compared to unsoaked 28-day CBR assessment presented above. However, although the specimens were reported absorb additional water, there was no reported water appearing at the specimen’s surface following the initial 4-day immersion prior to complete specimen submersion.

5.4.5 Furthermore, the immersion period didn’t result in significant loss of strength when compared to the unsoaked 28 Day specimens, with SP01 and SP03 reporting an 18% and 7% lower CBR Index respectively. SP02 reported a 36% strength loss when compared with the 28 Day assessment, however still achieving 110% CBR.

Sample ID	Composite ID	CBR Index (%)	Vertical Swell (mm)	Volumetric Swell (%)	Moisture Content (%)
Mix Design 3	SP01	110	0.02	0.02%	17
Mix Design 6	SP02	110	0.09	0.07%	15
Mix Design 9	SP03	150	0.09	0.07%	15

Table 5.5 Terminal CBR index and recorded swell for 3 No. of mix designs with 5% CEMI application rates.

5.4.6 CBR Swell certificates are presented within Appendix A.

5.5 Unconfined Compressive Strength (UCS)

5.5.1 The rate of strength gain for each of the mix designs investigated in this study has been assessed by Unconfined Compressive Strength (UCS). UCS determinations were undertaken on 120 x 100mm specimens manufactured in accordance with BS 1377-4, using light weight proctor compaction (2.5kg rammer).

5.5.2 CE Geochem are not aware of any compliance targets set against UCS.

5.5.3 UCS determinations were carried out on specimens cured over a 28-day period at time (t) = 7-days, 14-days, and 28-days. Results from UCS strength gain analysis are presented below in Table 5.6 and Figure 5.2, with certificates of analysis presented in Appendix A.

5.5.4 28-day UCS determinations for trial mixes incorporating 1% CEMI application rates achieved varied strength development across the stockpiled materials, with SP01 and SP02 achieving 0.74 and 0.61MPa respectively, whereas SP03 achieved approximately half, with a reported value of 0.37MPa. It is to be noted however that the SP03 28-day assessment is lower than the previous 7-day and 14-day assessments and could be associated with premature specimen failure due to the presence of near surface gravels.

5.5.5 Mix designs that were trialled with 3% binder application rate achieved 1.21MPa, 0.99MPa and 1.26MPa for stockpiles SP01, SP02 and SP03 respectively.

5.5.6 Mix designs incorporating 5% binder application rate were also all reported to achieve above 1.4MPa and demonstrated excellent consistency across the 3 stockpiled materials. Mix designs incorporating 5% binder application rate were also observed to achieve >1MPa following the 7-day curing period, with circa. 73 – 87% strength development achieved within the first 7 days. However, the 14-day assessments showed some unexplained variability within the samples, with a reduction in strength when compared to the 7-day results for SP01 and SP03.

Sample	Composite ID	Binder Addition	UCS Determination (MPa)		
			7 Day	14 Day	28 Day
Mix Design 1	SP01	1% CEMI	0.47	0.53	0.74
Mix Design 2	SP01	3% CEMI	0.63	0.79	1.21
Mix Design 3	SP01	5% CEMI	1.23	0.94	1.42
Mix Design 4	SP02	1% CEMI	0.44	0.38	0.61
Mix Design 5	SP02	3% CEMI	0.80	0.82	0.99
Mix Design 6	SP02	5% CEMI	1.15	1.30	1.43
Mix Design 7	SP03	1% CEMI	0.48	0.46	0.37
Mix Design 8	SP03	3% CEMI	0.86	0.82	1.26
Mix Design 9	SP03	5% CEMI	1.05	0.71	1.44

Table 5.6 Unconfined Compressive strength determinations for 9 No. mix designs.

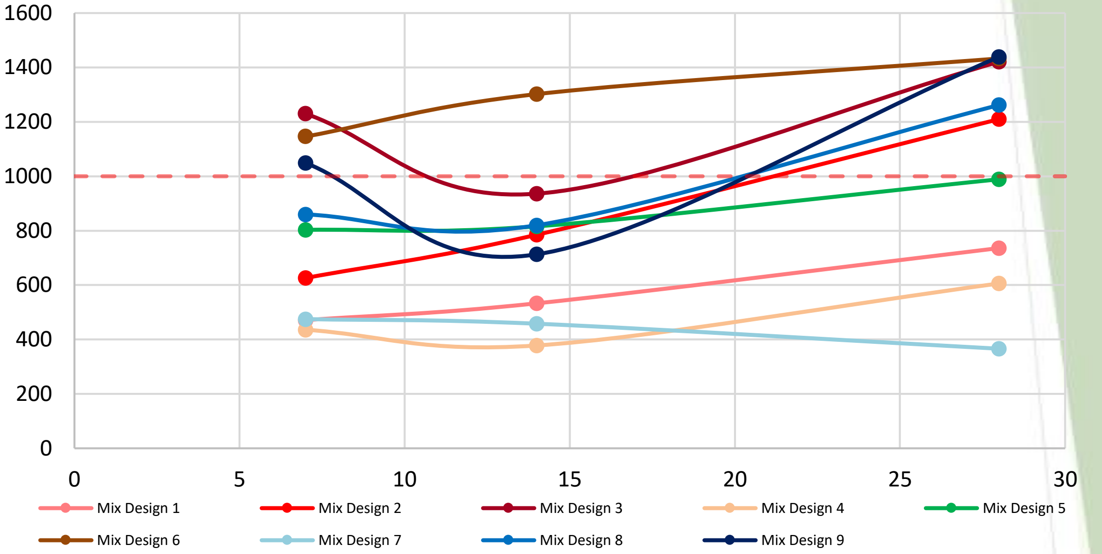


Figure 5.2 Strength gain curves for 9 No. trialled mix designs.

5.5.7 As observed within the 28-day CBR determinations, the 28-day UCS assessments for both SP01 and SP02 show excellent regression statistics for the effect of binder application on the derived strength development, with regression statistics $R^2 > 0.9532$. SP03 demonstrates a lower calculated regression statistic, with $R^2 = 0.8698$ associated with a greater than expected strength developed for 3% CEMI application rates.

5.5.8 As previously mentioned for the CBR assessments, the excellent regression statistics for the effect of the binder application rates on the UCS determinations, for SP01 and SP02, could allow for the extrapolation of the datasets, in order to calculate a minimum binder application rate to achieve any future onsite criteria. CE Geochem do however recommend that caution is used for any extrapolation for SP03 due to the somewhat lower derived statistic and that following any extrapolation of the datasets that additional trails are undertaken to demonstrate that sufficient strength development can be achieved.

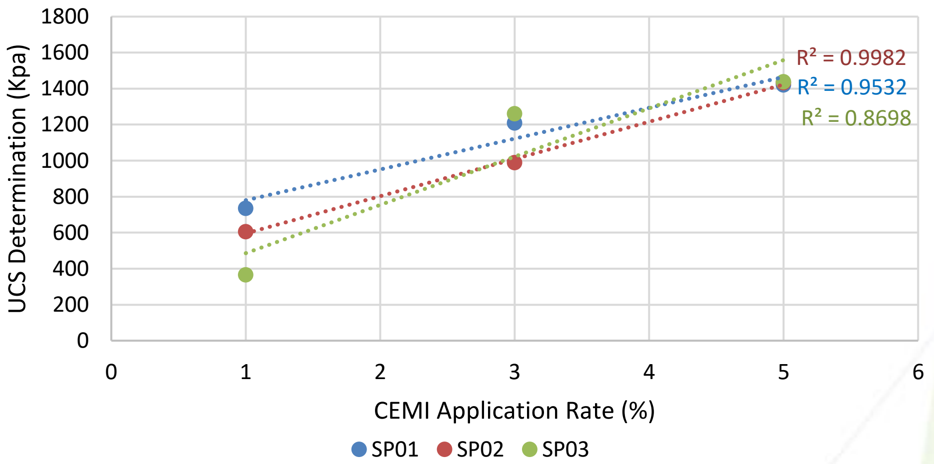


Figure 5.3 28-day CBR determinations for the 9 No. of trialled mix designs with calculated regression statistics.

5.6 Permeability

5.6.1 Falling head hydraulic permeability analysis was undertaken on each of the trialled mix designs following a 28-day curing period. Permeability determinations were undertaken using the method of K Head in modified triaxial cells at confining pressures of 50 kPa. All specimens were produced under light weight proctor compaction using a 2.5 kg rammer.

5.6.2 Permeability determinations are presented below in Table 5.7 and Figure 5.4.

5.6.3 Specimens were saturated for a minimum 3 days prior to execution of falling head measurements, typically undertaken over several days, following confirmation of equilibrium drainage conditions. All results are expressed as the average from 4 No. independent permeability runs (n=4).

5.6.4 As can be seen from inspection of Figure 5.4, permeability is negatively correlated with binder application rate (increased CEMI application rate leads to lower permeability).

5.6.5 Regression statistics calculated for the three stockpiles demonstrate that an excellent relationship can be obtained for the influence of binder application rates on permeability for stockpiles SP01 and SP03, with a calculated regression statistic of R^2 = 0.9444 or better. Stockpile SP02, has a slightly lower regression statistic of R^2 = 0.8710.

Sample ID	Composite ID	CEMI Application Rate (%)	Permeability - $k_{20}{}^{o}{}_{C}$(m/s)	Moisture Content (%)
Mix Design 1	SP01	1% CEMI	9.40E-08	14
Mix Design 2	SP01	3% CEMI	6.50E-08	16
Mix Design 3	SP01	5% CEMI	1.40E-08	15
Mix Design 4	SP02	1% CEMI	7.60E-08	17
Mix Design 5	SP02	3% CEMI	6.60E-08	16
Mix Design 6	SP02	5% CEMI	1.60E-08	15
Mix Design 7	SP03	1% CEMI	9.20E-08	14
Mix Design 8	SP03	3% CEMI	7.20E-08	16
Mix Design 9	SP03	5% CEMI	2.30E-08	14

Table 5.7 Permeability results for candidate mix designs.

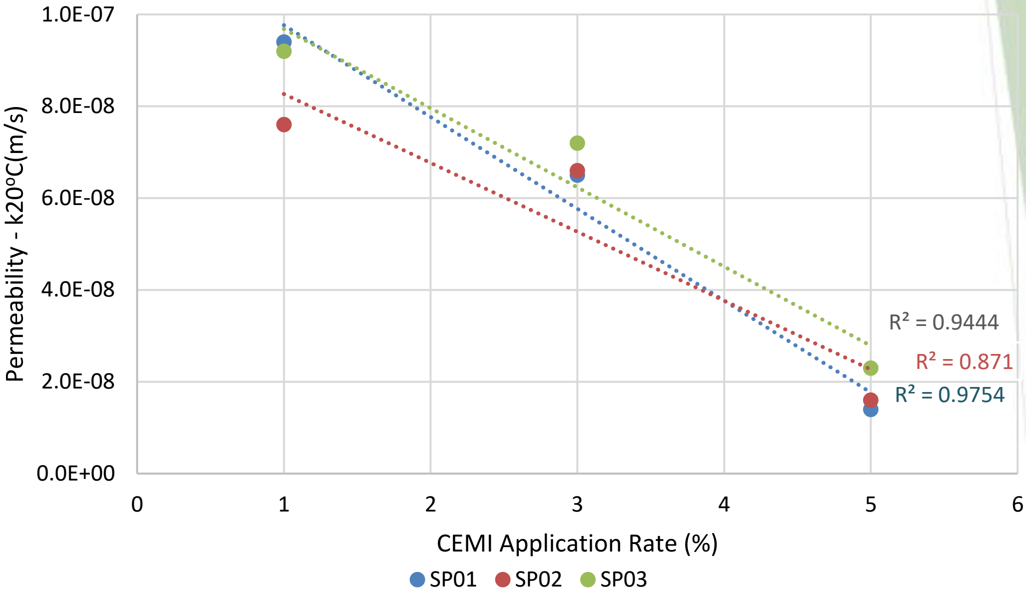


Figure 5.4 Hydraulic permeability determinations unbound samples following compaction.

5.6.6 Test certificates for Permeability analyses are presented in Appendix A.

5.7 BRE-SD1 Assessment.

5.7.1 BRE-SD1 analyses were conducted in triplicate for the 3 No. test work samples, to assess aggressive geochemical environments that may influence the behaviour of cementitious binders, and more specifically identify the potential risk for sulphate attack on hydraulic binders used in soil stabilisation (see Table 5.8 – 5.10).

5.7.2 BRE-SD1 assessments are based on the average of triplicate sub-samples from homogenised test work samples, considered to be representative of general site conditions likely to be encountered. It should be noted CE Geochem are not aware of any site-specific threshold TPS criteria. HA 74/07 however, outlines a TPS threshold of 0.25% which has been applied for the assessments below.

5.7.3 Average results for SP01, SP02 and SP03 samples reported Total Potential Sulphate (TPS) levels of 0.45%, 0.35% and 0.51% respectively. Stockpiled materials would all be classed as DS-2, therefore potentially producing mildly aggressive ground conditions, that may have the potential for affecting soil stabilisation using cementitious binders, such as those investigated in this mix design study. The above assessment is based on a TPS threshold criteria of 0.25%, as described by HA 74/07.

5.7.4 The CoV for the 3 No. samples is considered to be low, with a maximum calculated CoV of 7% for SP01, whilst SP02 and SP03 demonstrated a CoV of 5% and 0% respectively. The consistency from the analytical assessments provides good confidence that TPS of materials present at the subject site are well represented in the test work programme and furthermore, that the materials used in this test work programme show a good degree of homogeneity.

5.7.5 Although TPS levels indicate a potential risk for aggressive ground conditions that may affect cementitious binder phases, CBR swell testing did not provide any direct evidence for adverse binder phase reactions, such as may be anticipated from Delayed Ettringite Formation (DEF) or Thaumasite Sulphate Attack (TSA).

5.7.6 Based on the calculated oxidizable (OS) sulphur load expressed as sulphate, the potential for latent sulphide oxidation may exist within the soil matrix at the subject site. Although, average OS levels were found to be below 0.3% for all the test work samples the presence of pyrite in the subject materials is still possible.

5.7.7 Due to the Design classification and the potential for latent sulphide oxidation, CE Geochem recommend that a watching brief be maintained to monitor the potential for sulphate attack through daily control testing for BRE-SD1 sulphate suite during the construction phase operations, in addition to CBR swell monitoring.

5.7.8 Additionally, this assessment only related to BRE-SD1 interpretations from materials made available during this study, therefore pervasive hotspot areas of elevated TPS and/or OS may exist at the subject site which have not been identified within the test work samples used in this study.

BRE-SD1 Assessment - SP01 Sample				
	SP01 - A	**SP01 - B**	**SP01 - C**	**Average**
TPS (%)	0.45	0.48	0.42	0.45
WSS (mg/l)	730	630	610	656.7
ASS (%)	0.31	0.21	0.30	0.27
OS (%)	0.14	0.27	0.12	0.18
Organic Matter (%)	1.90	2.00	2.20	2.03

Table 5.8 BRE-SD1 for SP01 test work sample. TPS = Total Potential Sulphate; WSS = Water Soluble Sulphate (2:1 as SO_4); ASS = Acid Soluble Sulphate; OS = Oxidisable Sulphates.

BRE-SD1 Assessment - SP02 Sample				
	SP02 - A	**SP02 - B**	**SP02 - C**	**Average**
TPS (%)	0.36	0.36	0.33	0.35
WSS (mg/l)	440	500	490	476.7
ASS (%)	0.23	0.24	0.19	0.22
OS (%)	0.13	0.12	0.14	0.13
Organic Matter (%)	2.30	2.00	1.80	2.03

Table 5.9 BRE-SD1 for SP02 test work sample. TPS = Total Potential Sulphate; WSS = Water Soluble Sulphate (2:1 as SO_4); ASS = Acid Soluble Sulphate; OS = Oxidisable Sulphates.

BRE-SD1 Assessment - SP03 Sample				
	SP03 - A	SP03 - B	SP03 - C	Average
TPS (%)	0.51	0.51	0.51	0.51
WSS (mg/l)	700	680	690	690
ASS (%)	0.25	0.29	0.29	0.28
OS (%)	0.26	0.22	0.22	0.23
Organic Matter (%)	2.10	1.70	2.20	2.00

Table 5.10 BRE-SD1 for SP03 test work sample. TPS = Total Potential Sulphate; WSS = Water Soluble Sulphate (2:1 as SO_4); ASS = Acid Soluble Sulphate; OS = Oxidisable Sulphates.

5.7.9 Average concentrations of organic matter for the 3 No. test work samples provided a narrow range between 1.70 – 2.30% with an average reported value of 2.00% across all samples. CoV for each of the stockpiles is considered to be low, with calculated CoV for SP01, SP02 and SP03 being 8%, 12% and 13% respectively, again demonstrating good homogeneity was achieved during test work sample homogenisation.

5.7.10 Certificates of analyses for BRE-SD1 parameters are included in Appendix B.

6 Geochemical Performance

6.1 Diffusive Flux Leaching Assessments

6.1.1 Diffusive flux leaching assessments from all mix designs are presented below, including the experimentally derived effective diffusion coefficients (D_e). Mix design specific De parameters have enabled the long-term performance and environmental compliance of stabilised materials to be assessed. For site specific assessments, we have used the experimentally derived parameters within a Conceptual Design Model (CDM) that accounts for mass transfer over time using a semi-infinite diffusion model. The results of forward predictive modelling are presented in Section 7.

