REMEDIATION AND RECLAMATION STRATEGY - 2020 ADDENDUM

British Sugar, York

APRIL 2020

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Remediation and Reclamation Strategy - 2020 Addendum

British Sugar, York

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1 Introduction

Arcadis Consulting Ltd (Arcadis) was commissioned by British Sugar Plc (British Sugar) to provide an updated Remediation and Reclamation Strategy Addendum (RRSA) in relation to the former British Sugar York facility, Mill Lane, York, YO26 6PD (the 'Site').

A Site location plan is presented as Figure 1 and a Site Layout plan is presented as Figure 2.

Planning permissions have been granted in relation to the proposed residential redevelopment of the Site (as further detailed in Section 1.1) which were supported by the previous Remediation and Reclamation Strategy (2015 RRS) document prepared by AECOM (AECOM, February 2015, Document Reference: 7068825/DOC/01). The 2020 RRSA is intended to update the agreed 2015 RRS based on additional Site data collected and assessments undertaken since 2015. The updated RRSA maintains a broadly similar approach to that outlined in the 2015 RRS and has been developed to ensure the protection of human health and environmental receptors such that the Planning Authority is satisfied the Site will be suitable for the proposed end-use.

This RRSA report is provided as an addendum to, and should be read in conjunction with, the 2015 RRS document and will revise, reference or concisely summarise specific strategy elements provided within the 2015 RRS, as appropriate. The provisions of the 2015 RRS remain relevant unless specifically stated otherwise, and hence superseded, by this addendum.

The 2020 RRSA has been informed by further regulatory liaison undertaken by Arcadis and the current (at the time of writing) draft illustrative Masterplan for the proposed redevelopment (LDA Design Consulting Ltd, DWG No.6891-LDA-00-XX-DR-L-1100) which is presented as Figure 3. While it is noted that the illustrative masterplan is subject to final confirmation, further refinement is not anticipated to have a significant effect on the proposed remediation and reclamation strategy.

1.1 Planning Permissions for Site Reclamation and Redevelopment

The following approved planning permissions have been granted by the City of York (CoY) Council in relation to the Site which form the basis for the scope of the remediation and reclamation works outlined.

- Construction of development platform, engineering works and remediation and reclamation of site, Application Reference No: 14/02798/FULM, granted on 15th September 2017;
- Construction of 2 no. access roads onto Boroughbridge Road and Millfield Lane and a link road across the former Manor School Site in association with the redevelopment of the former British Sugar site, with associated demolition of former school buildings, Application Reference No: 17/01072/FUL, granted 12th September 2017; and
- Outline application for the development of the site comprising up to 1,100 residential units, community uses (D1/D2) and new public open space with details of access (to include new access points at Millfield Lane and Boroughbridge Road and a new link road, crossing the Former Manor School Site) and demolition of the Former Manor School buildings. Application Reference No: 15/00524/OUTM, granted on appeal 28th September 2018.

1.2 Report Objectives

The 2020 RRSA has been prepared in order to:

- Incorporate additional information collected and available since the publication of the 2015 RRS including from further regulatory liaison;
- Provide a strategy for the land reclamation and remediation works required at the site to mitigate potential environmental and geotechnical risks and facilitate Site redevelopment;
- Satisfy the Planning Authority that upon completion of the reclamation and remediation works, the site will be suitable for its proposed end-use, with respect to both human health and environmental receptors;
- Provide a validation/verification strategy for the works to verify that works achieve the reclamation and remediation objectives set out in this strategy;

- Provide alignment of the reclamation, remediation and verification works with the requirements of the Waste Recovery Permit and, as far as practicable, the Environmental Permit (EPR/QP3593NF) surrender process and completion criteria; and
- Provide a materials management strategy in respect of the works to be undertaken.

1.3 Sources of Information

The 2020 RRSA is based on historic data and reports by third parties, additional information collected by third parties since publication of the 2015 RRS as well as the following works undertaken by Arcadis:

- Additional Ground Investigation Factual Report, 10024487-AUK-XX-XX-RP-GE-0032-01, Arcadis, March 2020;
- Updated Hydrogeological Risk Assessment Report, 10024487-AUK-XX-XX-RP-GE-0020-01, Arcadis, January 2020; and
- Ground Investigation Factual Report, 10024487-AUK-XX-XX-RP-GE-0015-01, Arcadis, August 2019.

The following third party reports and additional information were available to Arcadis at the time of writing.

- British Sugar Stabilisation Trials, Laboratory Bench Scale Mix Design Study, CE Geochem, Report A190504, November 2019;
- Quarter 2 2019 Gas and Groundwater Permit Monitoring Factual Report, Golder Associates (UK) Ltd, 2019;
- EP Annual Monitoring Reports, Golder Associates, 2015 to 2019;
- Outline Construction Environment Management Plan (Version 1.1), June 2017;
- Remediation and Reclamation Strategy – Final, URS (AECOM) February 2015;
- Surrender Pre-Application Advice Letter (EAWML68681), EA, 28th August 2015;
- Notice of Variation and Consolidation Document (EPR/QP3593NF/V002), 14th October 2015;
- Environmental Permit Variation: Working Plan (47068825), URS, August 2015;
- URS (2013) Summary Report for Ground Gas and Groundwater Data, 2006 – 2012, British Sugar Former Factory Site, York for ABF;
- Factual Report on Ground Investigation: Ian Farmer Associates Limited (2010) Associated British Foods - British Sugar York Site - August 2010: Contract No:W10/40642;
- British Sugar Factory York: Factual Vendor Due Diligence Report: Golder Associates (UK) Ltd, April 2010: Ref. 09514540114.500/A.0;
- Definitive Closure Management Plan – Annual Reports, Golder Associates, 2010 to 2014;
- Phase II Geotechnical and Geo-environmental Assessment report (Scott Wilson, 2010);
- Phase III Geoenvironmental Remediation Options Appraisal, Scott Wilson, December 2010;
- Geotechnical and Geo-environmental Audit of Available Site Information: Scott Wilson Ltd, August 2009;
- Definitive Closure Report for Waste Management Licence NYCC/028, Golder Associates, July 2009;
- Preliminary Geotechnical Considerations Non-Technical Summary: Golder Associates (UK) Ltd , December 2008: Ref.08514540111.504/B.1;
- Preliminary Report on Intrusive Site Investigation of Northern and Southern Waste Water Treatment Plant Areas: British sugar Factory, York: Golder Associates (UK) Ltd, October 2008: Ref. 08514540111.500;
- York Sugar Factory: SPMP Reporting: Assessment of Groundwater and Gas Reference Data - Final: Enviros Consulting Ltd, March 2008;
- Further Assessment of Potential Risks Posed by Soil Gas to Residential Properties on the Western Boundary of the York Sugar Factory: Enviros Consulting Ltd, October 2007; and

- York Sugar Factory: SPMP First Phase Reporting: Assessment of Reference Data: Enviros Consulting Ltd, August 2006.

1.4 Reliability of Information / Limitations

Arcadis' liability, pursuant to the terms of the appointment of Arcadis by British Sugar, is strictly limited to the work undertaken and the matters contained and specifically referred to in this report. Readers are referred to the Study Limitations in Appendix A.

1.5 Reliance

This report is only valid when read in its entirety. Any information or advice included in this report should not be relied on unless considered in the context of the whole report. Reference should be made to the notes on study limitations appended to this report.

There are neither third party rights nor benefits conferred under this report. Use of this report is strictly limited to British Sugar and its direct and indirect subsidiaries, which are the sole parties to whom Arcadis intends to confer any rights. Any reliance on the contents of this report by any other party is the sole responsibility of that party.

2 Current Site Condition

2.1 Environmental Setting

2.1.1 Site Location & Description

The Site covers an area of 39.7 Ha and the location and layout is shown on Figures 1 and 2, respectively.

Following decommissioning in 2009, the factory buildings, storage tanks and other infrastructure associated with sugar beet processing have been removed, with the exception of the site security office, and the site now comprises the following main areas;

- The former Northern Wastewater Treatment Plant (NWWTP) area including the Sugar Factory Lime (SFL) (marketed as LimeX) storage area and the Soil Conditioning Area (SCA);
- The former Central Tank Farm area;
- The former Main Factory area;
- The former Southern Wastewater Treatment Plant (SWWTP) area; and
- Additional Areas including the sports field, the former Manor School site and the entrance area to the NWWTP, which includes a surface water pond.

The former NWWTP, SFL storage area, SCA and central tank farm areas are located within the boundary of the EP. The former main factory area, SWWTP and Additional Areas are located outside of the permitted area.

Figure 2 also shows the extent of the Environmental Permit boundary and location of the main site areas.

2.1.2 Geology, Hydrogeology and Hydrology

The regional geology, hydrogeology and hydrology is described in detail in multiple previous reports, including the 2015 RRS, and so a concise summary is provided below.

Geology

The BGS solid and drift geological map for York (Sheet 63) 1:50,000 indicates that the Site is predominantly underlain by Glaciofluvial Deposits (Sand and Gravel). A small fraction of the site in the southeast area is underlain by Alluvium, Lacustrine clay (lake derived) and Warp (sediments allowed to settle out of estuarine water to produce agricultural land) formations.

The BGS drift geological map for York (Sheet 63) 1:50,000 indicates that the underlying solid geology is comprised of Sherwood Sandstone Group (Sandstone).

Hydrogeology

The Glaciofluvial Deposits (Natural Superficial Deposits (NSD)) present beneath the majority of the site are classed by the Environment Agency (EA) as a Secondary A aquifer.

The underlying bedrock of the Permo-Triassic Sherwood Sandstone Group is classified as a Principal aquifer.

A review of published reports and site data was undertaken by AECOM in response to EA queries associayed with the 2015 RRS and specifically regarding the presence of nickel and manganese within the Secondary A aquifer and the potential hydraulic continuity between this aquifer and the underlying Principal Aquifer. AECOM conclude that the presence of manganese and nickel in the NSD and in the sandstone aquifer is natural; and that recharge to the sandstone is limited and occurs via the more permeable deposits in the NSD to the north of York and north of the site. At the site scale the presence of clay deposits in the NSD effectively confines the Sherwood Sandstone aquifer beneath the NSD and there is minimal mixing local to the site.

The Environment Agency designates the groundwater vulnerability for the site mainly as Minor Aquifer High. There are no Source Protection Zones (SPZs) within 5km of the site.

The Phase II Geotechnical and Geo-environmental Assessment report (Scott Wilson, 2010) as well as the findings from monitoring carried out by Golder Associates (from 2009 to 2019) indicates the groundwater flow is generally in a south easterly direction towards the River Ouse with a north easterly flow direction prevalent beneath the north western part of the Site (again towards the River Ouse).

Hydrology

The hydrological features within the site boundary are the soil settling ponds and water treatment ponds located in the North West area of the site. The main surface water feature in the vicinity of the site is the River Ouse, which ranges between 200m and 550m to the east of the site. The River Ouse is also the closest watercourse monitored by the Environment Agency (EA). The Envirocheck report (Ref. 33336222_1_1) indicates that there are three surface water abstraction points from the River Ouse identified within 500m of the site. These are abstractions licensed to the Yorkshire Water Services Ltd for potable public water supply.

2.2 Encountered Ground Conditions

2.2.1 Previous Investigations

A number of detailed site investigations have been undertaken between 2006 and 2019. The combined exploratory hole locations from all summarised ground investigation reports are presented on Figure 4. The scopes of the respective investigations are summarised in Table 1.1 of the 2015 RRS.

As noted above, Arcadis have carried out two additional investigations as summarised below:

Arcadis 2019

Sitewide investigation to obtain up to date information on ground conditions (including areas not previously investigated), the presence of obstructions following demolition works, geotechnical and environmental condition of site, and to assess quantity of sediment within settlement lagoons.

The scope of works included:

- 5 no cable percussion boreholes to depths of between 8.00 and 20.00m bgl.
- 25* no static cone penetration tests to depths of between 0.13 and 26.00m bgl.
- 7 no window sample boreholes to depths of up to 6.45m bgl.
- Excavation of 32 trial pits, and 10 trial trenches.

* where CPT testing encountered shallow refusals, up to 3no additional tests were carried out at each location.

Arcadis 2020

Limited additional investigation in the SWWTP to confirm ground conditions following vegetation removal.

- 2 no cable percussion boreholes each to 15.45m depth.

Reports on the respective investigations are listed in Section 1.3.

2.2.2 Underlying Strata Encountered

Made Ground is present across the entire site footprint. The nature and distribution of the made ground varies significantly and is related to the former usage of the area as summarised below.

2.2.2.1 Made Ground

NWWTP

Several distinct types of made ground were noted within the NWWTP including

- Soil Conditioning Area- Variable reworked natural soils (predominantly silts and clays locally mixed with Sugar Factory Lime), however sand was also noted where small bunds had been constructed during the handling process. Material is typically highly compressible, with a high moisture content and locally high organic content. Extends to depths of up to 12m bgl.

- Pond bunds- mixture of granular and cohesive material, typically consisting of reworked natural soils with minor amounts of anthropogenic material (concrete, brick, ash and SFL) used to form the structure of the above ground ponds.
- Infilled ponds-typically soft or very soft clay, often organic with fragments of brick, concrete etc. however other materials were also noted. Note the number of sampling locations were limited due to the difficulty accessing these areas.
- Settlement ponds-within the ponds settled fines were found to comprise very soft, settled fines of clay, silt or fine sand ranging in thickness from 0.2 to 2.7m. Note the estimated thickness in 2019 were significantly less than hose estimated in 2010.

Central Tank Farm Area

- Made ground was typically less than 1m in thickness of granular material -principally limestone and crushed concrete.
- Piled foundations were noted to extend beneath the made ground into the natural strata.
- A limited number of shallow trial pits were excavated into the toe of the Central Tank Farm Bund. These encountered conditions similar to those within the soil conditioning area (reworked predominantly cohesive soils with varying quantities of topsoil, however locally fragments of broken asbestos cement sheeting were also noted.

Main Factory and SWWTP

- Made ground was typically granular in nature and included abundant concrete, brick etc. Locally deposits of Sugar Factory Lime recorded as a silty gravel, or boulders were also encountered where the material had been used as engineering fill. Locally more cohesive deposits, and material with an ammoniacal odour were noted.
- Made ground was generally thicker (up to approximately 9m thick) in the SWWTP, than in the Main Factory Area (typically 2 to 3m thick).

Former Manor School

- Made ground beneath the former Manor School site and playing fields was limited to typically less than 1m in thickness.

2.2.2.2 Superficial Deposits

Natural Strata beneath the made ground was generally found to be consistent with the published geology of the area and included generally firm (locally soft) sandy clay, or loose to medium dense granular deposits of sand, gravel, or combinations of both. The exception to this was an area of very soft organic rich clay or fibrous peat which was encountered at the southernmost area of the site. A plan showing the approximate extent of the organic rich natural soils is included as Figure 5.

2.2.3 Current Geotechnical Condition

The geotechnical properties of the shallow soil is described in detail in multiple previous reports, including the 2015 RRS, and so a concise summary of the additional information gathered by Arcadis is provided below.

2.2.3.1 Moisture Content

A key factor determining the geotechnical properties of a soil is related to the soil's moisture content. For a given soil, a maximum degree of compaction can be achieved by compacting the soil at the Optimum Moisture Content (OMC). If the soil is compacted at lower or higher moisture content than the OMC, it will not be possible to adequately compact the soil, and issues such as long term settlement may occur. Typically soils with a natural moisture content of more than 4% above OMC require some form of improvement before they can be reused as earthworks fill.

For this reason OMC and natural moisture content testing data was obtained for a further 20 samples from across the site. OMC for the main soil types tested showed little variation and ranged from 11 to 15%, however natural moisture content ranged widely from 14 to 94%, with the higher moisture contents all being recorded within the soil conditioning area mound.

A sample of lagoon sediment (considered atypical of the main soil types on site) was found to have a natural moisture content of 133% and an OMC of 13%. The moisture contents are calculated on a % dry weight basis and so moisture contents >100% are possible.

A plan showing variation in moisture content across site from the recent and historical data is included in Figure 6.

2.2.3.2 Subsurface Obstructions

A number of subsurface obstructions were recorded on the demolition plans for the site, and Arcadis undertook trial pitting and trenching to target a number of these locations to confirm the current condition of these structures. The following significant features were encountered:

- Beet Reception Building basement- concrete base slab and basement walls encountered beneath main factory area. The location and extent were consistent with the demolition records.
- Central Tank Farm- redundant piles were encountered at the location of three of the former tanks. The locations were consistent with the demolition records

The following obstructions were also encountered at locations not identified within the demolition records:

- Former tank base west of weighbridge building. An extensive concrete foundation was encountered at approximately 1m depth, west of the current weighbridge. Ordnance Survey maps from 1957 suggest this may be associated with a former above ground storage tank, the date of demolition of which is unknown. The records indicate that the tank base may be in the order of 35m metres diameter.
- Former Manor School site. Concrete slab and shallow strip foundations encountered at location of former school building (outside of area covered in demolition records.
- Localised minor structures (strip footings/masonry walls) were encountered beneath the main factory site- these are assumed to be related to early phases of development at the site.

A plan showing the approximate location of these obstructions is presented as Figure 7.

2.2.4 Soil Contamination

Based on the information obtained on ground conditions and soils chemistry provided by the previous ground investigations, sources of contamination in soils, soil leachates and ground gas have been identified. Arcadis have undertaken additional ground investigation works since the production of the 2015 RRS (Arcadis Report Ref: 10024487-AUK-XX-XX-RP-GE-0015-01, August 2019).

The results of all previous third party investigations and recent works undertaken by Arcadis have been digitised and imported into an ESdAT database system which enables more effective data management and automated comparison to selected threshold values as well as supporting a Geographical Information systems (GIS) model created to visualise and conceptualise environmental data and material volumes for remediation.

2.2.4.1 Total Petroleum Hydrocarbons

The distribution of Sum Total Petroleum Hydrocarbons (TPH) concentrations (C_5 to C_{35}, aliphatic and aromatic hydrocarbons) measured within Site soils during previous phases of investigation, as well as during the 2019 Arcadis Site Investigation, are shown on Figure 8.

Measured concentrations were compared against the Soil Remedial Target Value (RTV), provided within the 2015 RRS and reproduced for reference in Table 7, Section 4.3.1, in order to assess the requirement for remediation of identified TPH contamination. The RTVs are discussed in further detail in Section 4.3.1.

The RTV for certain aliphatic and aromatic TPH fractions also include theoretical soil saturation limits which indicate where a measured soil concentration, if above this limit, may be indicative of the presence of free phase hydrocarbon (i.e. oil or fuel present within sore pores). Therefore, where soil concentrations were measured above the soil saturation limit additional review of visual and olfactory evidence of free phase hydrocarbons (recorded on exploratory trial pit and borehole logs) was undertaken to assess whether free phase hydrocarbons were indeed likely to be present. If there were no observations indicative of free phase liquid and TPH concentrations in soil were measured below the RTV then soil at this depth / location was not considered to require remediation for TPH.

Hydrocarbon compounds defined as volatile or non-volatile are listed in Table 5.8 of the 2015 RRS. Three exceedances of a ‘volatile’ (<C16) petroleum hydrocarbon were identified within soil sampled from GA-GW11, GP-TP02A and GA-TP03A.

Additional site investigation works undertaken by Arcadis in 2019 were specifically designed to address data gaps identified within the available site data and, therefore, further delineation of the six previously identified hotspots was undertaken. Locations of exceedances of RTVs as well as locations were free phase hydrocarbons were likely to be present (also marked as an exceedance) were used to further delineate TPH hotspots as shown on Figure 8.

The petroleum hydrocarbon fractions identified within Site soils generally comprised C_{12} to C_{35} range hydrocarbons corresponding with relatively low volatility, diesel range and heavier hydrocarbon fuels rather than gasoline with more volatile hydrocarbon compounds such as benzene, toluene, ethylbenzene and xylenes (BTEX) rarely measured above laboratory method detection limits.

2.2.4.2 Polycyclic Aromatic Hydrocarbons

The distribution of Sum Polycyclic Aromatic Hydrocarbons (PAHs) (USEPA 16 compounds) concentrations measured within Site soils during previous phases of investigation, as well as during the 2019 Arcadis Site Investigation, are shown on Figure 9.

Measured concentrations were compared against the RTVs, provided within the 2015 RRS and reproduced for reference in Table 7 (Section 4.3.1) in order to assess the requirement for remediation of identified PAH contamination. The RTV for individual PAH compounds are dependent on the organic matter content of the soil sample collected and so, where available the Total Organic Carbon (TOC) and Fraction of Organic Carbon (foc) data has been reviewed to determine the appropriate RTV. RTVs are discussed in further detail in Section 4.3.1.

This comparison identified isolated exceedances of individual PAH compounds within shallow (<1m bgl (below ground level)) soils collected from 5 locations located across the Main Factory area (SW-TP24, SW-TP31, SW-WS01, GA-TP26C, and GA-GW12). A review of soil descriptions associated with these exceedances recorded on third party exploratory logs indicates these PAH exceedances were frequently associated with sand and gravel Made Ground where ash and bituminous material were noted to be present.

Exceedances of RTVs were previously (2010) measured for Benzo(a)pyrene, Dibenzo(a,h)anthracene and Indeno(1,2,3-cd)pyrene in two sediment samples obtained from the north western pond (SW-GS1 and SW-GS2), however, PAHs concentrations in sediment samples collected by Arcadis in 2019 were below laboratory Method Detection Limits (MDL).

2.2.4.3 Asbestos

The 2015 RRS noted that asbestos (chrysotile / amosite) was recorded in samples from two locations in the southern half of the site. Further data review by Arcadis identified that these samples were SW-WS23b (1.0m bgl, Chrysotile asbestos) located in the Southern WWTP (AA4a) and SW-WS01 (shallow, Amosite asbestos) located in the southern west of the Main Factory area.

Further investigation undertaken by Arcadis in 2019 identified Asbestos Containing Material (ACM) (Amosite asbestos) within two locations; AUK_TP04 located in the Playing Fields area and AUK_TP24 located in Historic Pond 7. In addition, free asbestos fibres in soil (Chrysotile) were detected in AUK_BH04 located in the SCA as well as in AUK_TP33 (Amosite, Chrysotile and Crocidolite) located in the Northern WWTP area.

In addition, asbestos, present as free fibres, was identified in soil sampled from AUK_BH202 at depths of 1.0-1.5m bgl and 4.0-4.5m bgl during additional ground investigation works to install two perimeters wells undertaken by Arcadis in March 2020.

2.2.5 Soil Leachate Contamination

2.2.5.1 Ammoniacal Nitrogen

The distribution of ammoniacal nitrogen (reflective of both ammonia and ammonium) concentrations measured within Site soil leachates during previous phases of investigation, as well as during the 2019 Arcadis Site Investigation, are shown on Figure 10.

The derivation of the ammoniacal nitrogen RTV for soil leachates using the Remedial Target Methodology (RTM) has been described within the 2015 RRS with a Tier 3 assessment undertaken to assess the fate of ammoniacal nitrogen in leachate and groundwater under the aerobic conditions identified to be present. Additional sensitivity analysis was conducted in response to previous EA comments and included within the revised 2015 RRS. A review of these RTVs was undertaken by Arcadis as part of the updated Hydrogeological Risk Assessment (HRA) (Report Ref: 10024487-AUK-XX-XX-RP-GE-0020-01, 2020) which considered these RTVs to be supportive of achieving the Site Specific Assessment Criteria (SSAC) for the protection of groundwater and thus provide an appropriate level of source reduction.

Measured concentrations were therefore compared against the soil pore water RTVs provided within the 2015 RRS which were defined based on Averaging Areas shown in Table 1 below and on Figure 10.

Averaging Area	RTV for Leachate* (mg/L)
AA1a	46
AA1b	12
AA2	3
AA3a	5
AA3b	2
AA4a	2
AA4b	26

* the variation in RTV values is due to the differing distances to the receptor (River Ouse) and the variation in the length of each area.

Table 1 Soil Pore Water (Leachate) Remediation Target Values (RTV) for Ammoniacal Nitrogen

The distribution of elevated ammoniacal nitrogen concentrations, the locations of soil pore water RTV exceedances and well as soil descriptions and observations recorded within exploratory logs indicate that ammoniacal nitrogen contamination is strongly associated with Organic Rich Material historically deposited within the North West area (including the northern WWTP) and the southern WWTP. The average and maximum concentrations of ammoniacal nitrogen in soil leachate from Averaging Areas AA1a and AA1b (corresponding to the majority of the NWWTP area) are 27.8mg/L and 125mg/L (AA1a) and 22.2 mg/L and 67.2mg/L (AA1b), respectively.

Isolated exceedances of the soil pore water RTV were identified within Made Ground outside the NWWTP and SWWTP and these locations have been identified as ‘hotspots’ on Figure 10.

2.2.5.2 Metals and Metalloids

Localised exceedances of Environmental Quality Standards (EQS) values of a number of metals and metalloids have been recorded within a small number of soil leachate samples. The contaminants noted include arsenic, copper, manganese and zinc. However, these contaminants are not considered to present any unacceptable risk to environmental receptors due to their localised nature as well as the fact that the mean concentrations of these contaminants were all below their corresponding EQS value. Arsenic, copper, manganese and zinc in soil leachate are, therefore, not considered to require remediation. Additional assessment of Nickel has been undertaken by Arcadis as part of the Updated HRA (Report Ref: 10024487-AUK-XX-XX-RP-GE-0020-01, January 2020) as described in Section 3.3.1 and also is not considered to require active remediation.

2.2.6 Groundwater Conditions

During previous intrusive investigations (Enviros 2008, URS 2015 and Arcadis 2019), groundwater has generally been encountered within the superficial deposits, with an additional groundwater strike encountered where intrusive holes were progressed into the bedrock (URS 2015). The depth to groundwater across the Site varies due to the differing topography, while groundwater is indicated to flow towards the River Ouse in a north-easterly direction.

The most recent groundwater monitoring programme available at the time of review was undertaken by Golder Associates in 2018 and 2019 (Quarter 3) (referenced in Section 1.3). The Golder Associates environmental monitoring activities are to continue until the remediation and reclamation works commence.

Data provided as part of the 2018 EP Annual Monitoring Report (Golder Associates, 2018) showed that groundwater levels recorded ranged from 9.97 to 17.97m AOD and 1.18 to 16.25m bgl with this representing more variance than observed in previous years. Long term trends in the ammoniacal nitrogen concentrations in groundwater sampled from wells located on-site were generally stable with trends in down gradient wells generally stable or decreasing (with the exception of GA-GW04 which showed an upwards trend although this has been decreasing since September 2018).

2.2.7 Ground Gas Regime

Ground gas monitoring from a network of borehole standpipes across the site has been conducted over the period of several years from September 2008 to April 2019 and remains ongoing at the time of writing. Ground gas monitoring has comprised the measurement of carbon dioxide (CO_2), methane (CH_4), oxygen (O_2), carbon monoxide (CO), hydrogen sulphide (H_2S) and gas flow rate during the monitoring period. Based on the results of this monitoring it is considered that methane and carbon dioxide are the principal gases of concern in relation to the proposed development.

Additional ground gas data has been collected on a monthly basis and reported quarterly since the 2015 RRS was produced which has been reviewed to update the previous assessment of the ground gas regime detailed within the 2015 RRS report.

For the 2020 RRSA, the borehole flow rate and gas concentrations for carbon dioxide (CO_2) and methane (CH_4) have been compared to guidance values given in the following documents:

- BSI Standards Publication “Code of practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings”, BS 8485:2015+A1:2019
- CIRIA Report C665 “Assessing Risks Posed by Hazardous Ground Gases to Buildings”, 2007; and
- NHBC “Guidance on Evaluation of Development Proposals on Sites where Methane and Carbon Dioxide are Present” 2007.

Reference has also been made to the following UK publications;

- Contaminated Land: Applications in Real Environments (CL:AIRE) Research Bulletin RB17 (RB17) – A Pragmatic Approach to Ground Gas Risk Assessment, 2012; and
- NHBC Technical Extra, Issue 20, April 2016.

The BS8485 (2015+A1:2019) publication provides an empirical, semi-quantitative method of assessment of hazards from permanent ground gases and incorporates best practice as set out in CIRIA C665. This includes calculation of the borehole hazardous gas flow rate (Q_{hg} in litres/hour) for each borehole and each monitoring event for each hazardous gas, as shown below:

$$Q_{hg} = q\left(\frac{C_{hg}}{100}\right)$$

where:

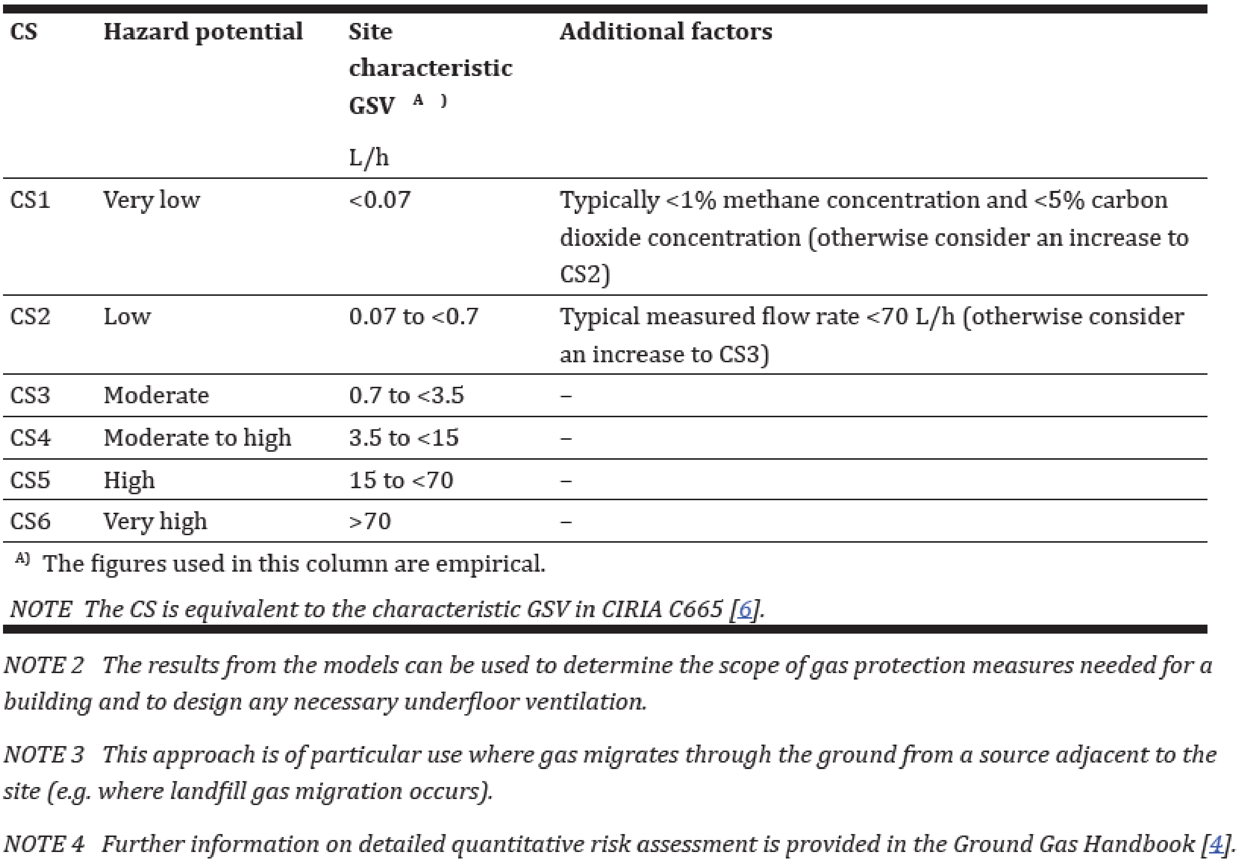
q is the measured flow rate (in litres per hour) of combined gases from the monitoring standpipe.

C_{hg} is the measured hazardous gas concentration (in percentage volume/volume).

It also sets out how measured Q_{hg} values can be used to adopt a Gas Screening Value (GSV) that represents the gas hazard present across the entire site or across different site zones. Where the dataset is representative and comprehensive, the GSV should be the maximum Q_{hg}. The guidance also recommends that plausible worst case conditions should be calculated for each hazardous gas by multiplying the maximum recorded flow in any standpipe in that strata (and zone) with the maximum gas concentration in any other standpipe in that strata (and zone) as a check on the adopted GSV. This 'worst case' check on the adopted GSV has also been requested in liaison with the EA Yorkshire Area Landfill Team (provided in Appendix B) in relation to EP surrender.

However, it is important to note that the existing ground conditions are not those pertaining to the post-reclamation conditions relevant to the intended redevelopment of the site. Materials present at the site will undergo excavation, segregation, remediation (as necessary) and compaction before use in the development with final consideration of GSV and any Site zoning based on post remediation ground gas conditions and material placement (described in Section 7.3).

The Characteristic Situation (CS) defines the minimum level of protection required by allocation of a required gas protection score, based on building type. As set out in BS8485 (2015+A1:2019) The CS should be determined for both methane and carbon dioxide from the adopted GSV and the ranges set out in the table below.



CS	Hazard potential	Site characteristic GSV A) L/h	Additional factors
CS1	Very low	<0.07	Typically <1% methane concentration and <5% carbon dioxide concentration (otherwise consider an increase to CS2)
CS2	Low	0.07 to <0.7	Typical measured flow rate <70 L/h (otherwise consider an increase to CS3)
CS3	Moderate	0.7 to <3.5	–
CS4	Moderate to high	3.5 to <15	–
CS5	High	15 to <70	–
CS6	Very high	>70	–

A) The figures used in this column are empirical.

NOTE The CS is equivalent to the characteristic GSV in CIRIA C665 [6].

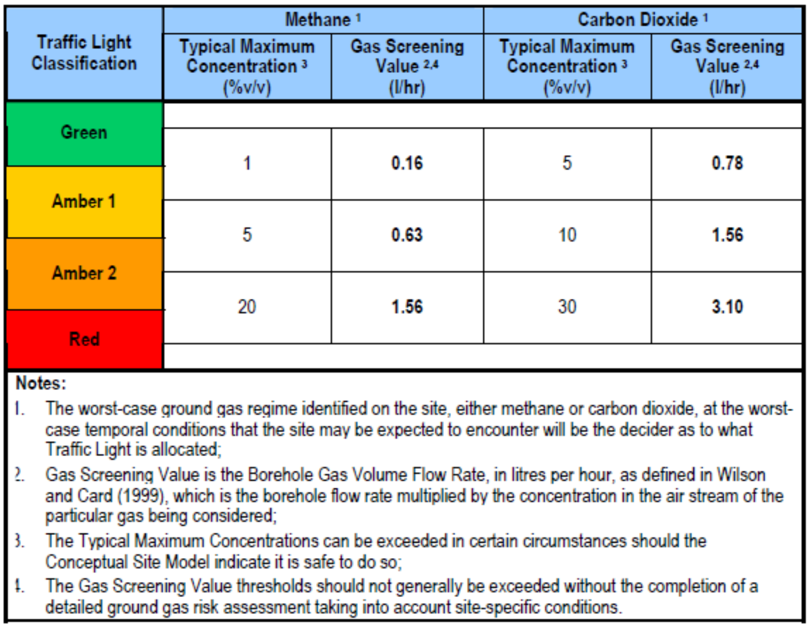
NOTE 2 The results from the models can be used to determine the scope of gas protection measures needed for a building and to design any necessary underfloor ventilation.

NOTE 3 This approach is of particular use where gas migrates through the ground from a source adjacent to the site (e.g. where landfill gas migration occurs).

NOTE 4 Further information on detailed quantitative risk assessment is provided in the Ground Gas Handbook [4].

Table 2 Characteric Situation (CS) by characteristic Gas Screening Value (reproduced from BS8485 (2015+A1:2019))

The NHBC Technical Extra, Issue 20 (2016) provided updated advice regarding alternative approaches for characterising gas regimes (referencing CL:AiRE 2012) and the design of measures to deal with gas risks. However, the NHBC guidance document (2007) and Traffic Light values remain applicable as summarised in the 2015 RRS and shown in the table below.



Traffic Light Classification	Methane [1]		Carbon Dioxide [1]	
	Typical Maximum Concentration [3] (%v/v)	Gas Screening Value [2,4] (l/hr)	Typical Maximum Concentration [3] (%v/v)	Gas Screening Value [2,4] (l/hr)
Green				
	1	**0.16**	5	**0.78**
Amber 1				
	5	**0.63**	10	**1.56**
Amber 2				
	20	**1.56**	30	**3.10**
Red				

Notes:

1. The worst-case ground gas regime identified on the site, either methane or carbon dioxide, at the worst-case temporal conditions that the site may be expected to encounter will be the decider as to what Traffic Light is allocated;
2. Gas Screening Value is the Borehole Gas Volume Flow Rate, in litres per hour, as defined in Wilson and Card (1999), which is the borehole flow rate multiplied by the concentration in the air stream of the particular gas being considered;
3. The Typical Maximum Concentrations can be exceeded in certain circumstances should the Conceptual Site Model indicate it is safe to do so;
4. The Gas Screening Value thresholds should not generally be exceeded without the completion of a detailed ground gas risk assessment taking into account site-specific conditions.

Table 3 Gas Risk Assessment – Traffic Light Classification (reproduced from NHBC, 2007)

2.2.7.1 Assessment of Current Ground Gas Conditions

Ground gas data collected by Golders as part of the monthly EP monitoring undertaken between 2010 and 2019 has been collated, digitised and reviewed within a Power BI Dashboard to facilitate data and trend analysis. The temporal trends in maximum carbon dioxide and methane concentrations, as well as maximum total gas flow rates between 2010 and 2019 are shown in Table 4 below, which includes data from locations within and outside the EP boundary.

The results of the trend analysis indicate that since 2015 maximum concentrations of methane and carbon dioxide have remained generally stable while total gas flow rates have significantly decreased. This is considered to reflect continued degradation of organic matter within deposited materials and associated reduction in the quantity of ground gas generated. Overall, the data indicates a significantly improved situation with respect to potential ground gas risks at the Site compared with those assessed as part of the 2015 RRS.

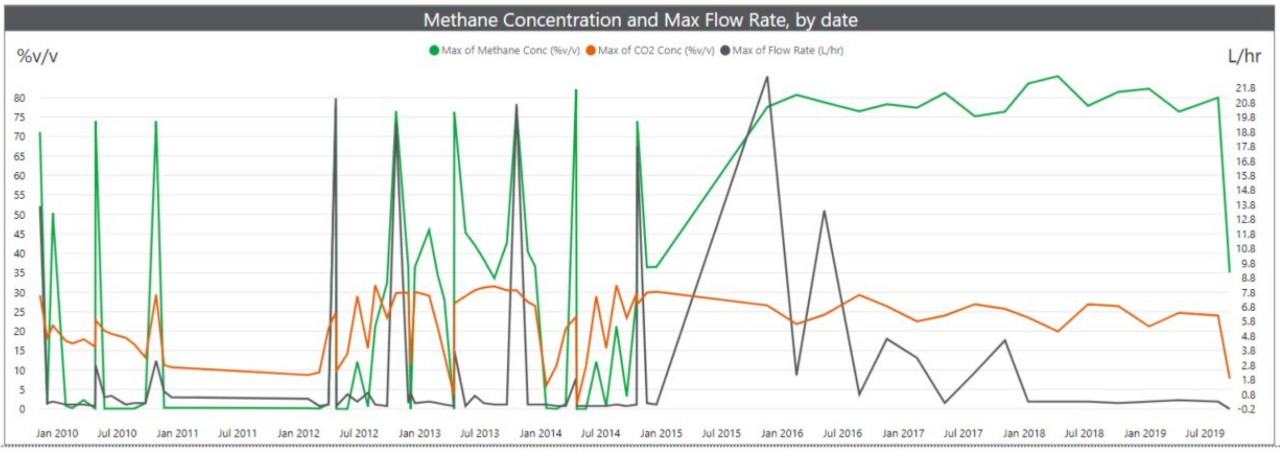


Table 4 Graph showing maximum flow rate, methane and carbon dioxide concentrations (2010-2019)

An assessment of the Q_{hg} between January 2018 and April 2019 show that while the maximum measured concentrations of carbon dioxide (26.9% v/v) and methane (85.5% v/v) remain elevated in some locations, total gas flow rates are very low (maximum of 0.4 l/hr (mean 0.2 l/hr)) resulting in a maximum Q_{hg} for carbon dioxide of 0.071 l/hr and 0.247 l/hr for methane. Assessment of a worst case scenario using the highest measured gas concentration multiplied by the highest measured total gas flow rate give worst case Q_{hg} values of 0.342 l/hr for methane and 0.108 l/hr for carbon dioxide.

Overall, the data indicates that a CS2 classification is appropriate for both methane and carbon dioxide. It is noted that only a single monitoring event between January 2018 and April 2019 gave a GSV value >0.07L/hr for carbon dioxide and so this classification is considered conservative.

Classification under the NHBC traffic light system indicates that ground gas wells GA-S25 and GA-S07 would be classified as 'Amber 1' based on the calculated Q_{hg} values. These two wells are located in the area of Historic Pond 7 (infilled). Maximum gas concentrations of methane and carbon dioxide in these two locations are above the threshold for Amber 2 and/or Red classifications and therefore consideration has been given to whether these locations should be classified at a higher level. These two ground gas wells are both located within a relatively small area of historic infilled pond 7 and several phases of site investigation have been undertaken to inform a robust Conceptual Site Model (CSM) from which it is clear that these elevated gas concentrations are associated with Organic Rich Material deposited prior to 2009 in this area. Ground gas monitoring has been undertaken monthly since 2009, incorporating a range of atmospheric conditions and including continuous monitoring (2015 RRS). Recent data from these wells (shown below in Table 5 and 6) demonstrates decreasing trends in total gas flow rates since 2016, with very low flow rates measured since January 2018, alongside stables trends in gas concentrations. This is considered to reflect continued degradation of organic matter and reduction in the generation of ground gas. Therefore, it is considered that Amber 2 is an appropriate and conservative NHBC classification for these wells.

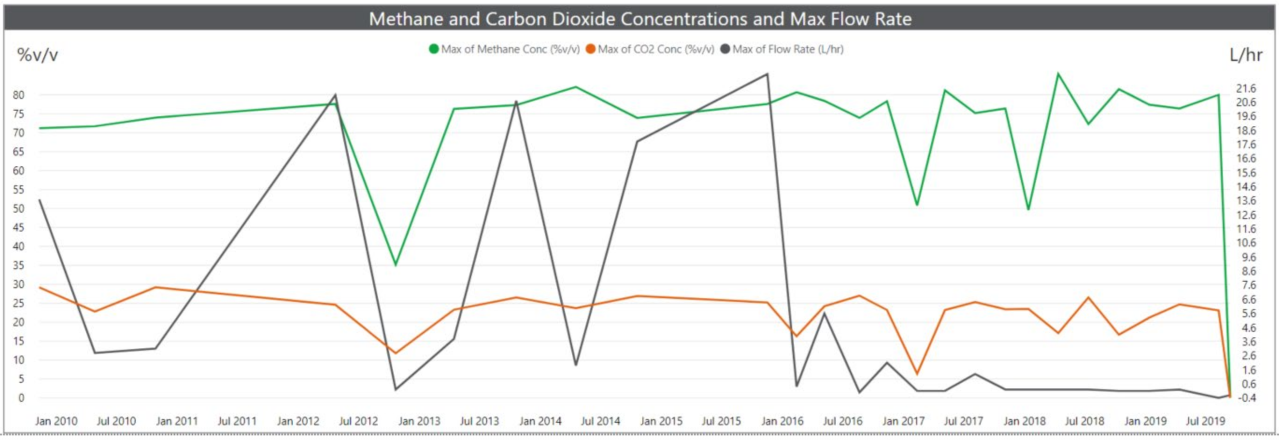


Table 5 Graph showing maximum flow rate, methane and carbon dioxide concentrations in GA-S07 (2010-2019)

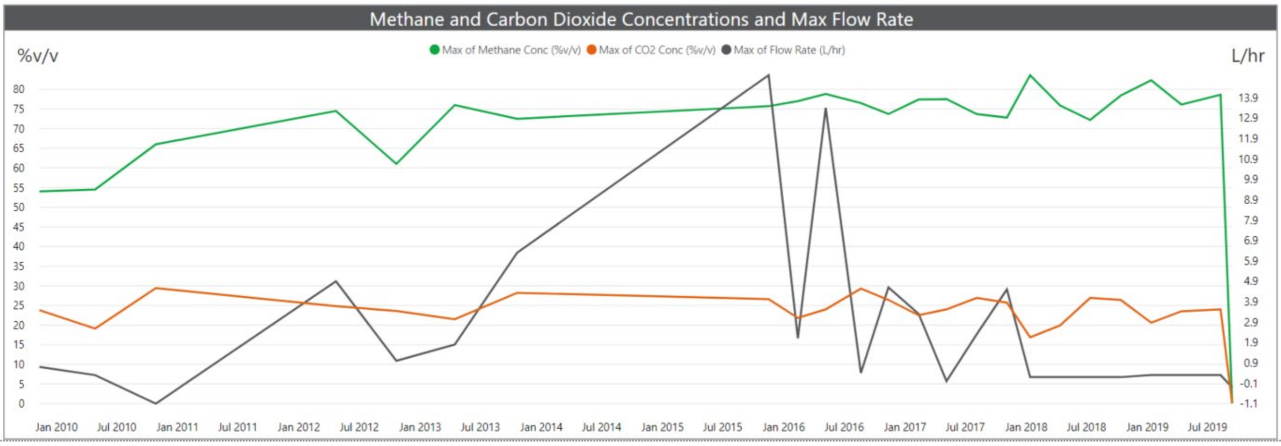


Table 6 Graph showing maximum flow rate, methane and carbon dioxide concentrations in GA-S25 (2010-2019)

The remaining ground gas monitoring wells across the Site are currently classified as Green based upon the calculated Q_{hg} value for both methane and carbon dioxide. While a number of locations have maximum measured carbon dioxide and methane concentrations above the threshold for Green classification, measured gas flow rates are generally decreasing and measured at very low flow rates since January 2018. It is considered that an extensive ground gas monitoring data set, as well as a robust CSM, supports classification of wells outside historic infill pond 7 as Green. The exception to this are 3 locations (GA-S24, GA-S38 and GA-S36), located within Historic Pond 7 and the SCA, where maximum methane concentrations are above the Red classification threshold (20% v/v) for which an Amber 1 classification is considered appropriate and conservative.

The distribution of NHBC traffic light ground gas classifications are shown on Figure 11.

As discussed above, the recent data and trend analysis indicates that the ground gas regime at the Site is stable with respect to carbon dioxide and methane concentrations, with a decreasing gas flow reflecting continued degradation of organic matter and a significantly improved situation compared with a previous assessment during production of the 2015 RRS.

Finally, monitoring data reviewed by AECOM within the 2015 RRS indicated that lateral migration of ground gas into surrounding land is not occurring. This was to be expected, as the gas source is located in the Made Ground present above the original, natural ground level and the route for gas to be emitted is preferentially upward to the atmosphere.

2.2.7.2 Conclusions from Assessment

The ground gas regime at the Site is based on current data and is characterised as follows:

- Assessment of the ground gas regime demonstrates a significantly improved situation compared with the previous assessment during production of the 2015 RRS.
- A wide range of ground gas monitoring results have been obtained at the Site. Some areas on the site (especially in the northern half) contain elevated concentrations of methane and carbon dioxide, whereas others contain low concentrations. The distribution of higher concentrations is highly variable;
- The elevated gas concentrations are present as a result of the presence of relatively higher concentrations of Organic Rich Material in the Made Ground;
- Based on data available at the time of review (January 2018 to April 2019) a Characteristic Situation of CS2 is considered appropriate in relation to both methane and carbon dioxide. NHBC classification based on the same data set and including further consideration of elevated gas concentrations determined two locations classified an Amber 2 and a further three locations classified as Amber 1. These were located within Historic Pond 7 and the SCA. All other ground gas monitored location monitored were classified as Green, with no locations classified as Red under the NHBC traffic light classification; and
- Trend analysis show that since 2015, maximum concentrations of methane and carbon dioxide have remained generally stable while total gas flow rates have significantly decreased (maximum 0.4L/hr). This is considered to reflect continued degradation of organic matter within deposited materials and associated reduction in the quantity of ground gas generated;

3 Conceptual Site Model

Drawing FBSS-URS-XX-XX-DR-GE-00016 presented within the 2015 RRS present the figurative Conceptual Site Model for the pre remediation works scenario. Drawing FBSS-URS-XX-XX-DR-GE-00017 presents the figurative CSM for the post remediation works scenario (2015 RRS).

The CSM for the Site has not significantly changed following additional phases of work by Arcadis and these CSM drawings are considered to remain appropriate.

An updated CSM was produced as part of the Update HRA (Arcadis, 2019) in relation to groundwater and water resource receptors which is presented in Figure 12 which complements previous CSMs which focus on contaminants within the Made Ground.

3.1 Active Pollutant Linkages

The following Source Pathway Receptor (SPR) pollutant linkages are considered active in relation to the site and, therefore, requirement management (e.g. via active remediation or other controls during earthworks) to address potential risks:

- PAHs in Made Ground identified in localised hotspots across the Main Factory area and Southern WWTP and the potential human health risks to future on-site residents associated with exposure by direct contact and/or plant uptake;
- TPHs in Made Ground identified in localised hotspots across the Main Factory area and Southern WWTP and the potential human health risks to future on-site residents associated with exposure by inhalation, direction contact and/or plant uptake;
- Asbestos present within ACM or free fibres in soil located in localised areas across the Site and potential human health risks to future residents and/or construction workers due to inhalation of dust and/or free asbestos fibres;
- The degradation of Organic Rich Material within Made Ground located primarily within the Northern and Southern WWTP areas have the potential to generate ground gas (carbon dioxide and methane) representing a potential risk to future on-site residents and residential dwellings via inhalation and explosion;

3.2 Additional Pollutant Linkages Considered

The following SPR linkage is also proposed to be addressed as part of the remediation works

- Ammoniacal nitrogen, representative of ammonia and ammonium, associated with Organic Rich Material in Made Ground leaching from Made Ground to groundwater and subsequent migration within the Secondary (A) aquifer (superficial deposits) to the River Ouse.

The previous Tier 3 risk assessment and sensitivity analysis undertaken by AECOM as part of the 2015 RRS as well as the updated Hydrogeological Risk Assessment (HRA) (Arcadis, January 2020) both included detailed assessment of the potential environmental risks posed by ammoniacal nitrogen. The updated HRA concluded that measured concentrations of ammoniacal nitrogen in groundwater were not identified in excess of the updated Site Specific Assessment Criteria (SSAC) derived for the protection of the Secondary A Aquifer or the River Ouse. As such, measured concentrations of ammoniacal nitrogen were not considered to represent a significant risk to water resources.

Therefore, while active remediation works will be undertaken with respect to Made Ground soils in order to reduce the concentrations and leachability of ammoniacal nitrogen this will be for the purposes of ‘Source Reduction’ and no active remediation of groundwater is considered to be required.

3.3 Metals and Metalloids

Concentrations of metal and metalloid determinants recorded within samples from the site are not considered to present a risk to human health for a residential with plant uptake end-use. Therefore, these determinants are not considered further in relation to potential human health risks.

Localised exceedances of Environmental Quality Standards (EQS) values of a number of contaminants have been recorded within a small number of soil leachate samples. The contaminants noted are as follows: arsenic, copper, manganese and zinc. However, these contaminants are not considered to present any risk because of their localised nature and that the mean concentrations of these contaminants were below their corresponding EQS value. Arsenic, copper, manganese and zinc in soil leachate are, therefore, not considered to require mitigation.

3.3.1 Nickel

Measured concentrations of nickel in groundwater were measured in excess of Drinking Water Standards (DWS) and EQS following the water standard quality screening undertaken as part of the updated HRA (January 2020) which provided a detailed discussion in relation to nickel in groundwater.

The conclusions of the is review were that elevated nickel concentrations in groundwater beneath the Site are associated with naturally occurring nickel. The presence of localised “highs” were considered to be associated with changes in aquifer hydrogeochemical conditions immediately beneath the organic waste mass (such as increased dissolved organic carbon and change from oxidising to reducing conditions), which may affect the partitioning and mobilisation of the naturally present nickel. The presence of nickel in selected locations on the hydraulic down gradient boundary at what would be considered background concentrations, suggests that the mobilisation of nickel is likely to be localised to beneath the organic waste mass. On this basis, nickel was not included for further assessment within the HRA and is not considered to require active remediation.

It is noted that the above conclusion is broadly in line with the considerations within the 2015 RRS which, following review of site investigation results and a detailed assessment of nickel in the surrounding area, suggested that the concentrations of nickel in soil were low and that the concentrations of nickel measured in groundwater beneath the Site were likely to have originated from natural soil minerals. The 2015 RRS ultimately concluded that nickel concentrations were representative of background concentrations and did not include nickel as a potential contaminant requiring modelling or further consideration.

It is noted that the proposed remediation strategy will involve aerobic bioremediation which will reduce levels of organic matter within deposited waste and thus reduce the source of dissolved organic matter and associated reducing conditions within the underlying aquifer. Furthermore, it should be noted that during the remediation works all the made gound at the will be re-engineered and reinstated which will reduce infiltration rates through the recovered material. It is anticipated that these activities will further reduce the occurrence of localised concentrations of elevated nickel in groundwater beneath remediated / recovered material.

4 Remediation and Reclamation Strategy

4.1 Remediation Objectives

4.1.1 Overall Objectives

The objectives of the 2020 RRSA remain in accordance with those outlined in the 2015 RRS, namely to provide for residential development with landscaping and amenity use at the Site as follows:

- to ensure that the site is geo-environmentally and geotechnically suitable for the proposed residential end use;
- to ensure that any on-site contamination is mitigated or remediated such that potential risks to human health, development infrastructure and the environment are minimised to a standard suitable for use of the site for residential development;
- to ensure that the development platform is geotechnically suitable for the construction of foundations and pavements associated with the proposed development;
- to ensure that the remediation and reclamation activities are undertaken in such a way as to prevent potential pollution of the environment; and
- to promote the recovery of waste and the reuse of site-won materials at the site as much as possible, minimising offsite disposal and the import of materials.

4.1.2 Soil Contamination Objectives

The objective of the works is to effectively manage the potential human health and environmental risks associated with identified TPH, PAH, ammoniacal nitrogen and asbestos contaminants in soil by active remediation and/or breaking SPR linkages through material management and thus facilitate recovery / reuse within the development platform.

To achieve this objective the remediation works are intended:

- to excavate, test, sentence and segregate all soil materials as required (but including identified TPH hotspots) and where soil materials are identified as having elevated concentrations of volatile hydrocarbons, in respect to the RTVs, they are to be sentenced for treatment by ex situ aerobic bioremediation (prior to any stabilisation required);
- to excavate, test, sentence and segregate all soil materials as required (but including identified PAH hotspots) and where soil materials are identified as having elevated concentrations of non-volatile hydrocarbons, in respect to the RTVs, they are to be placed below to top 1m of the development platform to break direct contact and plant uptake exposure pathways; and,
- to excavate, test, sentence and segregate all soil materials as required (but including identified ammoniacal nitrogen hotspots) and where such materials is identified as having elevated concentrations of ammoniacal nitrogen, in respect to the soil leachate RTVs, they are to be sentenced for treatment by stabilisation to reduce contaminant leachability;
- to stabilise soil materials excavated from across the Site to reduce moisture contents and improve compaction properties to allow compaction to achieve the criteria of 95% Maximum Dry Density (MDD) and 5% air voids and, therefore, reduce ground gas and pore water migration potential;
- to excavate, test, sentence and segregate all soil materials (including identified hotspots with free asbestos fibres), and, where visible ACM is identified this is to be removed and sentenced for off-site disposal. Otherwise, soil materials with detected quantities of asbestos fibres in soil are to be placed within the development platform at a minimum of 1m below the formation level to break dust/fibre inhalation pathways. Maintain a watching brief for the presence of ACM in all excavated soils with identified ACM handpicked or segregated from the soil, wherever possible, and sentenced for off-site disposal. Any areas of the site where soils containing asbestos have been permanently placed should have this clearly indicated on the soil audit and also be included on a marked up Site plan indicating location, depth and extent of any asbestos containing soils.

Remediation of diffuse metal contamination in the Made Ground is not an objective of this Remediation and Reclamation Strategy as the concentrations of metals in the Made Ground are below the levels at which remediation is necessary. However, as a secondary benefit of the remediation and reclamation, immobilisation of diffuse metal contamination in the Made Ground is anticipated. This will limit further any potential for the generation and migration into groundwater of leachable metals in made ground soil pore waters.

Hydrocarbon compounds defined as volatile or non-volatile are listed in Table 5.8 of the 2015 RRS.

4.1.3 Groundwater Objectives

As discussed in Section 3.3, concentrations of metal and metalloid determinants recorded within samples from the site are not considered to present a risk to human health for a residential with plant uptake end-use or to environmental receptors (principally the River Ouse), via leaching from soils and migration in groundwater. Similarly, measured concentrations of ammoniacal nitrogen are not considered to represent a significant risk to water resources and while active remediation works will be undertaken to reduce the leachability of ammoniacal nitrogen this will be for the purposes of 'Source Reduction' and no active remediation of groundwater is considered required.

Therefore, the objective of the works in relation to groundwater will be to minimise any temporary adverse effects to groundwater and/or surface water during the works, ensure there is no significant deterioration in groundwater quality following remediation and to reduce ammoniacal nitrogen leachability to the groundwater. To achieve this objective the remediation works are intended:

- to provide for groundwater monitoring prior to, during and following completion of the remediation and reclamation works with assessment of trends or statistics, in combination with comparison with set values (e.g. Updated SSAC for Groundwater derived as part of the updated HRA (Arcadis, 2019) where appropriate);
- to provide for leachate testing of materials during the works following excavation and following remediation prior to placement;
- to assess results of leachate chemical testing against Tier 3 risk assessment values for ammonia and ammonium;
- to remediate Made Ground materials to reduce ammonia and ammonium leachability via soil stabilisation.
- to provide temporary works capture, treatment and discharge of any perched water encountered during the works so to minimise the risk of adverse impact upon receiving surface waters and/or facilitate compliance with any discharge consent criteria; and
- to stabilise soil materials excavated from across the Site, where required, to improve compaction properties and to compact fill to reduce pore spaces and, therefore, reduce infiltration rates and contaminant leaching potential.

4.1.4 Ground Gas Objectives

The objective of the 2015 RRS and this RRSA is to reduce ground gas concentrations and flow to a level compliant with the Amber 1 level of the NHBC traffic light system, with the proviso that conditions following remediation and reclamation will be no greater than Amber 2.

As outlined within Section 2.2.7, recent data and trend analysis indicates a significantly improved situation compared with the 2015 RRS assessment due to continued degradation of Organic Rich Material within deposited Made Ground. Two ground gas monitoring locations are currently classified as Amber 2 (in accordance which are located in Historic Pond 7, three locations classified as Amber 1 and all remaining locations classified as Green.

Therefore, the focus of the remediation works in relation to ground gas will concern Organic Rich Material located within Historic Pond 7 where the two Amber 2 classifications are observed.

To achieve this objective the remediation and reclamation works are intended:

- to excavate any significant Organic Rich Material encountered within Made Ground present within Historic Pond 7 and subject sentenced materials to ex situ aerobic bioremediation in order to reduce the gassing potential of this material prior to placement (following any stabilisation required);
- to stabilise soil materials excavated from across the Site, to improve compaction properties and to compact fill to reduce pore spaces and, therefore, reduce ground gas migration potential. It is also noted that high pH conditions created by lime and/or cement addition are likely to be strongly inhibitory towards microbial degradation processes generating ground gas;
- Placement of remediated / recovered Organic Rich Material is to be primarily within areas of Green Infrastructure and Public Open Space (POS) as a greater degree of stabilisation is required to achieve geotechnical suitability if placed in other areas and to provide additional confidence residential dwellings are protected from ground gas;
- to provide for gas monitoring prior to, during and following completion of the remediation and reclamation works; and
- to create a residential development platform where ground gas conditions are appropriate to Amber 1 and at most is not greater than Amber 2 (NHBC Traffic Light System).

4.2 Unanticipated Contamination

The approach to addressing any unanticipated contamination during the works outlined within the 2015 RRS is considered to remain appropriate.

4.3 Remediation Criteria

4.3.1 Remediation Criteria for Soils

The remediation criteria for soils remains in accordance with those defined within the 2015 RRS and accepted as part of the full planning permission granted for the proposed redevelopment (14/02798/FULM granted 15 September 2017). These remediation criteria are reproduced below for ease of reference.

The geochemical suitability of all earthworks materials to be used in the development within 1m of the anticipated formation level including garden areas and the footprint of buildings are to be assessed against site specific soil Remedial Target Values (RTVs) derived for risks to human health for a Residential with Plant Uptake End use as detailed in Table 7. Where soil materials are identified as having elevated concentrations of non-volatile hydrocarbons, in respect to the RTVs, they are to be placed below to top 1m of the development platform to break direct contact and plant uptake exposure pathways. Table 5.8 within the 2015 RRS classifies the main contaminants as either volatile or negligible / non volatile.

The soil RTV for means of assessing human health risk from soils within 1m of the formation level at the site have been selected based on AECOM in-house Generic Assessment Criteria (GAC) derived using the CLEA v1.06 software (utilising toxicological and chemical parameter information from various sources including the EA, LQM/CIEH and CL:AIRE). The GAC provide a conservative Tier 1 screening assessment against which to compare the levels of contaminants recorded.

Determinant	Units	Residential with Plant Uptake End Use*
Metals and Metalloids		
Arsenic	mg/kg	31
Boron (water soluble)	mg/kg	291**
Cadmium	mg/kg	11
Chromium (III)	mg/kg	627
Chromium (VI)	mg/kg	4.3
Copper	mg/kg	2327**
Lead	mg/kg	450
Mercury (inorganic)	mg/kg	169

Determinant	Units	Residential with Plant Uptake End Use*		
Nickel	mg/kg	127		
Zinc	mg/kg	351		
Selenium	mg/kg	3750		
Cyanide (free)	mg/kg	1.2**		
PAHS	**At Organic Matter Content**	**1%**	**2.5%**	**6%**
Acenapthene	mg/kg	210	480	1000
Acenaphthylene	mg/kg	170	400	850
Anthracene	mg/kg	2300	4,900	9,200
Benzo(a)anthracene	mg/kg	3.1	4.7	5.9
Benzo(b)fluoranthene	mg/kg	5.6	6.5	7
Benzo(k)fluoranthene	mg/kg	8.5	9.6	10
Benzo(ghi)perylene	mg/kg	44	46	47
Benzo(a)pyrene	mg/kg	0.83	0.94	1
Chrysene	mg/kg	6	8	9.3
Dibenzo(ah)anthracene	mg/kg	0.76	0.86	0.9
Fluoranthene	mg/kg	260	460	670
Fluorene	mg/kg	160	380	780
Indeno (123cd) pyrene	mg/kg	3.2	3.8	4.2
Naphthalene	mg/kg	1.5	3.7	8.7
Phenanthrene	mg/kg	92	200	380
Pyrene	mg/kg	560	1,000	1,600
TPH (Speciated)	**At Organic Matter Content**	**1%**	**2.5%**	**6%**
Aliphatic > C5-C6	mg/kg	30	55	110
Aliphatic > C6-C8	mg/kg	73	160	370
Aliphatic > C8-C10	mg/kg	19	46	110
Aliphatic > C10-C12	mg/kg	93 (48)#	230 (116)	540 (282)
Aliphatic > C12-C16	mg/kg	740 (24)#	1,700 (59)	3000 (142)
Aliphatic > C16-C21	mg/kg	45,000 (8.5)#	64,000 (21)	76000
Aliphatic > C21-C35	mg/kg	45,000 (8.5)#	64,000	76000
Aromatic > C5-C7	mg/kg	65#	130	280
Aromatic > C7-C8	mg/kg	120#	270	611
Aromatic > C8-C10	mg/kg	27	65	151
Aromatic > C10-C12	mg/kg	69#	160	346
Aromatic > C12-C16	mg/kg	140#	310	593
Aromatic > C16-C21	mg/kg	250#	480	770
Aromatic > C21-C35	mg/kg	890#	1100	1230
BTEX				
Benzene	mg/kg			0.33
Ethylbenzene	mg/kg			350
Toluene	mg/kg			610

Determinant	Units	Residential with Plant Uptake End Use*		
Xylene (m)	mg/kg			250
Xylene (p)	mg/kg			240
Xylene (0)	mg/kg			230
OTHER				
Dioxins and Furans	µg/kg	8.5**		
Phenol	mg/kg	210	390	780
Asbestos	-	Presence not detected		

*	These are values based on published SGVs or GACs derived using CLEA model based on a sandy loam soil
**	URS derived GACs for residential with plant uptake end use
#	Note - Theoretical soil saturation limit given in brackets

Table 7 Soil Remedial Target Values (RTV) for Bulk Earthwork Material

The soil RTV are to be used as both ‘suitable for reuse’ criteria for soils located outside the EP boundary, which are proposed to be reused under the CLAiRE Definition of Waste Code of Practice (DoW CoP), as well as soil Compliance Criteria supporting a bespoke waste recovery permit in relation to waste deposited within the EP boundary (as part of the recovery of these wastes in line with a Deposit for Recovery Permit). Therefore, while different regulatory regimes are required to enable the recovery and reuse of material present on Site to create the development platform, the 2020 RRSA aims to align the scope of works and remediation criteria such that the protection of human health and environmental receptors is ensured. This is discussed further in Section 4.4.2. See section 4.3.1 and 4.3.1.2 for the re-use of soil at depths greater than 1 m below the formation level.

4.3.1.1 Non-Aqueous Phase Liquids

Where specific organic determinants are recorded at concentrations below the RTV but above the theoretical soil saturation limit (see Table 7) then assessment shall be made as to the presence of Non-Aqueous Phase Liquid (NAPL) within the soil matrix.

No site won materials and/or imported soils or materials shall be used within the bulk earthworks, where NAPL is identified.

4.3.1.2 Contaminant Odour & Volatility

Materials exhibiting exceedances of metal / inorganic or non/negligibly volatile organic RTV for residential with gardens end use shall be deemed geochemically suitable for use at depths greater than 1m below the formation level. Materials containing potential volatile contaminants exceeding the relevant RTV may not be present at any depth within the development platform unless subject to further site specific risk assessment indicating that the potential risk is acceptable. Any change to the RTV must be agreed with the client or the client’s representative and the EA.

Table 5.8 within the 2015 RRS classifies the main contaminants as either volatile or negligible / non volatile. The list of determinants in the table is not exhaustive and where exceedances of organic determinants not included in the table are identified during geochemical testing an assessment as to their potential volatility shall be made before determining final placement or disposal options for the material in question.

No material shall be used in the works within 1 m of the formation level, irrespective of whether the concentrations of organic determinants are within the RTV, should this material have the potential to give rise to odour nuisance.

4.3.1.3 Material Reuse as Plant Growth Media

During the remediation and reclamation works, excavated material which is considered potentially suitable for reuse as plant growth media (topsoil type material) within future residential gardens and/or within Public Open

Space (POS) will be identified, segregated and assessed in order to maximise the reuse of this material and minimise offsite disposal.

The overall approach in reusing material currently on site within the proposed development footprint as plant growth media is intended to be in accordance with the Waste Strategy for England 2007 (Defra, 2007) as well as the strategic objectives outlined in the Construction Code of Practice for the Sustainable Use of Soils on construction sites (Defra, September 2009) to 'increase diversion of non-municipal waste (including soil) from landfill and to secure better integration of treatment processes with the aim of reducing waste by making products with fewer natural resources'.

An initial survey of potentially suitable material has been undertaken by Arcadis (Ground Investigation Factual Report, Arcadis, August 2019) with laboratory analysis undertaken on 9 soil samples (collected from the top 0.6m bgl) for comparison with the specifications detailed within British Standards Institution (BS) Specification for Topsoil (BS 3882:2015). The results of this laboratory analysis are presented within Appendix C.

It is noted that BS 3882:2015 specifies requirements for natural and manufactured topsoils that are moved or traded for creating soil profiles intended to support plant growth. The standard is not applicable to subsoil, or to topsoil that is to remain in situ, such as potentially suitable material currently present on Site. BS 3882:2015 is not intended to preclude the use of topsoil that is already on site and suitable for its intended purpose. This standard specifies requirements for multipurpose topsoil, which is fit for the majority of needs.

Therefore, the specifications for multipurpose topsoil within BS 3882:2015 will be used as an initial screen to inform the suitability of Site soils for reuse as plant growth media. However, the specific end use and location for deposit of plant growth media will also be considered with a view to maximising reuse of material which may fail some of the BS 3882:2015 specifications, this will ensure suitable topsoil material on site can be classified as suitable for a specific purpose.

Table 8 below summarises the results of the topsoil analysis undertaken and the strategy employed to facilitate on site reuse.

Soil Sample ID	BS 3882:2015 Pass / Fail?	Reason for Fail	Strategy to Facilitate Reuse
AUK-TP-27 (0.0-0.6m bgl)	Fail	Texture Organic Silty Clay	Likely suitable in areas with low footfall such as sloped banking with trees or shrubbery
AUK-TP-28 (0.2m bgl)			
AUK-TP-23 (0.2m bgl)	Pass Multipurpose	-	Suitable for general purpose use
AUK-TP-08 (0.0-0.1m bgl)	Fail	pH, K and Mg	Likely suitable in grassed areas of Public Open Space and/or in areas with specific species of trees and shrubs
AUK-TP-32 (0.0-0.3m bgl)		K and Mg	
AUK-TP-03 (0.0-0.3m bgl)		K and Mg	
AUK-TP-04 (0.0-0.3m bgl)	Pass Specific Purpose: Low Fertility	-	
AUK-TP-01			

Soil Sample ID	BS 3882:2015 Pass / Fail?	Reason for Fail	Strategy to Facilitate Reuse
(0.0-0.3m bgl)			

Table 8 Summary of Topsoil Analysis and Reuse Approach

The results of the ground investigation works, initial soil survey and the strategy outlined here in relation to plant growth media will be incorporated into Materials Management Plan (MMP) and it is recommended that a Soil Resource Plan be developed as part of works implementation (either as a standalone document or as an update to the MMP) showing the areas and type of topsoil and subsoil to be stripped, haul routes, the methods to be used, and the location, type and management of each soil stockpile

4.3.2 Remediation Criteria for Soil Leachates

The chemical suitability of soil leachate (solutes from soil pore water) concentrations is to be assessed against the Tier 3 criteria for ammoniacal nitrogen (representative of ammonia and ammonium) detailed in Table 9 below.