6.1.2 9 No. specimens, representing the candidate mix designs considered in this study, were subjected to leaching assessments by 3D unconfined semi-dynamic tank testing. All mix designs were observed to retain complete structural integrity throughout the entire immersion period (64 days) following an initial 28 day curing period prior to submersion.

6.2 Semi-dynamic Diffusion Based Tank Testing

6.2.1 The interpretation of dynamic leaching trials such as the 64-day tank tests employed here is dependent upon the underlying modelling framework that is used to characterise release mechanisms and hence provide confidence in longer term leaching predictions.

6.2.2 The diffusion of contaminants from monoliths can most appropriately be characterised by a semi-infinite solid source. This modelling approach is based on the following physico-chemical assumptions:

1. The concentration of leaching contaminant species at the surface of the specimen is always zero: i.e., the contaminant is instantaneously removed by the liquid as soon as the species diffusing from the solid reaches the solid-liquid interface, hence surface sorption is neglected.
2. The composition of the liquid in contact with the solid being leached is constant. This implies that the leaching contaminant will not significantly change the liquid composition and the diffusion gradient at the solid-liquid interface is constant.
3. The stabilised monolith does not alter physically, chemically or mineralogically during the leaching process. Critically, this assumes that the mass of constituents leached are negligible in magnitude when compared to the contaminant source term, thus fulfilling the semi-infinite solid requirement.
4. The surface area of the solid is constant and does not change by surface processors such as dissolution / precipitation.
5. The kinetics of geochemical reactions are rapid enough so that a thermodynamic equilibrium always exists between leaching species in the solid and the aqueous phase.
6. Each contaminant exists as a single chemical species, hence any fractionation between geochemical retention mechanisms is ignored.

7. Bulk diffusion is the rate-limiting process for contaminant leaching.

6.2.3 Leaching of semi-infinite solids is described mathematically for cumulative leaching rates such as those determined through EA NEN 7375. The effective diffusion coefficient (D_e) is hence described by the governing equation.

$$D_e = \frac{\pi}{4}\left[\left(\frac{\sum a_n}{A_o}\right)\right]^2 \left[\frac{V}{S}\right]^2 \left[\frac{1}{t^{1/2}}\right]$$

D_e = effective diffusivity coefficient (m^2/s) for the cumulative leach interval, $t_n - t_0$
A_n = mass of contaminant leached during the leaching interval, $t_n - t_{n-1}$
$\sum a_n$ = total mass of contaminant cumulatively leached during the interval, $t_n - t_0$
A_0 = total initial contaminant concentration in the specimen
a_n/A_0 = fraction of contaminant leached during interval $t_n - t_{n-1}$
$\sum a_n/A_0$ = cumulative fraction of contaminant leached during the interval $t_n - t_0$
V = volume of the specimen, m^3
S = geometric surface area of the specimen, m^2
t = total elapsed time from leaching initiation in s.

6.2.4 The leachability index, referred to as pD_e in EA NEN 7375, can also be calculated from the effective diffusion coefficient values as:

$$L = \log(\beta/D_e)$$

L = leachability index
β = a constant = 1 m^2/s
D_e = average effective diffusion coefficient.

6.2.5 pD_e values give an indication of leaching potential whereby EA NEN 7375 provides the following interpretations

- $pD_e > 12.5$ low mobility
- $11.0 < pD_e < 12.5$ average mobility
- $pD_e < 11.0$ high mobility

6.2.6 It should be noted that the methodology employed in EA NEN 7375 requires a determination of the Maximum Availability in accordance with EA NEN 7371. However, we have adopted the mathematical approach described in ASTM C1308 but applying a linearization of leaching datasets to estimate De by plotting the cumulative fractional release over the square root of time.

6.2.7 The modelling approach employed by EA NEN 7375 describes diffusion as a process where the cumulative leaching with respect to Log(t) (referred to as rc) has a gradient of 0.5 ± 0.15. Where gradients exceed the upper limit, the aforementioned standard classifies the leaching mechanism as dissolution rather than diffusion. Where rc is below this lower limit, the process is interpreted as depletion, or where intervals include initial fractions, this may include an initial surface wash off event.

6.2.8 In addition, the spread of data points within leaching intervals must satisfy particular data quality indicators; whereby within the leaching interval of interest, the standard deviation of rc from independent data points (SD_{rc}) should be less than 0.5.

6.2.9 The usability of data for the determination of leaching mechanisms, and for the quantification of release rates, should have concentrations that are readily measurable, which is defined numerically as 1.5 x LOD.

6.2.10 It should be noted that where the concentration of contaminants remains low throughout all fractions of the semi-dynamic leaching trials, it is not technically feasible, or indeed desirable, to use these datasets for the identification of leaching mechanisms or derivation of D_e parameters.

6.2.11 Due to the aforementioned constraints imposed by analytical detection limits, the accurate interpretation of leaching behaviour, and derivation of effective diffusion coefficient is not technically justifiable for the following components from any of the candidate mix designs due to all fractions being reported at LOD:

- Cadmium
- Mercury
- Aliphatic TPH >C5-C6
- Aliphatic TPH >C6-C8
- Aliphatic TPH >C8-C10
- Aliphatic TPH >C10-C12
- Aliphatic TPH >C12-C16
- Aliphatic TPH >C16-C21
- Aliphatic TPH >C21-C35
- Aliphatic TPH >C35-C44
- Total Aliphatic Hydrocarbons
- Aromatic TPH >C5-C7
- Aromatic TPH >C7-C8
- Aromatic TPH >C8-C10
- Aromatic TPH >C10-C12
- Aromatic TPH >C12-C16
- Aromatic TPH >C16-C21
- Aromatic TPH >C21-C35
- Aromatic TPH >C35-C44
- Total Aromatic Hydrocarbons
- Total Petroleum Hydrocarbons
- Phenanthrene
- Anthracene
- Fluoranthene
- Pyrene
- Benzo[a]anthracene
- Chrysene
- Benzo[b]fluoranthene
- Benzo[k]fluoranthene
- Benzo[a]pyrene
- Indeno(1,2,3-c,d)Pyrene
- Dibenz(a,h)Anthracene
- Benzo[g,h,i]perylene
- Total Phenols

6.2.12 The following leaching trajectory analyses are based on the observed mass transfer for inorganic components only, predominately trace metals, which attained measurable concentrations during leaching trials. Further interpretation of mass flux profiles for mercury and cadmium is undertaken for completeness, however the derivation of diffusive flux parameters is restricted by the lack of measurable concentrations for these compounds.

The derived D_e parameters should therefore be regarded as conservative and a diffusive flux leaching mechanism implied.

6.3 Leaching Mechanisms and Upper Leaching Limits

6.3.1 The predicted leaching mechanisms for all candidate mix designs are presented in the Table 6.7. Full details are presented in Appendix C along with estimated upper leaching limits, graphical interpretations for leaching trajectories and experimentally derived effective diffusion coefficients (D_e) and partition coefficients (Kd).

6.3.2 Leaching under diffusion control was demonstrated for the majority of the compounds that exceeded detection limit for all mix designs (Tables 6.1 – Table 6.3).

6.3.3 Where a large spread in datasets is observed or the component is typically determined to be below the Method Reporting Limits (MRL), no determination of leaching mechanism is possible.

6.3.4 Where it has been possible to determine a leaching mechanism, it can be seen that most contaminants of interest are under diffusive flux control. Where it has not been possible to determine a leaching mechanism, this is mainly due to the analytical datasets being below 1.5 x LOD.

6.3.5 Upper Leaching Limits (ULL) are evaluated based on the framework presented in EA NEN 7375 for the complete 8 fractions. Surface wash off events are included in estimated ULLs where identified. Note, where no leaching mechanism is identified but measurable quantities of components are determined, the estimation of ULL is conservative.

6.3.6 ULL estimates for all investigated mix designs are presented in Tables 6.4 – Table 6.6. The ULL model provides an empirical extrapolation of leaching over defined periods and may be used for comparative purposes only. ULL’s should not be applied to longer term leaching extrapolations for assessing field scale application. The most appropriate framework for longer term leaching predictions is to apply a diffusion based leaching model using effective diffusion coefficients for contaminants identified as demonstrating diffusive flux.

6.3.7 Tables 6.4 – 6.6 present ULLs colour coded to provide a visual indication of the relative efficacy of each stabilisation mix design. Green signifies comparatively good geochemical retention and red signifies comparatively poor geochemical retention, based on the observed mass transfer, with amber signifying intermediate performance. The adopted colour coding does not provide any indication of performance with respect to any regulatory environmental criteria such as drinking water or environmental quality standards or indeed any site-specific leachate criteria.

	Leaching Mechanisms for SP01 Mix Designs		
Contaminant	**MD1**	**MD2**	**MD3**
Chloride	Diffusion	Diffusion	Diffusion
Sulphate	Diffusion	Diffusion with Delayed Diffusion or Dissolution	Diffusion with Delayed Diffusion or Dissolution
Calcium	Diffusion	Diffusion with Delayed Diffusion or Dissolution	Diffusion
Sodium	Diffusion	Diffusion	Diffusion
Arsenic	Diffusion with Delayed Diffusion or Dissolution	Diffusion with Delayed Diffusion or Dissolution	Diffusion
Barium	Diffusion	Diffusion	Diffusion with Delayed Diffusion or Dissolution
Cadmium	NPTDLM	NPTDLM	NPTDLM
Chromium	Diffusion with Surface wash-off	Diffusion	Diffusion
Copper	Diffusion	Diffusion	Diffusion
Mercury	NPTDLM	NPTDLM	NPTDLM
Molybdenum	Diffusion	Diffusion	Diffusion
Nickel	Diffusion	Diffusion	Diffusion
Lead	NPTDLM	NPTDLM	Diffusion
Antimony	Diffusion	Diffusion	Diffusion
Selenium	Depletion with Surface wash-off	Diffusion	Diffusion
Zinc	NPTDLM	NPTDLM	NPTDLM
Total Aromatic Hydrocarbons	NPTDLM	NPTDLM	NPTDLM
Total Petroleum Hydrocarbons	NPTDLM	NPTDLM	NPTDLM
Naphthalene	NPTDLM	NPTDLM	NPTDLM
Acenaphthylene	NPTDLM	NPTDLM	NPTDLM
Acenaphthene	NPTDLM	NPTDLM	NPTDLM
Fluorene	NPTDLM	NPTDLM	NPTDLM
Total Of 16 PAH's	NPTDLM	NPTDLM	NPTDLM
Total Phenols	NPTDLM	NPTDLM	NPTDLM

Table 6.1 Leaching mechanisms for SP01. Where the determination of leaching mechanisms was not possible this is typically due to measurands being reported below the LOD. NPTDLM = Not possible to Determine Leaching Mechanism.

	Leaching Mechanisms for SP02 Mix Design		
Contaminant	**MD4**	**MD5**	**MD6**
Chloride	Diffusion	Diffusion	Diffusion
Sulphate	Diffusion	Diffusion	Diffusion with Delayed Diffusion or Dissolution
Calcium	Diffusion	Diffusion with Delayed Diffusion or Dissolution	Diffusion
Sodium	Diffusion	Diffusion	Diffusion
Arsenic	Diffusion with Delayed Diffusion or Dissolution	Diffusion with Delayed Diffusion or Dissolution	Diffusion
Barium	Diffusion	Diffusion	Diffusion with Delayed Diffusion or Dissolution
Cadmium	NPTDLM	NPTDLM	NPTDLM
Chromium	Diffusion with Surface wash-off	Diffusion	Diffusion
Copper	Diffusion	Diffusion	Diffusion
Mercury	NPTDLM	NPTDLM	NPTDLM
Molybdenum	Diffusion	Diffusion	Diffusion
Nickel	Diffusion	Diffusion	Diffusion
Lead	NPTDLM	NPTDLM	NPTDLM
Antimony	Diffusion	Diffusion	Diffusion
Selenium	Depletion with Surface wash-off	Diffusion	Diffusion
Zinc	NPTDLM	NPTDLM	NPTDLM
Total Aromatic Hydrocarbons	NPTDLM	NPTDLM	NPTDLM
Total Petroleum Hydrocarbons	NPTDLM	NPTDLM	NPTDLM
Naphthalene	NPTDLM	NPTDLM	NPTDLM
Acenaphthylene	NPTDLM	NPTDLM	NPTDLM
Acenaphthene	NPTDLM	Diffusion	NPTDLM
Fluorene	NPTDLM	Diffusion	NPTDLM
Total Of 16 PAH's	NPTDLM	Diffusion	NPTDLM
Total Phenols	NPTDLM	NPTDLM	NPTDLM

Table 6.2 Leaching mechanisms for SP02. Where the determination of leaching mechanisms was not possible this is typically due to measurands being reported below the LOD. NPTDLM = Not possible to Determine Leaching Mechanism.

Contaminant	Leaching Mechanisms for SP03 Mix Designs MD7	MD8	MD9
Chloride	Diffusion	Diffusion	Diffusion
Sulphate	Diffusion	Diffusion	Diffusion with Delayed Diffusion or Dissolution
Calcium	Diffusion	Diffusion	Diffusion
Sodium	Diffusion	Diffusion	Diffusion
Arsenic	Diffusion	Diffusion with Delayed Diffusion or Dissolution	Diffusion with Delayed Diffusion or Dissolution
Barium	Diffusion	Diffusion with Delayed Diffusion or Dissolution	Diffusion with Delayed Diffusion or Dissolution
Cadmium	NPTDLM	NPTDLM	NPTDLM
Chromium	Diffusion with Surface wash-off	Diffusion with Surface wash-off	Diffusion
Copper	Diffusion	Diffusion	Diffusion
Mercury	NPTDLM	NPTDLM	NPTDLM
Molybdenum	Diffusion	Diffusion	Diffusion
Nickel	Diffusion	Diffusion	Diffusion
Lead	NPTDLM	NPTDLM	Diffusion
Antimony	Diffusion	Diffusion	NPTDLM
Selenium	Diffusion	Diffusion	Depletion
Zinc	NPTDLM	NPTDLM	NPTDLM
Total Aromatic Hydrocarbons	NPTDLM	NPTDLM	NPTDLM
Total Petroleum Hydrocarbons	NPTDLM	NPTDLM	NPTDLM
Naphthalene	NPTDLM	NPTDLM	NPTDLM
Acenaphthylene	NPTDLM	NPTDLM	NPTDLM
Acenaphthene	NPTDLM	NPTDLM	NPTDLM
Fluorene	NPTDLM	NPTDLM	NPTDLM
Total Of 16 PAH's	NPTDLM	NPTDLM	NPTDLM
Total Phenols	NPTDLM	NPTDLM	NPTDLM

Table 6.3 Leaching mechanisms for SP03. Where the determination of leaching mechanisms was not possible this is typically due to measurands being reported below the LOD. NPTDLM = Not possible to Determine Leaching Mechanism.

Upper Leaching Limit for SP01 Mix Designs (mg/m^2)			
Contaminant	**MD1**	**MD2**	**MD3**
Chloride	2430	1950	1920
Sulphate	38400	12000	4740
Calcium	21900	20000	26700
Sodium	2600	2350	2570
Arsenic	2.42	0.755	0.413
Barium	3.49	4.35	7.37
Cadmium	0.0417	0.0398	0.0404
Chromium	1.77	3.97	6.23
Copper	15.4	36.5	36.7
Mercury	0.0189	0.0181	0.0184
Molybdenum	5.65	4.24	2.8
Nickel	2.21	6.65	6.48
Lead	0.189	0.181	0.294
Antimony	0.644	0.381	0.297
Selenium	0.786	0.418	0.341
Zinc	1.03	0.905	0.918
Total Aromatic Hydrocarbons	1.89	1.81	1.84
Total Petroleum Hydrocarbons	3.79	3.62	3.67
Naphthalene	0.09	0.095	0.0688
Acenaphthylene	0.00379	0.00362	0.00367
Acenaphthene	0.00379	0.00362	0.00367
Fluorene	0.00379	0.00362	0.00367
Total Of 16 PAH's	0.081	0.0746	0.0748
Total Phenols	11.4	10.9	11

Table 6.4 Upper Leaching Limits (ULL) calculated from semi-dynamic tank test leaching datasets for SP01 mix designs. Colour coding relates to efficacy of mix design based on geochemical retention. ULLs are not normalised to source term concentrations (see text for further explanation).

Upper Leaching Limit for SP02 Mix Designs (mg/m^2)			
Contaminant	**MD4**	**MD5**	**MD6**
Chloride	2350	2770	3010
Sulphate	37100	8100	4770
Calcium	21100	19300	24800
Sodium	2510	2960	3160
Arsenic	2.34	0.946	0.454
Barium	3.37	3.61	6.02
Cadmium	0.0403	0.0397	0.0393
Chromium	1.71	3.94	5.8
Copper	14.8	33.1	35.5
Mercury	0.0183	0.018	0.0179
Molybdenum	5.45	4.19	2.9
Nickel	2.13	5.95	6.12
Lead	0.183	0.18	0.184
Antimony	0.622	0.349	0.357
Selenium	0.759	0.489	0.32
Zinc	0.997	0.902	0.908
Total Aromatic Hydrocarbons	1.83	1.8	1.79
Total Petroleum Hydrocarbons	3.66	3.61	3.58
Naphthalene	0.0869	0.0699	0.00443
Acenaphthylene	0.00366	0.0586	0.00358
Acenaphthene	0.00366	0.00757	0.00358
Fluorene	0.00366	0.00748	0.00358
Total Of 16 PAH's	0.0782	0.104	0.0715
Total Phenols	11	10.8	10.7

Table 6.5 Upper Leaching Limits (ULL) calculated from semi-dynamic tank test leaching datasets for SP02 mix designs. Colour coding relates to efficacy of mix design based on geochemical retention. ULLs are not normalised to source term concentrations (see text for further explanation).