Averaging Area	RTV for Leachate* (mg / l)
AA1a	46
AA1b	12
AA2	3
AA3a	5
AA3b	2
AA4a	2
AA4b	26

* the variation in RTV values is due to the differing distances to the receptor (River Ouse) and the variation in the length of each area.

Table 9 Soil Pore Water (Leachate) Remedial Target Values for Ammoniacal Nitrogen

Review of the RTV calculated for ammoniacal nitrogen in soil pore water (URS 2015) was undertaken by Arcadis (Updated HRA, January 2020), to confirm that the RTV will support the SSACs derived for the protection of groundwater. The RTV were derived by AECOM (formerly URS) using the EA's Remedial Target Worksheet (RTW,) in line with the Arcadis assessment of groundwater, and included Level 1 soil (predicted pore water concentration resulting from a soil source), Level 2 soil (dilution of pore water concentrations within the underlying aquifer) and Level 3 soil (lateral migration within the underlying aquifer). It is noted that Level 3 soil is equivalent to Level 3 groundwater within RTW (i.e. both sheets derive an attenuation factor associated with lateral migration in the dissolved phase).

To review the RTV in the context of the Arcadis groundwater model; the attenuation factor calculated in the most conservative groundwater model (Source 1 with an aquifer compliance point of 250m) has been multiplied by the compliance criteria (0.5 mg/l) and by the dilution factor calculated in the RTW Level 2 soil model (URS 2015) for each averaging area. The range in acceptable pore water concentrations calculated in the context of the revised groundwater model is 269 mg/l to 545 mg/l.

Given that the acceptable pore water concentration calculated in the context of the groundwater model are one to two orders of magnitude higher than the existing RTVs within the 2015 RRS, the existing RTVs are considered to be supportive of achieving the SSAC for the protection of groundwater.

It is noted that while the soil RTV comprises a single criteria value for each parameter across the entire site, the soil pore water RTV for ammoniacal nitrogen varies according to the Averaging Areas. Therefore, excavated material will be sentenced for remediation based on comparison of the concentration of ammoniacal nitrogen in soil leachate with the RTV of the Averaging Area from which the material was excavated. In addition, prior to placement and/or following any remediation or soil stabilisation, further soil leachate testing must be undertaken, as required, to demonstrate compliance with the RTV of the destination Averaging Area. This is to ensure material is not merely moved from one area to another but that genuine source reduction is achieved across the site as a whole. It is noted that the Green Infrastructure and areas of POS, where Organic Rich Material is to be primary placed, are located within and across multiple Averaging Areas.

4.3.3 Remediation Criteria for Ground Gas

4.3.3.1 Total Organic Carbon

The 2015 RRS included the approach that where "Made Ground materials contain hydrocarbon and / or ammoniacal nitrogen contamination at concentrations above the relevant RTV and / or contain organic matter concentrations indicative of a source of ground gas (indicative Total Organic Carbon (TOC) concentration of greater than 3% and soil organic matter content of greater than 5%) then this material will be sentenced for ex-situ aerobic bioremediation".

Guidance associated with this approach provided within the NHBC Technical Extra (April 2016) states that using TOC and an indicator for ground gas should be restricted to low-risk sites, which are defined as 'sites where the conceptual model has not identified any significant potential sources of ground gas, or gas protection is to be provided on sites where small volumes of gas may be generated'. The guidance also states that this approach cannot be used for materials associated with active or recent waste disposal sites. It could be argued that because gas protection measures will be provided as part of development, that volumes of gas are relatively small (see Section 2.2.7) and waste disposal activities have not been undertaken at the Site since before 2009 that this approach is appropriate.

However, the approach is primarily intended for use at low risk sites to avoid unnecessary soil gas monitoring by using soil data for TOC instead. Given the presence of Organic Rich Material which is a significant potential source of ground gas and the availability of ground gas data, a comparison of measured TOC data in soil with NHBC traffic light classifications was undertaken and is presented as Figure 12 (maximum TOC concentration from each location shown). As can be seen from this comparison, there does not appear to be a clear correlation between TOC in soil and ground gas generation (represented by the NHBC traffic classification). For example, only one out of 7 soil samples collected from Historic Pond 7 had measured TOC concentrations above the 3% TOC criteria yet this area has the highest measured hazardous gas flow rates and concentrations (classified as Amber 2). Therefore, this approach may underestimate the requirement for remediation in some instances.

Combining a forensic description of Made Ground materials with TOC analysis is required by this approach (i.e. adjusting the overall TOC concentration by the percentage of various discrete materials). However, given the widespread detections of TOC above 3% which do not correlate with ground gas concentrations, it is considered that (as well as underestimating requirements in some instances) sentencing soils to remediation using TOC as a criteria could also result in a significant overestimation of remediation requirements in other instances.

Organic matter typically includes readily degradable components as well as less degradable components (e.g. lignin) which do not generally generate ground gas at significant rates. However, these types of organic matter cannot be distinguished by TOC analysis and, given the age of the deposited Organic Rich Material at the Site, this may be a further cause of the poor correlation observed between ground gas and TOC.

Furthermore, there are multiple potential sources of elevated TOC within Site soils such as organic pollutants (e.g. TPH) and ash, as well as organic matter. For example, the highest measured TOC concentration was

19.1% measured in AUK_TP19 (0.6m bgl) and most likely due to the presence of black ashy sand (based on review of the exploratory log from this location) which has a much lower ground gas generation potential than organic matter despite the elevated TOC concentration.

Therefore, while analysis of TOC will be undertaken to characterise material and can be used to inform the sentencing of soil for aerobic bioremediation (alongside TPH and ammoniacal nitrogen RTVs) and earthworks classification, it is not proposed to use TOC as a remediation criteria to sentence potential ground gas generating material for remediation.

4.3.3.2 Ground Gas Criteria

As discussed in Section 4.1.4, the focus of the remediation works in relation to ground gas will concern Organic Rich Material located within Historic Pond 7 where the two Amber 2 classifications are observed.

Therefore, the remediation criteria to manage potential ground gas risks at the Site are as follows:

- Ground gas monitoring will be undertaken across the development platform following the remediation works to confirm that ground gas conditions are appropriate to Amber 1 and at most is not greater than Amber 2 (NHBC Traffic Light System).
- Ground gas monitoring following remediation works will also be used to demonstrate that where methane and carbon dioxide concentrations exceed 1.5%v/v and 5%v/v respectively (Scenario 1, EPR 5.02, EA Guidance) hazardous gas flow rates (Qhgs) will be calculated in line with Scenario 2 (EPR 5.02) in accordance with the required permit surrender Completion Criteria provided by the EA in Pre-Advice Letter (EAWML68681, EA, 28th August 2015 provided in Appendix B).
- Organic Rich Material within Historic Pond 7 will be targeted for ex situ aerobic bioremediation to reduce the readily degradable organic matter content. This will be demonstrated through carbon dioxide and methane concentrations recorded during bioremediation as well as other parameters (as detailed in Table 22, Section 6.1) which will provide lines of evidence to allow validation of the bioremediation works. Reductions in the TOC content, as well as forensic organic matter testing of the material may also be used as a line of evidence to support the reduction in readily degradable organic matter content.

The NHBC traffic light classification system is outlined in Section 2.2.7. The EP Scenario 1 and Scenario 2 completion criteria for ground gas are outlined below and detailed within the 'Landfill (EPR 5.02) and other permanent deposits of waste, How to surrender your environmental permit' (EA additional guidance, LIT 5144 / 1056_12, Version 2, Issued 13/12/2012).

Scenario 1 Completion criteria

Gas concentration

Maximum methane concentration is less than 1.5%v/v

Maximum carbon dioxide concentration is less than 5%v/v

Scenario 2 Completion criteria

Gas concentration

Maximum methane concentration is less than 5%v/v and

Maximum carbon dioxide concentration is less than 10%v/v

Flow rate

Qhgs is less than 0.7l/h

Maximum flow in any borehole is less than 70l/hr

As described in Section 6.2, ground gas monitoring will be undertaken at monthly intervals post works completion for a period of 24 months. Should 12 consecutive monthly monitoring visits indicate ground gas compliance criteria have been met then it is understood that this will be accepted by the EA (Pre-application Advice, August 2015) with no further ground gas monitoring required.

4.3.3.3 Ground Gas Protection Measures

The proposed remediation and reclamation works will modify the ground conditions, by increasing the in-situ density and decreasing air voids by optimised compaction and through bioremediation processes during treatment of selected hydrocarbon impacted materials and organic rich materials.

Therefore, in accordance with the 2015 RRS, ground gas protection measures for residential properties within the development will be determined following completion of the assessment of the post-works ground gas monitoring data.

It is recommended that gas protection measures for the residential properties follow the requirements of the NHBC Report Ed No4 (2007) and the British Standard Code of Practice (BS8485:2015).

As discussed in Section 2.2.7.1, the likely Characteristic Situation (CS) following remediation will be a maximum of CS2 with the CS value used in Table 4 of (BS8485:2015) to determine the minimum gas protection score (depending on the building type). Having determined the minimum gas protection score for the building, or each different part of the building an element or combination of elements should be chosen from Table 5, Table 6, and Table 7 with a combined score achieving the minimum recommended gas protection (BS8485:2015). The gas protection system should consist of at least two different elements; for example, a barrier element with either a membrane or a ventilation or dilution element (or both).

It is noted that, in accordance with the NHBC Report Ed No4 (2007) a gas protection membrane and ventilated sub-floor void is required for both Amber 1 and Amber 2 conditions, the difference being that for Amber 2 the membrane is to be fitted and fully certified by a specialist contractor.

4.3.4 Assessment Criteria for Groundwater

The updated HRA concluded measured concentrations of ammoniacal nitrogen were not considered to represent a significant risk to water resources and no active remediation of groundwater is considered required.

Therefore, the objective of the works in relation to groundwater will be to minimise any temporary adverse effects to groundwater during the works, ensure there is no significant deterioration in groundwater quality following remediation, and to reduce ammoniacal nitrogen leachability to the groundwater.

To support this objective, groundwater assessment criteria will focus on groundwater quality trend analysis with reference to pre remediation concentrations to demonstrate there has been no significant deterioration in groundwater quality following remediation and thus there remains no significant risks to identified water resource receptors. Groundwater assessment criteria will also attempt to align as far as practicable with the provisions of the EP Variation (EPR/QP3593NF/V002) and the updated EP Variation Working Plan (URS, October 2015).

Groundwater assessment criteria may include assessment of trends or statistics, in combination with comparison with set values, and are as follows:

- **During remediation** - to assess the groundwater quality in existing groundwater monitoring wells (defined in Section 6.3) against Control Levels defined within the updated EP Variation Working Plan (URS, October 2015) to determine whether the results are indicative of the prevailing groundwater conditions or whether the remediation and reclamation works have impacted the groundwater regime as a result of mobilisation of contamination. These control levels are based on the upper 95th percentile of monitoring data collected between 2010 and 2014, therefore, data collected subsequent to this period will also be considered. This could include assessment of the groundwater quality observed during the 3 monthly visits undertaken immediately prior to commencing remediation works to update this ‘baseline’;
    - Should this assessment conclude that the results are potentially indicative of a mobilisation of contaminants then the frequency of monitoring will be increased and a repeat monitoring round shall be undertaken. It is anticipated that disturbance of the sub surface during remediation may result in short term changes in groundwater conditions, such as a one-off “pulse” of mobilised contaminants. However, where the results consistently indicate elevated

concentrations of determinants then additional mitigation measures may be required to limit the potential risks to groundwater arising from the works.

- **Post remediation** – to assess groundwater quality trends within replacement monitoring wells (defined in Section 6.3) following remediation works to demonstrate there are no significant sustained increases in concentrations of ammoniacal nitrogen and other metal or metalloids contaminants listed in the EP Variation. Assessment of trends may include statistical analysis where appropriate, or comparison with simple descriptive statistics.
  - For replacement monitoring wells which are direct replacements for existing monitoring wells (listed within the EP Variation working Plan (URS, February 2015)) and for which representative data is likely available for pre remediation conditions, then reference will also be made to these pre remediation concentrations (including Control Levels) to demonstrate there is no significant deterioration in groundwater quality following remediation;
  - For replacement monitoring wells which are not direct replacements for existing monitoring wells and for which representative data is not likely available for pre remediation conditions then, if a sustained increasing trend is observed, reference will also be made to the updated Site Specific Assessment Criteria (SSAC) (Updated HRA, Arcadis, 2019) provided these replacement wells are associated with identified Sources (Updated HRA, Arcadis, 2019). Where these wells are not associated with a Source, then further risk assessment may be undertaken if deemed required, including reference to EQS and/or DWS standards, if relevant.

The Updated SSAC for Groundwater derived as part of the updated HRA (Arcadis, 2019) are shown below. Source 1 and Source 2 referenced within the table above are shown in Figure 3 of the Update HRA (Arcadis, 2019).

Contaminant of Concern	Updated Water Resources SSAC (mg/l)			
	Source 1 - Aquifer	Source 1 - Surface Water	Source 2 - Aquifer	Source 2 - Surface Water
	250m Compliance Point	400m Compliance Point	250m Compliance Point	250m Compliance Point
Ammoniacal Nitrogen	256	3520	308	370

Table 10 Update Site Specific Assessment Crities (SSAC) for Groundwater (mg/L) (Updated HRA, Arcadis 2020)

As described in Section 6.3, groundwater monitoring will be undertaken at monthly intervals during the works, then at post completion for a period of 24 months within a network of replacement wells installed across the Site. Should 12 consecutive monthly monitoring visits (post completion) indicate ground monitoring compliance criteria have been met then it is proposed that this will be accepted by the EA and no further monitoring required.

4.3.5 Criteria for Off Site Disposal

In accordance with the 2015 RRS, materials displaying characteristics that render them unsuitable for use in the development platform shall be segregated and sentenced for off-site disposal. It is envisaged that the volume of such material will be relatively small and all excavated material will be recovered / remediated and reused on site wherever possible.

Prior to the off-site disposal of material the concentrations of the contaminants in the material shall be reviewed to determine whether the material would be classified as Hazardous Waste in accordance with the Hazardous Waste Regulations (England & Wales) Regulations, 2005 and associated guidance. Note that this determination is relevant only where it is intended to discard material as waste. It is not relevant to materials, including waste material within the EP boundary, undergoing recovery and remediation processes which will be reused to construct the development platform.

All wastes to be disposed of off-site shall be subject to basic waste characterisation (e.g. source and origin of waste, composition of the waste, and the relevant European Waste Code (EWC)) and classified as being potentially inert, non-hazardous or potentially hazardous. Following this characterisation should the waste be potentially hazardous (or inert) then waste acceptance criteria (WAC) testing will also be undertaken to determine the suitability of the material for disposal to either an inert or hazardous landfill facility. The required testing will be carried out at the frequencies given in Table 22 (Section 6.1) in accordance with the Environmental Permitting (England & Wales) Regulations (2010), the List of Wastes (LoW) (England) Regulations (2005) and the Technical Guidance (WM3) on the classification and assessment of waste (Version 1.1, 2018).

The following EWC / LoW codes have been identified for waste currently deposited within the EP boundary which are considered likely relevant for soils located outside the EP boundary should these not be suitable or required for reuse within the development platform.

General Description	EWC Waste Code	EWC Description	Comments
Granular Made Ground	17 05 (03 / 04)	Soil and stones	Asbestos has been identified in 6 soil samples across the Site
Cohesive Made Ground			
Organic Rich Material	02 04 01	Soil from cleaning and washing beet	Includes current and historic lagoon sediments. Plant remains observed historically in some locations.
Sugar Factory Lime Material	02 04 02	Off-specification calcium carbonate	
Oversized Material	17 01 07	mixtures of, or separate fractions of concrete, bricks, tiles and ceramics	
Recovered Material	19 13 02	solid wastes from soil remediation	soils subject to a remediation process, meeting risk-based criteria and then suitable for re-use in the works, and generated entirely from within the site

Table 11 European Waste Catalogue (EWC) Codes for Waste Currently Deposited within the EP Boundary

The statutory limits that apply to the waste acceptance criteria are presented in Table 12 below (transposed from Council Decision annex 2003/33/EC). Waste materials shall only be disposed of at the appropriate classification of landfill for that type of waste. The landfill operator shall be issued with the basic characterisation and WAC testing results for review prior to disposal.

Parameter	Inert waste landfill	Stable non-reactive	Hazardous waste landfill
Parameters determined on the waste - total concentration			
Total organic carbon (% w/w)	3%	5%	6%*
Loss on ignition (% w/w)			10%*
BTEX (mg/kg)	6		
PCBs (7 congeners) (mg/kg)	1		
Mineral oil C10-C40 (mg/kg)	500		
PAHs (mg/kg)	100		

Parameter	Inert waste landfill	Stable non-reactive	Hazardous waste landfill
pH		>6	
Acid neutralisation capacity		To be evaluated	To be evaluated
Limit values (mg/kg) for compliance leaching test using BS EN 1247 at L/S 10 l/kg			
As (arsenic)	0.5	2	25
Ba (barium)	20	100	300
Cd (cadmium)	0.04	1	5
Cr (chromium (total))	0.5	10	70
Cu (copper)	2	50	100
Hg (mercury)	0.01	0.2	2
Mo (molybdenum)	0.5	10	30
Ni (nickel)	0.4	10	40
Pb (lead)	0.5	10	50
Sb (antimony)	0.06	0.7	5
Se (selenium)	0.1	0.5	7
Zn (zinc)	4	50	200
Cl (chloride)	800	15,000	25,000
F (fluoride)	10	150	50
SO_4 (sulphate)	1000	20,000	50,000
Total dissolved solids (TDS)	4,000	60,000	100,000
Phenol index	1		
Dissolved organic carbon at own pH or pH7.5-8.0	500	800	1,000

* Either loss on ignition or total organic carbon testing must be used for Hazardous Wastes

Table 12 Waste Acceptance Criteria (WAC)

4.4 Strategy Overview

4.4.1 Summary of Approach

In accordance with the 2015 RRS, the 2020 RRSA is based upon excavation, testing, sentencing, remediation (as necessary) to allow waste recovery and engineered reuse of site-won materials, physical stabilisation of wet soils to allow compaction, and a cut-to-fill operation to provide the development platform.

The following summarises the general remediation and reclamation works:

- Initial clearance of any vegetation and/or topsoil;
- Removal, testing and stockpiling of any potential topsoil for later placement within the development (following modification / amendment if required);
- Excavate to base of Made Ground, classify, test, stockpile and sentence the materials for the appropriate end use or to a remediation process prior for recovery / reuse;
- Apply the appropriate remediation processes in designated remedial treatment areas as required to render the material acceptable for use in the development platform; and
- Placement of materials to formation level with engineered fill compacted to target density, which for some of the materials will require stabilisation / modification.

The strategy has been informed by several phases of previous environmental investigation and risk assessment, including incorporating data collected since the 2015 RRS was completed. Laboratory bench scale trials have been used to develop the on-site remedial treatments with key findings provided within the

2015 RRS and Section 5.2.2 of this report. It is envisaged that site based pilot trails may also be undertaken, as required, to optimise the remediation and implementation processes.

4.4.2 Environmental Permitting and Soils Reuse Framework

4.4.2.1 Existing Environmental Permit & Waste Recovery Permit

The site is currently subject to an EP (EPR/QP3593NF) which has been in a state of Definitive Closure since October 2009 until EP variation consolidation in October 2015, when the period of aftercare monitoring & maintenance was commenced. The EP for the site previously permitted the activity of (D1) depositing aqueous solutions of soil and sludge in lagoons for precipitation and dewatering and other controlled wastes, with deposited soils originating from agricultural land supplying sugar beet to the site. Settled soils from the lagoons were principally sold commercially as topsoil. The EP variation (EPR/QP3593NF/V002, October 2015) includes for R3, R5 and R13 recovery and storage activities to support the proposed remediation and reclamation strategy and waste recovery operation.

The EP Boundary is shown on Figure 2.

Deposited waste material located within the EP boundary is to be recovered in accordance with a bespoke Waste Recovery Permit (WRP) as a ‘deposit for recovery’ operation. This permitting route has been determined as the most appropriate following on going regulatory liaison with the EA Yorkshire Area Landfill Team. At the time of writing, a Waste Recovery Plan (Arcadis Report Ref: 10024487-AUK-XX-XX-RP-GE-34-2-Waste Recovery Plan, March 2020) has been submitted to the Environment Agency (EA) National Permitting Service (NPS). The remediation and reclamation works strategy detailed within the 2015 RRS and the 2020 RRSA comprises the scope of works by which waste will be recovered. There is complete alignment between the RRS/RRSA and the waste recovery operation in terms of the scope of works, compliance criteria and monitoring.

The successful recovery of waste in accordance with the WRP, including post remediation monitoring, is intended to enable the surrender of the existing EP (EPR/QP3593NF). Pre-Application Advice received from the EA in relation to EP surrender (EAWML68681, August 2015 – Appendix B) as well as requirements of the EP and EP Working Plan (URS/AECOM, August 2015, Ref: 47068825 – Section 1.3) have also been used to inform the remediation strategy and waste recovery operation, particularly with regards to post remediation monitoring, to ensure alignment wherever possible.

Recovered waste will then be deposited both within and outside of the EP boundary in order to create the required development platform.

4.4.2.2 Reuse of Soils Outside Environmental Permit Boundary

As part of the site wide works any soils excavated that are currently located outside the EP boundary are to be reused in accordance the CL:AiRE Definition of Waste Code of Practice (DoWCoP) (CL:AiRE, September 2008) with soils demonstrated to be suitable for reuse based on the strategy and RTV defined with this 2020 RRSA. Soils suitable for reuse will be deposited outside of the EP boundary within a specific area (described below in Section 4.4.2.3).

A Materials Management Plan (MMP) will be produced prior to commencing works which will align with the materials movement strategy outlined in this document and which will define the suitability for use (including criteria), certainty of use and material quantities and which will be authorised and declared by a Qualified Person.

4.4.2.3 Delineation of Recovered Waste and Reused Soils

Following discussions with the EA Yorkshire Area Landfill Team it has been agreed that the deposit of recovered waste (from within the current EP boundary) and reused soils (recovered from the wider site) will be undertaken within specific site areas / zones to provide delineation of these materials and facilitate post remediation monitoring data interpretation and any future regulatory oversight or enforcement.

Figure 14 shows the zone in the southern end of the Site in which only soils reused under DoWCoP will be permanently deposited (noting that soils may originate from a wider area than this zone (i.e. anywhere outside the EP boundary). This ‘DoWCoP Zone’ has been defined to accommodate the estimated 282,300 m^3 of Made Ground soil currently located outside the EP boundary.

Made Ground soils to be excavated and reused via the DoWCoP process comprise different material types (e.g. granular or cohesive Made Ground, Organic Rich Material, Sugar Factory Lime (SFL)). Should there be limitations on the volumes of specific material types that are required in the DoWCoP Zone and/or there are requirements for additional volumes of specific material types then any significant (e.g. >10% in defined materials) deviation from the MMP must be recorded in the document control section of the MMP (or addendum) and detailed within the MMP Verification Report.

The volume of Made Ground to be excavated from Site areas located outside the EP boundary have been calculated using the GIS Site model with the proportion of specific material types then estimated using available exploratory logs to estimate the volumes of differing material types as shown in Table 20 in Section 5.3.2.

4.4.2.4 Environmental Permit (Mobile Treatment License)

Mobile treatment plant environmental permit(s) will be required in connection with carrying out activities included within the proposed remediation works which will cover Site wide activities relating to both waste recovery and soil reuse. Application for deployment of and the operation of the requisite mobile treatment plant(s) will be made in accordance with applicable legislative requirements.

4.4.2.5 Water Discharge Activity / Trade Effluent Consent

A WDA-EP and/or Trade Effluent Consent will be required for the temporary discharge of perched water and other incidental water during the remediation and reclamation works.

4.5 Earthworks Objectives

4.5.1 Earthworks Objectives

The objective of the earthworks is to provide a development platform suitable for supporting structural and pavement loads from the proposed development of the site.

In general, it is anticipated that structures will include traditional two storey structures and foundations will include shallow strips. It is however noted that in the southern area of the site, the presence of naturally occurring organic clays and peat may require additional earthworks or an alternate foundation solution to be adopted.

4.5.2 Earthworks Criteria

The criteria that are outlined within Section 5.2.1.2 of the 2015 RRS are considered to remain appropriate.

In general, soils will be classified and compacted in accordance with the requirements of the Series 600 of the Specification for Highways Works. Compacted soils will be required to achieve at least 95% of the maximum dry density, with a maximum permissible air void of 5%.

Soils used for fill should reach at least firm consistency with a minimum undrained strength C_u of 60 kN/m^2 if cohesive and/or be engineered to a relative density of at least medium dense if granular (may require stabilisation / modification; the extent of this will depend on the condition of the fill).

Where the natural formation is found to consist of compressible or highly plastic soils, additional earthworks, modification, or an alternate foundation solution will be adopted.

4.5.3 Lime Modification / Soil Stabilisation

Where the natural moisture content, or plasticity of the soil is such that material cannot be compacted to achieve 95% of the maximum dry density with an air voids content of no more than 5%, lime modification or approved stabilisation techniques will be carried out to render the soils suitable for compaction.

5 Remediation and Reclamation Works

5.1 Ex Situ Bioremediation

Ex situ aerobic bioremediation will be applied to excavated material where concentrations of volatile petroleum hydrocarbons are identified above the respective RTV (shown in Table 7 in Section 4.3.1) and to significant Organic Rich Material identified in Historic Pond 7. Hotspots areas of volatile TPH contamination have been identified based on available site data as described in Section 2.2.4.1 and shown on Figure 7. These hotspot areas will be specifically targeted for remediation as part of the works and the total volume of these hotspots is estimated to be 8,000m^3. The volume of significant Organic Rich Material in Historic Pond 7 is estimated to be 1,400m^3 with, therefore, the total volume of material estimated to require aerobic bioremediation being 9,400m^3 (volume estimation discussed in Section 5.2.1).

As detailed within Section 2.2.7, recent data and trend analysis indicates a significantly improved situation compared with the 2015 RRS assessment with two ground gas monitoring locations currently classified as Amber 2 located in Historic Pond 7 which the focus for remediation with respect to ground gas.

A laboratory study assessing aerobic bioremediation was undertaken as part of the 2015 RRS and it is noted that these trials indicated an increase in the Total Organic Carbon (TOC) content of treated material (albeit with large variations in results) most likely due to the addition of 5% compost to test specimens as shown below.

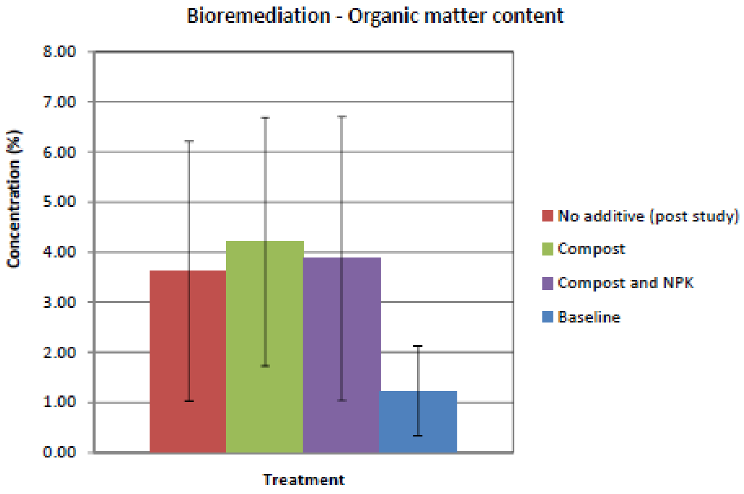


Table 13 Effect of Bioremediation Trials on Organic Matter Content (2015, RRS, AECOM)

While addition of compost as a carbon and energy source may be required to promote aerobic degradation of hydrocarbon contamination, the objective of remediating Organic Rich Material is to reduce organic content and, specifically, the readily biodegradable component of organic matter which has the potential to generate ground gas under certain conditions. Therefore, it is recommended that Made Ground excavated from TPH hotspots located across the Main Factory and Central Tank Farm areas are considered as separate material types (and as necessary remediated separately) to Organic Rich Material from Historic Pond 7 where addition of compost may be unrequired or unadvisable to achieve remediation objectives.

Where there is need for additional information on the applicability of bioremediation, Site based pilot trials of ex situ bioremediation may be undertaken at the Site. The potential scope of these pilot trials are outlined within the 2015 RRS in order to establish optimum treatment time and determine whether a biopile or a windrow system is more efficient.

Aerobic bioremediation was identified for remediation of ammoniacal nitrogen within the 2015 RRS. While this technology is considered suitable to promote nitrification of ammoniacal nitrogen to nitrate it is noted that this nitrate may subsequently be chemically reduced to form ammoniacal nitrogen again when deposited and compacted where anaerobic conditions may re-establish. The majority of ammoniacal nitrogen impacts have been identified within Organic Rich Material, which will also requires stabilisation to facilitate suitable reinstatement and compaction and this stabilisation will also reduce and mitigate the ability of the treated soils to release ammoniacal nitrogen into the environment. As such this approach would result in an unnecessary multi-stage treatment train process incorporating bioremediation followed by stabilisation. On this basis it is not proposed to undertake bioremediation of soils to treat ammoniacal nitrogen.

5.2 Soil Stabilisation

Following excavation and testing, soil stabilisation will be applied to all soil materials identified as having elevated concentrations of ammoniacal nitrogen, in respect to the soil leachate RTVs, as well as hotspots of ammoniacal nitrogen contamination currently identified and shown on Figure 9.

Remediation of ammoniacal nitrogen impacts will be achieved through soil stabilisation and compaction in order to reduce partitioning to soil pore water through encapsulation of soils within a solidified matrix as well as to reduce soil permeability and thus infiltration rates thereby reducing potential leaching of ammoniacal nitrogen in pore water to groundwater. Furthermore, as ammoniacal nitrogen is generated through anaerobic microbial degradation, it is also anticipated that the high pH conditions created by the lime stabilisation (typically >pH 12) will significantly limit microbial activity and thus the liberation of ammoniacal nitrogen from organic matter.

Chemical and ammoniacal odours have been noted associated with Organic Rich Material during previous phases of investigation and so will require careful management during handling and remediation of this material. It is noted that at the elevated pH associated with lime stabilisation deprotonation of ammonium to ammonia gas can occur which may further contribute to potential odour and gas issues requiring management. It is noted that, as described in Section 5.2.2.2, drying of Organic Rich Material to below 45% moisture content is required prior to soil stabilisation. While drying and aeration of ammoniacal nitrogen impacted material may also be advantageous to reduce ammoniacal nitrogen concentrations (via nitrification) and thus reduce potential odour generation during soil stabilisation this is not required to achieve the remediation objectives with respect to ammoniacal nitrogen (only those objectives related to soil stabilisation and odour management).

In addition to the treatment of ammoniacal nitrogen soil stabilisation will also be undertaken, where necessary, in order to reduce moisture contents and improve compaction properties so that earthworks performance criteria are achieved (as set out in Section 4.5.2) and to reduce ground gas and pore water migration potential.

5.2.1 Volumes of Ammoniacal Nitrogen Requiring Stabilisation

The distribution of ammoniacal nitrogen concentrations measured within Site soil leachates during previous phases of investigation are shown on Figure 10. Data indicates that ammoniacal nitrogen contamination is strongly associated with Organic Rich Material deposited within the North West area (including the northern WWTP) and the southern WWTP. Isolated exceedances of the soil pore water RTV were identified within Made Ground outside the NWWTP and SWWTP and these locations have been identified as ‘hotspots’ on Figure 10.

The Made Ground deposited across the site, particularly within the NWWTP and SWWTP, is highly variable (described within Section 2.2) as it has originated from numerous off site sources (associated within sugar beet transported to site for processing) as well as reflecting the various materials management, reworking and conditioning processes employed at the Site. It is considered that identified contamination was strongly associated with discrete material types and Site locations.

Therefore, the approach to estimating the volume of ammoniacal nitrogen material requiring remediation was as follows:

- Within each Site area (shown on Figure 2) all available historic and current exploratory locations were identified;
- The laboratory data concerning ammoniacal nitrogen in soil leachate for all locations in each site area was compared with the relevant soil pore water RTV for ammoniacal nitrogen. Any thickness / horizon of material where ammoniacal nitrogen was measured above the relevant soil pore RTV was considered to require remediation. Where no other laboratory data was available, the value of the ammoniacal nitrogen in soil leachate was conservatively assumed to represent all material with similar soil description, including olfactory evidence, at a particular location;

- Where no laboratory data was available from a particular location at all, the encountered geology was reviewed and any Organic Rich Material horizon where ammoniacal odours were encountered was also considered to require remediation;
- Within each exploratory location, the percentage thickness of material identified as requiring remediation (as a percentage of the total borehole depth) was calculated; and
- Within each Site area, the average percentage thickness of material requiring treatment was calculated and the volume of this material then calculated as a percentage of the total volume of Made Ground determined from the qGIS model (described in Section 5.3.2). Each location within each area was assumed to represent an equal proportion of that area (e.g. if 20 locations were present within an area then each location was assumed to represent 1/20th of the Made Ground volume).

This approach is considered a robust, pragmatic and reasonably conservative approach to determining volumes of material requiring remediation given the heterogeneity of the Made Ground and strong association between contamination and material type. It is noted that due to the lack of exploratory locations advanced through the Central Tank Farm bund this material was conservatively assumed to comprise similar materials to that within the SCA.

The volume of ammoniacal nitrogen contaminated material estimated to require material via this approach is shown in Table 14, below.

	Location	Total Excavated Volume (m^3)	Organic Rich Material (ORM) (m^3)	Ammoniacal Nitrogen Contaminated Material (m3)	Overlap Between ORM & Ammoniacal Nitrogen Contaminated Material* (m^3)	Potential Topsoil Type Material (m^3)	Sugar Factory Lime (SFL) (m^3)	Granular and Cohesive Made Ground (m^3)	Sediment (m^3)	Total Petroleum Hydrocarbon (TPH) Contaminated Material (m^3)
Outside EP Boundary	Former Manor School	-	-	-	-		-	-		-
	NWWTP / Beet	17,900	2,900	-	-	600	-	14,300	-	-
	Main Factory Area	164,700	-	4,200	-	-	12,200	146,200	-	2,100
	Playing Field Area	20,400		-	-	8,800	800	10,800	-	-
	SWWTP	79,300	4,400	6,200	-	300	1,100	64,900	2,400	-
	Outside EP Boundary Total	**282,300**	**7,300**	**10,400**	**-**	**9,700**	**14,100**	**236,200**	**2,400**	**2,100**
EP Boundary	Central Tank Bund	16,800	-	-	-	-	-	10,900	-	5,900
	NWWTP Lagoon Bunds	140,550	6,500	18,300	-	900	2,100	109,650	3,000	-
	Limex Pond	5,800	-	-	-	-	-	1,500	4,300	-
	Historic Pond 7	6,200	1,400	3,100	1,300	-	-	2,800	300	-
	Historic Pond 4	39,300	5,400	3,300	1,100	200	100	31,200	100	-
	Historic Pond 5	46,500	7,000	7,500	3,100	300	400	34,200	200	-
	Limex Pond Bund	85,400	5,400	17,100	-	0	100	62,500	-	-
	Weigh Bridge Area	74,900	5,000	10,700	900	100	100	59,800	100	-
	Soil Conditioning Area	188,600	53,800	45,800	21,800	3,500	13,400	94,000	-	-
	Tank Farm Bund	100,400	28,600	24,400	11,600	1,800	7,100	50,000	-	-
	Ponds and Lagoons	42,350	-	-	-	-	-	-	35,250	-
	Inside EP Boundary Total	**746,800**	**113,100**	**130,200**	**39,800**	**6,800**	**23,300**	**456,550**	**43,250**	**5,900**
Site Boundary	**Entire Site Boundary**	**1,029,100**	**120,400**	**140,600**	**39,800**	**16,500**	**37,400**	**692,750**	**45,650**	**8,000**

***While a significant volume of Organic Rich Material is contaminated with ammoniacal nitrogen this is not the case in all locations and the degree of overlap is presented to avoid double counting of ORM and ammoniacal nitrogen contaminated material.**

Table 14 Estimated Volumes of Material Types Based on GIS Modelling

As can be seen from the table above, it is estimated that approximately 39,800m^3 of Organic Rich Material with an ammoniacal nitrogen content requires remediation. Placement of remediated / recovered Organic Rich Material is to be within areas of Public Open Space (POS) where possible in order to achieve geotechnical suitability with a lower amount of stabilisation reagents (detailed below).

5.2.2 Laboratory Treatability Study and Optimum Mix Designs

Arcadis designed and managed a soil stabilisation laboratory treatability study which was undertaken by CE Geochem Ltd between August and November 2019 with the following objectives;

- Geochemically and geotechnically characterise bulk soil samples representing key soil types;
- Assess whether lagoon sediments are suitable for stabilisation and/or whether moisture reduction is required prior to stabilisation;

- Determine cost effective lime modification dosages which can achieve the required geotechnical performance (including strength gain and moisture reduction to achieve optimum compaction) without adversely effecting contaminant leaching;
- Assess other binder and additive combinations (including cement based mix designs) on selected soil types;
- Assess potential long term contaminant leachability of selected mix designs via monolith leaching tank tests (including assessment of Ammoniacal Nitrogen); and
- Interpret and report the findings of the laboratory study in a stand alone report to inform future detailed design of ground works associated with Site redevelopment.

Full details and results of the laboratory study are provided within Appendix D with key findings outline below.

5.2.2.1 Material Types

The following key material types were identified for separate assessment within the laboratory study to reflect the different material types likely requiring stabilisation during full scale remediation works.

- Granular Made Ground
- Cohesive Made Ground
- Organic Rich Material
- Sugar Factory Lime (marketed as LimeX)
- Lagoon Sediment
- Cohesive Natural Ground

Bulk soil samples of these material types were collected during the Arcadis ground investigation works (August 2019) with selected bulk soil samples mechanically homogenised prior to testing to reduce sample heterogeneity.

5.2.2.2 Optimum Soil Stabilisation Mix Designs

A summary of results of the soil stabilisation study, as well as the optimum mix designs selected following data review and interpretation, are shown in Table 15 below.

Key additional aspects related to remediation and reclamation design are as follows:

- Cost effective lime and cement dosages were identified during the laboratory study albeit further assessment and confirmation maybe considered necessary during site pilot trials with moisture contents confirmed during full scale implementation to ensure Optimum Moisture Content (OMC) is achieved for all stabilised soil;
- Organic Rich Material requires drying to at or below 45% moisture prior to lime stabilisation. It is envisaged this will be achieved via temporary spreading and/or turned windrows and/or biopiles. This drying and aeration process will also assist in the nitrification and reduction of ammoniacal nitrogen and hence likely reduce odour generation during lime addition;
- Limited strength gain was observed following lime stabilisation of Organic Rich Material and therefore an additional 3% cement has been included as part of the optimum mix design for any Organic Rich Material which is to be deposited outside areas of Public Open Space (POS);
- Sugar Factory Lime material was identified to already be at approximately OMC and therefore soil stabilisation of this material is not considered required.

Material Type	Mix Design	Lime	Cement	Tank Tested?	CBR 7 day		CBR 28 day		UCS 1 day	UCS 7 day	UCS 14 day	UCS 28 day
		%	%	N/*	2.5mm	5mm	2.5mm	5mm	N/mm2	N/mm2	N/mm2	N/mm2
Granular Made Ground	1	1.5	-	N	4.76	6.26	4.96	6.36	0.209	0.214	0.207	0.202
	2	3	-	N	19.72	27.11	27.51	34.83	0.31	0.44	0.414	0.434
	3	6	-	F1-4	112.76	121.17	115.37	120.4	0.378	0.664	0.821	0.656
Cohesive Made Ground	4	3	-	N	6.81	9.03	10.4	12.12	0.336	0.284	0.33	0.358
	5	6	-	N	40.38	45.48	45.12	49.95	0.714	0.721	0.648	0.988
	6	10	-	F1-4	127.66	115.92	83.84	74.96	0.946	0.978	0.985	1.046
Organic Rich Material	7	3	-	N	-	-	-	-	0.063	0.063	0.066	0.074
	8	6	-	N	-	-	-	-	0.065	0.066	0.078	0.077
	9	10	-	F1-8	2.61	2.57	2.97	1.65	0.129	0.14	0.149	0.166
Sugar Factory Lime	10	1.5	-	F1-4	40.28	54.08	35.98	27.15	0.713	0.733	0.584	0.824
	11	3	-	N	106.75	134.68	156.63	163.73	1.104	1.083	1.035	1.566
	12	6	-	N	206.8	205.23	164.31	152.57	0.514	0.55	0.59	0.591
Lagoon Sediment	13	-	3	N	5.11	5.45	6.63	7.09	0.064	0.114	0.118	0.118
	14	-	6	F1-8	5.91	6.56	9.74	10.83	0.051	0.097	0.169	0.163
	15	-	10	N	25.93	28.75	79.88	66.6	0.112	0.4	0.359	0.857
Cohesive Natural Ground	16	2.5		F1-4	63.08	57.99	73.01	64.44	0.644	0.601	0.814	0.639

* During monolith leaching (tank) testing, eluate from the first four sampling intervals (F1-4) were tested for selected specimens with all eight sampling intervals (F1-8) tested for MD9 and MD14.

Material Type	Mix Design	Lime	Cement	NMC	OMC	OMC + 4%	Moisture Content 1 day	Moisture Content 7 day	Moisture Content 14 day	Moisture Content 28 day	Final Lime / Cement Dosage	Comments
		%	%	% DW	% DW	% DW	% DW	% DW	% DW	% DW	%	
Granular Made Ground	1	1.5	-	18.6	13.3	17.3	13.5	16.26	16.33	16.5	1.5 - 2%	-
	2	3	-				13.59	15.36	15.5	15.64		
	3	6	-				10.45	12.03	12.29	12.76		
Cohesive Made Ground	4	3	-	22.9	12.4	16.4	19.07	20.09	18.27	18.67	3 - 4%	-
	5	6	-				16.08	16.25	16.3	15.61		
	6	10	-				12.16	12.7	12.94	11.65		
Organic Rich Material	7	3	-	79.9	31.6	35.6	61.04	63.43	60.44	50.23	5 - 10% + 3% cement in areas outside POS	dry to <45% moisture content prior to lime addition
	8	6	-				62.93	63.53	62.23	50.44		
	9	10	-				53.31	53.89	51.38	43.97		
Sugar Factory Lime	10	1.5	-	13.7	14.3	18.3	12.65	12.96	12.69	12.5	0%	No soil stabilisation likely required
	11	3	-				11.31	11.84	11.86	11.45		
	12	6	-				9.94	9.8	9.53	9.44		
Lagoon Sediment	13	-	3	133**	44**	48	28.68	29.94	27.71	26.53	3%	dewater to <45% moisture content prior to cement addition
	14	-	6				27.71	24.48	22.72	23.15		
	15	-	10				24.55	26.85	23.67	25.88		
Cohesive Natural Ground	16	2.5	-	15.7	11.9	15.9	13.79	14.22	13.62	13.72	1.5%	-

% DW = % Dry Weight

** Data from geotechnical testing undertaken during Arcadis Ground Investigation (2019)

Table 15 Summary of Soil Stabilisation Trials and Optimum Mix Designs

5.2.2.3 Assessment of Ammonia Gas Release

Assessment of ammonia gas release during lime stabilisation was undertaken to determine whether this could be significant in terms of ammoniacal nitrogen reduction, and hence form part of the remediation strategy, as well as inform odour management requirements. This assessment results from the potential for high soil pH typically achieved following lime addition to convert ammonium to ammonia gas.

Table 16 below displays a graph illustrating the mass flux rate and cumulative mass of ammonia gas released from Organic Rich Material stabilised with 10% lime which shows significant reduction in mass flux over time. The total mass of ammonia gas release during the experiment was calculated to be only approximately 3% of the ammoniacal nitrogen mass measured in soils during baseline analysis which is not considered significant in terms of source reduction (when considering gas evolution alone).

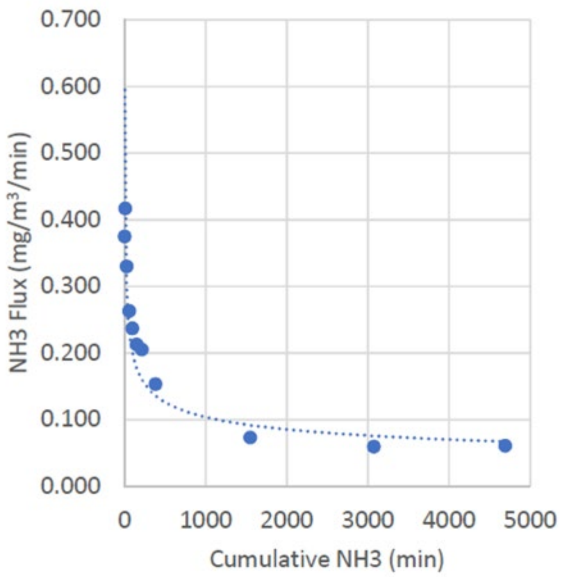


Table 16 Graph Showing Ammonia Gas Mass Flux Following Stabilisation

However, the ammonia gas flux data generated during the laboratory study could be used to inform air quality modelling to estimate concentrations of ammonia in outdoor air during full scale works, for example, from stockpiles, should this be considered required to inform odour management. Such an approach should include the likely wind velocity and direction, air pressure and other atmospheric variables alongside robust assumptions on the likely implementation scenario.

5.2.2.4 Semi Dynamic Tank Testing

Semi dynamic tank testing was undertaken on selected mix designs to assess the long term leaching potential of stabilised material in general accordance with EA NEN 7375. Stabilised material was formed into ‘monoliths’, cured for 14 days then suspended within glass tank filled with deionised water with the entire water volume emptied, tested and replaced at regular intervals. Table 15 in Section 5.2.2.2 details which mix designs were selected for tank testing with 1 mix design selected from each of the 6 material types for sampling of the first four sampling intervals (F1-4, over 2.25 days). Following interim data review, the mix designs from the Organic Rich Material and the lagoon sediment were selected for further testing over a further 4 sampling intervals (F5-8, over 16 days).

The results of tank testing in relation to ammoniacal nitrogen are shown in Table 17 below.

Material Type	Mix Design	Lime	Cement	Ammoniacal Nitrogen Concentration (mg/L) in Tank Test Leachate - Sampling Fractions 1 to 8								Soil Pore Water RTV
	#	%	%	1	2	3	4	5	6	7	8	
Granular Made Ground	3	6	-	0.64	0.43	0.62	1	-	-	-	-	2mg/L to 46mg/L dependant on Averaging Area
Cohesive Made Ground	6	10	-	0.58	0.58	1	1	-	-	-		
Organic Rich Material	9	10	-	5.1	3.9	6.1	5.9	0.3	1.4	1	1.5	
Sugar Factory Lime	10	1.5	-	0.75	0.68	0.51	0.53	-	-	-	-	
Lagoon Sediment	14	-	6	1.9	0.42	0.58	0.47	2.3	0.58	0.14	0.068	
Cohesive Natural Ground	16	2.5		0.35	0.28	0.93	0.43	-	-	-	-	

Table 17 Semi Dynamic Tank Testing – Ammoniacal Nitrogen Leaching

As can be send from the data within Table 17 the concentrations of ammoniacal nitrogen in tank test leachate are below the soil pore water RTV, regardless of Averaging Area (See Section 2.2.5.1) for Granular Made Ground, Cohesive Made Ground, Sugar Factory Lime, Cohesive Natural Ground and Lagoon Sediment (with the exception of the marginal exceedance at Fraction 5).

For the Organic Rich Soil concentrations of ammoniacal nitrogen were measured slightly above the lower end of the range of the soil pore water RTV during initial fractions (F104, over 2.25 days). However later fractions (reflecting longer term leaching) are all consistently below the lowest RTV. This is further illustrated by inspection of the leaching trajectory plot (shown below) where the plateau in transfer rates over longer leaching fractions indicates a depletion based leaching mechanism and that diffusive flux is relatively short-lived. This demonstrates that stabilised Organic Rich Material is not likely to present a significant long term source of ammoniacal nitrogen to groundwater.

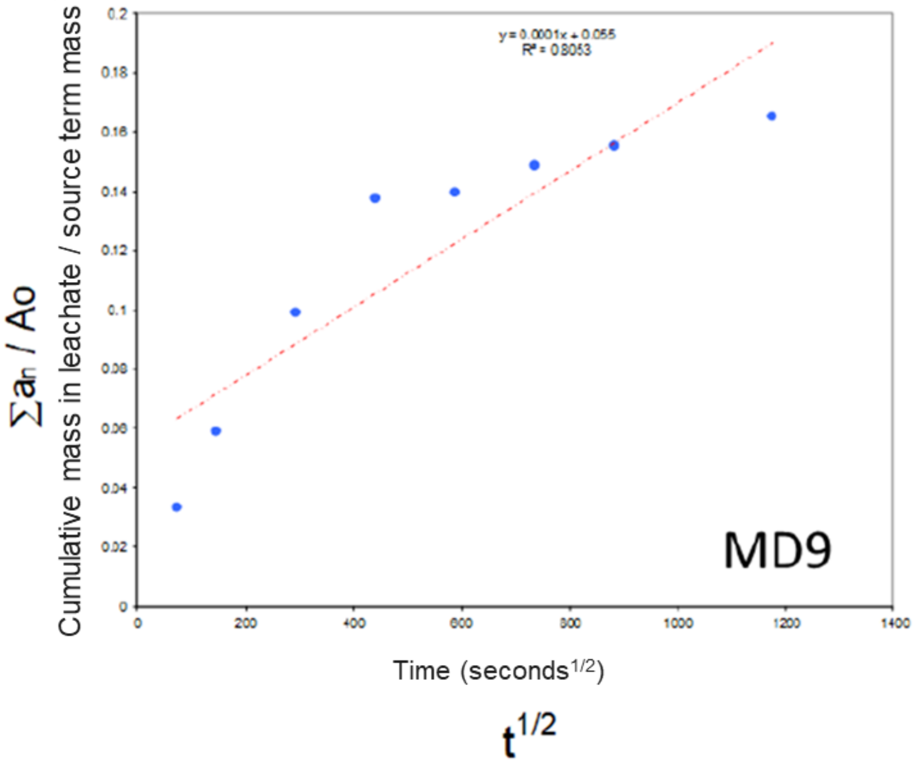


Table 18 Mass transfer rates for ammoniacal nitrogen during semi dynamic tank testing.

It is noted that the average and maximum concentrations of ammoniacal nitrogen in soil leachate from Averaging Areas AA1a and AA1b (corresponding to the majority of the NWWTP area) are 27.8mg/L and 125mg/L (AA1a) and 22.2 mg/L and 67.2mg/L (AA1b), respectively. Therefore, data indicates the proposed stabilisation will produce a significant reduction in soil pore water concentrations.

There are additional conservatisms built into this assessment and overall strategy which provide further confidence that the remediation approach for the treatment of ammoniacal nitrogen is appropriate and robust, specifically these are.

- Following stabilisation, all material will be deposited above the resting groundwater table and so there will be no (or sporadic) contact with groundwater whereas the semi dynamic tank testing involves complete and continuous submersion with leaching water;
- Organic Rich Material requires drying to <45% moisture content which will reduce the initial mass of ammoniacal nitrogen within soils available to leach and the actual soil pore water concentrations are likely to be lower than that measured during tank testing; and
- Following stabilisation, material will be compacted and physically improved which will reduce air voids and hence the potential for rainfall infiltration and soil pore water migration to the underlying aquifer.

5.3 Earthworks

5.3.1 Ground Model – Cut and Fill Balance

A GIS model was developed in qGIS by Arcadis to assist Site conceptualisation, contamination distribution assessment and the calculation of volumes of material requiring excavation, permanent deposit and remediation. The qGIS model was developed alongside an AutoCAD Civil 3D model developed to support the infrastructure and landscape elements of the proposed development. A cut and fill balance was determined using both models with the qGIS model assessing individual site areas as well as across the entire site boundary. Model outputs were cross checked to confirm accuracy.

Material volume estimates within the qGIS model were calculated by creating multiple 2D elevation surfaces between which the volume of material can be calculated, both over the entire Site boundary and for specific Site areas. The following elevation surfaces were created within the model:

- **Surface of the Vale of York bedrock formation** - which represents the base of the Made Ground and the base of the proposed excavation. This layer was created based on encountered geological conditions recorded within all available historic and recent exploratory logs. This required the digitisation and quality control checks of a large number of historic records as well as interpretation of soil descriptions and further ground investigation to inform and confirm the layer parameters. The elevation at ground surface of all current and historic boreholes were also required to ensure geological boundary elevations were accurate.

  This layer is shown in Figure 15;

- **Current Site Topography** – created based on the most recent topographical survey undertaken in April 2019 by Greenhatch Ltd and mapping the entire Site area to a resolution of 0.5m and taking spot levels at 20m centres. It is noted that the Former Manor School was not included within this survey as it was not part of the Site boundary at this time.

  This layer is shown in Figure 16; and

- **Proposed Development Surface** – based on the Arcadis Proposed Ground Model (BRS-AUK-XX-XXX-SK-102, February 2020). It is noted that the Former Manor School was not included within this development surface as it was not part of the Site boundary at this time.

  This layer is shown in Figure 17.

In addition to these layers, the Site was divided into several areas reflecting the use of the area during active Site operations, the type of Made Ground present and whether the area is within the EP boundary. These areas were also aligned with the topographic surface. These Site areas are shown on the Site Layout Plan, Figure 2.

The volume of Made Ground requiring excavation was determined through calculation within qGIS of the volume between the surface of the Vale of York formation (base of excavation) and the current site topography. The volume of fill (comprising remediated soils and recovered waste) was determined by calculating the volume between the surface of the Vale of York formation and the proposed development surface.

The cut and fill balance is determined by using the site topography to calculate the volume of material currently above the proposed development surface (cut - given a negative value) and the volume currently below the proposed development surface (fill - given a positive value). The difference between these two values provides the cut and fill balance. This balance does not include reference to the Vale of York formation or the actual volumes of material to be excavated or deposited.

All volumetric calculations were performed based on a 1m^2 resolution grid.

While the Former Manor School area is not included within the cut and fill balance estimations it is anticipated that there will be no significant alterations to ground surface elevations within this area and no requirement for remediation in this area has been identified.

Table 19 shows the volumes of Made Ground material to be excavated and deposited as well as the cut and fill balance across the Site and within individual Site areas.

	Location	Area (m^2)	Made Ground Excavated Volume (m^3)	Made Ground Fill Volume (m^3)	Fill (m^3)	Cut (m^3)	Cut and Fill Balance (m^3)
Outside EP Boundary	Former Manor School	15,800	-	-	-	-	-
	NWWTP / Beet	25,300	17,900	44,000	26,400	-900	25,500
	Main Factory Area	121,700	164,700	308,200	164,600	-2,800	161,800
	Playing Field Area	29,200	20,400	23,200	5,700	-4,300	1,500
	SWWTP	17,500	79,300	70,700	3,000	-13,000	-10,000
	Outside EP Boundary Total	**209,500**	**282,300**	**446,100**	**199,700**	**-21,000**	**178,700**
EP Boundary	Central Tank Bund	16,500	16,800	32,100	13,600	-100	13,600
	NWWTP Lagoon Bunds	56,200	140,550	184,700	56,300	-47,200	9,100
	Limex Pond	4,200	5,800	11,200	3,700	0	3,700
	Historic Pond 7	1,200	6,200	6,600	0	-1,300	-1,300
	Historic Pond 4	6,100	39,300	37,700	1,300	-4,500	-3,200
	Historic Pond 5	10,100	46,500	43,000	3,500	-8,700	-5,200
	Limex Pond Bund	11,800	85,400	37,600	500	-50,200	-49,800
	Weigh Bridge Area	8,500	74,900	29,900	2,400	-52,200	-49,900
	Soil Conditioning Area	18,100	188,600	28,600	100	-150,000	-149,900
	Tank Farm Bund	16,400	100,400	8,400	200	-100,300	-100,100
	Ponds and Lagoons	20,900	42,350	93,700	84,900	-100	84,800
	Inside EP Boundary Total	**170,000**	**746,800**	**513,500**	**166,500**	**-414,600**	**-248,200**
Site Boundary	**Entire Site Boundary**	**397,500**	**1,029,100**	**959,600**	**366,200**	**-435,600**	**-69,500**
	Construction Arisings	-	-	-	-	-17,800	-
	Green Infrastructure	66,400	216,100	130,200	35,200	-102,000	25,000

Table 19 Cut and Fill Balance and Material Volumes for Site Areas

As detailed in Table 19 it is currently estimated that there will be a net surplus of material amounting to 69,500 m^3 on completion of the remediation and earthworks. However, it should be noted that there are a number of factors not included in the above calculations that will reduce and mitigate some or all of this projected surplus.

The calculations in Table 19 do not make any allowance for any reduction in the actual volume of material due to the compactive efforts applied during reinstatement. When a material is compacted at its OMC there is typically a reduction in its overall volume of between 3-5% i.e. a void of 100m^3 would actually require 103-105 m^3 of compacted material to fill it. The actual level of volume reduction observed will vary dependant on material type and ground conditions. It should also be noted that any deleterious material (wood, metal, glass etc) encountered within the made ground will be segregated and not reused in the formation; this will reduce the amount of material available for fill operations by a corresponding amount. The recent topographical survey was used to inform the earthworks model but it should be noted that the Ponds and Lagoons area contains a volume of water that would have been recorded as the top surface in this area during the survey but which will be removed during the remediation and earthworks. In addition, and as previously noted, the underlying sediments have an elevated water content and they will require dewatering to allow them to be re-used on site. The removal of the excess water from the top of the lagoons and dewatering of the underlying sediments is estimated to reduce the volume of material in this area of the site by approximately 30,000-35,000 m^3.

So in consideration of all the above factors it is anticipated that the site will achieve a cut and fill balance with no projected significant surplus or deficit of material.

5.3.2 Materials Management

In accordance with the process outlined in Section 5.2.1 (in relation ammoniacal nitrogen contaminated material) approximate volumes of other key material types present on site were estimated and are shown in Table 20 below.

	Location	Total Excavated Volume (m^3)	Organic Rich Material (ORM) (m^3)	Ammoniacal Nitrogen Contaminated Material (m3)	Overlap Between ORM & Ammoniacal Nitrogen Contaminated Material* (m^3)	Potential Topsoil Type Material (m^3)	Sugar Factory Lime (SFL) (m^3)	Granular and Cohesive Made Ground (m^3)	Sediment (m^3)	Total Petroleum Hydrocarbon (TPH) Contaminated Material (m^3)
Outside EP Boundary	Former Manor School	-	-	-	-		-	-		-
	NWWTP / Beet	17,900	2,900	-	-	600	-	14,300	-	-
	Main Factory Area	164,700	-	4,200	-	-	12,200	146,200	-	2,100
	Playing Field Area	20,400		-	-	8,800	800	10,800	-	-
	SWWTP	79,300	4,400	6,200	-	300	1,100	64,900	2,400	-
	Outside EP Boundary Total	**282,300**	**7,300**	**10,400**	**-**	**9,700**	**14,100**	**236,200**	**2,400**	**2,100**
EP Boundary	Central Tank Bund	16,800	-	-	-	-	-	10,900	-	5,900
	NWWTP Lagoon Bunds	140,550	6,500	18,300	-	900	2,100	109,650	3,000	-
	Limex Pond	5,800	-	-	-	-	-	1,500	4,300	-
	Historic Pond 7	6,200	1,400	3,100	1,300	-	-	2,800	300	-
	Historic Pond 4	39,300	5,400	3,300	1,100	200	100	31,200	100	-
	Historic Pond 5	46,500	7,000	7,500	3,100	300	400	34,200	200	-
	Limex Pond Bund	85,400	5,400	17,100	-	0	100	62,500	-	-
	Weigh Bridge Area	74,900	5,000	10,700	900	100	100	59,800	100	-
	Soil Conditioning Area	188,600	53,800	45,800	21,800	3,500	13,400	94,000	-	-
	Tank Farm Bund	100,400	28,600	24,400	11,600	1,800	7,100	50,000	-	-
	Ponds and Lagoons	42,350	-	-	-	-	-	-	35,250	-
	Inside EP Boundary Total	**746,800**	**113,100**	**130,200**	**39,800**	**6,800**	**23,300**	**456,550**	**43,250**	**5,900**
Site Boundary	**Entire Site Boundary**	**1,029,100**	**120,400**	**140,600**	**39,800**	**16,500**	**37,400**	**692,750**	**45,650**	**8,000**

***While a significant volume of Organic Rich Material is contaminated with ammoniacal nitrogen this is not the case in all locations and the degree of overlap is presented to avoid double counting of ORM and ammoniacal nitrogen contaminated material.**

Table 20 Calculated Approximate Volumes of Material Types in Site Areas

The management plan for materials outlined in Section 10 of the 2015 RRS is considered to be appropriate with the following superseding updates.

Materials Classification (Section 10.2, 2015 RRS)

All excavated material will be segregated based on visual assessment and classified into the following material types detailed in the table below.

Material Type	Classification	Anticipated Final Destination of Material
Granular Made Ground	GMG (W)	Use as general fill (in accordance with acceptability criteria)
Cohesive Made Ground	CMG (W)	Use as general fill (in accordance with acceptability criteria)
Organic Rich Material	ORM (W)	Use primarily within green infrastructure and Public Open Space (POS). Additional stabilisation required if used as general fill
Sugar Factory Lime (SFL)	SFL (W)	Use as general fill (in accordance with acceptability criteria)
Lagoon Sediment	LS (W)	Use as general fill (in accordance with acceptability criteria)
Cohesive Natural Ground	CNG (W)	Use as general fill (in accordance with acceptability criteria)
Plant Growth Media	PGM (W)	Use primarily within green infrastructure and Public Open Space (POS). Limited imported topsoil may be required.
Concrete & Aggregate	CA (W)	Use primarily as secondary aggregate in e.g. founding layer for roads and hard standings and as general fill (in accordance with acceptability criteria).

Table 21 Materials Management – Material Types and Classification

These material types have been selected to support appropriate materials processing, remediation, soil stabilisation and end use.

Excavated waste from within the EP boundary will be further classified denoted by (W) as shown in the table above and segregated from soils excavated from outside the EP boundary throughout the entire material handling process. Remediated soils originating outside the EP boundary will be reused and placed within the DoWCoP Zone shown on Figure 14. Recovered waste will be permanently deposited across the remaining development footprint, outside the DoWCoP Zone.

Materials Tracking and Storage (Section 10.3, 2015 RRS)

A Materials Management Plan (MMP) will be produced to detail provisions outlined in Section 10 of the 2015 RRS including materials segregation and data management as well as provide lines of evidence regarding material quantities, suitability and certainty of use to support soils reuse under the DoWCoP framework.

Any areas of the site where soils containing asbestos have been permanently placed should have this clearly indicated on the soil audit and also be included on a marked up Site plan indicating location, depth and extent of any asbestos containing soils.

A revised Materials Management Flowchart has been produced and is shown in Figure 18.

5.4 Water Protection

5.4.1 Measures to Avoid a Pulse of Contaminated Water

There may be perched water of limited vertical and lateral extent present within the Made Ground that will have to be removed, collected and managed as part of the reclamation works.

Perched water in the Made Ground materials could contain elevated concentrations of various metals (e.g. chromium, cadmium, manganese, nickel, zinc), inorganic compounds (e.g. ammonia, ammonium, sulphate) and organic compounds (TPH and PAHs). To enable the discharge of this water a suitable effluent discharge consent will have to be obtained for the works. Any such consent will have discharge criteria associated with it and any recovered waters will require testing and potentially treatment prior to discharge.

All such encountered water shall be collected in a storage tank or lined lagoon prior to any treatment and discharge. Chemical analysis of this water shall be carried out at the frequencies given in Table 24 in Section 6.3 or as required by any discharge consent once obtained. The suite of determinants to be included in the laboratory analysis of this incidental water is detailed in the notes to Table 24 but must also include any parameters required to demonstrate compliance with any applicable discharge consent.

The recovered water shall either be:

- discharged to foul sewer under a trade effluent consent agreed with the local sewerage undertaker; and/or;
- discharged to surface water under a water discharge activity environmental permit (WDA-EP) from the Environment Agency.

The ultimate discharge location shall be determined following consultation with the local sewerage undertaker and/or the Environment Agency during the detailed design stage of the works.

No discharge to foul sewer or surface water courses shall be made without the required consent.

5.4.2 Perched Water Capture and Treatment

The provisions for perched water capture and treatment outlined within Section 5.2.1.1 of the 2015 RRS are considered to remain appropriate.

5.4.3 Surface Waters

The provisions for control of surface water runoff outlined within Section 5.2.1.2 of the 2015 RRS are considered to remain appropriate.

5.4.4 Protection of Water Courses

The provisions for protection of water courses outlined within Section 5.2.1.3 of the 2015 RRS are considered to remain appropriate which includes the development of a construction stage surface water management plan.

5.5 Earthworks Controls

The criteria are outlined within Section 6.2 of the 2015 RRS are considered to remain appropriate.

All made ground will be excavated and screened to remove oversize or deleterious material. Oversize material will be crushed for reuse, while deleterious material will be removed from site.

All remaining material will be placed into stockpiles and subjected to testing to ensure suitability as defined in series 600 of the Specification for Highways. Where the material does not meet the suitability criteria, it will be subjected to physical treatment, modification or stabilisation as required to achieve the necessary degree of compaction.

6 Testing and Monitoring

6.1 Geochemical Testing of Materials

Testing of all earthwork materials shall be undertaken at a minimum frequency listed in Table 22 below.

All earthworks materials shall be subject to geochemical testing from stockpiles following excavation and segregation according to material type as well as from stockpiles of remediated material prior to placement. Additional testing is to be undertaken on materials undergoing treatment via aerobic bioremediation. Geotechnical testing shall be done on a volumetric basis, rather than on a Site area basis, to reflect the varying thicknesses of deposited material requiring placement in different areas.

Materials will be sentenced for remediation and other material handling processes based on the material types identified (see Section 5.3.2) and the results of geochemical testing which will be assessed against the Remediation Criteria detailed in Section 4.3.

Where concentrations of contaminants are measured above the respective RTV and/or are from the specific locations, hotspots or material types defined within the Remediation Criteria these will be sentenced to remediation. Additional stockpile sampling may be undertaken where considered appropriate to reflect the heterogeneity of the material within a particular stockpile in order to assist in obtaining a representative average (mean) result for all samples collected from that stockpile which can be then compared with Remediation Criteria.

Work, Goods or Material	Test	Frequency of Testing
Chemical Control Testing (Notes a, b, c, d, and g)		
All material requiring excavation (excluding potential Plant Growth Media / Topsoil)	Soil Analysis Suite (Note d) and soil Leachability Suite (Note e) Screening test for asbestos	1 test per 2,000 m^3 (including a minimum of three samples where potential contamination is suspected)
All potential Plant Growth Media / Topsoil material requiring stripping	Soil Analysis Suite (Note f)	1 test per 500 m^3 (with minimum of 3 samples per source)
All material, as required, to demonstrate compliance with soil pore water RTV of destination Averaging Area prior to placement	Leachability Suite (Note e)	1 test per 2,000 m^3
Additional Chemical Control Testing (Note a, b, c, d and g)		
All imported materials for each individual source and type	Soil Analysis Suite (Note d) and soil Leachability Suite (Note e)	1 test per 500 m^3 with minimum 12 tests per material source
Imported landscape fill (topsoil/subsoil) for each individual source and type	Soil Analysis Suite (Note d) and soil Leachability Suite (Note e)	2 tests per 500 m^3 with minimum 12 tests per material source
All materials sentenced for remediation within bioplies	Soil Analysis Suite (Note d). Soil Leachability Suite (Note e) and Bioplie Physical Characterisation Laboratory Suite, Biopile Chemical Characterisation Laboratory Suite (Note h).	1 test per 300 m^3
All materials undergoing treatment within Biopiles	Soil Analysis suite (Note h) (including Organic matter content, moisture content, and Phosphorous as Orthophosohate)	Fortnightly

Work, Goods or Material	Test	Frequency of Testing
	Temperature °C (Biopile and Air) Carbon dioxide concentrations (% v/v) Methane concentration (% v/v) Oxygen concentrations (% v/v) pH, Weather conditions	Daily (minimum five points acrossthe biopile/window)
All materials having undergone successful treatment within biopiles	Soil Analysis suite (Note d) and soil Leachability Suite (Note e) and Biopile Physical Characterisation Laboratory suite (Note h).	1 test per 300 m3
All materials sentenced for remediation by stabilisation/solidification	Soil Analysis Suite (Note d), Soil Leachability Suite (Note e) (additional testing to be determined following laboratory trials)	1 test per 300 m^3
All materials having undergone treatment by stabilisation/solidification following maturation of a minimum of 7 days	Soil Analysis Suite (Note d), Soil Leachability Suite (Note e) (Additional testing to be determined following laboratory trials)	1 test per 500 m^3 of material placed into permanent works
All materials sentenced for off-site disposal	WAC testing Suite	1 test per 100 m^3 with minimum of 3 test per batch of material

Notes:

a) Testing specified in this table is to be undertaken on all materials.

b) All chemical analysis shall be UKAS and MCERTS accredited as appropriate.

c) All sampling shall be carried out in accordance with the BS 5930:2015, the code of practice for site investigations. Reporting shall be in digital form, which is compatible with Microsoft Excel, Esdat or Access, in addition to paper records.

d) Soil analysis suite to include the following determinants:

Polycyclic Aromatic Hydrocarbons (speciated USEPA 16)
Total Petroleum Hydrocarbons Criteria Working Group (TPH CWG)
Ammoniacal Nitrogen
Total Organic Carbon
Asbestos Screen
Asbestos Identification and Quantification (if asbestos screen proves positive)

e) Leachate analysis suite to include the following determinants:

Ammoniacal Nitrogen

f) Analysis to enable Topsoil classification in accordance within (BS 3882:2015) to include the following determinants:

Texture Class (clay, silt, sand) Organic Matter Content Particle Size Distribution (>2mm, >20mm,>50mm) Soil pH	Carbonate Nitrogen Phosphorus Potassium Magnesium Available sodium Available Calcium	Carbon: Nitrogen Ratio Exchangeable Sodium Percentage Zinc Copper Nickel Visible Contaminants

g) The limits of detection for the analyses shall be as specified within the 2015 RRS or lower;

h) Materials sentenced for treatment within biopiles shall be subjected to testing of the following additional determinants as well as those detailed in Note d): Soils Analysis Suite:

Particle Size Distribution (Dry or wet sieving – dependant on silt/clay content) BS1377-2:1990
Determination of permeability (constant head method) BS1377-5:1990
Compaction Test 2.5kg (‘Proctor’ Test) BS1377-4:1990
Moisture content
Total Organic Carbon
Soil Organic Matter content
Ammoniacal nitrogen
Phosphorous as Orthophosphate

Table 22 Schedule of Geochemical Testing of Materials

6.2 Ground Gas Monitoring

A programme of ground gas monitoring shall be carried out prior to the commencement of the remediation and reclamation works, during those works and post completion at the frequencies given in Table 23 below.