Upper Leaching Limit for SP03 Mix Designs (mg/m2)			
Contaminant	**MD7**	**MD8**	**MD9**
Chloride	1380	2050	1810
Sulphate	34600	9330	11900
Calcium	19500	17900	28100
Sodium	2290	2310	2490
Arsenic	1.95	0.641	0.282
Barium	2.98	4.36	8.79
Cadmium	0.0399	0.0399	0.0395
Chromium	1.92	4.9	6.15
Copper	19.7	33	30.7
Mercury	0.0181	0.0182	0.018
Molybdenum	5.32	3.6	2.16
Nickel	3.38	6.65	5.88
Lead	0.181	0.182	0.282
Antimony	0.61	0.38	0.223
Selenium	0.679	0.352	0.261
Zinc	0.906	0.908	0.898
Total Aromatic Hydrocarbons	1.81	1.82	1.8
Total Petroleum Hydrocarbons	3.62	3.63	3.59
Naphthalene	0.00444	0.0679	0.185
Acenaphthylene	0.00362	0.00363	0.00359
Acenaphthene	0.00362	0.00363	0.00359
Fluorene	0.00362	0.00363	0.00359
Total Of 16 PAH's	0.0725	0.0731	0.0871
Total Phenols	10.9	10.9	10.8

Table 6.6 Upper Leaching Limits (ULL) calculated from semi-dynamic tank test leaching datasets for SP03 mix designs. Colour coding relates to efficacy of mix design based on geochemical retention. ULLs are not normalised to source term concentrations (see text for further explanation).

6.4 Experimentally Derived Effective Diffusion Coefficients (De)

6.4.1 As previously discussed, the calculation of effective diffusion coefficients is only technically justified for contaminants observed to fulfil diffusion based leaching criteria.

6.4.2 All experimentally derived effective diffusion coefficients have been normalised to source term concentrations to account for the influence of binders and admixture components on the dilution of contaminant mass. This approach allows for the direct comparison of D_e parameters from mix designs employing different mix ratios.

6.4.3 All mix designs demonstrate relatively similar performance with respect to the relative release rates of contaminants.

6.4.4 The effective diffusion coefficients presented in Tables 6.7 – 6.9 may be used for forward prediction of mass transfer rates by leaching over defined time periods. As previously discussed, this approach should only be applied to contaminants that demonstrate diffusion-controlled transport as presented in Tables 6.1 – 6.3. The implementation of a diffusive flux leaching assessment, however, should provide conservative estimates of mass transfer rates where depletion is observed or where datasets are influence by LODs or large spread in leaching datasets.

6.4.5 Alternatively, ULLs may be used to provide simple estimates of total mass flux over the time periods of the leaching trials (64 days). Linear extrapolation of ULLs over longer periods will be conservative for all leaching mechanisms, particularly diffusion based and is not advised.

6.4.6 Contaminant release expressed as mass releases per unit surface area with respect to a defined time interval can be calculated for diffusional control by:

$$U_{diff} = 2A\rho U \bullet \sqrt{\frac{D_e t}{\pi}}$$

Where U_{dif} is the quantity of a contaminant leached over time (*t*) expressed in mg/kg, *U* is the source term concentration of the contaminant (mg/kg), D_e is the effective diffusion coefficient (m^2/s), t is the duration of the leaching event (s), *A* is the surface are of the monolith (m^2), ρ is the density of the monolith (kg/m^3).

6.4.7 The above equation enables site specific assessment to be undertaken for stabilised materials based on source term characterisation data and the dimensions of proposed stabilisation zones when applying the geometric surface area of hydraulically bound engineered fill.

6.4.8 Furthermore, this approach allows source-term leaching (declining source-term), to be implemented as the source term (C_o) for groundwater fate and transport models using analytical approaches such as the Ogata-Banks or Domenico equations should higher levels of assessment for risks to groundwater be required.

Effective Diffusion Coefficient De for SP01 Mix Designs (m^2/s)			
Contaminant	**MD1**	**MD2**	**MD3**
Chloride	9.3E-12	5.4E-12	5.9E-12
Sulphate	3E-11	4.2E-12	6.9E-13
Calcium	5E-15	4.6E-15	9.9E-15
Sodium	1.4E-12	1.5E-12	1.8E-12
Arsenic	8.8E-16	9.6E-17	3.1E-17
Barium	2.1E-17	3.4E-17	1.2E-16
Cadmium	4.4E-16	4.9E-16	5.1E-16
Chromium	3.7E-16	8.8E-16	1.2E-15
Copper	9.4E-16	7.8E-15	8E-15
Mercury	1.1E-16	1.2E-16	1.2E-16
Molybdenum	1.7E-13	1.2E-13	5.6E-14
Nickel	1.8E-16	2.3E-15	2.2E-15
Lead	6.9E-20	8E-20	1.1E-19
Antimony	9.6E-16	2.8E-16	1.2E-16
Selenium	3.1E-13	7.9E-14	4.8E-14
Zinc	2.5E-18	1.5E-18	1.6E-18
Total Aromatic Hydrocarbons	1.3E-19	1.2E-19	1.3E-19
Total Petroleum Hydrocarbons	3.6E-19	2.6E-19	2.8E-19
Naphthalene	7.8E-18	1.9E-15	3.4E-18
Acenaphthylene	9.2E-18	9.1E-18	9.6E-18
Acenaphthene	1.7E-17	1.7E-17	1.8E-17
Fluorene	1.7E-17	1.7E-17	1.8E-17
Total Of 16 PAH's	1.6E-19	1.6E-19	1.7E-19
Total Phenols	4.6E-10	4.6E-10	4.8E-10

Table 6.7 Effective diffusion coefficients for SP01 mix designs.

Effective Diffusion Coefficient De for SP02 Mix Designs (m^2/s)			
Contaminant	**MD4**	**MD5**	**MD6**
Chloride	2.5E-11	2.8E-11	2.8E-11
Sulphate	3.3E-11	1.9E-12	6.9E-13
Calcium	5.5E-15	5.1E-15	8.6E-15
Sodium	9.5E-13	1.8E-12	1.8E-12
Arsenic	7E-16	1.1E-16	3E-17
Barium	1.2E-17	2.1E-17	5.5E-17
Cadmium	4.9E-16	4.8E-16	4.6E-16
Chromium	3.3E-16	8.8E-16	9.8E-16
Copper	1.3E-15	9.4E-15	1E-14
Mercury	7.4E-17	7.1E-17	6.8E-17
Molybdenum	1.5E-13	1.3E-13	6.3E-14
Nickel	1.7E-16	1.8E-15	1.8E-15
Lead	8.9E-20	8.6E-20	8.3E-20
Antimony	1.9E-15	4.3E-16	4.3E-16
Selenium	2.8E-13	1.4E-13	5.8E-14
Zinc	2.5E-18	1.5E-18	1.6E-18
Total Aromatic Hydrocarbons	1.7E-18	1.7E-18	1.6E-18
Total Petroleum Hydrocarbons	4E-18	3.9E-18	3.7E-18
Naphthalene	1.1E-17	5.5E-18	5.3E-18
Acenaphthylene	8.2E-18	3.9E-18	7.6E-18
Acenaphthene	3.4E-17	1.6E-17	3.1E-17
Fluorene	1.8E-17	8.8E-18	1.7E-17
Total Of 16 PAH's	2.2E-19	1.1E-19	2.1E-19
Total Phenols	5.1E-10	5E-10	4.8E-10

Table 6.8 Effective diffusion coefficients for SP02 mix designs.

Effective Diffusion Coefficient De for SP03 Mix Designs (m^2/s)			
Contaminant	**MD7**	**MD8**	**MD9**
Chloride	1.4E-11	1.3E-11	2E-11
Sulphate	2.5E-11	2.2E-12	4.9E-12
Calcium	4.1E-15	4.3E-15	1.1E-14
Sodium	9.8E-13	1.1E-12	1.3E-12
Arsenic	7.9E-16	6.8E-17	1.8E-17
Barium	1.6E-17	4E-17	1.6E-16
Cadmium	5.5E-16	5.7E-16	5.5E-16
Chromium	5.5E-16	1.3E-15	1.3E-15
Copper	2.5E-15	8.6E-15	7.7E-15
Mercury	1E-16	1.1E-16	1.1E-16
Molybdenum	1.7E-13	8.5E-14	3.2E-14
Nickel	4.8E-16	2.3E-15	1.9E-15
Lead	9.9E-20	1E-19	1.2E-19
Antimony	1.7E-15	5.1E-16	2E-16
Selenium	2.4E-13	7.2E-14	4.7E-14
Zinc	1.6E-18	1.7E-18	1.6E-18
Total Aromatic Hydrocarbons	9.5E-19	9.7E-19	9.5E-19
Total Petroleum Hydrocarbons	2.3E-18	2.3E-18	2.3E-18
Naphthalene	1.6E-17	5.3E-18	4.4E-18
Acenaphthylene	3.9E-18	4E-18	3.9E-18
Acenaphthene	3.4E-18	3.5E-18	3.4E-18
Fluorene	2.9E-18	3E-18	2.9E-18
Total Of 16 PAH's	4E-20	4.2E-20	5.2E-20
Total Phenols	4.6E-10	4.7E-10	4.6E-10

Table 6.9 Effective diffusion coefficients for SP03 mix designs.

6.5 Partition Co-efficient (Kd)

6.5.1 As an alternative approach, experimentally derived partition coefficients (Kd) for stabilised materials are presented in Table 6.10 – 6.12. The Kd's produced from this study *may* allow existing Remedial Target Values (RTVs) to be linearly scaled with respect to the original Kd parameters used for controlled waters risk assessment, or existing Kd values to be superseded for revised hydrogeological risk models. The suitability of this approach should be judged on a project and modelling scenario specific basis.

6.5.2 CE Geochem acknowledges the common use of the Kd approximation for source term leaching; however, we strongly recommend the use of effective diffusion coefficients for assessing diffusive flux from stabilised materials. In particular, the D_e approach better describes the declining source term leaching observed for stabilised materials (i.e., mass transport under diffusive flux) rather than an application of distribution coefficients that tend to better describe advective flow systems under the local equilibrium approximation.

6.5.3 If Kd parameters are adopted, professional judgement should be used on a contaminant specific basis where the derived Kd values for stabilised materials are dominated by either low concentrations at or below LODs in either the source, leachate or both.

6.5.4 Particular care should also be taken when applying either Kd or D_e parameters from this study to materials that differ considerably in source term composition, binder composition or textural composition from the samples investigated. The use of effective diffusion coefficients should however allow confident predictions to be applied to materials similar to those described herein.

6.5.5 Although we do not recommend using Kds for predictive modelling purposes, the Kd parameters generated through these laboratory investigations do provide an indication of the geochemical retardation experienced by contaminants through the application of hydraulic binders.

6.5.6 Experimentally derived Kd values are available in Appendix C for all contaminants reported above LOD from monolithic leaching trials undertaken on optimum mix designs.

6.5.7 The predicted time averaged groundwater concentrations below the stabilised source area are presented in the following section for the main potential contaminants of concern.

Average Partition Coefficient Kd for SP01 Mix Designs (L/Kg)			
Contaminant	**MD1**	**MD2**	**MD3**
Chloride	26.4	29.2	30.5
Sulphate	14	50.8	126
Calcium	1140	1130	956
Sodium	55.1	57.2	52.4
Arsenic	2960	8830	16500
Barium	17400	12800	8120
Cadmium	3210	3150	3080
Chromium	19200	4030	2030
Copper	2350	1060	1050
Mercury	6600	6470	6330
Molybdenum	180	241	367
Nickel	5470	1880	1920
Lead	250000	245000	198000
Antimony	3200	4490	5380
Selenium	108	227	272
Zinc	55000	56900	55700
Total Aromatic Hydrocarbons	201000	197000	193000
Total Petroleum Hydrocarbons	113000	111000	108000
Naphthalene	22300	19100	21500
Acenaphthylene	23400	23000	22500
Acenaphthene	17200	16800	16500
Fluorene	17200	16800	16500
Total Of 16 PAH's	170000	170000	168000
Total Phenols	3.3	3.23	3.17

Table 6.10 Distribution coefficients for SP01 mix designs presented in units of L/kg. Data represents average values from all 8 No. fractions. Minimum, maximum, and median statistics for Kd parameters are presented within EA NEN 7375 interpretive reports.

Average Partition Coefficient Kd for SP02 Mix Designs (L/Kg) Contaminant	MD4	MD5	MD6
Chloride	17.1	13.4	12.1
Sulphate	14	67.1	116
Calcium	1140	1160	1030
Sodium	69.2	56.8	52.3
Arsenic	3490	8430	18200
Barium	18800	16400	10400
Cadmium	3360	3290	3220
Chromium	21700	5970	2430
Copper	2080	1060	982
Mercury	8710	8540	8360
Molybdenum	180	244	349
Nickel	5940	2330	2230
Lead	251000	246000	235000
Antimony	2410	3670	3410
Selenium	108	194	286
Zinc	57500	59500	57500
Total Aromatic Hydrocarbons	56800	55600	54500
Total Petroleum Hydrocarbons	37300	36500	35800
Naphthalene	19400	19100	19500
Acenaphthylene	26100	22500	25000
Acenaphthene	12900	11200	12400
Fluorene	17500	15200	16800
Total Of 16 PAH's	151000	142000	152000
Total Phenols	3.3	3.23	3.17

Table 6.11 Distribution coefficients for SP02 mix designs presented in units of L/kg. Data represents average values from all 8 No. fractions. Minimum, maximum, and median statistics for Kd parameters are presented within EA NEN 7375 interpretive reports.

Average Partition Coefficient Kd for SP03 Mix Designs (L/Kg)			
Contaminant	**MD7**	**MD8**	**MD9**
Chloride	22.5	16.5	16.3
Sulphate	15.1	59	60.4
Calcium	1130	1210	884
Sodium	67.3	67.8	60.7
Arsenic	3760	10100	24000
Barium	17500	11800	6150
Cadmium	3000	2940	2880
Chromium	17400	2810	1890
Copper	1470	938	1010
Mercury	6670	6530	6400
Molybdenum	185	282	461
Nickel	3310	1790	2010
Lead	224000	220000	180000
Antimony	2450	3290	4120
Selenium	141	271	291
Zinc	55400	54300	53200
Total Aromatic Hydrocarbons	72600	71100	69700
Total Petroleum Hydrocarbons	46900	45900	45000
Naphthalene	19200	17100	14000
Acenaphthylene	35600	34900	34200
Acenaphthene	38300	37500	36700
Fluorene	41300	40400	39600
Total Of 16 PAH's	353000	344000	301000
Total Phenols	3.3	3.23	3.17

Table 6.12 Distribution coefficients for SP03 mix designs presented in units of L/kg. Data represents average values from all 8 No. fractions. Minimum, maximum and median statistics for Kd parameters are presented within EA NEN 7375 interpretive reports.

7 Diffusive Flux Modelling

7.1 Conceptual Design Model

7.1.1 The Conceptual Design Model (CDM) used to assess leaching potential from stabilised materials over time is enclosed as an interactive Excel™ model included in Appendix D. CDM models have been provided for both Milton Creek and the Chalk.

7.1.2 The CDM is based on an open system pore water exchange model, whereby the pore water flushing rate is a function of modelling parameters that define; (i) infiltration rate, (ii) source area, (iii) interfacial exchange region thickness and (iv) the porosity of contacting soils within the pore water exchange region.