Scope of Monitoring	Test	Frequency of Testing
GROUND GAS MONITORING		
Ground gas monitoring prior to and during works will be taken from 36 wells currently monitored as part of the EP monitoring programme (tables S3.1 and S3.3 within the EP Variation (EPR/QP3593NF/V002). This includes 11 wells located within the EP boundary and 25 wells located outside the EP boundary. Locations shown on Figure 19. Ground gas monitoring following works will be taken from 36 replacement wells located within the EP boundary (listed within tables	Including peak and field stable measurements of carbon dioxide, carbon monoxide and methane concentrations, total gas flow, atmospheric pressure and conditions during monitoring. Detailed in Table 9.1 of the 2015 RRS	Standpipe installations located around the site to be sampled prior to the works (3 monthly visits), then at monthly intervals during the works, then at monthly intervals post works completion for a period of 24 months. Post completion should 12 consecutive monthly monitoring visits indicate ground gas compliance criteria have been met then it is understood that this will be accepted by the EA (Pre-application Advice,

Scope of Monitoring	Test	Frequency of Testing
S3.2 and S3.4 in the EP (EPR/QP3593NF/V002). This includes 11 wells located within the EP boundary and 25 wells located outside the EP boundary. Locations shown on Figure 20.		August 2015) with no further ground gas monitoring required.

Table 23 Ground Gas Monitoring Schedule

Where the concentrations of ground gases (and flow rates) recorded during the programme of monitoring are substantially elevated above levels previously recorded additional monitoring / increased frequency may be required at selected locations. However, the Remediation and Reclamation Strategy is intended to mitigate the ground gas risk to Amber 1, with the proviso that it is no greater than Amber 2. Where monitoring locations are within areas of the development that will be subject to earthworks excavations, placement of materials or construction, the monitoring locations shall be preserved and monitored for as long as reasonably practicable.

6.3 Water Monitoring

A programme of groundwater, surface water and water arisings monitoring shall be carried out prior to commencement of the remediation and reclamation works, during those works and post completion for the suite of determinants and frequencies given in Table 24 below.

Scope of Monitoring	Test	Frequency of Testing
GROUNDWATER MONITORING		
Groundwater monitoring prior to and during works will be taken from 23 wells currently monitored as part of the EP monitoring programme (table S3.5 within the EP Variation (EPR/QP3593NF/V002). This includes 11 wells located within the EP boundary and 12 wells located outside the EP boundary. Locations shown on Figure 19. Groundwater monitoring following works will be taken from 14 replacement wells located within the EP boundary (listed within tables S3.6 in the EP (EPR/QP3593NF/V002). This includes 4 wells located within the EP boundary and 10 wells located outside the EP boundary. Locations shown on Figure 20.	Representative samples of groundwater submitted for laboratory analysis of parameters required by the EP (EPR/QP3593NF/V002) which are listed in Note b.	From 23 existing monitoring wells located around the site to be sampled on 3No (monthly) occasions prior to the works, then at monthly intervals during the works, then from 14 replacement wells post completion for a period of 24 months. Should 12 consecutive monthly monitoring visits, post remediation, indicate groundwater assessment criteria (Section 4.3.4) have been met then it is proposed that this will be accepted by the EA and no further monitoring required.
SURFACE WATER MONITORING		
Surface water monitoring (sampling and laboratory testing) shall be undertaken from the River Ouse including at a minimum, upstream and downstream locations, and one intermediate location along the length of the River opposite the site.	Representative samples of surface water submitted for laboratory analysis of parameters listed in Note b.	Samples to be obtained on 1No occasion prior to the works, then at monthly intervals during the works, then at monthly intervals during and post completion for a period of 12-months

Scope of Monitoring	Test	Frequency of Testing
ANY HOLDING TANK/ LAGOON FOR INCIDENTAL ARISINGS OF WATER (PRE & POST TREATMENT)		
Holding tank/ lagoon water (where site waters have been collected) prior to treatment and discharge	Representative samples of holding tank / lagoon water submitted for laboratory analysis of parameters listed in Note b plus any other parameters required to demonstrate compliance with a discharge consent.	Samples to be taken before and post treatment on a monthly basis during the works or at the frequency required in the water discharge activity environmental permit (WDA-EP) and/or trade effluent consent.

Notes:

a) All chemical analysis shall be UKAS and MCERTS accredited as appropriate
b) Water analysis suite to include the following determinants:

Arsenic Cadmium Nickel	Ammoniacal Nitrogen Sulphate Nitrate Nitrite	pH Temperature Electrical Conductivity Dissolved Oxygen Redox Potential	Total Petroleum Hydrocarbons (carbon banded C5 – C40) Phenols Polycyclic Aromatic Hydrocarbons (speciated USEPA 16)

Table 24 Groundwater, Surface Water and Holding Tank / Lagoon Water Monitoring Schedule

6.4 Additional Notes on Monitoring

The additional notes provided in relation to soil testing, gas monitoring and water testing in Section 9.3 of the 2015 RRS are considered to remain appropriate with the exception of the following superseding updates.

- Changes to best practice sampling, storage, preservation and transport of samples as required by the analytical laboratory will supersede any previous provision within Section 9.3;
- The location of surface water monitoring locations will be confirmed as part of the Surface Water Management Plan (See Section 5.4.4);
- Where leachate analysis is specified, a sample of leachate shall be prepared from a soil sample following the procedure set out in British Standard (BS, 2002) BS 12457 Part 1 – one stage test using a liquid to solid ratio of 2:1 l/kg, unless otherwise stated. This is considered a pragmatic and robust, initial assessment of potential contaminant leachability which may be sufficient in many cases.
- It is recommended that, where appropriate, semi dynamic tank testing be undertaken on suitable samples of stabilised and compacted soil monoliths (cured for at least 14 days) to assess long term leaching in a more representative manner than the one stage, 2:1 British standard leach test. This requires suitable samples to be collected and prepared at the time of stabilisation and be appropriately stored prior to leaching. It must be ensured that any prepared monoliths are representative of the relevant material stabilised on site.

6.5 Airborne Dust Monitoring Locations and Specification

The provisions for airborne dust monitoring, default criteria and complaints management outlined within Section 9.7 of the 2015 RRS are considered to remain appropriate.

Further provision for dust monitoring and management are provided within the Outline Construction Environmental Management Plan (CEMP) (Version 1.1, June 2017), submitted as part of the granted planning permission (14/02798/FULM, September 2017) and any subsequent updates to this CEMP.

6.6 Odour Monitoring Locations and Specification

The provisions for odour monitoring, default criteria and complaints management outlined within Section 9.8 of the 2015 RRS are considered to remain appropriate.

Further provision for odour monitoring and management are provided within the CEMP (Version 1.1), submitted as part of the granted planning permission (14/02798/FULM, September 2017), and any subsequent updates to this CEMP.

Chemical and ammoniacal odours have been noted associated with Organic Rich Material during previous phases of investigation and so will require careful management during handling and remediation of this material. It is noted that at the elevated pH associated with lime stabilisation deprotonation of ammonium to ammonia gas can occur, which may further contribute to potential odour and gas issues requiring management. Drying of Organic Rich Material is required prior to soil stabilisation which may also be advantageous to reduce ammoniacal nitrogen concentrations (via nitrification) and thus reduce potential odour generation during soil stabilisation. Aeration of ammoniacal nitrogen impacted material should therefore be considered as an additional means of odour control as required, provided this is effectively managed.

6.7 Noise and Vibration Locations and Specification

The provisions for odour monitoring, default criteria and complaints management outlined within Section 9.9 of the 2015 RRS are considered to remain appropriate.

Further provision for noise and vibration monitoring and management are provided within the CEMP (Version 1.1), submitted as part of the granted planning permission (14/02798/FULM, September 2017), and any subsequent updates to this CEMP.

6.8 Geotechnical Acceptability

6.8.1 General

Materials will be classified in accordance with the requirements of series 600 of the Specification for Highways. The provisions for testing set out in Section 6.2 of the 2015 RRS are considered to remain appropriate.

Materials which fall outside of the specification will be processed, modified or stabilised as appropriate to make them suitable for reuse.

6.8.2 Slope Stability

Slopes have been designed based on RRa maximum gradient of 1 vertical to 3 horizontal.

Detailed slope stability calculation is being carried out to confirm the suitability of the design in the permanent condition.

Temporary slopes on site will be no steeper than 1 vertical to 2 horizontal. Such slopes will be subject to regular inspection by a competent person.

6.8.3 Validation of Compaction

The provisions for testing set out in Section 6.2 of the 2015 RRS are considered to remain appropriate.

Confirmation that adequate compaction has been achieved (95% of MDD, <=5% air voids) will be achieved by undertaking nuclear density testing and sand replacement density or core cutter (subject to material type).

7 Validation / Verification Strategy

7.1 Demonstrating Effective Removal of Soil Contamination

Contaminated materials will be identified through excavation of identified hotspots, visual segregation of materials according to specific material types and the material testing regime specified in Table 22. The sampling and testing is required to confirm that the underlying materials comply with the RTVs for the residential development and associated uses of the site.

All earthworks materials shall be subject to geochemical testing from stockpiles following excavation and segregation according to material type as well as from stockpiles of remediated material prior to placement. Where the materials comply with the RTVs at point of excavation then the material may be used within the works. However, the materials must also comply with the geotechnical acceptability criteria. Where at point of excavation the materials do not meet the RTVs then the material will be segregated and sentenced to bioremediation, stabilisation/solidification or off-site disposal. Additional stockpile sampling may be undertaken where considered appropriate to reflect the heterogeneity of the material within a particular stockpile in order to assist obtaining a representative average (mean) result for all samples collected from that stockpile which can be then compared with Remediation Criteria.

The method(s) for validating treated materials is presented in Sections 4.3 and 6.1. Materials which fail the acceptability testing for use within 1m depth of the formation level can be used at depths greater than 1m below the formation level, where failure is due to non-volatile or negligibly volatile determinants. This includes materials where free asbestos fibres have been identified noting that visible ACM material will be identified and segregated by handpicking for off site disposal as far as practicable. For volatile contaminants and material where residual free phase product is identified the material will be subject to ex situ bioremediation.

During excavation visual inspections of the cut areas will be undertaken and any observations of areas of contamination and any odours, such as hydrocarbon odours, indicating the presence of potential contamination will also be recorded.

Unacceptable materials will be segregated and stored in a dedicated stockpile for remediation or disposal.

Confirmatory sampling and chemical testing will be undertaken from stockpiles of remediated material prior to placement. Where failures in comparison to the RTVs are identified the soil materials will be removed and sentenced to either further remediation for volatile substances or to placement at depths greater than 1m below formation level for non-volatile and negligibly volatile substances or to off-site disposal.

7.2 Demonstrating Effective Treatment of Soil Contamination

Where excavated materials contain volatile hydrocarbons at concentrations exceeding the soil RTVs and/or ammoniacal nitrogen at concentrations exceeding the soil leachate RTVs and/or comprise Organic Rich Material from Historic Pond 7 they shall be recovered / rendered suitable for use by remediation within biopiles and/or windrows.

During the bioremediation process monitoring via field measurements and laboratory sampling of the materials within the biopile/windrow shall be undertaken as described in Table 22. During treatment testing will be undertaken at approximately fortnightly intervals and at a rate of 1 set of results per 300 m^3 of material in treatment; field measurements will be taken on a daily basis from a minimum of five points across the biopile/windrow.

Weather conditions will also be recorded on a daily basis.

The results of the laboratory testing and field measurements will provide lines of evidence to allow validation of the bioremediation works in addition to comparison of contaminant concentrations against the RTVs. The metal determinants are required in the fortnightly testing schedule as a control to provide evidence that the concentration of biodegradable contaminants have been reduced by bioremediation and not through dilution. The validation of the materials treated within each biopile/windrow batch will be undertaken before the treated material can be used in the development. Where materials cannot be validated as having been treated to the required standard they will either be sentenced for further treatment within the biopile/windrow or if this is considered to be impractical the material will be sentenced for offsite disposal.

It is noted that while soil RTVs comprise a single criteria value for each parameter across the entire boundary, soil pore water RTV for ammoniacal nitrogen vary according to the Averaging Areas. Therefore, excavated material will be sentenced for remediation based on comparison of the concentration of ammoniacal nitrogen in soil leachate with the RTV of the Averaging Area from which the material was excavated. In addition, prior to placement and/or following any remediation or soil stabilisation, further soil leachate testing must be undertaken, as required, to demonstrate compliance with the RTV of the destination Averaging Area. This is to ensure material is not merely moved from one area to another but that genuine source reduction is achieved across the site as a whole. It is noted that the Green Infrastructure and areas of POS, where Organic Rich Material is to be primary placed, are located within and across multiple Averaging Areas.

7.3 Demonstrating Effective Treatment of Ground Gas

Data on the chemical and geotechnical composition of the excavated and placed materials, collected via the testing requirements specified in Tables 22, will be used to increase the confidence of the engineering ground model and conceptual site model.

The specific remediation objectives with regarding to ground gas include excavating any significant Organic Rich Material encountered within Made Ground present within Historic Pond 7 and subjecting this material to ex situ aerobic bioremediation in order to reduce the gassing potential of this material prior to placement (following any stabilisation required).

As well as the lines of evidence collected during bioremediation described in the previous Section, reductions in the TOC content, as well as forensic organic matter testing of the material, may also be used as a line of evidence to support the reduction in readily degradable organic matter content and hence demonstrate a reduction in ground gas generating potential.

It is intended that the excavated Made Ground materials which are acceptable for use will be placed and compacted as bulk fill to formation level. The material is intended to be compacted to 95% MDD and 5% air voids. Gas monitoring (detailed in Section 7.2) will be undertaken across the site, before, during and after the works. Before and during the works selected existing monitoring wells will be used. New monitoring wells will be installed during the works as the original set of monitoring wells are destroyed by the progress of the works. The new monitoring wells will continue to be monitored following completion of the works.

The information from the testing and gas monitoring undertaken during excavation and placement of works materials and the data from the remedial treatment will be used to confirm that the ground gas remediation and reclamation objectives have been achieved.

Ground gas data will be used to demonstrate that ground gas conditions following remediation are appropriate to Amber 1 and at most is not greater than Amber 2 (NHBC Traffic Light System). In addition, where methane and carbon dioxide concentrations exceed 1.5%v/v and 5%v/v respectively (Scenario 1, EPR 5.02, EA Guidance) hazardous gas flow rates (Qhgs) will be calculated in line with Scenario 2 (EPR 5.02) in accordance with the required permit surrender Completion Criteria provided by the EA in Pre-Advice Letter (EAWML68681, EA, 28th August 2015). Assessment of hazardous gas flows rates based on geographical zoning of the site will be undertaken where appropriate and with agreement of the EA.

An assessment of the ground gas regime will inform the level of gas protection measures required for the new properties to be built on the residential development platforms.

7.4 Assessment of Groundwater Quality Post Remediation

As described in Section 4.3.4, ground water assessment post remediation may include assessment of trends or statistics, in combination with comparison with set values, and are as follows:

- Post remediation – to assess groundwater quality trends within replacement monitoring wells (defined in Section 6.3) following remediation works to demonstrate there are no significant sustained increases in concentrations of ammoniacal nitrogen and other metal or metalloids contaminants listed in the EP Variation. Assessment of trends may include statistical analysis where appropriate, or comparison with simple descriptive statistics.
    - For replacement monitoring wells which are direct replacements for existing monitoring wells (listed within the EP Variation working Plan (URS, February 2015)) and for which

representative data is likely available for pre remediation conditions, then reference will also be made to these pre remediation concentrations (including Control Levels) to demonstrate there is no significant deterioration in groundwater quality following remediation;

- For replacement monitoring wells which are not direct replacements for existing monitoring wells and for which representative data is not likely available for pre remediation conditions then, if sustained increasing trend is observed, reference will also be made to the (SSAC (Updated HRA, Arcadis, 2019) provided these replacement wells are associated with identified Sources (Updated HRA, Arcadis, 2019). Where these wells are not associated with a Source, then further risk assessment may be undertaken if deemed required, including reference to EQS and/or DWS standards, if relevant.

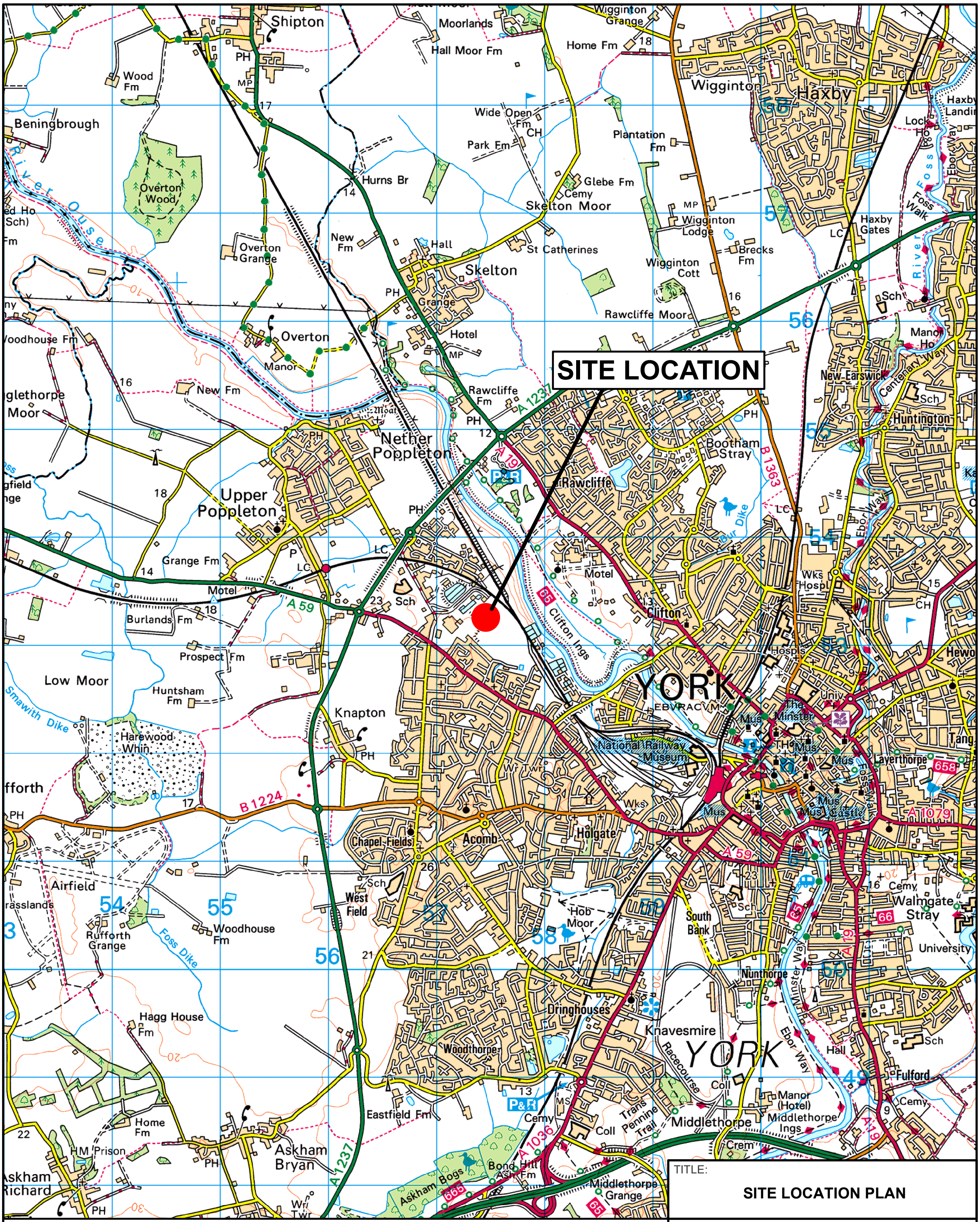
7.5 Monitoring

As described in Section 6.2, ground gas monitoring will be undertaken at monthly intervals post works completion and for a period of 24 months. Should 12 consecutive monthly monitoring visits indicate ground gas compliance criteria have been met then it is understood that this will be accepted by the EA (Pre-application Advice, August 2015) with no further ground gas monitoring required.

As described in Section 6.3, groundwater monitoring will be undertaken at monthly intervals during the works, then at post completion for a period of 24 months within a network of replacement wells installed across the Site. Should 12 consecutive monthly monitoring visits (post completion) indicate ground monitoring compliance criteria have been met then it is proposed that this will be accepted by the EA and no further monitoring required.

7.6 Validation / Verification Reporting

The provisions for validation and verification reporting outlined within Section 11.3 of the 2015 RRS are considered to remain appropriate.



TITLE:	**SITE LOCATION PLAN**
SITE :	**BRITISH SUGAR YORK**
CLIENT :	**BRITISH SUGAR**
PROJECT : **10024487**	**FIGURE 1**
DATE : 30/07/19	DRAWN BY : AP
DRG No. : 10024487-AUK-XX-XX-DR-ZZ-0002-P1.GIS	
SCALE : **1 : 50,000**	PRINT : **A4**

LEGEND

● SITE LOCATION

NOTES

SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE.

0 0.2 0.4 0.8 1.2 1.6 2 Kilometres

N

ARCADIS Design & Consultancy for natural and built assets

Legend

▨ Former Water Treatment Area
▨ Former Factory Area
▨ Historic Ponds and Soil Conditioning Area
☐ Site Boundary
▨ Current Ponds on Site
— Site Wide Topo Countors

Under the Microsoft® BingTM Maps

N

Issued for Information			
Design	S.Sohni	3-4-2020	
Drawn	S.Sohni	3-4-2020	
Checked	J.Hurst	3-4-2020	
Approved	C.Piddington	3-4-2020	
Scale	1:4000	Datum	AOD
Original Size	A3	Grid	OS
Suitability Code:		Project Number	10024487

Client - British Sugar Plc

Figure 2

PROJECT

British Sugar, York

TITLE

Site Layout Plan

ARCADIS Design & Consultancy for natural and built assets

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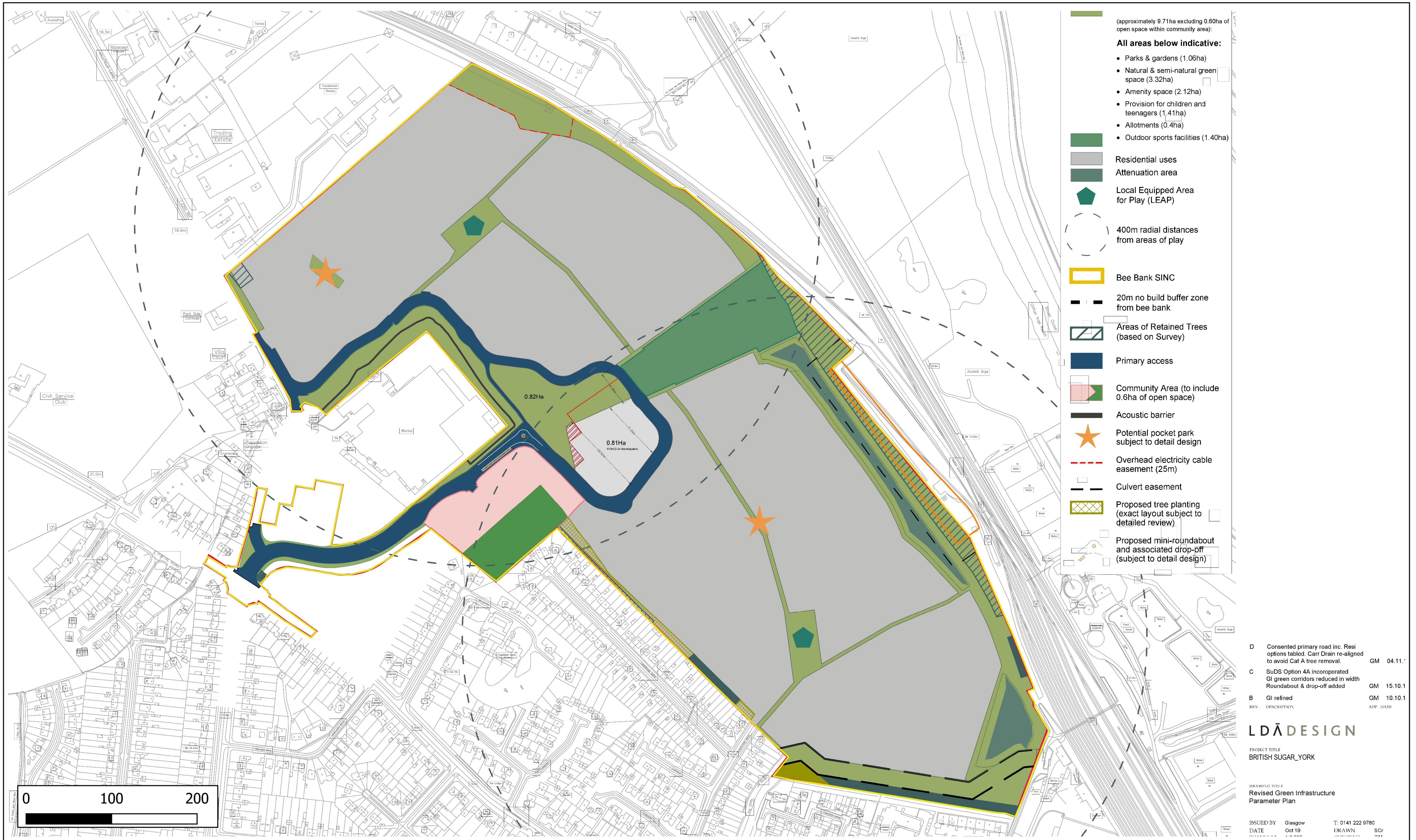
Arcadis House
34 York Way,
London
N1 9AB

Co-Ordinating office:
1 Whitehall Riverside
Leeds
LS1 4BN
United Kingdom
T: +44 (0)113 284 5300

Drawing Number:
10024487-AUK-XX-XX-DR-ZZ-0047-P1-Site layout Plan



Legend

🟨 Site Boundary

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Design	S.Sohni	3-4-2020	
Drawn	S.Sohni	3-4-2020	
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Approved		3-4-2020	
Scale	1:4000	Datum	AOD
Original Size	A3	Grid	OS
Suitability Code:		Project Number	10024487

Client - British Sugar Plc

British Sugar

Figure 3

PROJECT

British Sugar, York

TITLE

Draft Illustrative Masterplan

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Drawing Number:
10024487-AUK-XX-XX-DR-ZZ-0056-P1-Masterpan Map

Legand

LocationDetails3D

- ● Arcadis Exploratory Location
- ● Enviros Exploratory Location
- ● Golder Exploratory Location
- ● Scott Wilson Exploratory Location
- ⊙ Arcadis Additional Boreholes
- ▭ Site Boundary

N

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Issued for Information

Design	S.Sohni	3-4-2020	
Drawn	S.Sohni	3-4-2020	
Checked	J.Hurst	3-4-2020	
Approved	C.Piddington	3-4-2020	
Scale	1:4000	Datum	AOD
Original Size	A3	Grid	OS
Suitability Code:		Project Number	10024487

Client - British Sugar Plc

BritishSugar

Figure 4

PROJECT

British Sugar, York

TITLE

Exploratory Borehole, Trial Pit and Gas Monitoring Well Location Plan

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London
N1 9AB

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Leeds
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United Kingdom
T: +44 (0)113 284 5300

Drawing Number:
10024487-AUK-XX-XX-DR-ZZ-0035-P1-Borehole Location Map - Historic and Current Locations

Legend

🟥 Area of Identified Peat Deposits

☐ Site Boundary

Under the Microsoft® BingTM Maps

Issued for Information

Design	S.Sohni	6-4-2020	
Drawn	S.Sohni	6-4-2020	
Checked	D.Calvert	6-4-2020	
Approved	C.Piddigton	6-4-2020	
Scale	1:4000	Datum	AOD
Original Size	A3	Grid	OS
Suitability Code:		Project Number	10024487

Client - British Sugar Plc

BritishSugar

Figure 5

PROJECT

British Sugar, York

TITLE

Area of Identified Peat Deposits

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United Kingdom
T: +44 (0)113 284 5300

Drawing Number:10024487-AUK-XX-XX-DR-ZZ-0055-P1-Peat

Legend

Moisture Content (MC) and Optimum Moisture Content (OMC)

- ● Moisture Content < OMC
- ● MoistureContent >= OMC and Moisture Content < OMC +4%MC
- ● Moisture Content >= OMC +4% MC and Moisture Content < 150% MC
- ● Moisture Content >= 150% OMC and Moisture Content < 250% OMC
- ● Moisture Content >= 250% OMC and Moisture Content < 350% OMC
- ● Moisture Content >= 350% OMC
- ☐ Site Boundary

Under the Microsoft® BingTM Maps

N

Issued for Information

Design	S.Sohni	6-4-2020	
Drawn	S.Sohni	6-4-2020	
Checked	D.Calvert	6-4-2020	
Approved	C.Piddigton	6-4-2020	
Scale	1:4000	Datum	AOD
Original Size	A3	Grid	OS
Suitability Code:		Project Number	10024487

Client - British Sugar Plc

BritishSugar

Figure 6

PROJECT

British Sugar, York

TITLE

Optimum Moisture Content Distribution Map

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Drawing Number:10024487-AUK-XX-XX-DR-ZZ-0051-P1-Moisture Content and OMC distribution Plot

Legend

▨ Obstructions Layer

☐ Site Boundary

▨ Floor Slab from Manor School

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N

Issued for Information			
Design	S.Sohni	16-4-2020	
Drawn	S.Sohni	16-4-2020	
Checked	J.Hurst	16-4-2020	
Approved	C.Piddington	16-4-2020	
Scale	1:4000	Datum	AOD
Original Size	A3	Grid	OS
Suitability Code:		Project Number	10024487

Client - British Sugar Plc

Figure 7

PROJECT

British Sugar, York

TITLE

Subsurface Obstructions Drawing

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United Kingdom
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Drawing Number:10024487-AUK-XX-XX-DR-ZZ-0053-P1-Obstruction Pile Map

Legend

Sum Total Petroleum Hydrocarbons

- ● < Method Detection Limit
- ● 10 - 50 mg/kg
- ● 50 - 100 mg/kg
- ● 100 - 500 mg/kg
- ● 500 - 1000 mg/kg
- ● > 1000 mg/kg
- ◇ Exceedance
- ▨ TPH Hotspots
- ☐ Site Boundary

Under the Microsoft® BingTM Maps

N

Issued for Information			
Design	S.Sohni	3-4-2020	
Drawn	S.Sohni	3-4-2020	
Checked	J.Hurst	3-4-2020	
Approved	C.Piddington	3-4-2020	
Scale	1:3988	Datum	AOD
Original Size	A3	Grid	OS
Suitability Code:		Project Number	10024487

Client - British Sugar Plc

BritishSugar

Figure 8

PROJECT

British Sugar, York

TITLE

Distribution of Sum Total Petroleum Hydrocarbons in Soil

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Drawing Number:
10024487-AUK-XX-XX-DR-ZZ-0044-P1-TPH Distribution Map

Legend

Sum Polycyclic Aromatic Hydrocarbons

● <Method Detection Limit

● 0.05 - 0.5 mg/kg

● 0.5 - 5 mg/kg

● 5 - 50 mg/kg

● 50 - 100 mg/kg

● >100 mg/kg

◇ Exceedance

▨ PAH Hotspots

☐ Site Boundary

N

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Issued for Information

Design	S.Sohni	3-4-2020	
Drawn	S.Sohni	3-4-2020	
Checked	J.Hurst	3-4-2020	
Approved	C.Piddington	3-4-2020	
Scale	1:4000	Datum	AOD
Original Size	A3	Grid	OS
Suitability Code:		Project Number	10024487

Client - British Sugar Plc

BritishSugar

Figure 9

PROJECT

British Sugar, York

TITLE

Distribution of Sum Polycyclic Aromatic Hydrocarbons in Soil

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Drawing Number:
10024487-AUK-XX-XX-DR-ZZ-0045-P1-PAH Distribution Map

Legend

Ammonical Nitrogen Districution and Hotspot Area

AA1b
● Monitoring Locations in Averaging Area AA1b

AA1a
● Monitoring Locations in Averaging Area AA1a

AA4b
● Monitoring Locations in Averaging Area AA4b

AA4a
● Monitoring Locations in Averaging Area AA4a

AA3b
● Monitoring Locations in Averaging Area AA3b

AA3a
● Monitoring Locations in Averaging Area AA3a

AA2
● Monitoring Locations in Averaging Area AA2

◇ Exceedance of Soil Pore RTV
▨ Ammonical Nitrogen Hotsdpot
☐ Averaging Areas
☐ Site Boundary

N

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Issued for Information

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Drawn	S.Sohni	3-4-2020	
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Scale	1:4000	Datum	AOD
Original Size	A3	Grid	OS
Suitability Code:		Project Number	10024487

Client - British Sugar Plc

BritishSugar

Figure 10

PROJECT

British Sugar, York

TITLE

Exceedances of Soil Pore Water RTV for Ammoniacal Nitrogen and Hotspot Areas

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Drawing Number:
10024487-AUK-XX-XX-DR-ZZ-0042-P1-Ammonical Nitrogen Distribution and Hotspot Area

Legand

NHBC Classification

- 🟢 Green
- 🟡 Amber1
- 🟠 Amber 2
- ○ No Ground Gas Monitoring Undertaken between Jan 2018 - Apr 2019
- ▭ Site Boundary

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Issued for Information

Design	S.Sohni	3-4-2020	
Drawn	S.Sohni	3-4-2020	
Checked	J.Hurst	3-4-2020	
Approved	C.Piddington	3-4-2020	
Scale	1:4000	Datum	AOD
Original Size	A3	Grid	OS
Suitability Code:		Project Number	10024487

Client - British Sugar PLC

Figure 11

PROJECT

British Sugar, York

TITLE

Distribution of NHBC Classification of Ground Gas

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Leeds
LS1 4BN
United Kingdom
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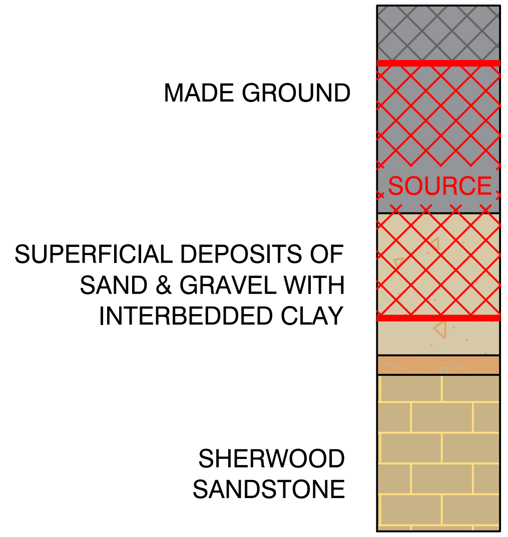
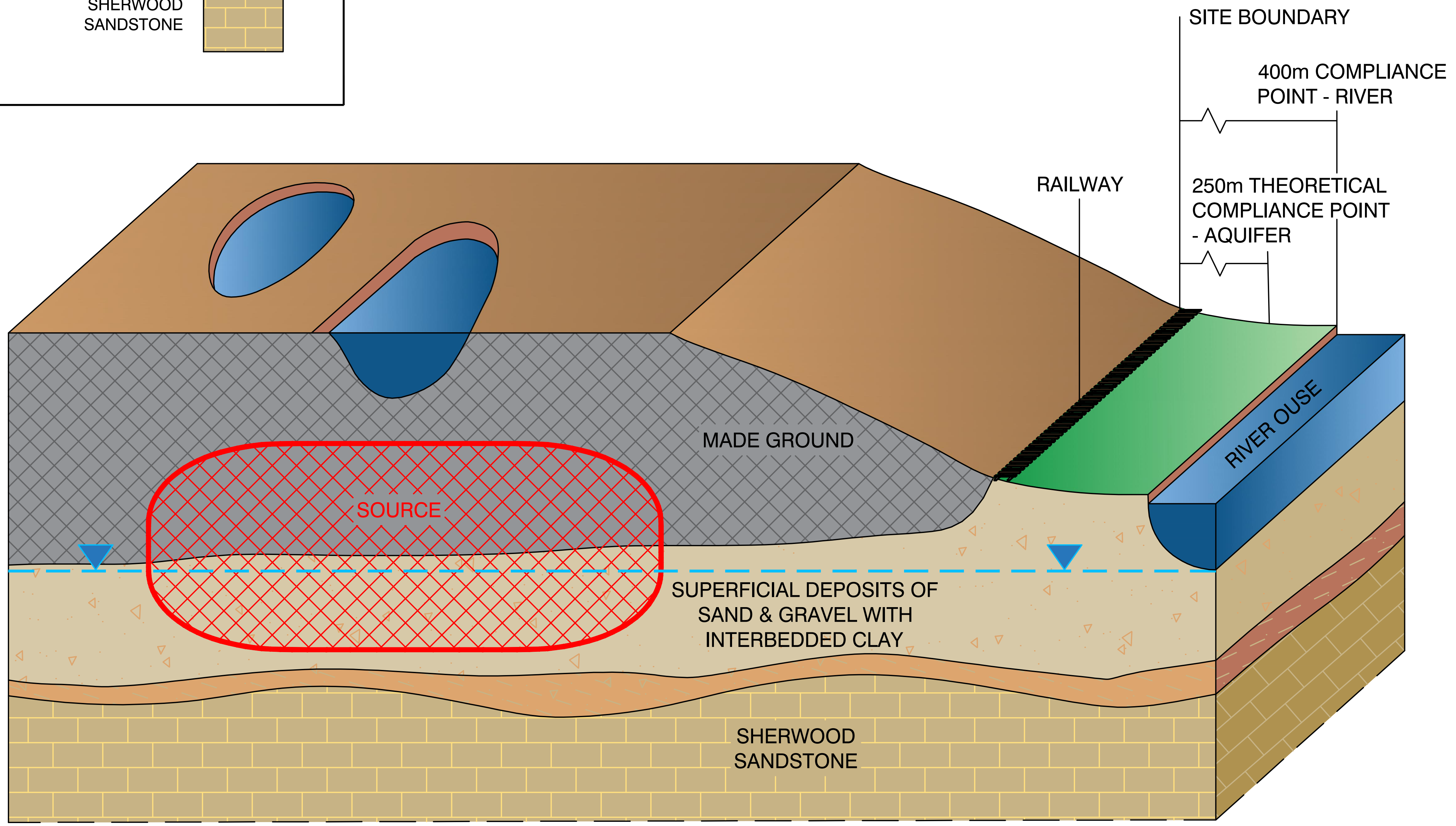
Drawing Number:
10024487-AUK-XX-XX-DR-ZZ-0036-P1-Distribution of NHBC Classification of Ground Gas



Conceptual Zone	Physical Characteristics	Justification
Saturated Zone	Sand & Gravel	Representative of the deposits ecountered beneath the site through which off-site migration of groundwater in anticapted to take place.