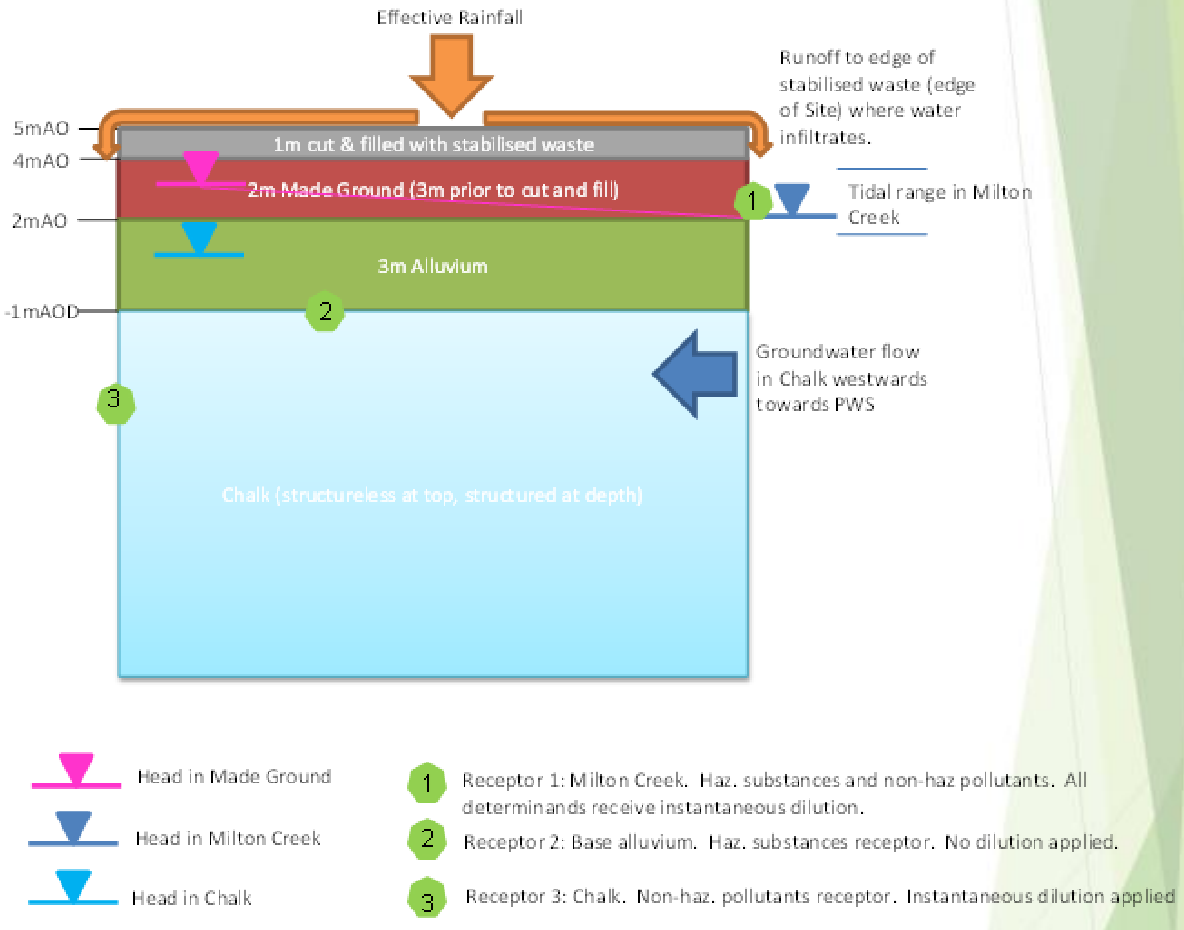


Figure 7.1 Conceptual Design Model (CDM) provided by Stantec for the implementation of Dilution Attenuation Factors (DAF) on surface water receptors and non-hazardous pollutants in the chalk groundwater aquifer.

7.1.3 The CDM presented in Appendix D and shown graphically in Figure 7.1, is based on computing predicted mass flux rates from the effective diffusion coefficient (D_e) discussed in section 6. The diffusive flux source term leaching model is formulated from the numerical framework presented in USEPA 1315, which is consistent with the model also discussed in EA NEN 7375. Here, contaminant release is expressed as mass released per unit area with respect to a defined time interval. This approach provides mass flux rate estimates in mg/m^2 from the following equation as also presented in 6.4.6;

$$U_{diff} = 2\rho A C_{o,MDR} \bullet \sqrt{\frac{D_e t}{\pi}}$$

7.1.4 In the above equation $C_{o,MDR}$ is the source term concentration of the contaminant (mg/kg) scaled with respect to the mix design ratio, D_e is the effective diffusion coefficient (m^2/s), t is the duration of the leaching event (s), A is the surface area of the monolith (m^2), ρ is the density of the monolith (kg/m^3).

7.1.5 The above equation allows direct parameterisation for site specific applications taking into consideration a scale correction factor to correct for the difference between leachant volume : monolith surface area conditions used in laboratory leaching assessments and contact infiltration volume : monolith surface areas at the subject site.

7.1.6 The mass transfer model is based on deriving absolute mass leaching rates (mg/m^2), which are subsequently dimensionalised to the site-specific geometric surface area of the stabilised monolith. We have based calculations on a stabilised pad area of 17,418 m^2. The CDM assume that were the stabilised soils interface with the imported low permeability cohesive waste (shown as yellow in Figure 7.2), diffusive flux rates will be negligible.

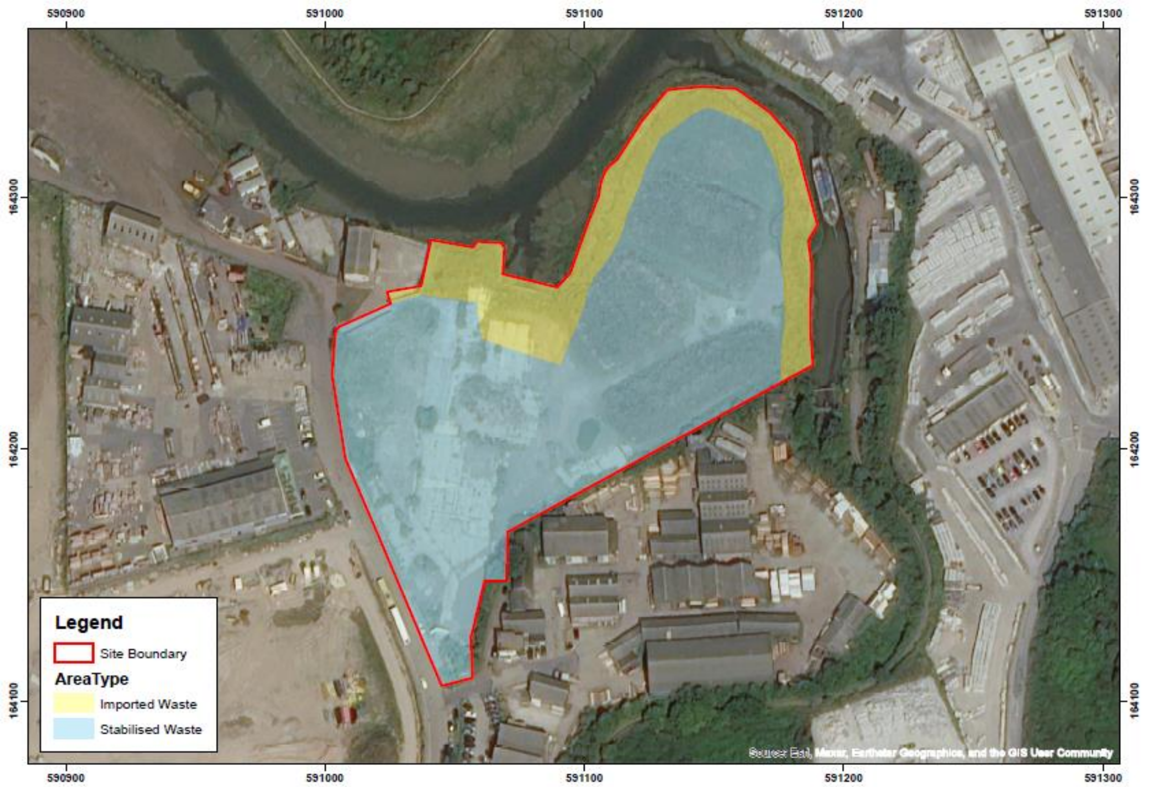


Figure 7.2 Stabilised source area and diffusive flux perimeter boundary used in CDM (provided by Stantec).

7.1.7 Assuming both upper and lower surfaces act as diffusive flux boundaries, in addition to the perimeter of the stabilised soil monolith that doesn't interface with the low permeability cohesive imported waste (372 m x 1.0m deep), we calculate a total active diffusive flux surface area of 35,208 m^2.

7.1.8 The absolute mass flux, in terms of total contaminant mass leached per unit time, is diluted by the interfacial pore water exchange volume where diffusive flux boundary conditions are present, in order to calculate a pore-water leachate concentration, ignoring any solubility control.

7.1.9 Pore-water flushing rates are derived for the interfacial exchange volume (zone next to the monolith where diffusive flux will influence pore water concentrations). The interfacial exchange pore volume is calculated from the monolith active leaching surface area (m^2) x the interfacial zone thickness (m) x porosity. Infiltration rates are used to define a time step for one pore water flushing event, allowing discretisation of the model in time for simulation steps equivalent to 0.1 pore volume.

7.1.10 Pore-water concentrations are scaled with respect to the dilution attenuation factor for the receiving aquifer and the creek. The dilution attenuation factor has been provided by Stantec for both Milton Creek (DAF = 10,160) and the Chalk (DAF = 8.77).

7.1.11 A summary of hydrogeological parameters used in the CDM are described in Table 7.1.

Parameter	Value	Unit	Source
Infiltration Rate	0.166	m/yr.	Stantec
Effective Infiltration Rate	0.166	m/yr.	Stantec
Effective Diffusion Coefficients	Contaminant Specific	m^2/sec	Derived from this study
Monolith Dimensions	176(L) x 97(W) x 1.0(D)	m	Keltbray (average site depth) and Stantec Drawing
Monolith Surface Area	35,208	m^2	Computed from dimensions
Porosity	0.33		Assumed
Density	1.999 – 2.077	Mg/m^3	Bulk density from OMC-MDD
Interfacial Exchange Zone	0.1	m	Assumed
Source Concentrations	Contaminant Specific	mg/kg	Derived from test work samples used in this study
Dilution Attenuation Factors	8.77 – Chalk 10,160 – Milton Creek		Stantec

Table 7.1 Hydrogeological model parameters used to define pore water exchange rates and calculate pore water concentrations in the CDM.

7.1.12 All components have been modelled under the CDM with simulated leaching trajectories available for inspection in Appendix D for both Milton Creek and the Chalk, for each of the mix designs investigated for each of the test work samples included in the study. Please note that where components were not detected above LOD from semi-dynamic tank testing, D_e parameters and hence modelled diffusive flux rates should be regarded as conservative.

7.2 Pore-water Exchange Simulations

7.2.1 This section reports the modelling outputs from the CDM presented above for both Milton Creek and the underlying chalk aquifer. Compliance with the Milton Creek surface water receptor has been assessed against Annual Average Environmental Quality Standards (AA-EQS) where available, whilst groundwater compliance for the chalk aquifer is assessed against Drinking Water Standards (DWS) where available for non-hazardous compounds and analytical limits of detection for hazardous compounds.

7.2.2 As summary of adopted compliance criteria are presented in Tables 7.2 and 7.3 for Milton Creek and the underlying chalk aquifer respectively.

Analyte	Units	Threshold	Source
Chloride	mg/l		
Sulphate	mg/l		
Calcium	mg/l		
Sodium	mg/l		
Arsenic	ug/l	25	EQS -AA
Barium	ug/l		
Cadmium	ug/l	0.2	EQS -AA
Chromium	ug/l		
Copper	ug/l	3.76	EQS -AA
Mercury	ug/l	0.07	EQS -MAC
Molybdenum	ug/l		
Nickel	ug/l	8.6	EQS -AA
Lead	ug/l	1.3	EQS -AA
Antimony	ug/l		
Selenium	ug/l		
Zinc	ug/l	6.8	EQS -AA
Total Aromatic Hydrocarbons	ug/l		
Total Petroleum Hydrocarbons	ug/l		
Naphthalene	ug/l	2	EQS -AA
Acenaphthylene	ug/l		
Acenaphthene	ug/l		
Fluorene	ug/l		
Total Of 16 PAH's	ug/l	0.00017	EQS -AA
Total Phenols	ug/l		

Table 7.2 Surface water compliance targets for Milton Creek.

Analyte	Units	Threshold	Source	Hazardous / Non-hazardous	Source
Chloride	mg/l	250	DWS 2018	Non hazardous pollutant	JAGDAG, 2001
Sulphate	mg/l	250	DWS 2018		
Calcium	mg/l				
Sodium	mg/l	200	DWS 2018		
Arsenic	ug/l	5	LOD	Hazardous pollutant	JAGDAG, 2017
Barium	ug/l				
Cadmium	ug/l	5	DWS 2018	Non hazardous pollutant	JAGDAG, 2017
Chromium	ug/l	1	LOD	Hazardous pollutant	JAGDAG, 2017
Copper	ug/l	2000	DWS 2018	Non hazardous pollutant	JAGDAG, 2001
Mercury	ug/l	0.02	LOD	Hazardous pollutant	JAGDAG, 2001
Molybdenum	ug/l			Non hazardous pollutant	JAGDAG, 2017
Nickel	ug/l	20	DWS 2018	Non hazardous pollutant	JAGDAG, 2017
Lead	ug/l	0.2	LOD	Hazardous pollutant	JAGDAG, 2017
Antimony	ug/l	5	DWS 2018	Non hazardous pollutant	JAGDAG, 2017
Selenium	ug/l	10	DWS 2018	Non hazardous pollutant	JAGDAG, 2017
Zinc	ug/l			Non hazardous pollutant	JAGDAG, 2001
Total Aromatic Hydrocarbons	ug/l	5	LOD	Hazardous pollutant	JAGDAG, 2001
Total Petroleum Hydrocarbons	ug/l	10	LOD	Hazardous pollutant	JAGDAG, 2001
Naphthalene	ug/l			Non hazardous pollutant	JAGDAG, 2017
Acenaphthylene	ug/l				
Acenaphthene	ug/l	0.01	LOD	Hazardous pollutant	JAGDAG, 2002
Fluorene	ug/l				
Total Of 16 PAH's	ug/l	0.1	DWS 2018		
Total Phenols	ug/l	0.5	DWS 2000	Non hazardous pollutant	JAGDAG, 2017

Table 7.3 Groundwater compliance targets for the underlying chalk aquifer.

7.2.3 Predicted ground and surface water concentrations are presented from diffusive flux simulations between 1.5 month following installation up to 10 years. As can be seen from inspection of the models presented in Appendix D, the imposition of diffusive flux control over contaminant release from stabilised materials is predicted to produce declining receptor concentration profiles over time (declining source term leaching model). Note that concentrations are plotted on a logarithmic axis.

7.2.4 Diffusive flux calculations show that, in general, a similar performance is achieved for all test work samples representing 3 No. stockpiles, and each of the 3 No. candidate mix designs (1% CEMI, 3% CEMI, 5% CEMI) modelled.

7.2.5 Partially due to the large dilution effect within Milton Creek, no modelled compounds are predicted to impact this surface water receptor above AA-EQS. Moreover, based on the predicted flux for the majority of analytes, it is unlikely that stabilised materials will have any detectable effect on water quality within this receptor (i.e. contaminant mass input remains below analytical detection limits).

7.2.6 Adopting the precautionary principle, chromium flux into the chalk aquifer has been assessed against the hexavalent chromium analytical detection limit (1 ug/l) as a hazardous groundwater pollutant, assuming all chromium is present as Cr(VI). Short term exceedances are observed for this compound, generally up to circa. 0.6 years as shown in Figure 7.3.

7.2.7 Although not detected in any of the semi-dynamic tank fractions above the analytical laboratory LOD of 0.05 ug/l, mercury concentrations are predicted to marginally exceed the hazardous substance derived groundwater threshold criteria of 0.02 ug/l. This is likely an artefact of modelling datasets at LOD.

7.2.8 A similar scenario arises for phenol where no analytical detections were observed for any of the leachate fractions analysed. As discussed in section 6, the derivation of De parameters used in these diffusive flux simulations should be considered conservative where the actual concentration of determinands remained below detection limits through-out the 64-day semi-dynamic leaching assessment.

7.2.9 The effective diffusion coefficients calculated for lead are also impacted by the analytical LOD of 0.2 ug/l. Inspection of lead leaching datasets reveal that only 5% CEMI mix designs generate leachate concentrations marginally above analytical detection limits (1.3 ug/l maximum reported concentration) over longer leaching intervals. Similar to the above discussion for mercury and phenol, exceedances likely arise through the imposition of detection limits on the calculated diffusion coefficient. This is particularly evident for 1% and 3% CEMI mix designs.

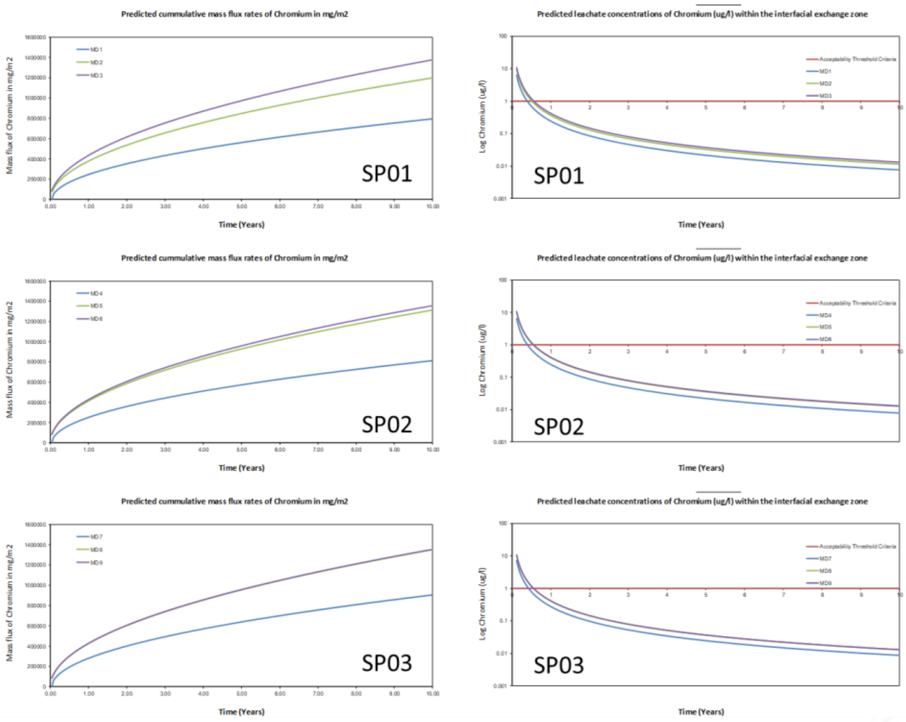


Figure 7.3. Predicted chromium groundwater concentration profiles within the chalk aquifer (left) with predicted mass flux profiles (right). Compliance target based on hexavalent chromium.

7.2.10 As can be seen from inspection of Figure 7.3, chromium flux rates are more heavily retarded at lower CEMI application rates. All trialled mix designs are predicted to temporarily exceed groundwater compliance targets based on LOD threshold criteria, however the duration of the exceedance is lowest for 1% CEMI addition rates.

7.2.11 Table 7.4 presents the chromium exceedance duration for each of the trialled mix designs from each of the 3 No. test work samples (SP01, SP02 and SP03).

	Duration of groundwater exceedance for chromium (years)		
	SP01	SP02	SP03
1% CEMI	0.36	0.36	0.40
3% CEMI	0.44	0.52	0.52
5% CEMI	0.56	0.52	0.52

Table 7.4 Predicted duration of groundwater exceedances for arsenic in the chalk aquifer.

7.2.12 The current diffusive flux model assumes no intervening alluvium layer is present, leading to direct instantaneous mass flux from the stabilised soils into the underlying chalk aquifer. Based on the predicted magnitude of exceedances, and hence relatively low pore water input concentrations entering the alluvial layer, the vertical component of contaminant flux for chromium through this geological unit is likely to be heavily retarded. In particular, the presence of naturally occurring iron oxides and clay minerals within the alluvium is likely to provide a significant sorption capacity and high sorption affinity (large kd) which is expected to provide a significantly retarded travel time for this compound.

7.2.13 From the diffusive flux simulations presented in Appendix D, which implements a DAF of 8.77 for non-hazardous pollutants, no exceedances against groundwater compliance targets are predicted.

8 Conclusions & Recommendations

8.1.1 This test work programme has demonstrated that geotechnical improvement of the stockpiled waste soils currently present at the subject site can be achieved through deployment of soil stabilisation ground engineering techniques utilising a CEMI based mix design. Although CE Geochem are not aware of any site-specific criteria, all mix designs showed good strength gain behaviour with 28-day CBR index values >30% which is likely to be suitable for most standard ground engineering applications.

8.1.2 Trialled mix designs exhibited a range of permeability values between 1.4 x 10^{-8} m/s to 9.4 x 10^{-8} m/s, strongly correlated to binder application rates. Where diffusive flux boundaries will be created through emplacement of stabilised waste fill, CE Geochem assume that the differential permeability at the interface between hydraulically bound soils and existing unbound soils (assumed $k = 10^{-5}$-10^{-6} m/s) will create a flow-around rather than flow through system.

8.1.3 BRE-SD1 assessments suggest a minor potential risk of sulphate induced heave, however CBR swell monitoring has confirmed no volumetric expansion following 28 days immersion. We recommend a watching brief is maintained during the construction phase through continued BRE-SD1 analysis coupled with validation CBR swell testing for all stabilisation works.

8.1.4 The results from simulated diffusive flux profiles for contaminants of potential concern, predict no surface water impacts for the Milton Creek receptor.

8.1.5 No exceedances are predicted for the underlying chalk aquifer groundwater receptor for any of the modelled non-hazardous pollutants when assessed against drinking water compliance standards or any hazardous pollutants when assessed against analytical detection limits, with the exception of arsenic.

8.1.6 Short term exceedances are predicted for chromium within the chalk aquifer using a compliance target of 1 ug/l. The duration of groundwater exceedances spans a range from circa. 0.36 years for 1% CEMI mix designs to circa 0.56 years for 5% CEMI mix designs.

8.1.7 The current Conceptual Design Model (CDM) assumes direct instantaneous discharge of porewaters from the based of the stabilised source zone into the underlying chalk aquifer. This excludes any potential retarded travel through the intervening 3m alluvial layer.

8.1.8 Care should be taken when using any of the geochemical parameters presented in this report for matrices that differ considerably from the source term concentrations, contaminant profiles or binder addition rates employed within this test work programme without further investigation.

8.1.9 We wish to draw your attention to the experimental conditions under which leaching trajectories were derived. All semi-dynamic tank testing datasets relate to monolithic specimens under constant immersion and subjected to sequential replenishment with de-ionised water. This latter condition ensures the maximum diffusion gradient is re-established during each tank exchange. In the opinion of CE Geochem, this leads to conservative estimates of mass flux rates.

8.1.10 Following mix design trials, field trials should be undertaken on site prior to the commencement of full-scale site operations to assess the suitability of plant and stabilisation methods for achieving the desired end-product performance, assuming such specifications are pertinent to the subject site.

8.1.11 CE Geochem strongly recommend that independent site control testing is implemented throughout the field trials and stabilisation works programme. This should include;

- Determination of Moisture content at a minimum density of 1 per 500 m^2 (assuming placement and mixing of materials in 250-320 mm layers) to achieve 95% compaction
- Determination of Degree of Pulverisation (DoP) at a minimum density of 1 per 500 m^2 (assuming placement and mixing of materials in 250-320 mm layers) to achieve a minimum DoP of 30%, preferably >60%.
- Initial monitoring of compaction density by sand replacement, in situ core cutter or nuclear / non-nuclear density gauge methods
- Daily control testing for BRE-SD1 analysis.
- Daily CBR swell specimen manufacture for testing in accordance with BS 1377-4.

8.1.12 Geotechnical validation testing should be undertaken by either;

- Light Weight Deflectometry
- In Situ CBR
- Plate Bearing Tests (Equivalent CBR or Incremental)

whereby the most suitable validation method will be defined by the earthworks specification and associated geotechnical design criteria.

Appendix A: Geotechnical Assessment

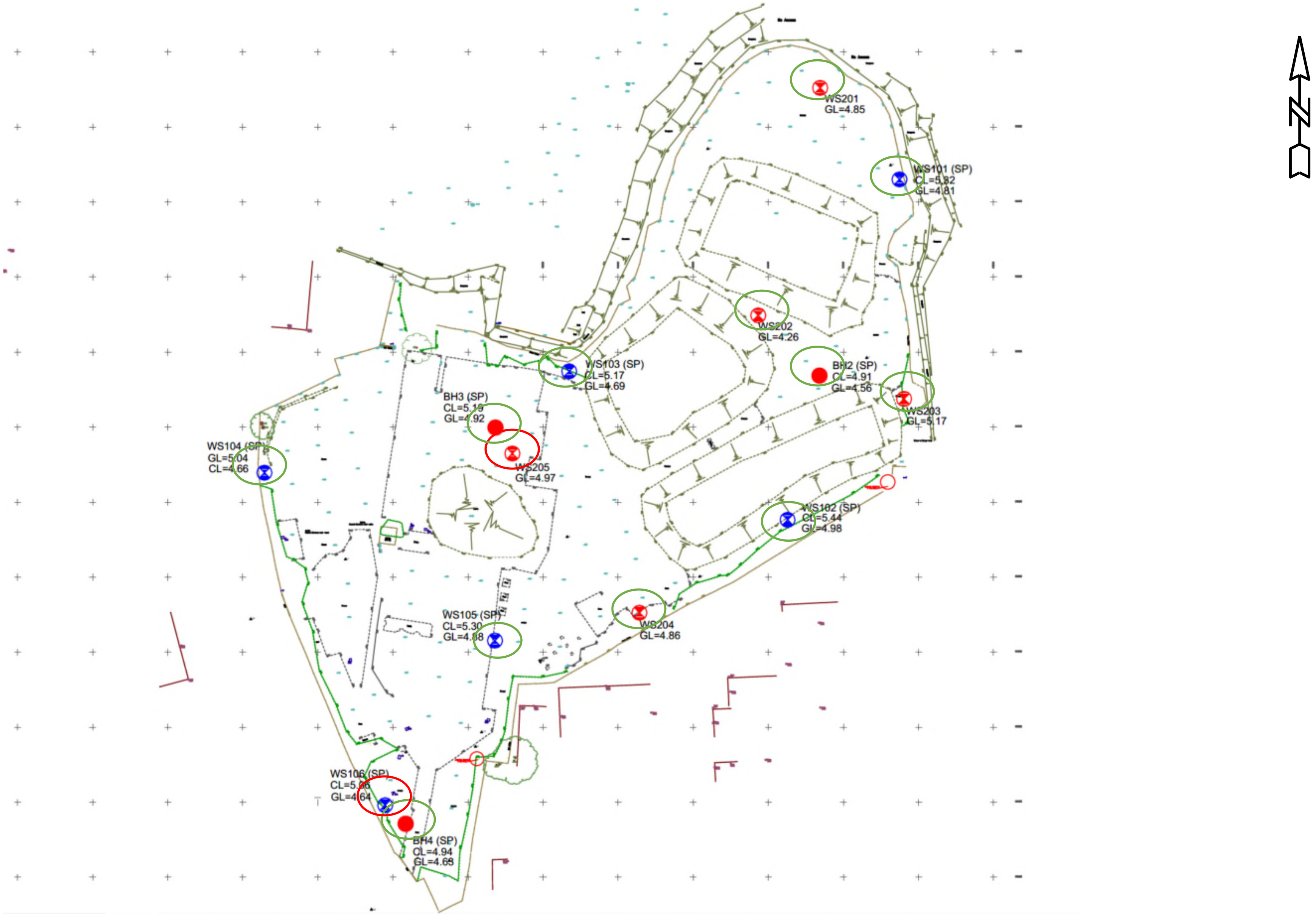
Appendix B: Chemical Analysis

Appendix C: EA NEN 7375 Reports

Appendix D: CDM

Appendix B

Trial pits and borehole logs



leap environmental

Client:	Bellway Homes (Kent Division)	Date:	25/01/2021	Project ID:	LP2448
Site:	Crown Quay Lane, Sittingbourne	Title:	Monitoring Well Plan	Figure No.:	4

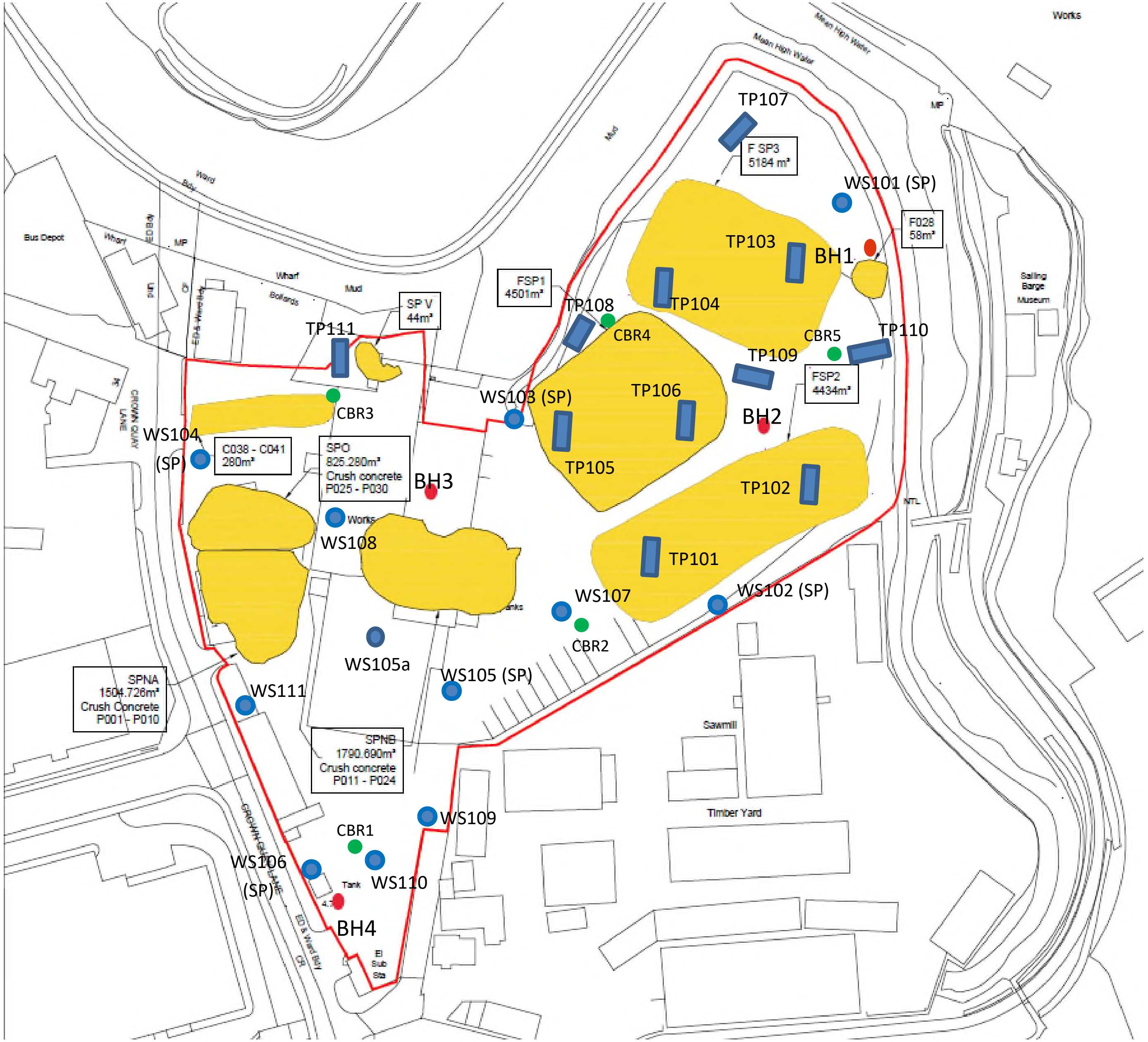
Key

▮ Trial Pits

● Windowless Sampler Positions

● Cable Percussion Boreholes

● CBR Test Positions



leap environmental	**Client :**	Bellway Homes (Kent Division)	**Date :**	25/01/2021	**Project ID:**	LP2448
	Project :	Crown Quay Lane, Sittingbourne	**Title :**	Trial Hole Location Plan (2017 investigation)	**Fig. No.**	5

APPENDIX C – Trial Hole Logs

Trial Hole Logs

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Borehole Log

Borehole No.
BH1
Sheet 1 of 3

Project Name: Crown Quay	Project No. LP01205	Co-ords: -	Hole Type CP
Location: Crown Quay Lane, Sittingbourne		Level:	Scale 1:50
Client: Bellway Homes		Dates: 10/01/2017 - 11/01/2017	Logged By ML

Samples and In Situ Testing Depth (m)	Type	Results	Depth (m)	Level (m)	Stratum Description
0.15	D		0.15		Topsoil.
0.15	ES				MADE GROUND: Brown gravelly sandy clay. Gravel is fine to coarse flint, brick, chalk and occasional ash.
0.50	D				
0.50 - 1.00	ES				
1.00	D				
1.50	D		1.50		MADE GROUND: Soft dark grey brown sandy gravelly clay with a slight alluvial odour. Gravel is fine to coarse flint and brick.
1.50		N=8 (1,2/3,2,2,1)			
1.50 - 2.00	B				
2.50	D				
3.00		N=4 (1,2/1,0,1,2)			
3.00 - 3.50	B				
4.00	D				
4.40	D		4.40		Soft to firm grey and dark grey mottled silty slightly sandy CLAY with an alluvial/organic odour. *Hand Pen at 4.4m = 80kPa (UCS)*
4.50 - 4.95	U	Ublow=10			
5.00	D				
5.80	D				*with occasional shell and chalk fragments below 5.8m*
6.00		N=6 (1,0/1,2,1,2)			
6.00 - 6.45	D				
7.00	D		7.00		Off white and grey structureless CHALK recovered as gravelly silt (80% silt, 20% gravel of chalk.)
7.50		N=7 (1,1/2,2,1,2)			
7.50 - 7.95	D				
8.50	D				
9.00		N=5 (1,2/1,1,1,2)			
9.00 - 9.50	B				
10.00	D				

Continued on next sheet

Remarks
Borehole cased to 25m. Water strike at 8.2m - SWL on completion: 5.7m.