NOTE: ALL ENTITIES SHOWN ON THIS DRAWING ARE TO BE REGARDED AS APPROXIMATE AND ARE INDICATIVE ONLY. NO MEASUREMENTS TAKEN FROM THIS DRAWING SHOULD BE USED FOR THE LOCATION OF INTRUSIVE INVESTIGATION WORKS ON SITE. SYMBOLS FOR BOREHOLES, TRIAL PITS AND OTHER SPECIFIC FEATURES ARE REPRESENTATIONS OF LOCATION ONLY AND UNLESS OTHERWISE SPECIFIED, DO NOT REPRESENT THE TRUE SIZE OF THE FEATURE. - CONTACT ARCADIS UK IN CASE OF ANY QUERY

KEY

╌ ╌ GROUNDWATER LEVEL

REV	DATE	COMMENT	CAD

TITLE: CONCEPTUAL SITE MODEL

SITE: BRITISH SUGAR YORK

CLIENT: BRITISH SUGAR

PROJECT: 10024487 FIGURE 12

DATE: 12/11/19 DRAWN: JC REV: -

DRG.No.: 10024487-AUK-XX-XX-DR-ZZ-0021 PRINT: A3

ARCADIS Design & Consultancy for natural and built assets

Legend

NHBC Gas Classification
- ● Green
- ● Amber1
- ● Amber 2
- ● No Ground Gas Monitoring Undertaken between Jan 2018 - Apr 2019

Total Organic Carbon
- ● TOC < 3%
- ● TOC > 3%
- ▭ Site Boundary

Under the Microsoft® BingTM Maps

Issued for Information

Design	S.Sohni	6-4-2020	
Drawn	S.Sohni	6-4-2020	
Checked	J.Hurst	6-4-2020	
Approved	P.Wrigley	6-4-2020	
Scale	1:3800	Datum	AOD
Original Size	A3	Grid	OS
Suitability Code:		Project Number	10024487

Client - Associated Britsh Foods

BritishSugar

Figure 13

PROJECT

British Sugar, York

TITLE

Total Organic Carbon and NHBC classification distribution Map

ARCADIS Design & Consultancy for natural and built assets

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London
N1 9AB

Co-Ordinating office:
1 Whitehall Riverside
Leeds
LS1 4BN
United Kingdom
T: +44 (0)113 284 5300

Drawing Number:
10024487-AUK-XX-XX-DR-ZZ-0040-P1-TOC Distribution and NHBC Gas Classification

Legend

- 🟦 Material Storage and Processing Area
- 🟪 DoWCop Zone
- 🟩 Green Infrastructure Area within the DoWCoP Zone
- 🟩 Green Infrastructure Around the DoWCoP Zone
- ☐ Site Boundary

Under the Microsoft® BingTM Maps

N

Issued for Information			
Design	S.Sohni	6-4-2020	
Drawn	S.Sohni	6-4-2020	
Checked	J.Hurst	6-4-2020	
Approved	C.Piddington	6-4-2020	
Scale	1:4000	Datum	AOD
Original Size	A3	Grid	OS
Suitability Code:		Project Number	10024487

Client - British Sugar Plc

BritishSugar

Figure 14

PROJECT

British Sugar, York

TITLE

DoWCoP Zone and Materials Storage and Processing Area

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1 Whitehall Riverside
Leeds
LS1 4BN
United Kingdom
T: +44 (0)113 284 5300

Drawing Number:
10024487-AUK-XX-XX-DR-ZZ-0046-P1-DowCop Zone and Material Storage area

Legend

Upper Surface of the Vale of York Formation - mAOD

- 🟦 5.74
- 🟩 9.6425
- 🟨 13.545
- 🟧 17.4475
- 🟥 21.35
- ▭ Site Boundary

Under the Microsoft® BingTM Maps

N

Issued for Information			
Design	S.Sohni	20-4-2020	
Drawn	S.Sohni	20-4-2020	
Checked	J.Hurst	20-4-2020	
Approved	C.Piddington	20-4-2020	
Scale	1:4000	Datum	AOD
Original Size	A3	Grid	OS
Suitability Code:		Project Number	10024487

Client - British Sugar Plc

BritishSugar

Figure 15

PROJECT

British Sugar, York

TITLE

Upper Surface of the Vale of York Formation - (QGIS 2D Elevation Layer)

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Drawing Number:
10024487-AUK-XX-XX-DR-ZZ-0039-P1-Top of Vale of York

Legend

Current Site Topography (QGIS 2D Elevation Layer)

- 🟦 5.97
- 🟩 12.36
- 🟨 18.74
- 🟧 25.12
- 🟥 31.5
- ▭ Site Boundary

Under the Microsoft® BingTM Maps

N

Issued for Information			
Design	S.Sohni	3-4-2020	
Drawn	S.Sohni	3-4-2020	
Checked	J.Hurst	3-4-2020	
Approved	C.Piddington	3-4-2020	
Scale	1:4000	Datum	AOD
Original Size	A3	Grid	OS
Suitability Code:		Project Number	10024487

Client - British Sugar Plc

Figure 16

PROJECT

British Sugar, York

TITLE

Current Site Topography (QGIS 2D Elevation Layer)

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London
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Co-Ordinating office:

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Leeds
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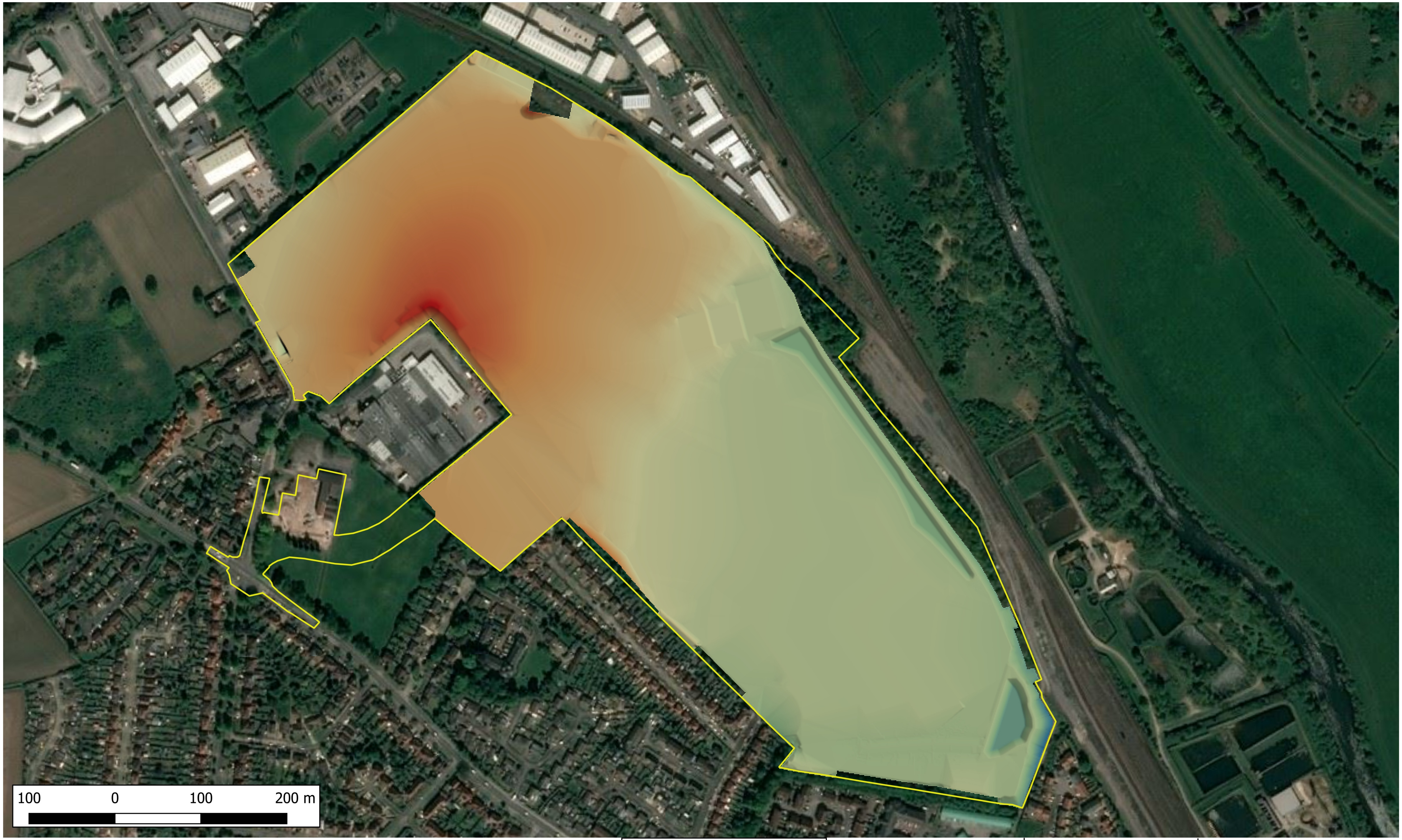
United Kingdom
T: +44 (0)113 284 5300

Drawing Number:
10024487-AUK-XX-XX-DR-ZZ-0037-P1-New Topo Survey Map



Legend

Proposed Development Surface (QGIS 2D Elevation Layer)

- 🟦 9.3
- 🟩 13.30
- 🟨 17.27
- 🟧 21.25
- 🟥 25.23
- ☐ Site Boundary

Under the Microsoft® BingTM Maps

N

Issued for Information			
Design	S.Sohni	3-4-2020	
Drawn	S.Sohni	3-4-2020	
Checked	J.Hurst	3-4-2020	
Approved	C.Piddington	3-4-2020	
Scale	1:4000	Datum	AOD
Original Size	A3	Grid	OS
Suitability Code:		Project Number	10024487

Client - British Sugar Plc

BritishSugar

Figure 17

PROJECT

British Sugar, York

TITLE

Proposed Development Surface (QGIS 2D Elevation Layer)

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United Kingdom
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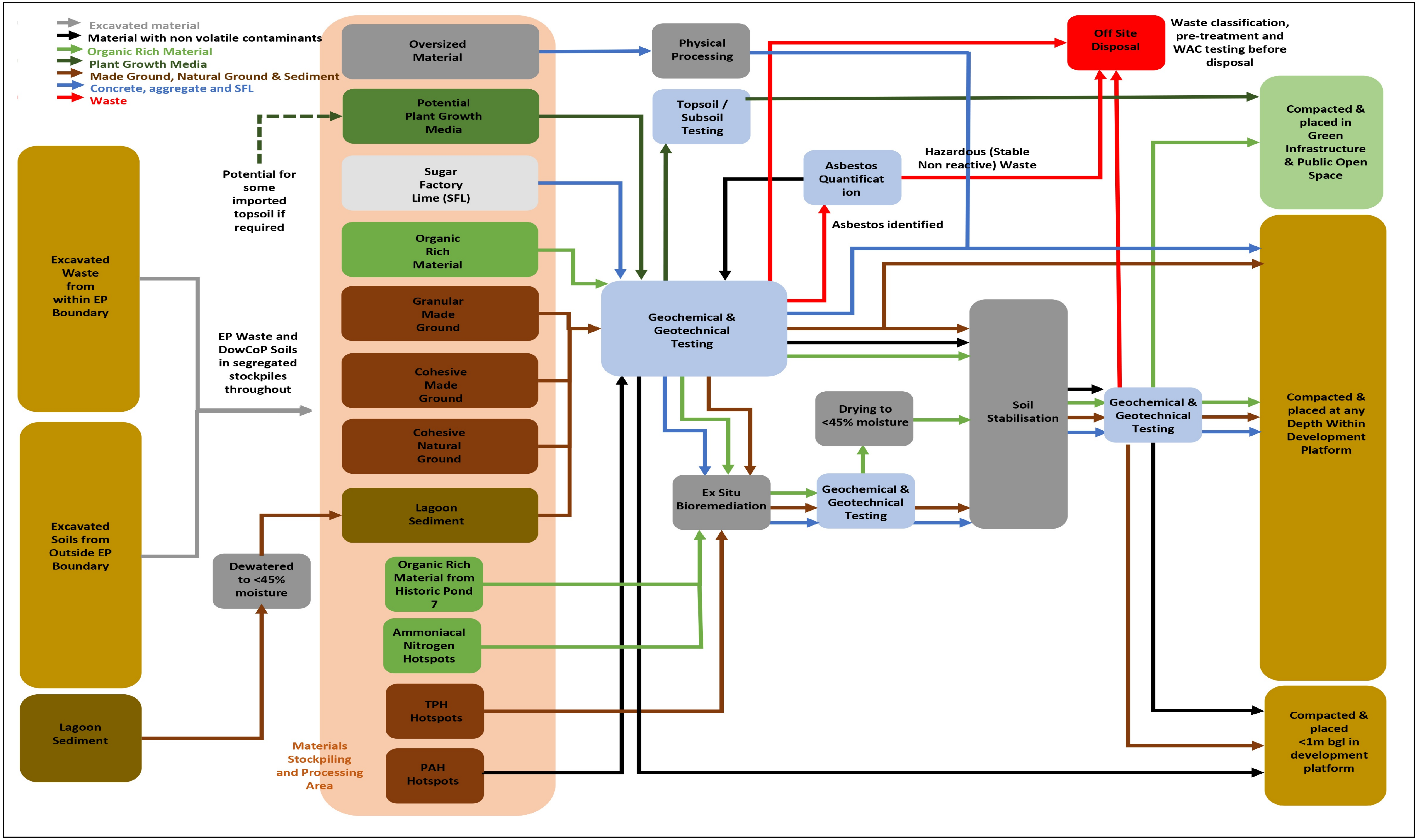
Drawing Number:
10024487-AUK-XX-XX-DR-ZZ-0038-P1-Arcadis Proposed Surface



Legend

Material Management Flow Chart

Under the Microsoft® BingTM Maps

N

Issued for Information

Design	S.Sohni	6-4-2020	
Drawn	S.Sohni	6-4-2020	
Checked	D.Calvert	6-4-2020	
Approved	C.Piddigton	6-4-2020	
Scale	1:1	Datum	AOD
Original Size	A3	Grid	OS
Suitability Code:		Project Number	10024487

Client - British Sugar Plc

BritishSugar

Figure 18

PROJECT

British Sugar, York

TITLE

Material Management Flowchart

ARCADIS Design & Consultancy for natural and built assets

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United Kingdom
T: +44 (0)113 284 5300

Drawing Number:10024487-AUK-XX-XX-DR-ZZ-0057-P1-Material Management Flowchart

Legend

Monitoring Locations

- ● Ground gas Monitoring Locations
- ● Groundwater and Groundgas Monitoring Well
- ● Groundwater Monitoring

- ▭ Site Boundary
- ▭ Permit Boundary

N

Under the Microsoft® BingTM Maps

Issued for Information

Design	S.Sohni	16-4-2020	
Drawn	S.Sohni	16-4-2020	
Checked	J.Hurst	16-4-2020	
Approved	C.Piddington	16-4-2020	
Scale	1:4000	Datum	AOD
Original Size	A3	Grid	OS
Suitability Code:		Project Number	10024487

Client - British Sugar Plc

Figure 19

PROJECT

British Sugar, York

TITLE

Existing Ground Gas and Groundwater Monitoring Well Location Plan

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34 York Way,
London
N1 9AB

Co-Ordinating office:
1 Whitehall Riverside
Leeds
LS1 4BN
United Kingdom
T: +44 (0)113 284 5300

Drawing Number:
10024487-AUK-XX-XX-DR-ZZ-0043-P1-Groundgas and Groundwater monitoring Location Map

Legend

Proposed Ground Gas and Groundwater Monitoring Locations

- ● Proposed Ground Gas Monitoring Location
- ● Proposed Ground Gas Monitoring Location in Natural Strata
- ● Proposed Groundwater Monitoring Location
- ☐ Site Boundary

Under the Microsoft® BingTM Maps

N

Issued for Information

Design	S.Sohni	3-4-2020	
Drawn	S.Sohni	3-4-2020	
Checked	J.Hurst	3-4-2020	
Approved	C.Piddington	3-4-2020	
Scale	1:4000	Datum	AOD
Original Size	A3	Grid	OS
Suitability Code:		Project Number	10024487

Client - British Sugar Plc

BritishSugar

Figure 20

PROJECT

British Sugar, York

TITLE

Proposed Replacement Ground Gas and Groundwater Monitoring Wells

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London
N1 9AB

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Leeds
LS1 4BN
United Kingdom
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Drawing Number: 10024487-AUK-XX-XX-DR-ZZ-0054-P1-Proposed Ground gas and Groundwater Monitoring Locations

APPENDIX A

Study Limitations

IMPORTANT. This section should be read before reliance is placed on any of the information, opinions, advice, recommendations or conclusions contained in this report.

1 This report has been prepared by Arcadis (UK) Limited (‘Arcadis’), with all reasonable skill, care and diligence within the terms of the Appointment and with the resources and manpower agreed with British Sugar (the ‘Client’). Arcadis does not accept responsibility for any matters outside the agreed scope.

2 This report has been prepared for the sole benefit of the Client unless agreed otherwise in writing. otherwise in writing. The contents of this report may not be used or relied upon by any person other than this party without the express written consent and authorisation of Arcadis.

3 Unless stated otherwise, no consultations with authorities or funders or other interested third parties have been carried out. Arcadis is unable to give categorical assurance that the findings will be accepted by these third parties as such bodies may have unpublished, more stringent objectives. Further work may be required by these parties.

4 All work carried out in preparing this report has used, and is based on, Arcadis’ professional knowledge and understanding of current relevant legislation. Changes in legislation or regulatory guidance may cause the opinion or advice contained in this report to become inappropriate or incorrect. In giving opinions and advice, pending changes in legislation, of which Arcadis is aware, have been considered. Following delivery of the report, Arcadis has no obligation to advise the Client or any other party of such changes or their repercussions.

5 This report is only valid when used in its entirety. Any information or advice included in the report should not be relied upon until considered in the context of the whole report.

6 Whilst this report and the opinions made are correct to the best of Arcadis’ belief, Arcadis cannot guarantee the accuracy or completeness of any information provided by third parties. provided by third parties. Arcadis has taken reasonable steps to ensure that the information sources used for this assessment provided accurate information, and has therefore assumed this to be the case.

7 This report has been prepared based on the information reasonably available during the project programme. All information relevant to the scope may not have been received.

8 This report refers, within the limitations stated, to the condition of the Site at the time of the inspection. No warranty is given as to the possibility of changes in the condition of the Site since the time of the investigation.

9 The content of this report represents the professional opinion of experienced environmental consultants. Arcadis does not provide specialist legal or other professional advice. The advice of other professionals may be required.

10 Where intrusive investigation techniques have been employed they have been designed to provide a reasonable level of assurance on the conditions. Given the discrete nature of sampling, no investigation technique is capable of identifying all conditions present in all areas. In some cases the investigation is further limited by Site operations, underground obstructions and above ground structures. Unless otherwise stated, areas beyond the boundary of the Site have not been investigated.

11 If below ground intrusive investigations have been conducted as part of the scope, safe location of exploratory holes has been carried out with reference to the Arcadis ground disturbances procedure. No guarantee can be given that all services have been identified. Additional services, structures or other below ground obstructions, not indicated on the drawing, may be present on Site.

12 Unless otherwise stated the report provides no comment on the nature of building materials, operational integrity of the facility or on any regulatory compliance issues.

13 Unless otherwise stated, an inspection of the Site has not been undertaken and there may be conditions present at the Site which have not been identified within the scope of this assessment.

14 Unless otherwise stated, samples from the Site (soil, groundwater, building fabric or other samples) have not been obtained.

15 Arcadis has relied upon the accuracy of documents, oral information and other material and information provided by the Client and others, and Arcadis assumes no liability for the accuracy of such data, although in the event of apparent conflicts in information, Arcadis would highlight this and seek to resolve.

16 Unless otherwise stated, the scope of works has not included an environmental compliance review, health and safety compliance review, hazardous building materials assessment, interviews or contacting Local Authority, requests for information to the petroleum officer, sampling or analyses of soil, ground water, surface water, air or hazardous building materials or a chain of title review.

17 Unless otherwise stated, this assessment has considered the ongoing use of the Site and has not been prepared for the purposes of redevelopment which may act as a trigger for Site investigation and remediation works not needed for ongoing use.

APPENDIX B

Regulatory Correspondence

creating a better place

Environment
Agency

FAO Paul Hardy
British Sugar PLC
Sugar Way
PE2 9AY

Our ref: EAWML68681
Your ref:
Date: 28th August 2015

Dear Mr Hardy,

At our meeting on the 21st July, we outlined our proposal to deal with the landfill surrender criteria separately from the current permit variation determination. We agreed to write to you and provide detailed pre-application advice on what will be required in order to consider a surrender application at your York site. As we have discussed previously, the removal and/ or remedial treatment of the existing waste mass and its redeposit does not in itself mean that the site permit is ready to be surrendered.

Please note that we provide up to 15 hours of pre-application advice. We have now reached the limit of 15 hours of advice pertaining to a surrender application, if further discussions are required beyond this we will charge you.

Please find our pre-application advice attached to this letter.

Yours sincerely,

Charlie Eddington
Landfill Regulatory Specialist
01904 822545

Environment Agency,
Coverdale House,
Aviator Court,
Amy Johnson Way,
Clifton Moor,
York, YO30 4GZ

Pre-application surrender advice – British Sugar Landfill site, York

Requirements for your surrender application

This advice is based on the current landfill and the waste deposits therein; we refer to all materials within the permitted site boundary as waste. We have, as far as possible, provided advice which recognises that you intend to undertake future remediation works on the site in order to; reduce the existing gassing and leaching waste source-term, to shorten the site's aftercare period and to collect sufficient evidence to demonstrate that the site is unlikely to present a hazard either to the environment or human health.

The residual treated material following the proposed treatment and remediation of the original waste has as yet not been agreed as either waste suitable for recovery or non-waste. As it has not be determined that the re-deposits will not be waste, we refer to all materials as waste in the remainder of this advice.

Your environmental permit is required to be surrendered in line with our current published guidance, 'Landfill (EPR 5.02) and other permanent deposits of waste – How to surrender your environmental permit and Regulatory Guidance Note 9'.

In order for us to **accept an application** to surrender an environmental permit for a site accepting the permanent deposit of waste, we must be satisfied that:

a) The site has ceased accepting waste
b) Relevant closure procedures have been complied with
c) An appropriate period of aftercare has passed to allow the waste to stabilise and to gather evidence to demonstrate that the pollution control measures are no longer necessary
d) The deposits of waste are in a satisfactory state that, if left undisturbed, will not cause pollution of the environment.

You will need to **produce a surrender report** in which you should:

- identify any impact on the surrounding environment, taking into account the use of the land.
- consider any receptors present and any specific land use approved by the planning authority.

In ***determining your surrender*** application we will take into consideration:

- the types of waste deposited (originally),
- the treatment of the original waste and re-deposited treated waste,
- the controls you have employed to protect the environment and
- the sensitivity of the location.

Under normal aftercare conditions, where the waste remains in-situ to the point of surrender, we would expect you to demonstrate that the residual waste deposit is unlikely to present a hazard to the environment. This will involve a 'Standard Surrender application' based on intrusive investigations which requires both the monitoring of pollutants generated by the original waste mass and potentially by the re-deposited treated waste and the impact both have on the surrounding environment.

Factors governing the duration of aftercare include the stabilisation of the waste mass, degradation of passive control measures and the travel time between the waste mass and the external monitoring infrastructure.

However, we recognise that in order to shorten the length of natural contaminant degradation and shorten the aftercare period you are proposing to undertake the excavation and remedial treatment of the site waste (as outlined in your remedial statement) to reduce the overall source-term of the re-deposited waste and hence reduce the impact on the surrounding environment. The requirement for you to demonstrate that the re-deposited waste plus any waste left insitu are unlikely to present a hazard to the environment remains and we outline below the completion criteria we consider you need to achieve in order to surrender the environmental permit pertaining to this landfill.

We also recognise that the landfill site along with the wider factory site is currently being considered by the planning authority for a large housing development; which we are taking into consideration.

Groundwater completion criteria

Summary - Given the age of the landfill and the variable nature of the strata and based on the simple calculations we have undertaken we believe a worst case scenario of a 6-year monitoring programme post remediation of the source-term should be sufficient to demonstrate the landfill is no longer posing a risk to the groundwater or surface water. A reduction in the length of the monitoring programme could be agreed if more detailed site measured values were obtained from purpose designed boreholes, or the determinants are consistently below the proposed surrender completion criteria values.

For a standard surrender we would normally discuss and agree suitable leachate completion criteria, based on the monitoring of leachate levels and quality during aftercare. However this site has no engineered lining system or infrastructure in place to monitor the leachate. There is evidence of non-hazardous pollutants in the groundwater at the site boundary (down hydraulic gradient). We recognise in older sites such as this it is difficult to assess the leachate completion directly. An alternative scheme of assessment must be adopted as outlined in section 5.2.1 of our surrender guidance. In similar previous situations we have agreed with permit holders (as we have with you) that you may use a combination of monitoring the impact on groundwater from the landfill and monitoring the landfill gas generation rate.

During our meeting in July, Liz Hart outlined why she considered setting groundwater completion criteria limits based on site specific data and a simplistic Monte Carlo based calculation tool (RQP)[1] provided meaningful results that correlated with the current site data rather than using a contaminant transport model such as Consim or the Environment Agency's Remedial Targets Methodology tool; neither has provided results that correlate to the actual site data. We acknowledge that whilst there may be some uncertainties with the methodologies and the application of a surface water distribution assessment to groundwater, our intention is to try to establish realistic groundwater completion criteria values that provide a clear indication for surrender ensuring protection of groundwater and surface water resources. These values will ensure no further deterioration of either the aquifer or the receiving surface water (River Ouse).

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[1] The River Quality Planning (RQP) tool has been developed by the Environment Agency and is available on request. Further technical details are found within our H1 Annex D2 guidance (Appendix A) https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/395421/H1_Annex_D2.pdf

We are happy to discuss further the thinking behind our approach and work with you in developing this further using additional site based data.

For the purposes of surrendering of your environmental permit you should demonstrate that the re-deposited waste and any residual waste not excavated is unlikely to present a hazard to the groundwater and surface water environment.

Section 5.2.2 of our surrender guidance note explains that '*for sites where leachate completion criteria are being based on groundwater quality, we consider the site to have met the criteria when you can show that the emissions from the site are not causing a significant increase over background concentration for any particular substances when compared to up-hydraulic gradient quality'*.

Your groundwater monitoring on the down gradient site boundary has identified ammonia and nickel at concentrations in excess of the environmental quality standards (EQS). Up-gradient monitoring locations confirm that the ammonia is not representative of background concentrations and as such it is reasonable to assume this has originated from the landfill. With regards to nickel concentrations these should be considered against representative up-gradient values which also exceed EQS targets, the site should not add to the loading of nickel in groundwater and this should be demonstrated by representative monitoring. There is no off-site groundwater monitoring data available to assess the extent of this plume and given the potable abstraction, approximately 500m from the site we would not wish to see ammonia reach the river.

The landfill is considered more a land raise than landfill, with areas around the former lagoons believed to be more in continuity with the underlying alluvium. This is supported by site measured values and historic knowledge of the site. Due to the mixed lithologies within alluvium it is often difficult to determine single values for hydraulic properties and reported, or indeed site measured, ranges can be extreme. However whilst lower permeable strata such as silts may be water bearing it is reasonable to assume these are not free flowing groundwater. The sands and gravel horizons however are likely to have free moving groundwater and are also most likely to represent the impacted groundwater moving under and off-site, currently recorded at the down gradient site boundary.

Using a basic calculation, amended from Darcy's Law, and some simple, yet justifiable, assumptions about the aquifer properties, it is possible to predict the approximate rate of groundwater flow. In doing this it is therefore possible to set the minimum groundwater monitoring period after remedial works have been undertaken. Assumptions have been detailed in the table 1 below;

$Q = KiA$

Q = Rate of groundwater flow m^3/s

K = Conductivity (permeability) m/s

i = gradient

A = Cross sectional area of flow m^2

Table 1

	Site measured value	**Consim value**
Conductivity	1.2E-6 – 8.3E-6 m/s	Min for gravel 3E-4 m/s **Min for Sand 9E-7 m/s* Min for Silt 1E-9 m/s
Gradient	0.001 – 0.0056	
Area	140m approx width of lagoon area 6m approx depth of alluvium that could be in continuity with the river. = 840m^2	
Distance to receptor	140m (a point 50m off the site boundary)	Measured distance from site lagoons to site boundary plus 50m

**Assumed conductivity for surrender values below*

Assuming a gradient of 0.001 and an area of flow of 840m^2 the range of conductivities reported in the table above results in a flow rate of 5.4 days to 5073yrs. Clearly these two extreme values are not an accurate reflection of the site as the first would have resulted in all contamination flushing from the site and the second no contamination reaching the site boundary. Values between these included 0.63yrs, 4.4yrs and 5.8yrs.

This basic calculation does not account for dilution, dispersion or attenuation. However, given the age of the landfill and the variable nature of the strata we believe a worst case scenario of a 6-year monitoring programme post remediation of the source-term should be sufficient to demonstrate the landfill is no longer posing a risk to the groundwater or surface water. A reduction in this monitoring programme could be agreed if more detailed site measured values were obtained from purpose designed boreholes, or the determinants are consistently below the proposed surrender completion criteria values outlined below in table 3.

In calculating these groundwater completion criteria values, it is possible to estimate an appropriate site boundary control limit that would ensure compliance with an appropriate environmental quality standard (EQS). In order to do this certain assumptions must be made regarding water flow and contaminant loading. The calculation[2] (Monte Carlo Mass Balance) is used with surface water and assumes complete mixing. It does not account for dispersion, attenuation or degradation which would normally be expected in groundwater but it does allow for dilution. As such the proposed values represent worst case values. It should be noted that all but two of the determinants are already below the suggested target EQS values.