Leap Environmental Ltd The Atrium, Curtis Road Dorking, Surrey RH4 1XA Tel: 01306 646510 www.leapenvironmental.com	**Borehole Log**	Borehole No. **BH1** Sheet 2 of 3

Project Name: Crown Quay	Project No. LP01205	Co-ords: -	Hole Type CP
Location: Crown Quay Lane, Sittingbourne		Level:	Scale 1:50
Client: Bellway Homes		Dates: 10/01/2017 - 11/01/2017	Logged By ML

Well	Water Strikes	**Samples and In Situ Testing**			Depth (m)	Level (m)	Legend	Stratum Description
		Depth (m)	Type	Results				
		10.50		N=12 (1,2/3,6,2,1)				
		10.50 - 11.00	B					
		11.50	D					
		12.00		N=7 (1,2/2,1,2,2)				
		12.00 - 12.50	B					
		13.00	D					
		13.50		N=5 (1,0/0,1,2,2)				
		13.50 - 14.00	B					
		14.50	D					
		15.00		N=6 (1,0/1,1,2,2)				
		15.00 - 15.45	D					
		16.00	D					
		16.50		N=14 (2,3/2,3,5,4)	16.50			Off white and grey structured CHALK recovered as gravelly silt. (60% silt, 40% gravel of weak, low density chalk and flints).
		16.50 - 16.95	D					
		17.50	D					
		18.00		N=20 (3,5/4,5,6,5)				
		18.00 - 18.45	D					
		19.00	D					
		19.50		N=27 (4,5/5,6,9,7)				
		19.50 - 19.95	D					

Continued on next sheet

Remarks

Borehole cased to 25m. Water strike at 8.2m - SWL on completion: 5.7m.

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Borehole Log

Borehole No.
BH1
Sheet 3 of 3

Project Name:	Crown Quay	Project No. LP01205	Co-ords: -	Hole Type CP
Location:	Crown Quay Lane, Sittingbourne		Level:	Scale 1:50
Client:	Bellway Homes		Dates: 10/01/2017 - 11/01/2017	Logged By ML

Well	Water Strikes	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
		Depth (m)	Type	Results				
		20.50	D					
		21.00		N=26 (3,7/5,7,7,7)				
		21.00 - 21.45	D					
		22.00	D					
		22.50		N=28 (5,5/5,7,7,9)				
		22.50 - 22.95	D					
		23.50	D					
		24.00		N=39 (5,10/13,9,8,9)				
		24.00 - 24.45	D					
		25.00		N=31 (6,5/6,7,9,9)	25.00			End of borehole at 25.00 m
		25.00 - 25.45	D					

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Remarks
Borehole cased to 25m. Water strike at 8.2m - SWL on completion: 5.7m.

AGS

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Borehole Log

Project Name: Crown Quay	Project No. LP01205	Co-ords: -	Borehole No. **BH2** Sheet 1 of 3
Location: Crown Quay Lane, Sittingbourne		Level:	Hole Type CP
			Scale 1:50
Client: Bellway Homes		Dates: 09/01/2017 - 10/01/2017	Logged By ML

Well	Water Strikes	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
					0.15			Asphalt.	
		0.20	D					MADE GROUND: Dark orange brown gravelly sandy clay. Gravel is fine to coarse flint, brick, occasional chalk and ash.	
		0.50	D						
		0.50	ES						
		1.00	D						1
		1.50		N=7 (2,1/2,1,2,2)					
		1.50 - 2.00	B						
								with an alluvial odour below 2.0m	2
		2.50	D						
		2.50	ES						
		3.00		N=5 (1,0/1,1,1,2)					3
		3.00 - 3.30	B						
		3.30	D		3.30			Soft grey green brown sandy silty CLAY with an alluvial/organic odour. *Hand Pen at 3.3m = 80kPa (UCS)*	
		4.00	D						4
		4.50 - 4.95	U	Ublow=12					
		5.00	D						5
		5.90	D					*becoming brown below 5.9m*	
		6.00		N=7 (1,2/1,2,2,2)				*with organic matter between 5.9m and 6.0m*	6
		6.00 - 6.45	D					*becoming lighter brown with much fine to coarse gravel of flint and chalk below 6.2m*	
		7.00		N=5 (1,0/1,1,2,1)					7
		7.20	D		7.20			Off white structureless CHALK recovered as gravelly silt (80% silt, 20% gravel of chalk.)	
	▼	7.50 - 7.95	D						
									8
		8.50	D						
		9.00		N=7 (1,2/3,1,2,1)					9
		9.00 - 9.45	D						
		10.00	D					Continued on next sheet	10

Remarks
Borehole cased to 25m. Water strike at 7.5m - SWL on completion: 7.8m. Borehole chiselled between 13.5m and 13.9m. Backfilled with gravel to 15m, standpipe installed to 15m: Top 3.5m plain pipe with bentonite surround, remainder slotted with gravel surround. Fitted with end caps and upstanding security cover.

Borehole Log

Borehole No.
BH2
Sheet 2 of 3

Project Name: Crown Quay	Project No. LP01205	Co-ords: -	Hole Type CP
Location: Crown Quay Lane, Sittingbourne		Level:	Scale 1:50
Client: Bellway Homes		Dates: 09/01/2017 - 10/01/2017	Logged By ML

Well	Water Strikes	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
		Depth (m)	Type	Results				
		10.50		N=9 (1,2/2,3,2,2)				
		10.50 - 10.95	D					
		11.50	D					
		12.00		N=11 (1,2/3,2,3,3)	12.00			Off white structured CHALK recovered as gravelly silt. (60% silt, 40% gravel of weak, low density chalk and flints).
		12.00 - 12.50	B					
		13.00	D					
		13.50		N=50 (25 for 100mm/50 for 20mm)				
		13.50 - 14.00	B					
		14.50	D					
W		15.00		N=10 (2,2/2,2,3,3)				
		15.00 - 15.45	D					
		16.00	D					
		16.50		N=15 (2,3/2,3,4,6)				
		16.50 - 16.95	D					
		17.50	D					
		18.00		N=45 (5,6/6,10,16,13)				
		18.00 - 18.45	D					
		19.00	D					
		19.50		N=25 (4,5/5,7,6,7)				
		19.50 - 19.95	D					

Continued on next sheet

Remarks
Borehole cased to 25m. Water strike at 7.5m - SWL on completion: 7.8m. Borehole chiselled between 13.5m and 13.9m. Backfilled with gravel to 15m, standpipe installed to 15m: Top 3.5m plain pipe with bentonite surround, remainder slotted with gravel surround. Fitted with end caps and upstanding security cover.

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Borehole Log

Borehole No. **BH2**
Sheet 3 of 3

Project Name: Crown Quay	Project No. LP01205	Co-ords: -	Hole Type CP
Location: Crown Quay Lane, Sittingbourne		Level:	Scale 1:50
Client: Bellway Homes		Dates: 09/01/2017 - 10/01/2017	Logged By ML

Well	Water Strikes	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
		Depth (m)	Type	Results				
		20.50	D					
		21.00 21.00 - 21.45	D	N=28 (4,5/5,9,6,8)				
		22.00	D					
		22.50 22.50 - 22.95	D	N=27 (5,5/5,6,7,9)				
		23.50	D					
		24.00 24.00 - 24.45	D	N=28 (5,9/7,7,7,7)				
		25.00 25.00 - 25.45	D	N=37 (5,8/11,9,9,8)	25.00			End of borehole at 25.00 m

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Remarks
Borehole cased to 25m. Water strike at 7.5m - SWL on completion: 7.8m. Borehole chiselled between 13.5m and 13.9m. Backfilled with gravel to 15m, standpipe installed to 15m: Top 3.5m plain pipe with bentonite surround, remainder slotted with gravel surround. Fitted with end caps and upstanding security cover.

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Borehole Log

Borehole No.
BH3
Sheet 1 of 3

Project Name: Crown Quay	Project No. LP01205	Co-ords: -	Hole Type CP
Location: Crown Quay Lane, Sittingbourne		Level:	Scale 1:50
Client: Bellway Homes		Dates: 12/01/2017 - 13/01/2017	Logged By ML

Well	Water Strikes	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
		Depth (m)	Type	Results				
								MADE GROUND: Brown gravelly clayey sand. Gravel is fine to coarse flint, brick, concrete and occasional chalk and ash.
		1.20	D					
		1.50		N=28 (1,2/6,5,10,7)				
		1.50 - 2.00	B					
	▼	2.50	D					*becoming sandy clay below 2.5m*
		2.50	ES					
		3.00		N=4 (1,0/0,1,2,1)	3.00			MADE GROUND: Dark grey brown sandy gravelly clay with a strong organic odour. Gravel is fine to coarse flint and brick.
		3.00 - 3.50	B					
		4.00	D					
		4.50		N=6 (1,1/1,2,1,2)				
		4.50 - 5.00	B					
		5.50	D					*with much gravel of chalk below 5.5m*
		5.50	ES					
		6.00		N=10 (1,2/2,2,3,3)				
		6.00 - 6.30	B					
		6.30	D		6.30			MADE GROUND: Orange brown sandy silty clay with occasional fine to coarse gravel of flint and brick (reworked).
	▽	7.40	D		7.40			Off white structureless CHALK recovered as gravelly silt (80% silt, 20% gravel of chalk.)
		7.50		N=6 (1,1/2,1,1,2)				
		7.50 - 7.95	D					
		8.50	D					
		9.00		N=5 (2,1/2,1,1,1)				
		9.00 - 9.45	D					
		10.00	D					

Continued on next sheet

Remarks
Borehole cased to 25m. Water strike at 7.4m - SWL on completion: 5.7m. Backfilled with gravel to 15m, standpipe installed to 15m: Top 6.5m plain pipe with bentonite surround, remainder slotted with gravel surround. Fitted with end caps and upstanding security cover.

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Borehole Log

Borehole No.
BH3
Sheet 2 of 3

Project Name: Crown Quay	Project No. LP01205	Co-ords: -	Hole Type CP
Location: Crown Quay Lane, Sittingbourne		Level:	Scale 1:50
Client: Bellway Homes		Dates: 12/01/2017 - 13/01/2017	Logged By ML

Well	Water Strikes	Samples and In Situ Testing Depth (m)	Type	Results	Depth (m)	Level (m)	Legend	Stratum Description
		10.50 10.50 - 10.95	D	N=9 (2,1/2,3,2,2)	10.50			Off white structured CHALK recovered as gravelly silt (60% silt, 40% gravel of weak, low density chalk and flints).
		11.50	D					
		12.00 12.00 - 12.45	D	N=12 (2,1/2,3,4,3)				
		13.00	D					
		13.50 13.50 - 13.95	D	N=14 (3,2/6,2,3,3)				
		14.50	D					
W		15.00 15.00 - 15.45	D	N=19 (5,5/6,3,5,5)				
		16.00	D					
		16.50 16.50 - 16.95	D	N=36 (5,5/8,8,9,11)				
		17.50	D					
		18.00 18.00 - 18.45	D	N=33 (5,7/7,9,7,10)				
		19.00	D					
		19.50 19.50 - 19.95	D	N=40 (6,7/7,10,10,13)				

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Continued on next sheet

Remarks
Borehole cased to 25m. Water strike at 7.4m - SWL on completion: 5.7m. Backfilled with gravel to 15m, standpipe installed to 15m: Top 6.5m plain pipe with bentonite surround, remainder slotted with gravel surround. Fitted with end caps and upstanding security cover.

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Borehole Log

Borehole No.
BH3
Sheet 3 of 3

Project Name: Crown Quay	Project No. LP01205	Co-ords: -	Hole Type CP
Location: Crown Quay Lane, Sittingbourne		Level:	Scale 1:50
Client: Bellway Homes		Dates: 12/01/2017 - 13/01/2017	Logged By ML

Well	Water Strikes	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
		Depth (m)	Type	Results				
▨		20.50	D				▦	
▨		21.00 21.00 - 21.45	D	N=31 (8,7/8,8,7,8)			▦	
▨		22.00	D				▦	
▨		22.50 22.50 - 22.95	D	N=32 (9,10/7,8,8,9)			▦	
▨		23.50	D				▦	
▨		24.00 24.00 - 24.95	D	N=39 (5,9/10,9,9,11)			▦	
		25.00 25.00 - 25.45	D	N=41 (6,10/10,9,11,11)	25.00			End of borehole at 25.00 m

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Remarks
Borehole cased to 25m. Water strike at 7.4m - SWL on completion: 5.7m. Backfilled with gravel to 15m, standpipe installed to 15m: Top 6.5m plain pipe with bentonite surround, remainder slotted with gravel surround. Fitted with end caps and upstanding security cover.

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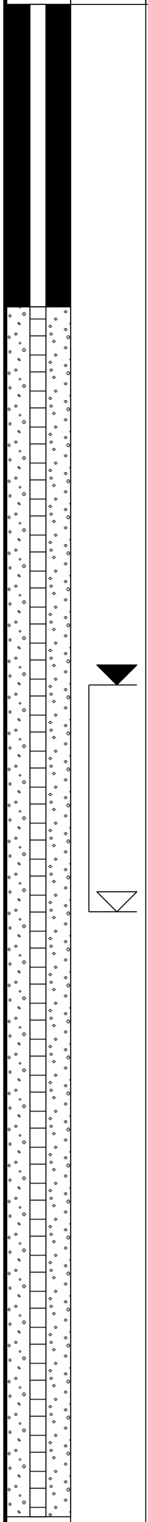
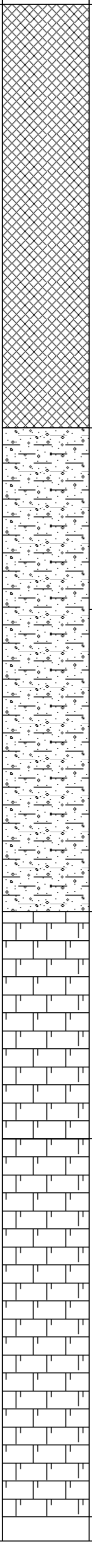
Borehole Log

Borehole No.
BH4
Sheet 1 of 3

Project Name: Crown Quay	Project No. LP01205	Co-ords: -	Hole Type CP
Location: Crown Quay Lane, Sittingbourne		Level:	Scale 1:50
Client: Bellway Homes		Dates: 12/01/2017 - 13/01/2017	Logged By ML



Samples and In Situ Testing			Depth (m)	Level (m)	Stratum Description
Depth (m)	Type	Results			
					MADE GROUND: Brown gravelly clayey sand. Gravel is fine to coarse flint, brick, clinker, concrete and occasional shell.
1.50		N=18 (4,3/2,2,4,10)			
1.50 - 2.00	B				
1.50 - 2.00	ES				
2.50	D				
2.50	ES				
2.80	D		2.80		Orange brown sandy gravelly CLAY. Gravel is fine to coarse flint.
3.00		N=7 (1,/2,1,2,2)			
3.00 - 3.45	D				
3.50	D				
					becoming very sandy between 4.0m and 5.0m
4.50	D				
4.50		N=5 (1,/1,,2,2)			
5.00	D				
5.50	D				
6.00		N=4 (1,/1,,1,2)	6.00		Off white structureless CHALK recovered as gravelly silt (80% silt, 20% gravel of chalk.)
6.00 - 6.45	D				
6.50	D				
7.50	D		7.50		Off white structured CHALK recovered as gravelly silt (60% silt, 40% gravel of weak, low density chalk and flints).
7.50		N=9 (3,2/2,2,2,3)			
8.50	D				
9.00		N=15 (3,3/4,3,4,4)			
9.00 - 9.45	D				
9.50	D				



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Remarks
Borehole cased to 25m. Water strike at 6.0m - SWL on completion: 4.0m. Borehole chiselled 11.2m-11.4m, 13.6m-13.8m and 24.3m-24.5m. Backfilled with arisings to 15m, standpipe installed to 15m: Top 2.0m plain pipe with bentonite surround, remainder slotted with gravel surround. Fitted with end caps and upstanding security cover.

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Borehole Log

Borehole No. **BH4**
Sheet 2 of 3

Project Name: Crown Quay	Project No. LP01205	Co-ords: -	Hole Type CP
Location: Crown Quay Lane, Sittingbourne		Level:	Scale 1:50
Client: Bellway Homes		Dates: 12/01/2017 - 13/01/2017	Logged By ML

Well	Water Strikes	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
		10.50	D						
		10.50		N=20 (4,5/5,4,6,5)					
									11
		11.50	D						
		12.00		N=40 (7,8/9,9,10,12)					12
		12.00 - 12.95	D						
		12.50	D						
									13
		13.50	D						
		13.50		N=50 (20,5/50 for 80mm)					
									14
		14.50	D						
Ⓦ		15.00		N=50 (8,11/50 for 245mm)					15
		15.00 - 15.45	D						
		15.50	D						
									16
		16.50	D						
		16.50		N=37 (9,9/7,8,10,12)					
									17
		17.50	D						
		18.00		N=40 (7,12/7,10,9,14)					18
		18.00 - 18.45	D						
		18.50	D						
									19
		19.50	D						
		19.50		N=42 (8,9/8,10,11,13)					
		19.50 - 19.95	D					Continued on next sheet	20

Remarks
Borehole cased to 25m. Water strike at 6.0m - SWL on completion: 4.0m. Borehole chiselled 11.2m-11.4m, 13.6m-13.8m and 24.3m-24.5m. Backfilled with arisings to 15m, standpipe installed to 15m: Top 2.0m plain pipe with bentonite surround, remainder slotted with gravel surround. Fitted with end caps and upstanding security cover.