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[2] See Appendix 1 for RQP model input datasheets, output results and modelling notes

Table 2 - Input assumptions

Determinant	Target µg/L (EQS)	Assumptions
Arsenic	50 AA	
Cadmium	0.25 AA	Hardness dependant. Due to surrounding geology assumed EQS for the hardest water value
Nickel	34 MAC	AA value is a bioavailable standard which would not be appropriate therefore modelled the MAC only
Ammonia	2000	Surface water (potable) abstraction applied, adopted A3 standard assuming full treatment required. Assumed 90% compliance standard to allow for a suitable distribution therefore in practice every 9 out of 10 readings should be below the target. However this is considered suitably protective.
Sulphate	400000 AA	
Napthalene	2.4 AA	
Benzo(a)pyrene	0.27 MAC	Modelled as 95%ile standard
Phenols	7.7 AA	

AA – Annual Average; MAC – Maximum Allowable Concentration

The calculation adopts the following formula:

FC+(fc) / F+f where:

F = Water flow assumed to be constant (Groundwater flow below site assumed to be $7.56^{-7}m^3/s$)

C = Up gradient groundwater concentration (taken from site measured data GAGW22)

f = effluent flow (based on infiltration across the lagoon area assumed to be 25% of total annual rainfall met office data assumed to be constant)

Area of infiltration assumed to be lagoon area approximately 140m x 120m

c = effluent concentration (based on a mean from down gradient boreholes GAGW03 and GAGW04 measured from 2010 to 2013) taken from the site Closure Reports

The proposed groundwater surrender criteria values for achieving EQS compliance at 50m beyond the site boundary are outlined in table 3 below:

Table 3 – surrender completion criteria values

Determinant	Target µg/L	Current mean at down gradient boundary µg/L	Currently compliant?
Arsenic	50	39	√
Cadmium	0.25	0.24	√
Nickel	13	101	**X***
Ammonia	1mg/L	20mg/L	**x**
Sulphate	400mg/L	51mg/L	√
Naphthalene	2	0.1	√
Benzo(a)pyrene	0.1	0.01	√
Phenols	8	0.6	√

NB Values have been rounded where appropriate to whole values.

* Nickel concentrations should be considered against representative up gradient values which also exceed targets, the site should not add to the loading of Nickel in groundwater and this should be demonstrated by representative monitoring.

You have asked us to provide you with information pertaining to the surrender of the landfill permit with respect to groundwater surrender completion criteria in the absence of leachate completion criteria. We recognise that you have proposed remedial target values (RTV) within your Remediation and Reclamation Strategy document as required by the local planning authority (LPA) for the purpose of remediating the existing waste mass by biochemically treating it. As stated at our meeting we will focus on the permitting applications (permit variation and eventual surrender and the mobile plant deployment). The LPA have consulted with us regarding your planning application and we have provided written comments to them. Whilst we do not accept the proposed RTVs as surrender completion criteria, it is for you to decide whether your Remedial Target Methodology or Consim assessment you have undertaken to derive the RTVs will ensure you meet the our proposed EQS groundwater completion criteria values detailed in table 3 above. As we have stated previously, the removal and/ or remedial treatment of the existing waste mass and its redeposit does not in itself mean that the site permit is ready to be surrended. Although the overall source-term should reduce, the residual contamination in the groundwater (caused by the original waste) still needs to be taken account of. We will only consider surrender with respect to groundwater when the contaminants of concern are below the proposed EQS groundwater completion criteria values as outlined in table 3 above or agreed alternative values as monitored in the sites down hydraulic groundwater monitoring boreholes.

We confirm that the location and number of up, cross and down hydraulic gradient groundwater monitoring boreholes are acceptable as shown on Drawing No. FBSS-URS-XX-XXX-DR-GE-00104 Rev A. And that the frequency of monitoring as outlined in table 6.1, 6.2 and 6.3 of the proposed working plan are appropriate for the purposes of surrender. The sampling suite should be the same as table X of the working plan, this does not require the monitoring of manganese but monitoring of nickel is required.

Landfill Gas completion criteria

Summary - We recognise that relying on simple gas concentration within a site means that it may take several decades before you can consider surrender, and that the concentration alone does not reflect the true risk assessment associated with the gas. Where methane and carbon dioxide concentrations exceed 1.5%v/v and 5%v/v respectively (see scenario 1 of our surrender guidance[3]), in deciding whether the site meets its completion criteria we will take into account the gas generation rates (gas concentration and flow of the gases within the monitoring boreholes) and calculate hazardous gas flow rates (Qhgs) in line with scenario 2 of our surrender guidance.

Completion criteria for pollutants arising from landfill gas are outlined in our surrender guidance document. For the purposes of this site we recognise that you have recently undertaken a detailed gas assessment and provided the details to us (Remediation and Reclamation Strategy, Final 2015). The conclusions drawn from your assessment (summarised at paragraph 2.3.7 and reproduced below) confirm that within the current waste mass that:

- "*Some areas of the site (especially in the northern half) contain elevated concentrations of methane and carbon dioxide, where as others contain low concentrations. The distribution of higher concentrations is patchy.*
- *The elevated gas concentrations are present as a result of the presence of relatively high concentrations of organic matter in the* [landfill].*made ground*
- *Generally low flows (5l/hr) were recorded across the site with some sporadic high flows detected in a few locations.*
- *The continuous gas monitoring results validates the previous periodic monitoring by confirming the presence of elevated gas concentrations in some locations.*
- *Based on the data from all the monitoring results, the ground gas regime appears to be steady. The source gas can only become smaller as a result of decomposition. This would take place slowly if the site was left in its current condition. A remediation and reclamation process will provide a means to reduce the source of the gas relatively quickly"*.

You state that the objective of the remediation and reclamation process will be to reduce the ground [landfill] gas concentrations and flow to a level compliant with Amber 1 level of the NHBC traffic light system, with the proviso that conditions following the remediation will be no greater than Amber 2. We discussed this at our meeting and clarified that for the purpose of landfill surrender the completion criteria measured within the re-deposited treated waste for methane and carbon dioxide may exceed the gas surrender completion criteria as set out in scenario 1 of our surrender guidance (section 5.3.3). We recognise that relying on simple gas concentration within a site means that it may take several decades before you can consider surrender, and that the concentration alone does not reflect the true risk assessment associated with the gas. Where in-waste gas concentrations are higher than 1.5%v/v (methane) and/or 5%v/v (carbon dioxide), in seeking to demonstrate the site meets its completion criteria we will allow you to take account of the gas generation rates (gas concentration and flow of the gases within the monitoring boreholes) and calculate hazardous gas flow rates (Qhgs) as outlined in section 5.3.4 of our surrender guidance. Following discussions at our meeting we agreed that the most appropriate surrender scenario (described in our guidance) with respect to this site would be scenario 2 (produced below).

Scenario 2 – is where the observed methane concentration is less than 5 %v/v (the lower explosive limit) and there is therefore little risk that the gas migration off site could present an explosion hazard. This landfill gas completion criteria is taken from, 'Landfill (EPR 5.02) and other permanent deposits of waste – How to surrender your environmental permit.'

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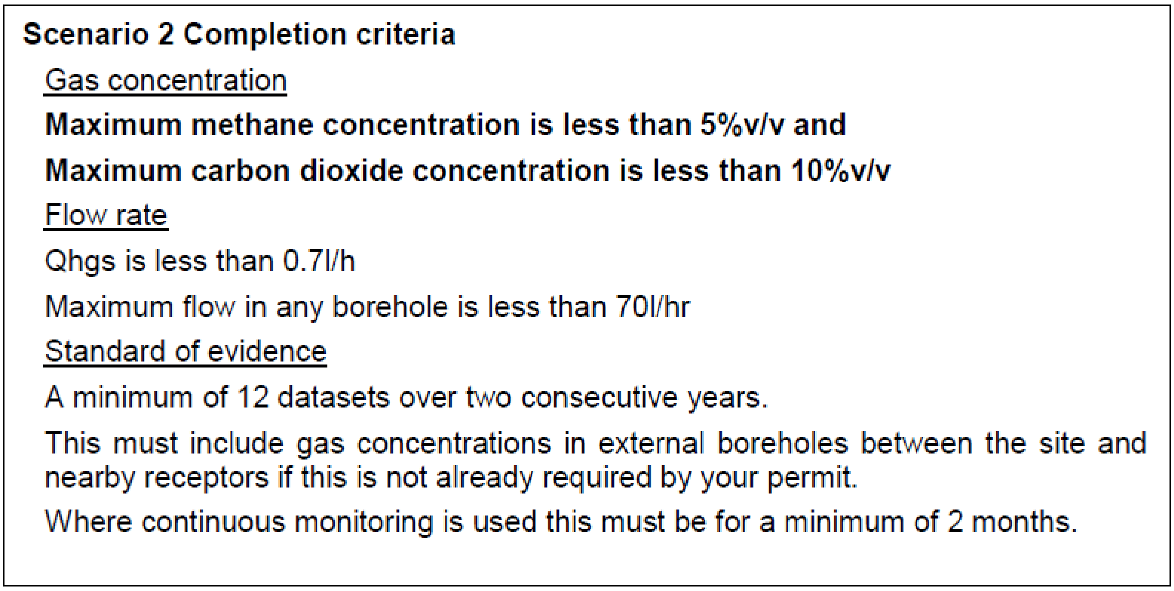
[3] 'Landfill (EPR 5.02) and other permanent deposits of waste – How to surrender your environmental permit



Scenario 2 Completion criteria

Gas concentration

Maximum methane concentration is less than 5%v/v and

Maximum carbon dioxide concentration is less than 10%v/v

Flow rate

Qhgs is less than 0.7l/h

Maximum flow in any borehole is less than 70l/hr

Standard of evidence

A minimum of 12 datasets over two consecutive years.

This must include gas concentrations in external boreholes between the site and nearby receptors if this is not already required by your permit.

Where continuous monitoring is used this must be for a minimum of 2 months.

The above limits apply to gas concentrations and flow rates measured within the treated waste mass. With regards to the length of time monitoring should be undertaken we agreed that rather than waiting the full two years the data can be submitted and reviewed once you have completed monitoring to provide a minimum 12 consecutive monthly datasets over a minimum 12 month period (we acknowledge that you may wish to review and submit the data after nine months to pre-empt whether further monitoring will be required). Depending on the outcome of the review further monitoring may or may not be required. If the data meets the above completion criteria on the collection of a full 12 months of data, we will accept this. Likewise if the data indicates further monitoring we would expect a further 12 months as a minimum.

We accept that the original in-waste gas boreholes will be removed / destroyed during the excavation of the waste and that the new boreholes will be installed incrementally and monitoring commences as the works progress. This is why we have included landfill CQA conditions in the draft permit variation to cover this. We also recognise that there should be a benefit of monitoring results being collected from boreholes installed incrementally as works progress, in addition to the 12 months of post-remediation & reclamation monitoring.

Please note that when calculating hazardous gas flow rates we expect you to consider the ‘worst case’ scenario, this means you should consider the highest gas concentration and gas flow over the 12 month period, you may find that the highest concentration and flow come from differing monitoring boreholes. If the worst case scenario fails, further assessment of hazardous gas flows rates based on geographical zoning of the site may be considered acceptable but will require further discussion based on the evidence presented.

In addition to the above, you will be required to demonstrate that no landfill gas is migrating sub-laterally beyond the permitted site boundary within the superficial deposits on which the existing housing along Langholme Drive is likely to be founded upon. We will not accept a surrender application where landfill gas concentrations measured in the boreholes outside of the waste mass exceed either any gas compliance limit[4] or a methane concentration above 1.5%v/v. A methane compliance limit for landfill gas perimeter monitoring boreholes which are located outside of the waste mass and in surrounding natural strata is usually set at 1%v/v (unless there is evidence of other natural sources for the methane detected). For the purposes of surrender we use an indicative 5%v/v upper limit for carbon dioxide gas but recognise that background concentrations in some natural strata can be in excess of this and we will take this into account. For this reason we agreed that during the installation of the six new gas boreholes (GNS01 to

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[4] Taken from section 5.3 - Landfill (EPR 5.02) and other permanent deposits of waste – How to surrender your environmental permit.’

GNS06) which will be installed within the natural strata[5] you will collect samples of borehole arising (which you may decide to analyse) and log the boreholes to establish whether there is evidence of the presence of any natural source of carbon dioxide and/or methane, noting that the natural superficial deposits may contain organic substances which could be a natural source. Following the characterisation of the strata and having undertaken gas monitoring at these boreholes you will submit the information in order for us to agree representative natural baseline / background concentrations for carbon dioxide and if relevant methane. We do not anticipate that you will detect methane gas in these new boreholes. If however methane is detected and there is no evidence of other organic substance within the natural strata then we will assume the methane is from the landfill and migrating beyond the site boundary. We note that you will monitor both gas concentrations and gas flow within the perimeter gas boreholes to improve your understanding of the risks posed and to provide further lines of evidence in the surrender report. However, as stated earlier will not accept a surrender application where landfill gas concentrations measured in the boreholes outside of the waste exceed either a gas compliance limit or a methane concentration above 1.5%v/v as this suggests a lack of on-site gas control and may present an unacceptable risk to the nearby properties and the environment.

With regards to the number and location of the gas monitoring points we confirm that the external gas monitoring boreholes, that is, those not located within waste, (as per Drawing Number FBSS-URS-XX-XXX-DR-GE-00104 Rev A February 2015 entitled, Proposed ground gas and groundwater monitoring locations after site remediation / reclamation) are considered acceptable. This includes the proposed six new gas boreholes to be located within the natural ground along the western and northern site boundaries between the site and housing and commercial receptors.

The proposal for eleven in-waste boreholes is not acceptable for the purpose of surrender. Landfill gas monitoring must be undertaken from permanent monitoring points installed within the re-deposited waste at a frequency of no less than two monitoring boreholes per hectare, with a minimum of four per site[6]. Based on the plan labelled FBSS-URS-XX-XXX-DR-GE-00104 Rev A the permitted site is approximately 20 hectares, we would therefore expect approximately 40 permanent in-waste gas monitoring boreholes to be installed. We recognise that that you consider this number of points excessive and we welcome any justification you wish to submit and /or discuss with respect to reducing this number of boreholes. Please note that two boreholes per hectare is the minimum number we require for an inert landfill site. Sites where biodegradable organic matter has been deposited often require a higher frequency. Based on your proposal to use an indicative 3% TOC as the endpoint for the proposed remedial treatment, in terms of gas monitoring this could be considered akin to an inert landfill.

With regards to landfill gas monitoring parameters and further monitoring requirements, we expect you to comply fully with section 5.3.1 of our landfill surrender guidance.

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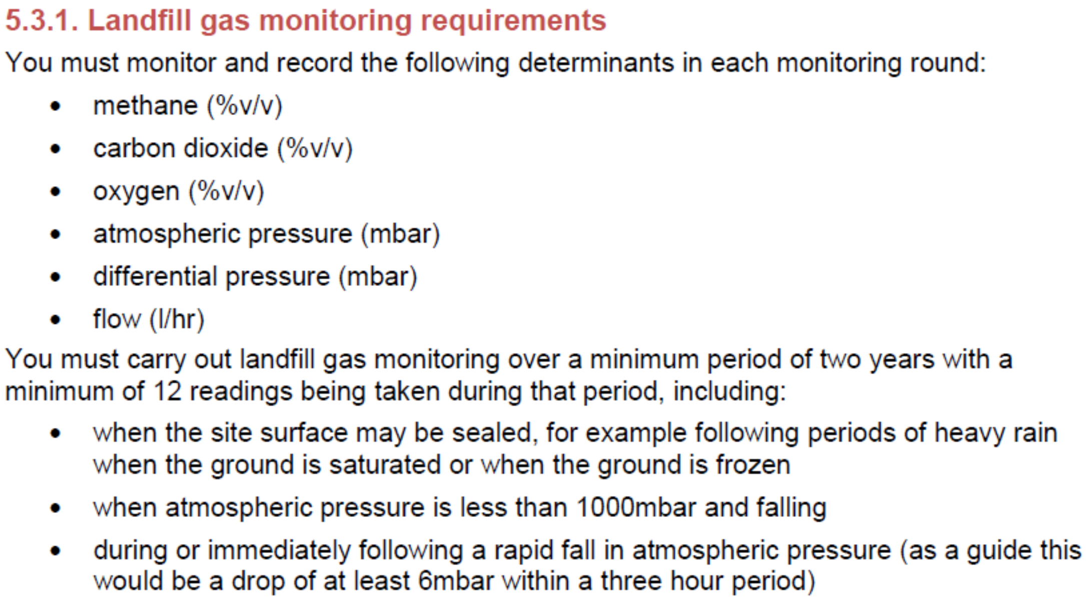
[5] The natural strata are superficial alluvium deposits consisting of silts, clays and sands and gravels.

[6] Taken from section 5.3.1 - Landfill (EPR 5.02) and other permanent deposits of waste – How to surrender your environmental permit.'



5.3.1. Landfill gas monitoring requirements

You must monitor and record the following determinants in each monitoring round:

- methane (%v/v)
- carbon dioxide (%v/v)
- oxygen (%v/v)
- atmospheric pressure (mbar)
- differential pressure (mbar)
- flow (l/hr)

You must carry out landfill gas monitoring over a minimum period of two years with a minimum of 12 readings being taken during that period, including:

- when the site surface may be sealed, for example following periods of heavy rain when the ground is saturated or when the ground is frozen
- when atmospheric pressure is less than 1000mbar and falling
- during or immediately following a rapid fall in atmospheric pressure (as a guide this would be a drop of at least 6mbar within a three hour period)

Appendix 1

British Sugar Monte Carlo Mass Balance - Notes

Up gradient quality, single sample, assume it is the mean. Create a distribution by applying Environment Agency standard coefficient of variation (CoV) values:

Substance	**CoV**
Arsenic	0.7
Cadmium	0.8
Nickel	0.5
Ammonia	0.6
Sulphate	1.0
Naphthalene	1.0
B(a)P	1.0
Phenols	1.0

Mean x CoV = Standard Deviation

- Groundwater flow assume figure is a constant
- “Effluent flow” assumes that it is 25% of rainfall and that rate is constant. This may miss peak in concentration after prolonged dry period when there may be a flush after a rainfall event that could exceed any maximum admissible concentration (MAC).
- Cadmium standard is hardness dependent. I think that we’re in a part of the world that is quite hard so have assumed the EQS is for the hardest water. This is the most relaxed standard.
- Annual average EQS for Nickel is a bioavailable standard. There is also an absolute MAC. Have only modelled against the MAC.

- Ammonia is ammoniacal nitrogen, not unionised ammonia. No EQS and anyway the EQS for unionised ammonia only applies to TraC[7] waters.
- EQSs used for the exercise:

Substance	EQS (ug/l)
Arsenic	50 AA
Cadmium	0.25 AA
Nickel	34 MAC
Ammonia	2000 90% sample compliance*
Sulphate	400000 AA
Naphthalene	2.4 AA
B(a)P	0.27 MAC**
Phenols	7.7 AA 46 95%ile

* Ammonia standard used of 2mg/l (90%ile) is taken from the repealed Surface Water Abstraction Directive:

<u>Surface Water Intended for Abstraction for Drinking Water</u>

Standard values:-

A1 Waters (1);

Guide: 0.05 mg NH4/l

Imperative: none set

A2 Waters (2);

Guide: 1 mg NH4/l

Imperative: 1.5 mg NH4/l

A3 Waters (3);

Guide: 2 mg NH4/l

Imperative: 4 mg NH4/l (4)

Notes

In December 2007, the Directive through which these standards were established was repealed under the Water Framework Directive (2000/60/EC).

(1) A1 Waters: Surface waters needing simple physical treatment and disinfection, e.g. rapid filtration and disinfection, for transformation into drinking water.

(2) A2 Waters: Surface waters needing normal physical treatment, chemical treatment and disinfection, e.g. pre-chlorination, coagulation, flocculation, decantation, filtration, and disinfection (final chlorination), for transformation into drinking water.

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[7] TraC – Transitional and coastal waters, i.e. everything tidal to and including the sea. The River Ouse is a TraC water from Naburn on the outskirts of York, that is downstream of the British Sugar and therefore not applicable.

(3) A3 Waters: Surface waters needing intensive physical and chemical treatment, extended treatment and disinfection, e.g. chlorination to break-point, coagulation, flocculation, decantation, filtration, adsorption (activated carbon) and disinfection (ozone, final chlorination), for transformation into drinking water.

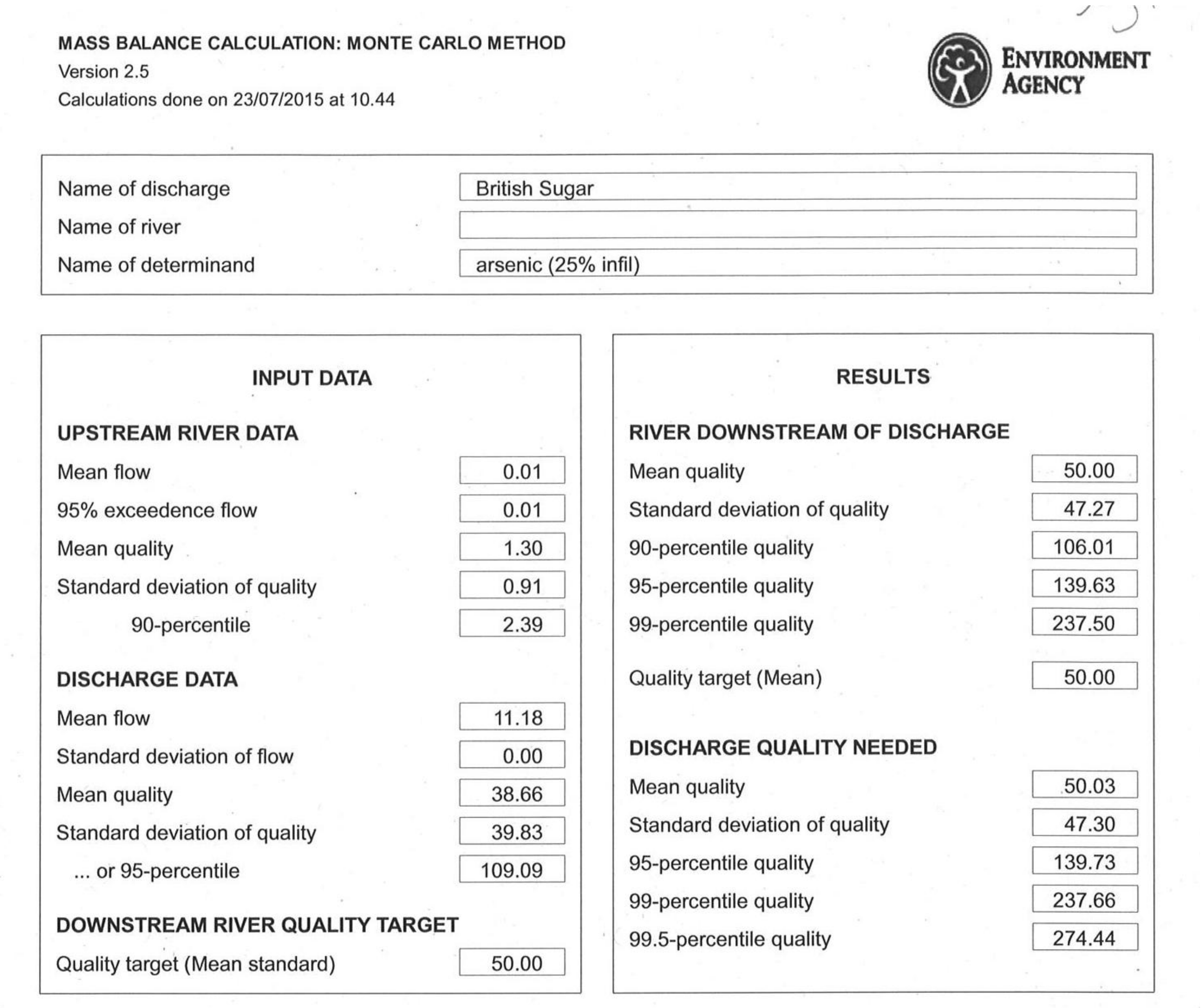
(4) The Directive may be waived for this standard under exceptional climatic or geographical conditions.

Guide values based on 90% of samples; imperative based on 95% of samples.

Ammonia is a 90% compliance standard, i.e. 9 out of 10 standards must be less than 2mg/l but 1 out of 10 could be any figure. Had to treat as a 90%ile statistic in terms of a distribution, if there is a control on the maximum figure that could be accepted, i.e. is more stringent.

** For the purpose of the model a MAC is assumed to be a 95%ile.

RQP Modelling input datasheets and model outputs



MASS BALANCE CALCULATION: MONTE CARLO METHOD
Version 2.5
Calculations done on 23/07/2015 at 10.44

ENVIRONMENT AGENCY

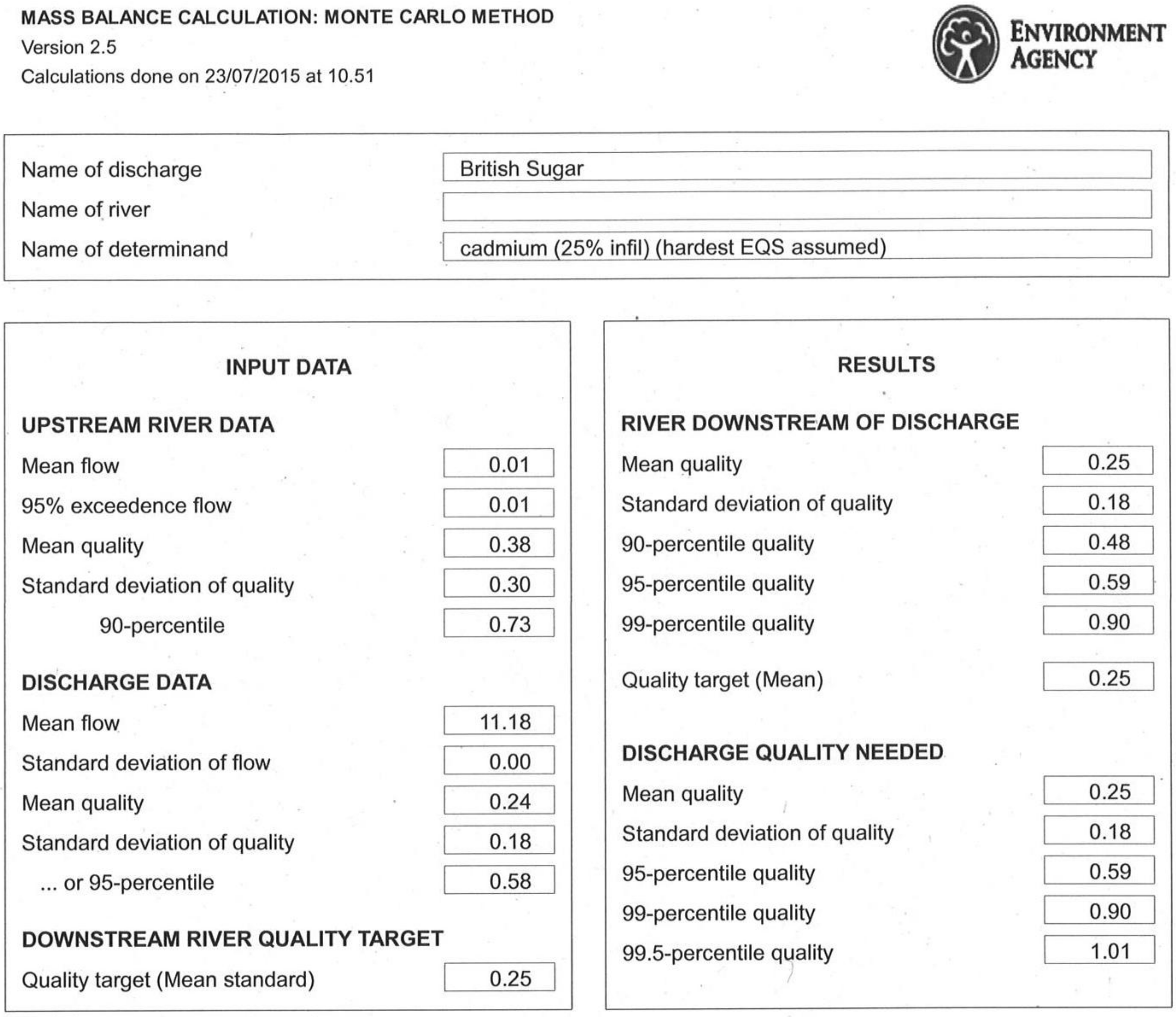
Name of discharge	British Sugar
Name of river	
Name of determinand	arsenic (25% infil)

INPUT DATA

UPSTREAM RIVER DATA	
Mean flow	0.01
95% exceedence flow	0.01
Mean quality	1.30
Standard deviation of quality	0.91
90-percentile	2.39
DISCHARGE DATA	
Mean flow	11.18
Standard deviation of flow	0.00
Mean quality	38.66
Standard deviation of quality	39.83
... or 95-percentile	109.09
DOWNSTREAM RIVER QUALITY TARGET	
Quality target (Mean standard)	50.00

RESULTS

RIVER DOWNSTREAM OF DISCHARGE	
Mean quality	50.00
Standard deviation of quality	47.27
90-percentile quality	106.01
95-percentile quality	139.63
99-percentile quality	237.50
Quality target (Mean)	50.00
DISCHARGE QUALITY NEEDED	
Mean quality	50.03
Standard deviation of quality	47.30
95-percentile quality	139.73
99-percentile quality	237.66
99.5-percentile quality	274.44



MASS BALANCE CALCULATION: MONTE CARLO METHOD
Version 2.5
Calculations done on 23/07/2015 at 10.51

ENVIRONMENT AGENCY

Name of discharge	British Sugar
Name of river	
Name of determinand	cadmium (25% infil) (hardest EQS assumed)

INPUT DATA

UPSTREAM RIVER DATA

Mean flow	0.01
95% exceedence flow	0.01
Mean quality	0.38
Standard deviation of quality	0.30
90-percentile	0.73

DISCHARGE DATA

Mean flow	11.18
Standard deviation of flow	0.00
Mean quality	0.24
Standard deviation of quality	0.18
... or 95-percentile	0.58

DOWNSTREAM RIVER QUALITY TARGET

Quality target (Mean standard)	0.25

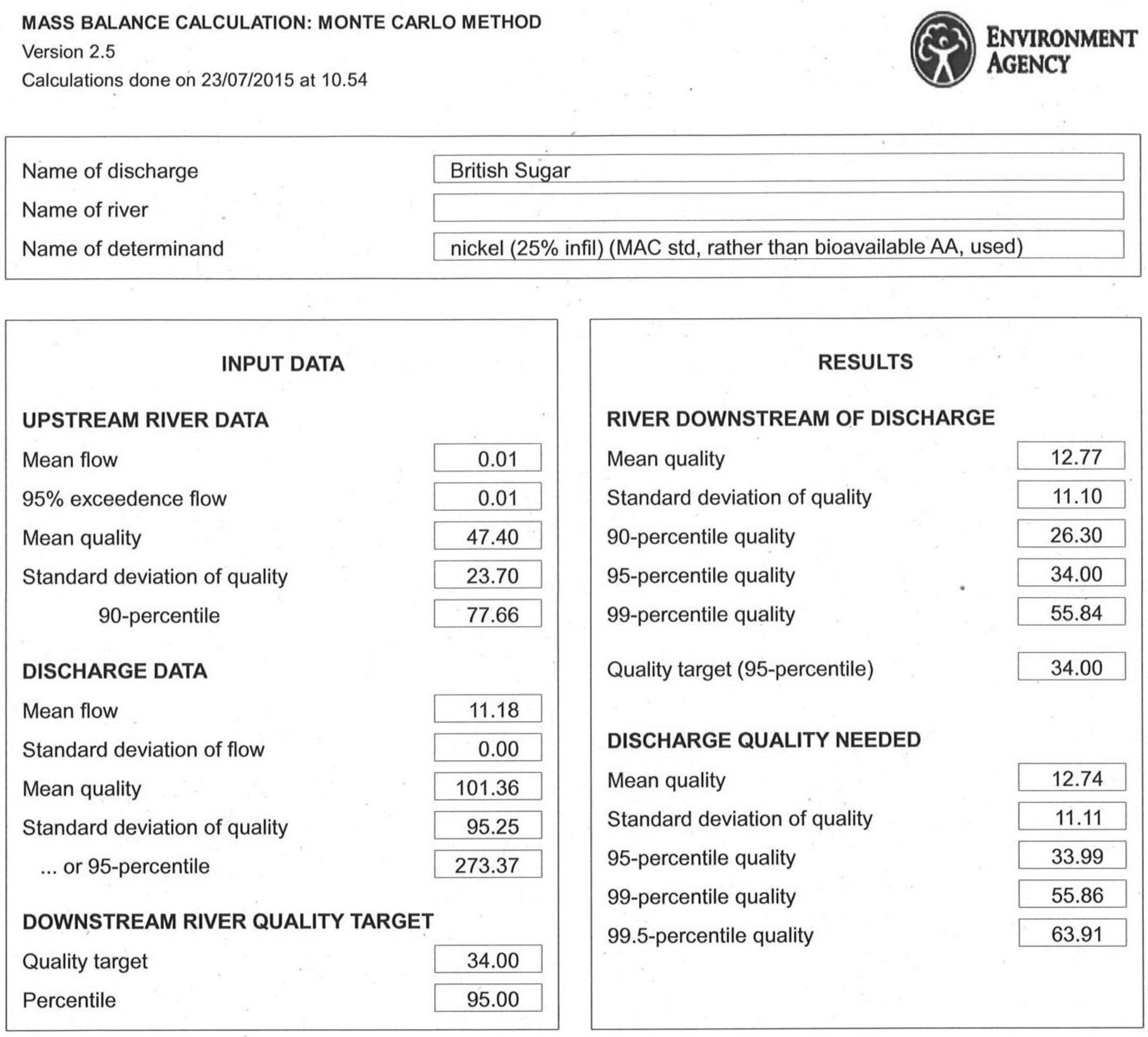
RESULTS

RIVER DOWNSTREAM OF DISCHARGE

Mean quality	0.25
Standard deviation of quality	0.18
90-percentile quality	0.48
95-percentile quality	0.59
99-percentile quality	0.90
Quality target (Mean)	0.25

DISCHARGE QUALITY NEEDED

Mean quality	0.25
Standard deviation of quality	0.18
95-percentile quality	0.59
99-percentile quality	0.90
99.5-percentile quality	1.01



MASS BALANCE CALCULATION: MONTE CARLO METHOD
Version 2.5
Calculations done on 23/07/2015 at 10.54

Name of discharge	British Sugar
Name of river	
Name of determinand	nickel (25% infil) (MAC std, rather than bioavailable AA, used)

INPUT DATA

UPSTREAM RIVER DATA	
Mean flow	0.01
95% exceedence flow	0.01
Mean quality	47.40
Standard deviation of quality	23.70
90-percentile	77.66
DISCHARGE DATA	
Mean flow	11.18
Standard deviation of flow	0.00
Mean quality	101.36
Standard deviation of quality	95.25
... or 95-percentile	273.37
DOWNSTREAM RIVER QUALITY TARGET	
Quality target	34.00
Percentile	95.00

RESULTS

RIVER DOWNSTREAM OF DISCHARGE	
Mean quality	12.77
Standard deviation of quality	11.10
90-percentile quality	26.30
95-percentile quality	34.00
99-percentile quality	55.84
Quality target (95-percentile)	34.00
DISCHARGE QUALITY NEEDED	
Mean quality	12.74
Standard deviation of quality	11.11
95-percentile quality	33.99
99-percentile quality	55.86
99.5-percentile quality	63.91

MASS BALANCE CALCULATION: MONTE CARLO METHOD
Version 2.5
Calculations done on 23/07/2015 at 13.58

ENVIRONMENT AGENCY

Name of discharge	British Sugar
Name of river	
Name of determinand	ammonia (25% infil)

INPUT DATA

UPSTREAM RIVER DATA

Mean flow	0.01
95% exceedence flow	0.01
Mean quality	0.20
Standard deviation of quality	0.12
90-percentile	0.35