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Borehole Log

Borehole No.
BH4
Sheet 3 of 3

Project Name: Crown Quay	Project No. LP01205	Co-ords: -	Hole Type CP
Location: Crown Quay Lane, Sittingbourne		Level:	Scale 1:50
Client: Bellway Homes		Dates: 12/01/2017 - 13/01/2017	Logged By ML

Well	Water Strikes	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
		Depth (m)	Type	Results				
		20.50	D					
		21.00		N=50 (10,11/50 for 220mm)				
		21.00 - 21.45	D					
		21.50	D					
		22.50	D					
		22.50		N=41 (8,8/9,9,10,13)				
		22.50 - 22.95	D					
		23.50	D					
		24.00		N=50 (7,12/50 for 120mm)				
		24.00 - 24.45	D					
		24.50	D					
		25.00		N=50 (9,9/50 for 250mm)	25.00			End of borehole at 25.00 m
		25.00 - 25.45	D					

21 22 23 24 25 26 27 28 29 30

Remarks
Borehole cased to 25m. Water strike at 6.0m - SWL on completion: 4.0m. Borehole chiselled 11.2m-11.4m, 13.6m-13.8m and 24.3m-24.5m. Backfilled with arisings to 15m, standpipe installed to 15m: Top 2.0m plain pipe with bentonite surround, remainder slotted with gravel surround. Fitted with end caps and upstanding security cover.

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Trial Pit Log

Trialpit No
TP101
Sheet 1 of 1

Project Name: Crown Quay	Project No. LP01205	Co-ords: - Level:	Date 06/10/2016
Location: Crown Quay Lane, Sittingbourne		Dimensions (m):	Scale 1:25
Client: Bellway Homes		Depth 3.70	Logged MP

Water Strike	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
	Depth	Type	Results				
				0.10			Blacktop.
				0.30			MADE GROUND: Gravel of medium to coarse brick and rubble.
				1.90			MADE GROUND: Dark brown and black silty slightly clayey sandy gravel. Gravel is fine to coarse flint, slate, glass, brick, concrete and rare metal. Occasional pockets of light brown silty clay with gravel of brick.
	1.00	ES					*PID @ 1.0m = 0.4ppm*
				3.40			Grey brown, orange green and orange brown silty CLAY with a gravel of flint with an organic odour.
							PID @ 2.4m = 1.7ppm
	2.70	ES					
				3.70			Dark grey and black fine sandy SILT with fine sandy partings and an organic odour.
	3.50	ES					*PID @ 3.5m = 0.3ppm*
							End of pit at 3.70 m

Remarks: Remained dry.

Stability: Stable.

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Trial Pit Log

Trialpit No
TP102
Sheet 1 of 1

Project Name: Crown Quay
Project No. LP01205
Co-ords: -
Level:
Date 06/10/2016
Location: Crown Quay Lane, Sittingbourne
Dimensions (m):
Depth 2.80
Scale 1:25
Client: Bellway Homes
Logged MP

Water Strike	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
	Depth	Type	Results				
				0.08			Blacktop.
				0.40			MADE GROUND: Compacted clinker, brick and flint with a hardcore subbase.
				1.00			MADE GROUND: Dark red brown silty very sandy gravel of fine to coarse chalk, brick and concrete.
	1.80	ES		2.50			MADE GROUND: Dark brown and black silty very sandy gravel. Gravel is fine to coarse chalk, brick, flint, metal and boulders of concrete and part brick wall. *PID @ 1.7m = 0.1ppm*
	2.70	ES		2.80			Black and dark grey silty fine sandy CLAY with fine fiberous organic matter and rare fine gravel of flint. *PID @ 2.7m = 0.2ppm*
							End of pit at 2.80 m

Remarks: Seepage from 1.9m.

Stability: Overbreak in made ground to 0.9m.

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Trial Pit Log

Trialpit No
TP103
Sheet 1 of 1

Project Name: Crown Quay	Project No. LP01205	Co-ords: - Level:	Date 06/10/2016
Location: Crown Quay Lane, Sittingbourne		Dimensions (m): Depth 3.70	Scale 1:25
Client: Bellway Homes			Logged MP

Water Strike	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
	Depth	Type	Results				
						▨	MADE GROUND: Dark brown silty sandy gravelly clay. Gravel is fine to coarse and cobbles of brick, tile, concrete, metal and chalk fragments. Also plastic, food wrappers, cloth and fabric.
	1.50	ES				▨	*PID @ 1.5m = 0.7ppm*
				2.40		▨	MADE GROUND: Dark brown and grey silty gravelly clay. Gravel of fine to coarse flint, brick and rare chalk.
				3.50		▤	Green grey and grey silty fine sandy CLAY with occasional coarse gravel of flint.
	3.60	ES				▤	*PID @ 3.6m = 0.6ppm*
				3.70			End of pit at 3.70 m

Remarks: Moderate seapage at 2.4m.

Stability: Slight overbreak to 1.2m.

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Trial Pit Log

Trialpit No
TP104
Sheet 1 of 1

Project Name: Crown Quay
Project No. LP01205
Co-ords: -
Level:
Date 06/10/2016
Location: Crown Quay Lane, Sittingbourne
Dimensions (m):
Depth 3.70
Scale 1:25
Client: Bellway Homes
Logged MP

Water Strike	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
	Depth	Type	Results				
				0.08		░	Blacktop.
				0.38		░	Roadstone.
				0.50		▨	Compacted chalk.
	1.20	ES		2.70		▨	MADE GROUND: Red brown and light brown silty slightly gravelly clay. Gravel is fine to coarse and rare boulders of brick and flint. *PID @ 1.2m = 0.3ppm*
				3.10		▨	MADE GROUND: Dark brown and black sandy gravelly silty clay. Gravel is fine to coarse and cobbles of brick, metal and cable.
	3.60	ES		3.70		✕	Dark grey silty fine sandy CLAY with slight organic odour. Occasional fiberous organic material. *Becoming black from 3.4m.* *PID @ 3.6m = 0.4ppm*
							End of pit at 3.70 m

Remarks: Moderate water inflow at 2.7m.

Stability: Slight overbreak to 1.0m.

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Trial Pit Log

Trialpit No
TP105
Sheet 1 of 1

Project Name: Crown Quay	Project No. LP01205	Co-ords: - Level:	Date 06/10/2016
Location: Crown Quay Lane, Sittingbourne		Dimensions (m): Depth 3.70	Scale 1:25
Client: Bellway Homes			Logged MP

Water Strike	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
	Depth	Type	Results				
				0.15		░	Blacktop.
				0.70		▨	MADE GROUND: Black and white with organic brown silty clayey gravel. Gravel is fine to coarse brick, concrete, flint and chalk.
				1.20		▨	MADE GROUND: Dark brown silty sandy gravelly clay. Gravel is fine to coarse brick concrete, glass, metal and clinker.
	1.40	ES		1.60		▨	MADE GROUND: Dark grey brown silty sand. Sand is fine to coarse ash, brick and clinker.
				2.90		▨	MADE GROUND: Black and dark grey silty sandy clay with occasional gravel of brick, flint and rare metal.
	3.20	ES		3.70		▤	Dark grey and light grey silty slightly sandy CLAY with fine sandy partings.
							End of pit at 3.70 m

Remarks: Rapid inflow of water at 2.4m with a slight sheen.

Stability: Stable.

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Trial Pit Log

Trialpit No
TP106
Sheet 1 of 1

Project Name: Crown Quay	Project No. LP01205	Co-ords: - Level:	Date 06/10/2016
Location: Crown Quay Lane, Sittingbourne		Dimensions (m): Depth 4.60	Scale 1:25
Client: Bellway Homes			Logged MP

Water Strike	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
	Depth	Type	Results				
				0.08			Blacktop.
				1.00			MADE GROUND: Brown silty sand. Sand is fine to coarse with brick and concrete fragments.
	1.20	ES		1.60			MADE GROUND: Dark brown and black slightly gravelly clay. Gravel of fine to coarse flint, brick, chalk and concrete with metal wire and plastic.
	2.80	ES		2.90			MADE GROUND: Brown silty clay with occasional gravel of brick and flint.
	3.30 4.40	ES ES		4.60			MADE GROUND: Dark brown silty slightly gravelly clay with timber and rare glass bottles. Also slight chemical solvent odour.
							End of pit at 4.60 m

Remarks: Standing water at 4.45m with a slight sheen.

Stability: Stable.

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Trial Pit Log

Trialpit No
TP107
Sheet 1 of 1

Project Name: Crown Quay	Project No. LP01205	Co-ords: - Level:	Date 14/02/2017
Location: Crown Quay Lane, Sittingbourne		Dimensions (m): Depth 3.00	Scale 1:25
Client: Bellway Homes			Logged MP

Water Strike	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
	Depth	Type	Results				
						▨	MADE GROUND: Dark brown and brown sandy very gravelly clay. Gravel is fine to coarse flint, brick, concrete, ceramic tile and rare cobble of brick and concrete and rare wood and plastic pipe.
	0.50	ES					
	1.00	ES					
				1.50		▨	MADE GROUND: Dark brown gravelly clay with occasional pockets of fine sand and fiberous organic material. Gravel is fine to coarse brick, flint and concrete.
	2.10	ES					
				3.00			End of pit at 3.00 m

Remarks: Seepage from 1.8m.

Stability: Stable.

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Trial Pit Log

Trialpit No
TP108
Sheet 1 of 1

Project Name: Crown Quay	Project No. LP01205	Co-ords: - Level:	Date 14/02/2017
Location: Crown Quay Lane, Sittingbourne		Dimensions (m): Depth 1.70	Scale 1:25
Client: Bellway Homes			Logged MP

Water Strike	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
	Depth	Type	Results				
				0.20		▨	MADE GROUND: Brown silty gravelly clay. Gravel is fine to coarse brick and concrete.
				0.40		▨	MADE GROUND: Black coarse gravel of limestone.
	0.50 0.90	ES ES		1.70		▨	MADE GROUND: Brown sandy gravelly clay. Gravel is fine to coarse brick, mortar, glass and ceramic.
							End of pit at 1.70 m

Remarks: Trial pit remained dry. No further progress- brick obstruction.

Stability: Stable.

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Trial Pit Log

Trialpit No
TP109
Sheet 1 of 1

Project Name:	Crown Quay	Project No. LP01205	Co-ords: - Level:	Date 14/02/2017
Location:	Crown Quay Lane, Sittingbourne		Dimensions (m): Depth 2.50	Scale 1:25
Client:	Bellway Homes			Logged MP

Water Strike	**Samples and In Situ Testing** Depth	Type	Results	Depth (m)	Level (m)	Legend	Stratum Description
				0.08			Blacktop.
				0.12			MADE GROUND: Black ashy gravel of limestone.
							MADE GROUND: Brown sandy very gravelly clay. Gravel is fine to coarse flint, concrete and brick with occasional coarse gravel and cobbles of chalk.
	0.50	ES					
							Chalk becoming abundant below 1.1m.
				1.30			MADE GROUND: Grey brown very silty gravelly clay. Gravel is fine to coarse chalk with occasional brick and flint.
	1.40	ES					
	2.40	D					
				2.50			End of pit at 2.50 m

Remarks: Slight ingress of water from 2.5m.

Stability: Stable.

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Trial Pit Log

Trialpit No
TP110
Sheet 1 of 1

Project Name: Crown Quay	Project No. LP01205	Co-ords: - Level:	Date 14/02/2017
Location: Crown Quay Lane, Sittingbourne		Dimensions (m): Depth 2.90	Scale 1:25
Client: Bellway Homes			Logged MP

Water Strike	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
	Depth	Type	Results				
				0.12		░	Blacktop.
	0.40	ES		0.70		▩	MADE GROUND: Dark brown silty gravel of fine to coarse limestone, clinker and brick with cobbles of whole brick.
				1.00		▩	MADE GROUND: Brown and dark brown silty clayey sandy gravel. Gravel is fine to coarse clinker and brick.
	1.50	ES		1.80		▩	MADE GROUND: Brown and orange brown fine sandy gravelly clay. Gravel is fine to coarse flint and brick with plastic sheeting and rare boulders of concrete.
				2.30		▩	MADE GROUND: Light grey brown, grey brown and occasionally yellow brown silty very sandy gravelly clay. Gravel is fine to coarse brick, flint and rare rubber, metal and timber.
	2.40 2.50	ES ES		2.90		▤	Black silty sandy CLAY with fiberous organic matter and a strong organic odour.
							End of pit at 2.90 m

Remarks: Moderate water ingress at 2.2m. Standing water level after 5 minuites = 1.4m.

Stability: Overbreak below 1.4m.

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Trial Pit Log

Trialpit No
TP111
Sheet 1 of 1

Project Name:	Crown Quay	Project No. LP01205	Co-ords: - Level:	Date 14/02/2017
Location:	Crown Quay Lane, Sittingbourne		Dimensions (m): Depth 1.50	Scale 1:25
Client:	Bellway Homes			Logged MP

Water Strike	**Samples and In Situ Testing**			Depth (m)	Level (m)	Legend	Stratum Description
	Depth	Type	Results				
	0.40	ES				▨	MADE GROUND: Dark brown and brown sandy gravelly clay. Gravel is fine to coarse brick, concrete and flint.
						▨	*With much wood, roots, plastic and occasional timber at 0.7m.*
	1.30	ES		1.20		▨	MADE GROUND: Dark brown and dark grey very sandy gravel. Gravel is fine to coarse with cobbles and rare boulders of concrete.
				1.50			End of pit at 1.50 m

Remarks: Trial pit remained dry. No further progress- brick obstruction.

Stability: Stable.

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Borehole Log

Borehole No.
WS101
Sheet 1 of 1

Project Name: Crown Quay	Project No. LP01205	Co-ords: -	Hole Type WLS
Location: Crown Quay Lane, Sittingbourne		Level:	Scale 1:20
Client: Bellway Homes		Dates: 14/02/2017 - 14/02/2017	Logged By MT

Well	Water Strikes	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
		Depth (m)	Type	Results				
								MADE GROUND: Brown sandy very gravelly clay. Gravel is fine to coarse flint, brick, clinker, charcoal, textile, concrete, mortar, chalk and slate.
		0.25	ES					
								Becoming orange brown and grey brown below 0.7m.
		0.80	ES					*With ashy pockets below 0.8m.*
		1.00		N=6 (1,1/2,1,2,1)				
					1.10			MADE GROUND: Dark grey gravelly clay with an organic alluvial odour and organic fiberous straw. Gravel is fine to coarse brick, flint, clinker, chalk, slate and mortar.
		1.50	ES					
								With much black organic staining and fiberous organic material above 1.9m.
		2.00		N=5 (1,1/1,1,1,2)				*Poor recovery between 2m and 3m.*
		3.00	ES		3.00			End of borehole at 3.00 m
		3.00		N=4 (1,1/0,1,2,1)				

Remarks
Borehole remained dry and stable. Standpipe installed to 3.0m, top 1.0m plain with bentonite seal, remainder slotted with gravel surrounding. Completed with gas tap and 0.5m upstanding cover.

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Borehole Log

Borehole No.
WS102
Sheet 1 of 1

Project Name: Crown Quay	Project No. LP01205	Co-ords: -	Hole Type WLS
Location: Crown Quay Lane, Sittingbourne		Level:	Scale 1:20
Client: Bellway Homes		Dates: 14/02/2017 - 14/02/2017	Logged By MT

Well	Water Strikes	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
■					0.10		▨	Asphalt.	
■		0.30	ES				▨	MADE GROUND: Grey brown and black sandy gravelly clay. Gravel is fine to coarse flint, brick, concrete, clinker, roadstone and chalk.	
■		0.65	ES				▨		
▨		1.00		N=10 (1,2/2,2,3,3)			▨		1
▨							▨	*With much chalk below 1.4m.*	
▨					1.60		▨	MADE GROUND: Red brown and grey brown very gravelly clay. Gravel is fine to coarse brick, mortar, chalk and asphalt.	
▨		1.80	ES				▨		
▨		2.00		N=18 (1,1/2,4,6,6)			▨	*Poor recovery between 2m and 3m.*	2
▨							▨	*Becoming a clayey fine to coarse gravel of brick, mortar, chalk and asphalt at 2.2m.*	
		3.00	ES		3.00		▨	End of borehole at 3.00 m	3
		3.00		N=8 (2,0/1,2,2,3)					
									4

Remarks
Borehole wet at 3.0m and collapsed to 2.5m. Standpipe installed to 2.5m, top 1.0m plain with bentonite seal, remainder slotted with gravel surrounding. Completed with gas tap and 0.5m upstanding cover.

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Borehole Log

Borehole No.
WS103
Sheet 1 of 1

Project Name: Crown Quay	Project No. LP01205	Co-ords: -	Hole Type WLS
Location: Crown Quay Lane, Sittingbourne		Level:	Scale 1:20
Client: Bellway Homes		Dates: 14/02/2017 - 14/02/2017	Logged By MT

Well	Water Strikes	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
		Depth (m)	Type	Results				
		0.10	ES				▨	MADE GROUND: Grey brown slightly gravelly clay. Gravel is fine to coarse brick, mortar, flint, chalk, ash and fragments of plastic sheet.
		1.00		N=4 (1,1/0,1,1,2)				
					1.40		▨	MADE GROUND: Orange brown and grey brown gravelly clay. Gravel is fine to coarse brick, flint, mortar, clinker, chalk, limestone and ash.
		1.50	ES					
		2.00		N=5 (1,1/1,1,2,1)				
					2.30		▨	MADE GROUND: Grey green silty clay. With some black organic staining and occasional fine to coarse gravel of flint, brick, chalk and clinker.
					2.90		▨	MADE GROUND: Grey clayey sandy gravel of fine to coarse clinker, brick, roadstone and glass.
		2.95	ES					
		3.00		N=0 (0,1/0,0,0,0)	3.00			End of borehole at 3.00 m

Remarks
Borehole remained wet at 3.0m and stable. Standpipe installed to 3.0m, top 1.0m plain with bentonite seal, remainder slotted with gravel surrounding. Completed with gas tap and 0.5m upstanding cover.

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Project Name: Crown Quay	Project No. LP01205	Co-ords: -	Hole Type WLS
Location: Crown Quay Lane, Sittingbourne		Level:	Scale 1:20
Client: Bellway Homes		Dates: 14/02/2017 - 14/02/2017	Logged By MT

Well	Water Strikes	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
		Depth (m)	Type	Results				
		0.35	ES		0.60			MADE GROUND: Dark brown very gravelly sandy clay. Gravel is much fine to coarse brick, flint, mortar and clinker with occasional chalk and whole flint. *With much fine to medium gravel of flint and shell at base.*
		0.80	ES					
		1.00	D					
		1.00		N=8 (0,1/2,2,2,2)	2.00			Firm becoming stiff orange brown silty CLAY with brown veining. *Hand Pen @ 0.8m UCS = 120 kPa* *Hand Pen @ 1.5m UCS = 210 kPa*
		2.00	D					
		2.00		N=9 (1,2/1,2,3,3)	3.00			Loose pale orange brown silty slightly clayey SAND. With occasional dark black speckling and veining and occasional fine to coarse gravel of flint and siltstone. *Becoming green brown and grey mottled below 2.9m.*
		3.00	D					End of borehole at 3.00 m
		3.00		N=9 (1,1/2,2,2,3)				

Remarks
Borehole remained dry and stable. Standpipe installed to 3.0m, top 1.0m plain with bentonite seal, remainder slotted with gravel surrounding. Completed with gas tap and 0.5m upstanding cover.

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Borehole Log

Borehole No.
WS105
Sheet 1 of 1

Project Name: Crown Quay	Project No. LP01205	Co-ords: -	Hole Type WLS
Location: Crown Quay Lane, Sittingbourne		Level:	Scale 1:20
Client: Bellway Homes		Dates: 23/02/2017 - 23/02/2017	Logged By MP

Samples and In Situ Testing

Depth (m)	Type	Results
0.60	ES	
1.00		N=13 (3,3/2,2,5,4)
1.20	ES	
2.00		N=0 (1,0/0,0,0,0)
2.50	ES	
3.00		N=6 (2,2/1,2,2,1)

Depth (m)	Level (m)	Stratum Description
0.15		Asphalt.
0.90		MADE GROUND: Dark brown sandy gravel. Gravel is fine to coarse gravel and cobbles of brick rubble, concrete, limestone. With occasional lenses of dark brown silty clayey sandy ash.
1.30		MADE GROUND: Black, brown and dark grey silty sandy clay with occasional fine to coarse gravel of fine to coarse flint, clinker and brick.
2.20		MADE GROUND: Dark brown and dark red brown silty very sandy gravelly clay. Gravel is fine to coarse brick and clinker with occasional pockets of off white chalk.
3.00		MADE GROUND: Dark grey and black grey silty clay with occasional coarse gravel of brick. *With a coarse sand layer at 2.9m.*

End of borehole at 3.00 m

Remarks
Borehole remained dry and stable. Standpipe installed to 3.0m, top 1.0m plain with bentonite seal, remainder slotted with gravel surrounding. Completed with gas tap and 0.5m upstanding cover.

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Borehole Log

Borehole No.	**WS106**	Sheet 1 of 1	
Project Name: Crown Quay	Project No. LP01205	Co-ords: -	Hole Type WLS
Location: Crown Quay Lane, Sittingbourne		Level:	Scale 1:20
Client: Bellway Homes		Dates: 14/02/2017 - 14/02/2017	Logged By MT

Well	Water Strikes	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
		Depth (m)	Type	Results				
		0.15	ES		0.20			MADE GROUND: Brown clayey gravelly sand. Gravel is fine to coarse brick, roadstone, mortar and concrete. *With a paving slab at 0.1m.*
		0.60	ES					MADE GROUND: Brown, yellow and red brown clayey sandy gravel of fine to coarse brick, mortat, flint, clinker and much cobbles of brick.
		1.00		N=6 (1,2/2,2,1,1)	1.40			
		1.60	ES					Firm becoming stiff orange brown silty CLAY with red brown staining and veining.
		2.00	D					*Hand Pen @ 2.0m UCS = 200 kPa*
		2.00		N=6 (2,1/1,2,1,2)	2.10			
								Stiff pale orange brown silty CLAY with some grey brown mottling. *With occasional fine to medium gravel of chalk below 2.8m.*
		3.00	D		3.00			*Hand Pen @ 3.0m UCS = 360 kPa*
		3.00		N=11 (1,2/2,3,3,3)				End of borehole at 3.00 m

Remarks
Borehole remained dry but collapsed to 2.5m. Standpipe installed to 2.5m, top 1.0m plain with bentonite seal, remainder slotted with gravel surrounding. Completed with gas tap and 0.5m upstanding cover.

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Borehole Log

Borehole No.
WS107
Sheet 1 of 1

Project Name: Crown Quay	Project No. LP01205	Co-ords: -	Hole Type WLS
Location: Crown Quay Lane, Sittingbourne		Level:	Scale 1:20
Client: Bellway Homes		Dates: 23/02/2017 - 23/02/2017	Logged By MP

Well	Water Strikes	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
		Depth (m)	Type	Results				
					0.15			Concrete.
		0.30	ES		0.70			MADE GROUND: Dark brown and black silty clayey sandy gravel of fine to coarse brick, clinker, mortar and concrete.
		0.80	ES		1.00			MADE GROUND: Dark grey brown silty slightly gravelly clay. Gravel is fine to coarse brick, chalk and ash with a slight organic odour.
		1.00		N=23 (1,5/5,5,6,7)	1.20			MADE GROUND: Brown and dark brown silty slightly sandy clay with occasional fine to coarse gravel of flint and brick.
		2.00		0 (5,50/0 for 0mm)	2.20			MADE GROUND: Dark grey and grey sandy gravel of fine to coarse gravel and cobbles of brick, chalk and clinker. *With a purple silty clay layer at 1.6m.*

End of borehole at 2.20 m

Remarks
Borehole remained dry and stable. No further progress due to refusal at 2.2m.

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Borehole Log

Borehole No.	**WS108**	Sheet 1 of 1	
Project Name:	Crown Quay	Project No. LP01205	Co-ords: -
Hole Type	WLS		
Location:	Crown Quay Lane, Sittingbourne	Level:	
Scale	1:20		
Client:	Bellway Homes	Dates:	23/02/2017 - 23/02/2017
Logged By	MP		

Well	Water Strikes	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
		Depth (m)	Type	Results				
					0.25		░	Reinforced concrete.
					0.45		▩	MADE GROUND: Grey brown sandy gravel of fine to coarse flint.
		0.50	ES		0.80		▩	MADE GROUND: Brown and grey brown silty gravelly sand. Gravel is fine to coarse brick, flint and concrete with frequent whole and half bricks.
		1.00 1.00	ES	N=26 (11,10/8,7,7,4)	1.10		▩	MADE GROUND: Dark grey brown very silty clay with fine to coarse gravel of flint, brick and ash.
					1.70		▩	MADE GROUND: Dark grey very silty sand with occasional fine gravel of brick and ash.
		2.00		N=0 (0,0/0,0,0,0)	2.40		▩	MADE GROUND: Dark grey and black silty sandy clay with a slight solvent odour. *With gravel of chalk at 2.0m.*
		3.00		N=10 (1,2/2,3,2,3)	3.00		▤	Stiff brown and orange brown very silty CLAY.
								End of borehole at 3.00 m

Remarks
Borehole remained dry and stable.

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Borehole Log

Borehole No.
WS109
Sheet 1 of 1

Project Name: Crown Quay	Project No. LP01205	Co-ords: -	Hole Type WLS
Location: Crown Quay Lane, Sittingbourne		Level:	Scale 1:20
Client: Bellway Homes		Dates: 23/02/2017 - 23/02/2017	Logged By MP

Well	Water Strikes	**Samples and In Situ Testing**			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
					0.05		▨	Asphalt.	
					0.20		▨	MADE GROUND: Black slightly sandy gravel of fine to coarse limestone.	
		0.30	ES		0.55		▨	MADE GOUND: Dark brown very sandy gravel of fine to coarse and cobbles of brick, mortar and concrete.	
								End of borehole at 0.55 m	
		1.00		N=15 (6,4/5,4,3,3)					1
		2.00		N=4 (1,0/1,1,1,1)					2
		3.00		N=6 (1,1/1,1,2,2)					3
									4

Remarks
Borehole remained dry and stable. No further progress due to obstruction.

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Borehole Log

Borehole No.
WS110
Sheet 1 of 1

Project Name: Crown Quay	Project No. LP01205	Co-ords: -	Hole Type WLS
Location: Crown Quay Lane, Sittingbourne		Level:	Scale 1:20
Client: Bellway Homes		Dates: 23/02/2017 - 23/02/2017	Logged By MP

Well	Water Strikes	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
		Depth (m)	Type	Results				
					0.05			Asphalt.
					0.25			MADE GOUND: Black slightly sandy gravel of fine to coarse limestone.
		0.40	ES					MADE GROUND: Dark brown silty gravelly sand. Gravel is fine to coarse metal, brick, mortar and flint. *With much cobbles of brick below 0.5m.*
		1.00		N=15 (6,4/5,4,3,3)	1.30			
		1.40	ES					Firm brown and orange brown silty CLAY.
		2.00		N=4 (1,0/1,1,1,1)				
		2.50	ES					
		3.00		N=6 (1,1/1,1,2,2)	3.00			End of borehole at 3.00 m

Remarks
Borehole remained dry and stable.

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Borehole Log

Borehole No.
WS111
Sheet 1 of 1

Project Name: Crown Quay	Project No. LP01205	Co-ords: -	Hole Type WLS
Location: Crown Quay Lane, Sittingbourne		Level:	Scale 1:20
Client: Bellway Homes		Dates: 23/02/2017 - 23/02/2017	Logged By MP

Well	Water Strikes	Samples and In Situ Testing Depth (m)	Samples and In Situ Testing Type	Samples and In Situ Testing Results	Depth (m)	Level (m)	Legend	Stratum Description
		0.50	ES		0.90		▨	MADE GROUND: Black and red brown clayey very sandy gravel of fine to coarse limestone, concrete, metal and brick wih occasional cobbles of brick and pockets of ash.
								End of borehole at 0.90 m

1
2
3
4

Remarks
Borehole remained dry and stable. No further progress due to concrete slab at base.

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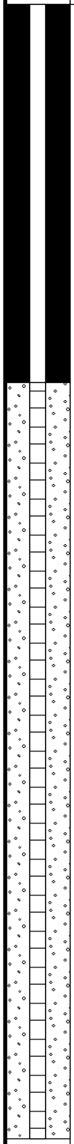
Borehole Log

Project Name: Crown Quay Planning	Project No. LP1802	Co-ords: 591154 - 164330	Borehole No. **WS201** Sheet 1 of 1 Hole Type WLS
Location: Sittingbourne		Level: 4.85	Scale 1:20
Client: Bellway Homes Ltd		Dates: 04/12/2018 - 04/12/2018	Logged By TK



Well	Water Strikes	**Samples and In Situ Testing**			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
					0.40	4.45	▨	MADE GROUND: Brown/dark brown gravelly sandy silty clay. Gravel is fine to coarse brick, flint and sandstone. Sand is fine to coarse.	
					3.00	1.85	▨	MADE GROUND: Dark brown and grey gravelly sandy silty clay. Gravel is fine to coarse brick, flint and organic matter. *Becoming dark grey with an organic odour below 1.1m.*	1 2
								End of borehole at 3.00 m	3
									4

Remarks
Borehole remained stable. Water ingress at 2.0m. Standpipe installed to 3.0m, top 1.0m plain with bentonite seal and remaining 2.0m slotted with gravel surround. Completed with gas tap and safety cover.

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Borehole Log

Borehole No.
WS202
Sheet 1 of 1

Project Name: Crown Quay Planning	Project No. LP1802	Co-ords:	591137 - 164270	Hole Type WLS
Location: Sittingbourne		Level:	4.26	Scale 1:20
Client: Bellway Homes Ltd		Dates:	04/12/2018 - 04/12/2018	Logged By TK

Well	Water Strikes	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
		Depth (m)	Type	Results				
■					0.25	4.01	▨	MADE GROUND: Grey brown sandy clayey fine to coarse gravel of flint, brick and tiling.
■					1.00	3.26	▨	MADE GROUND: Brown grey gravelly sandy silty clay. Gravel is fine to coarse flint, brick and charcoal.
▤					3.00	1.26	▨	MADE GROUND: Grey gravelly sandy silty clay with organic odour. Gravel is fine to coarse brick, chalk, coal and flint.

End of borehole at 3.00 m

1
2
3
4

Remarks
Borehole remained stable. Water ingress at 2.0m. Standpipe installed to 3.0m, top 1.0m plain with bentonite seal and remaining 2.0m slotted with gravel surround. Completed with gas tap and safety cover.

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Project Name: Crown Quay Planning	Project No. LP1802	Co-ords:	591176 - 164248	Hole Type WLS
Location: Sittingbourne		Level:	5.17	Scale 1:20
Client: Bellway Homes Ltd		Dates:	04/12/2018 - 04/12/2018	Logged By TK

Well	Water Strikes	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description	
		Depth (m)	Type	Results					
■							▨	MADE GROUND: Dark brown gravelly sandy silty clay. Gravel is fine to coarse brick, clinker, flint and tile. Sand is fine to coarse.	1
∘					1.60	3.57	▨	MADE GROUND: Yellow brown gravelly sandy silty clay. Gravel is fine to coarse brick, coal, flint and organic matter. Sand is fine to coarse.	
∘					2.00	3.17	☒	Firm to stiff grey and light grey mottled silty CLAY with occasional orange iron staining. *Hand Penetrometer UCS at 2.5m = 180kPa.*	2
					3.00	2.17		End of borehole at 3.00 m	3
									4

Remarks
Borehole remained dry and stable. Standpipe installed to 3.0m, top 1.0m plain with bentonite seal and remaining 2.0m slotted with gravel surround. Completed with gas tap and safety cover.

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Borehole Log

Borehole No.
WS204
Sheet 1 of 1

Project Name:	Crown Quay Planning	Project No. LP1802	Co-ords: 591106 - 164191	Hole Type WLS
Location:	Sittingbourne		Level: 4.86	Scale 1:20
Client:	Bellway Homes Ltd		Dates: 04/12/2018 - 04/12/2018	Logged By TK

Well	Water Strikes	**Samples and In Situ Testing**			Depth (m)	Level (m)	Legend	Stratum Description
		Depth (m)	Type	Results				
								MADE GROUND: Brown very clayey gravelly sand. Gravel is fine to coarse brick, flint, mortar, sandstone and clinker.
					1.30	3.56		MADE GROUND: Black sandy fine to coarse gravel of clinker and blacktop.
		1.80	ES					
								Becoming grey and clayey below 2.5m.
					3.00	1.86		End of borehole at 3.00 m

1
2
3
4

Remarks
Borehole collapsed to 2.0m. Water ponding in base of borehole. Standpipe installed to 2.0m, top 1.0m plain with bentonite seal and remaining 1.0m slotted with gravel surround. Completed with gas tap and safety cover.

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Borehole Log

Borehole No.
WS205
Sheet 1 of 1

Project Name: Crown Quay Planning	Project No. LP1802	Co-ords: 591072 - 164233	Hole Type WLS
Location: Sittingbourne		Level: 4.97	Scale 1:20
Client: Bellway Homes Ltd		Dates: 04/12/2018 - 04/12/2018	Logged By TK

Well	Water Strikes	Samples and In Situ Testing			Depth (m)	Level (m)	Legend	Stratum Description
		Depth (m)	Type	Results				
					0.17	4.80	░	CONCRETE
					0.60	4.37	▨	MADE GROUND: Brown gravelly fine to coarse sand. Gravel is fine to coarse brick, flint and mortar.
					0.95	4.02	▨	MADE GROUND: Yellow brown sandy fine to coarse gravel of yellow brick.
					1.70	3.27	▨	MADE GROUND: Dark grey gravelly sandy silty clay. Gravel is fine to coarse brick, charcoal, clinker and flint. Sand is fine to coarse.
		2.10	ES		2.20	2.77	▨	MADE GROUND: Black sandy fine to coarse gravel of clinker and blacktop. Sand is fine to coarse.
					2.50	2.47	▨	MADE GROUND: Black gravelly sandy silty clay with organic odour. Gravel is fine to coarse brick, flint and charcoal.
								End of borehole at 2.50 m

Remarks
Borehole remained dry and stable. No further progress below 2.5m as too dense. Standpipe installed to 2.5m, top 1.0m plain with bentonite seal and remaining 1.5m slotted with gravel surround. Completed with gas tap and safety cover.

Appendix C

RAM model and water balance (electronic files)

References

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