DISCHARGE DATA

Mean flow	11.18
Standard deviation of flow	0.00
Mean quality	19.75
Standard deviation of quality	18.59
... or 95-percentile	53.30

DOWNSTREAM RIVER QUALITY TARGET

Quality target	2.00
Percentile	90.00

RESULTS

RIVER DOWNSTREAM OF DISCHARGE

Mean quality	0.97
Standard deviation of quality	0.85
90-percentile quality	2.00
95-percentile quality	2.59
99-percentile quality	4.26
Quality target (90-percentile)	2.00

DISCHARGE QUALITY NEEDED

Mean quality	0.97
Standard deviation of quality	0.85
95-percentile quality	2.59
99-percentile quality	4.26
99.5-percentile quality	4.87

MASS BALANCE CALCULATION: MONTE CARLO METHOD
Version 2.5
Calculations done on 23/07/2015 at 11.31

ENVIRONMENT AGENCY

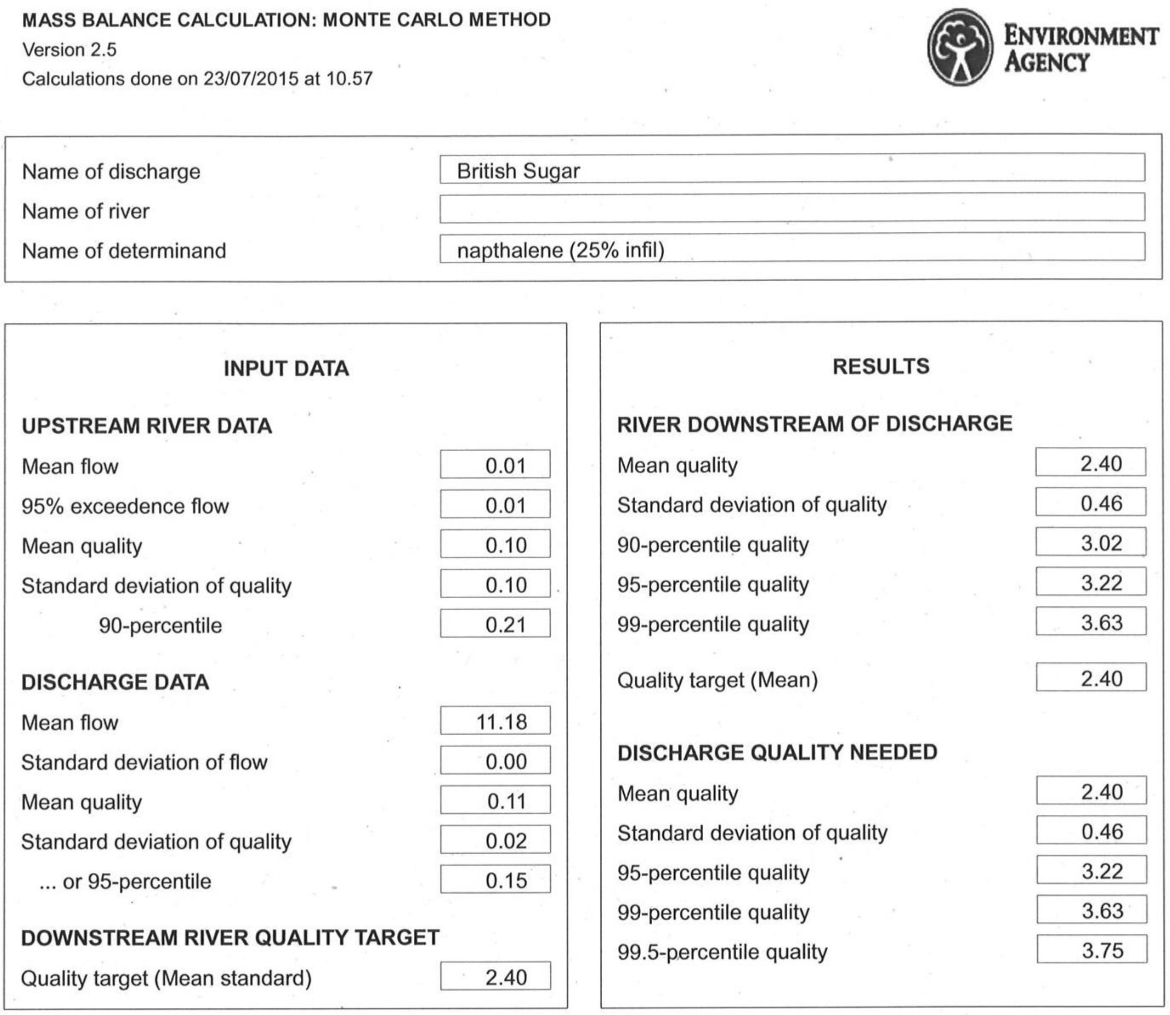
Name of discharge	British Sugar
Name of river	
Name of determinand	sulphate (25% infil)

INPUT DATA

UPSTREAM RIVER DATA	
Mean flow	0.01
95% exceedence flow	0.01
Mean quality	106.00
Standard deviation of quality	106.00
90-percentile	217.83
DISCHARGE DATA	
Mean flow	11.18
Standard deviation of flow	0.00
Mean quality	50.58
Standard deviation of quality	38.12
... or 95-percentile	121.73
DOWNSTREAM RIVER QUALITY TARGET	
Quality target (Mean standard)	400.00

RESULTS

RIVER DOWNSTREAM OF DISCHARGE	
Mean quality	400.00
Standard deviation of quality	285.31
90-percentile quality	765.62
95-percentile quality	951.28
99-percentile quality	1446.0
Quality target (Mean)	400.00
DISCHARGE QUALITY NEEDED	
Mean quality	400.20
Standard deviation of quality	285.51
95-percentile quality	951.86
99-percentile quality	1447.0
99.5-percentile quality	1620.9



MASS BALANCE CALCULATION: MONTE CARLO METHOD
Version 2.5
Calculations done on 23/07/2015 at 10.57

ENVIRONMENT AGENCY

Name of discharge	British Sugar
Name of river	
Name of determinand	napthalene (25% infil)

INPUT DATA

UPSTREAM RIVER DATA	
Mean flow	0.01
95% exceedence flow	0.01
Mean quality	0.10
Standard deviation of quality	0.10
90-percentile	0.21
DISCHARGE DATA	
Mean flow	11.18
Standard deviation of flow	0.00
Mean quality	0.11
Standard deviation of quality	0.02
... or 95-percentile	0.15
DOWNSTREAM RIVER QUALITY TARGET	
Quality target (Mean standard)	2.40

RESULTS

RIVER DOWNSTREAM OF DISCHARGE	
Mean quality	2.40
Standard deviation of quality	0.46
90-percentile quality	3.02
95-percentile quality	3.22
99-percentile quality	3.63
Quality target (Mean)	2.40
DISCHARGE QUALITY NEEDED	
Mean quality	2.40
Standard deviation of quality	0.46
95-percentile quality	3.22
99-percentile quality	3.63
99.5-percentile quality	3.75

MASS BALANCE CALCULATION: MONTE CARLO METHOD
Version 2.5
Calculations done on 23/07/2015 at 10.58

ENVIRONMENT AGENCY

Name of discharge	British Sugar
Name of river	
Name of determinand	BaP (25% infil)

INPUT DATA

UPSTREAM RIVER DATA

Mean flow	0.01
95% exceedence flow	0.01
Mean quality	0.01
Standard deviation of quality	0.01
90-percentile	0.02

DISCHARGE DATA

Mean flow	11.18
Standard deviation of flow	0.00
Mean quality	0.01
Standard deviation of quality	0.01
... or 95-percentile	0.03

DOWNSTREAM RIVER QUALITY TARGET

Quality target	0.27
Percentile	95.00

RESULTS

RIVER DOWNSTREAM OF DISCHARGE

Mean quality	0.10
Standard deviation of quality	0.09
90-percentile quality	0.21
95-percentile quality	0.27
99-percentile quality	0.45
Quality target (95-percentile)	0.27

DISCHARGE QUALITY NEEDED

Mean quality	0.10
Standard deviation of quality	0.09
95-percentile quality	0.27
99-percentile quality	0.45
99.5-percentile quality	0.52

MASS BALANCE CALCULATION: MONTE CARLO METHOD

Version 2.5

Calculations done on 23/07/2015 at 11.00

ENVIRONMENT AGENCY

Name of discharge	British Sugar
Name of river	
Name of determinand	phenols (25% infil)

INPUT DATA

UPSTREAM RIVER DATA

Mean flow	0.01
95% exceedence flow	0.01
Mean quality	3.51
Standard deviation of quality	3.51
90-percentile	7.21

DISCHARGE DATA

Mean flow	11.18
Standard deviation of flow	0.00
Mean quality	0.62
Standard deviation of quality	0.22
... or 95-percentile	1.03

DOWNSTREAM RIVER QUALITY TARGET

Quality target (Mean standard)	7.70

RESULTS

RIVER DOWNSTREAM OF DISCHARGE

Mean quality	7.70
Standard deviation of quality	2.71
90-percentile quality	11.39
95-percentile quality	12.75
99-percentile quality	15.84
Quality target (Mean)	7.70

DISCHARGE QUALITY NEEDED

Mean quality	7.70
Standard deviation of quality	2.71
95-percentile quality	12.75
99-percentile quality	15.85
99.5-percentile quality	16.81

	GAGW22	GAGW03				GAGW04				No	Mean	Std/d
	2013	2010	2011	2012	2013	2010	2011	2012	2013			
Arsenic µg/L	1.3	2	2.02	1.55	1.52	77.7	86.3	66.4	71.8	8	38.66125	39.82898
Cadmium µg/L	0.38	0.544	0.22	0.27	0.46	0.1	0.1	0.1	0.1	8	0.23675	0.177455
Nickel µg/L	47.4	17.1	15	17.1	11.7	137	183	210	220	8	101.3625	95.25144
NH4 as N mg/L	0.2	2.47	3.44	3.56	1.59	30.5	33.3	39.1	44	8	19.745	18.58635
Sulphate mg/L	106	99.5	91.7	81.7	65.4	16.6	9.1	10.5	30.2	8	50.5875	38.11466
Napth µg/L	0.1	0.1	0.1	0.1	0.1	0.1	0.16	0.1	0.1	8	0.1075	0.021213
BaP µg/L	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	8	0.009	0
Phenols µg/L	3.51	0.5	1.14	0.64	0.5	0.5	0.5	0.64	0.5	8	0.615	0.221359
	Background											

Rain gauge data 2.3mm/day (average) Area of infiltration (m2) 16800 Monte Carlo Mass Balance coverts volumes to L/s

2.66204E-05 mm/s

2.66204E-06 m/s Effluent flow 0.044722 m3/s

GW Flow = 7.56E-7m3/s

APPENDIX C

Topsoil Laboratory Analysis Certificates

Certificate of Analysis

Client: JANET JONES
(K920) JONES ENVIRONMENTAL LAB
UNIT 3 DEESIDE
ZONE 3
DEESIDE IND EST
DEESIDE CH5 2UA

Originator: 11014
EMT 177411
EMT 177411

Lab ID: 61881 - 441955
Sample ID: AUK-TP-27 0.00-0.60
Sample Weight: 386g

Date Received: 11/07/2019
Date Reported: 18/07/2019

BS 3882 : 2015 SPECIFICATION FOR TOPSOIL

Fails BS 3882

						Compliant with range (Y/N)				
		Unit	**Result**		**Multi-P**	**Acid**	**Calc**	**Low-F**	**Low-F Acid**	**Low-F Calc**
Texture:	Clay	% w/w	49							
	Silt	% w/w	46			*See area of permitted soil textural classes in Fig. 1.*				
	Sand	% w/w	5							
	Textural Class		Organic Silty Clay		N	N	N	N	N	N
Organic Matter:		% w/w	10.7							
Coarse Fragment Content:	>2 mm	% w/w	0.0		Y	Y	Y	Y	Y	Y
	>20 mm	% w/w	0.0		Y	Y	Y	Y	Y	Y
	>50 mm	% w/w	0.0		Y	Y	Y	Y	Y	Y
Soil pH:			8.1		Y	N	Y	Y	N	Y
Carbonate:		% w/w	5.3				Y			Y
Available Plant Nutrients:	Nitrogen	% w/w	0.514		Y	Y	Y			
	Phosphorus	mg/l	101.8	(6)*	Y	Y	Y	N	N	N
	Potassium	mg/l	928.8	(6)*	Y	Y	Y			
	Magnesium	mg/l	181.1	(4)*	Y	Y	Y			
Carbon:Nitrogen Ratio:		:1	12.1		Y	Y	Y	Y	Y	Y
Exchangeable Sodium Percentage:		%	0.4							
Phytotoxic Contaminants:	Total Zinc	mg/kg	165		Y	Y	Y	Y	Y	Y
	Total Copper	mg/kg	36.5		Y	Y	Y	Y	Y	Y
	Total Nickel	mg/kg	35.9		Y	Y	Y	Y	Y	Y
Visible Contaminants:	> 2mm	% w/w	0.00		Y	Y	Y	Y	Y	Y
	Plastics	% w/w	0.00		Y	Y	Y	Y	Y	Y
	Number of Sharps		0		Y	Y	Y	Y	Y	Y
Additional Analysis:	Available Sodium	mg/l	14.5							
	Available Calcium	mg/l	2503.2							
	Conductivity	uS/cm	2182		Y					
Compliancy:					**N**	**N**	**N**	**N**	**N**	**N**

Results are expressed on a dry matter basis.
* Soil indices from RB209

Released by: Joe Cherrie **Date: 18/07/2019**

DECLARATION: I certify that this sample has been analysed by NRM in accordance with BS 3882 Specification for Topsoil (2015).

Analytical Report

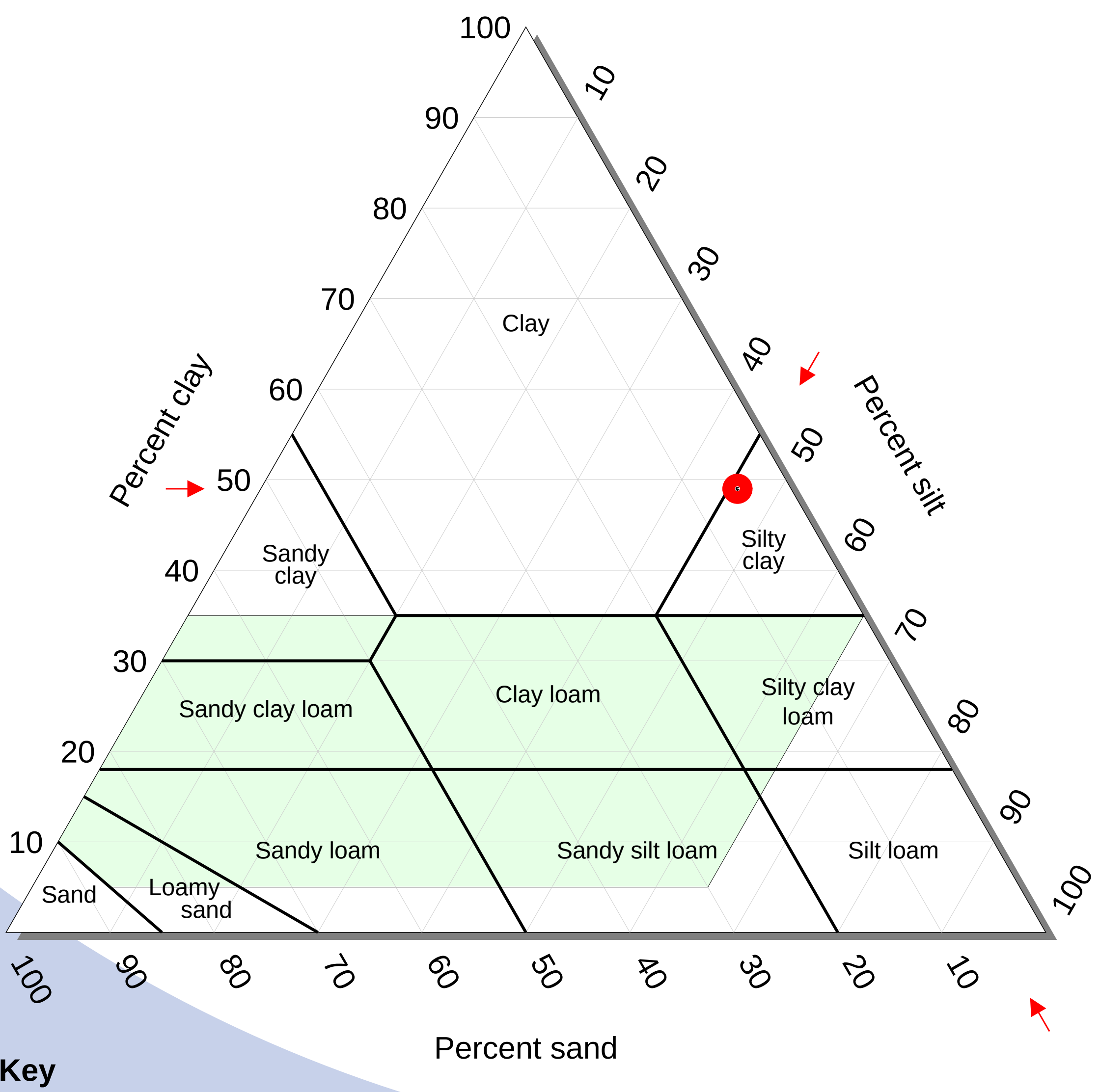
Client: JANET JONES
(K920) JONES ENVIRONMENTAL LAB
UNIT 3 DEESIDE
ZONE 3
DEESIDE IND EST
DEESIDE CH5 2UA

Originator: 11014
EMT 177411
EMT 177411

Lab ID: 61881 - 441955
Sample ID: AUK-TP-27 0.00-0.60
Sample Weight: 386g

Date Received: 11/07/2019
Date Reported: 18/07/2019

Fig. 1. Textural Class: Organic Silty Clay (non-compliant)



Key

🟩 Area within which texture of topsoil is required to fall.

Certificate of Analysis

Client: JANET JONES
(K920) JONES ENVIRONMENTAL LAB
UNIT 3 DEESIDE
ZONE 3
DEESIDE IND EST
DEESIDE CH5 2UA

Originator: 11014
EMT 177411
EMT 177411

Lab ID: 61881 - 441956
Sample ID: AUK-TP-23 0.00-0.30
Sample Weight: 529g

Date Received: 11/07/2019
Date Reported: 18/07/2019

BS 3882 : 2015 SPECIFICATION FOR TOPSOIL
Multipurpose Grade

					Compliant with range (Y/N)					
		Unit	**Result**		**Multi-P**	**Acid**	**Calc**	**Low-F**	**Low-F Acid**	**Low-F Calc**
Texture:	Clay	% w/w	25							
	Silt	% w/w	40				*See area of permitted soil textural*			
	Sand	% w/w	35				*classes in Fig. 1.*			
	Textural Class		Clay Loam		Y	Y	Y	Y	Y	Y
Organic Matter:		% w/w	7.9		Y	Y	Y	Y	Y	Y
Coarse Fragment Content:	>2 mm	% w/w	0.0		Y	Y	Y	Y	Y	Y
	>20 mm	% w/w	0.0		Y	Y	Y	Y	Y	Y
	>50 mm	% w/w	0.0		Y	Y	Y	Y	Y	Y
Soil pH:			8.1		Y	N	Y	Y	N	Y
Carbonate:		% w/w	5.3				Y			Y
Available Plant Nutrients:	Nitrogen	% w/w	0.313		Y	Y	Y			
	Phosphorus	mg/l	51.0	(4)*	Y	Y	Y	N	N	N
	Potassium	mg/l	814.5	(5)*	Y	Y	Y			
	Magnesium	mg/l	129.6	(3)*	Y	Y	Y			
Carbon:Nitrogen Ratio:		:1	14.6		Y	Y	Y	Y	Y	Y
Exchangeable Sodium Percentage:		%	3.5							
Phytotoxic Contaminants:	Total Zinc	mg/kg	78.9		Y	Y	Y	Y	Y	Y
	Total Copper	mg/kg	18.4		Y	Y	Y	Y	Y	Y
	Total Nickel	mg/kg	17.5		Y	Y	Y	Y	Y	Y
Visible Contaminants:	> 2mm	% w/w	0.00		Y	Y	Y	Y	Y	Y
	Plastics	% w/w	0.00		Y	Y	Y	Y	Y	Y
	Number of Sharps		0		Y	Y	Y	Y	Y	Y
Additional Analysis:	Available Sodium	mg/l	96.7							
	Available Calcium	mg/l	1686.4							
	Conductivity	uS/cm	2363		Y					
Compliancy:					**Y**	**N**	**Y**	**N**	**N**	**N**

Results are expressed on a dry matter basis.
* Soil indices from RB209

Released by: Joe Cherrie **Date: 18/07/2019**

DECLARATION: I certify that this sample has been analysed by NRM in accordance with BS 3882 Specification for Topsoil (2015).

Analytical Report

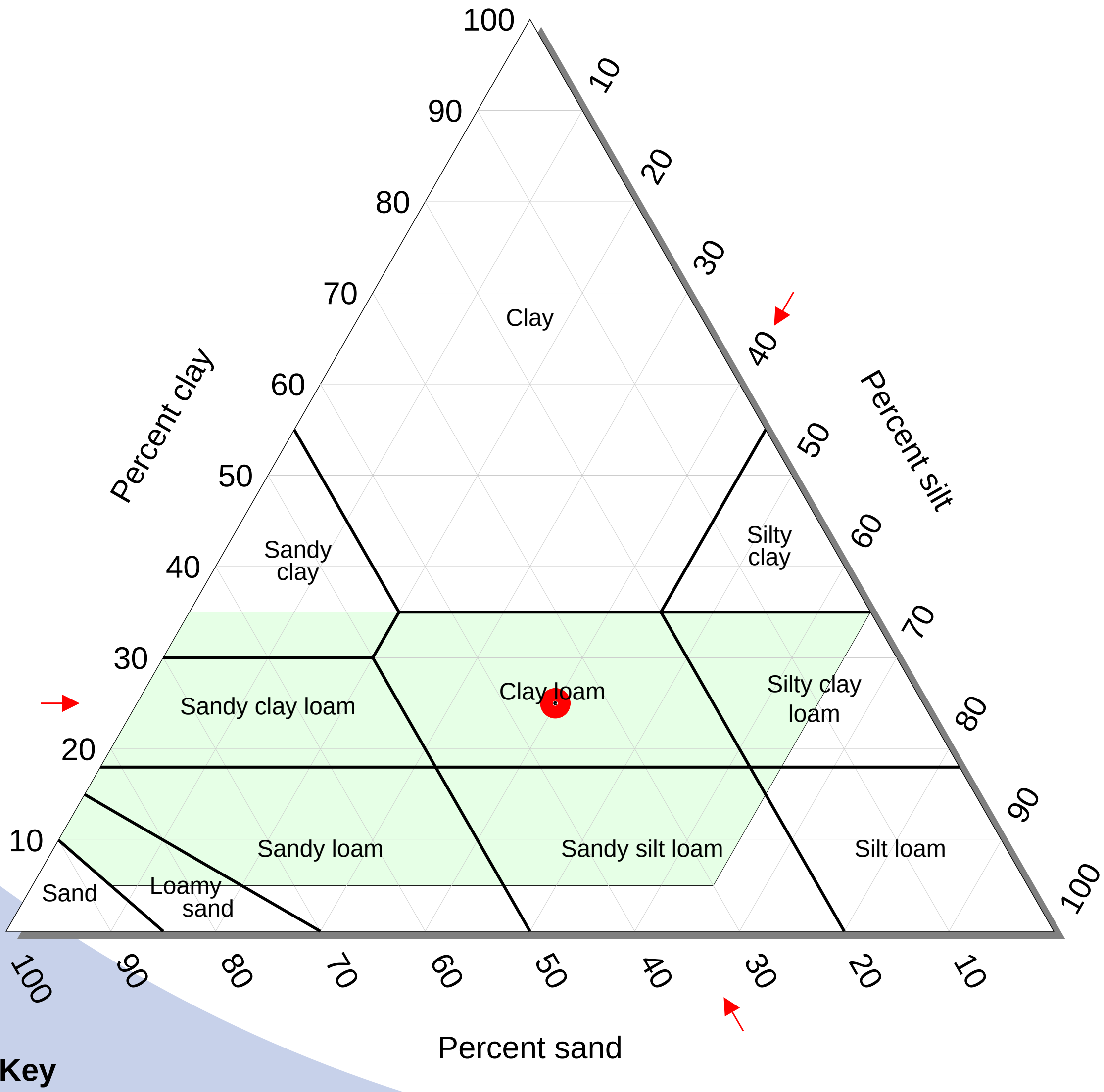
Client: JANET JONES
(K920) JONES ENVIRONMENTAL LAB
UNIT 3 DEESIDE
ZONE 3
DEESIDE IND EST
DEESIDE CH5 2UA

Originator: 11014
EMT 177411
EMT 177411

Lab ID: 61881 - 441956
Sample ID: AUK-TP-23 0.00-0.30
Sample Weight: 529g

Date Received: 11/07/2019
Date Reported: 18/07/2019

Fig. 1. Textural Class: Clay Loam (compliant)



Key

🟩 Area within which texture of topsoil is required to fall.

Certificate of Analysis

Client: JANET JONES
(K920) JONES ENVIRONMENTAL LAB
UNIT 3 DEESIDE
ZONE 3
DEESIDE IND EST
DEESIDE CH5 2UA

Originator: 11014
EMT 177411
EMT 177411

Lab ID: 61881 - 441957
Sample ID: AUK-TP-08 0.00-0.10
Sample Weight: 448g

Date Received: 11/07/2019
Date Reported: 18/07/2019

BS 3882 : 2015 SPECIFICATION FOR TOPSOIL

Fails BS 3882

					Compliant with range (Y/N)					
		Unit	**Result**		**Multi-P**	**Acid**	**Calc**	**Low-F**	**Low-F Acid**	**Low-F Calc**
Texture:	Clay	% w/w	15							
	Silt	% w/w	16				*See area of permitted soil textural classes in Fig. 1.*			
	Sand	% w/w	69							
	Textural Class		Sandy Loam		Y	Y	Y	Y	Y	Y
Organic Matter:		% w/w	5.0		Y	Y	Y	Y	Y	Y
Coarse Fragment Content:	>2 mm	% w/w	11.8		Y	Y	Y	Y	Y	Y
	>20 mm	% w/w	8.5		Y	Y	Y	Y	Y	Y
	>50 mm	% w/w	0.0		Y	Y	Y	Y	Y	Y
Soil pH:			8.6		N	N	Y	Y	N	Y
Carbonate:		% w/w	25.1				Y			Y
Available Plant Nutrients:	Nitrogen	% w/w	0.250		Y	Y	Y			
	Phosphorus	mg/l	22.0	(2)*	Y	Y	Y	N	N	N
	Potassium	mg/l	113.4	(1)*	N	N	N			
	Magnesium	mg/l	38.4	(1)*	N	N	N			
Carbon:Nitrogen Ratio:		:1	11.6		Y	Y	Y	Y	Y	Y
Exchangeable Sodium Percentage:		%	0.3							
Phytotoxic Contaminants:	Total Zinc	mg/kg	94.5		Y	Y	Y	Y	Y	Y
	Total Copper	mg/kg	33.4		Y	Y	Y	Y	Y	Y
	Total Nickel	mg/kg	20.7		Y	Y	Y	Y	Y	Y
Visible Contaminants:	> 2mm	% w/w	0.06		Y	Y	Y	Y	Y	Y
	Plastics	% w/w	0.00		Y	Y	Y	Y	Y	Y
	Number of Sharps		0		Y	Y	Y	Y	Y	Y
Additional Analysis:	Available Sodium	mg/l	7.8							
	Available Calcium	mg/l	1814.1							
	Conductivity	uS/cm	2110		Y					
Compliancy:					**N**	**N**	**N**	**N**	**N**	**N**

Results are expressed on a dry matter basis.
* Soil indices from RB209

Released by: Joe Cherrie **Date: 18/07/2019**

DECLARATION: I certify that this sample has been analysed by NRM in accordance with BS 3882 Specification for Topsoil (2015).

Analytical Report

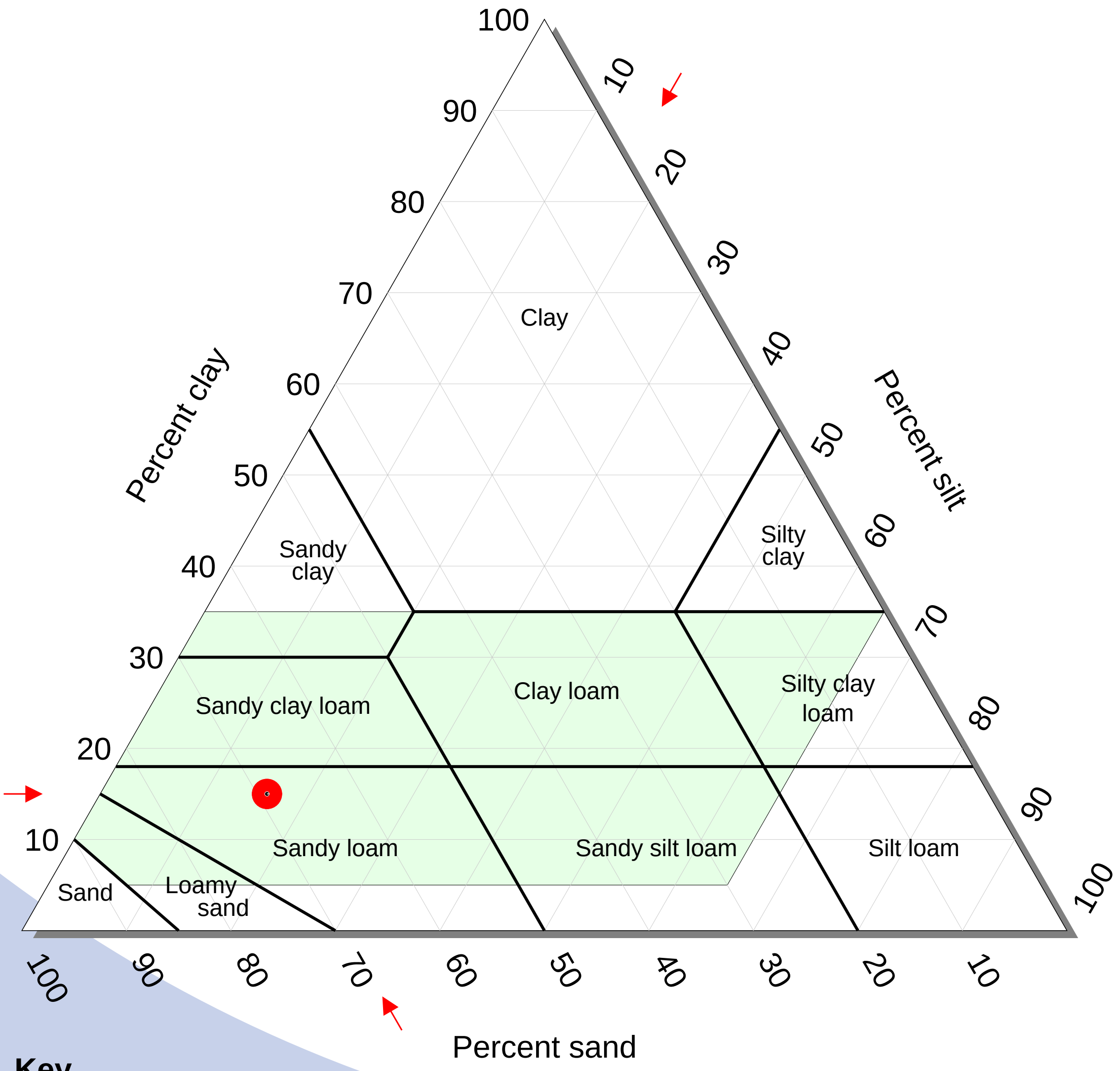
Client: JANET JONES
(K920) JONES ENVIRONMENTAL LAB
UNIT 3 DEESIDE
ZONE 3
DEESIDE IND EST
DEESIDE CH5 2UA

Originator: 11014
EMT 177411
EMT 177411

Lab ID: 61881 - 441957
Sample ID: AUK-TP-08 0.00-0.10
Sample Weight: 448g

Date Received: 11/07/2019
Date Reported: 18/07/2019

Fig. 1. Textural Class: Sandy Loam (compliant)



Key

🟩 Area within which texture of topsoil is required to fall.

Certificate of Analysis

Client: JANET JONES
(K920) JONES ENVIRONMENTAL LAB
UNIT 3 DEESIDE
ZONE 3
DEESIDE IND EST
DEESIDE CH5 2UA

Originator: 11014
EMT 177411
EMT 177411

Lab ID: 61881 - 441958
Sample ID: AUK-TP-28 0.20
Sample Weight: 414g

Date Received: 11/07/2019
Date Reported: 18/07/2019

BS 3882 : 2015 SPECIFICATION FOR TOPSOIL

Fails BS 3882

					Compliant with range (Y/N)					
		Unit	**Result**		**Multi-P**	**Acid**	**Calc**	**Low-F**	**Low-F Acid**	**Low-F Calc**
Texture:	Clay	% w/w	49							
	Silt	% w/w	47			*See area of permitted soil textural classes in Fig. 1.*				
	Sand	% w/w	4							
	Textural Class		Organic Silty Clay		N	N	N	N	N	N
Organic Matter:		% w/w	11.1							
Coarse Fragment Content:	>2 mm	% w/w	0.0		Y	Y	Y	Y	Y	Y
	>20 mm	% w/w	0.0		Y	Y	Y	Y	Y	Y
	>50 mm	% w/w	0.0		Y	Y	Y	Y	Y	Y
Soil pH:			8.1		Y	N	Y	Y	N	Y
Carbonate:		% w/w	6.1				Y			Y
Available Plant Nutrients:	Nitrogen	% w/w	0.536		Y	Y	Y			
	Phosphorus	mg/l	107.2	(6)*	Y	Y	Y	N	N	N
	Potassium	mg/l	1116.1	(6)*	Y	Y	Y			
	Magnesium	mg/l	198.9	(4)*	Y	Y	Y			
Carbon:Nitrogen Ratio:		:1	12.0		Y	Y	Y	Y	Y	Y
Exchangeable Sodium Percentage:		%	0.9							
Phytotoxic Contaminants:	Total Zinc	mg/kg	172		Y	Y	Y	Y	Y	Y
	Total Copper	mg/kg	38.4		Y	Y	Y	Y	Y	Y
	Total Nickel	mg/kg	33.8		Y	Y	Y	Y	Y	Y
Visible Contaminants:	> 2mm	% w/w	0.00		Y	Y	Y	Y	Y	Y
	Plastics	% w/w	0.00		Y	Y	Y	Y	Y	Y
	Number of Sharps		0		Y	Y	Y	Y	Y	Y
Additional Analysis:	Available Sodium	mg/l	37.3							
	Available Calcium	mg/l	2637.8							
	Conductivity	uS/cm	2298		Y					
Compliancy:					**N**	**N**	**N**	**N**	**N**	**N**

Results are expressed on a dry matter basis.
* Soil indices from RB209

Released by: Joe Cherrie **Date: 18/07/2019**

DECLARATION: I certify that this sample has been analysed by NRM in accordance with BS 3882 Specification for Topsoil (2015).

Analytical Report

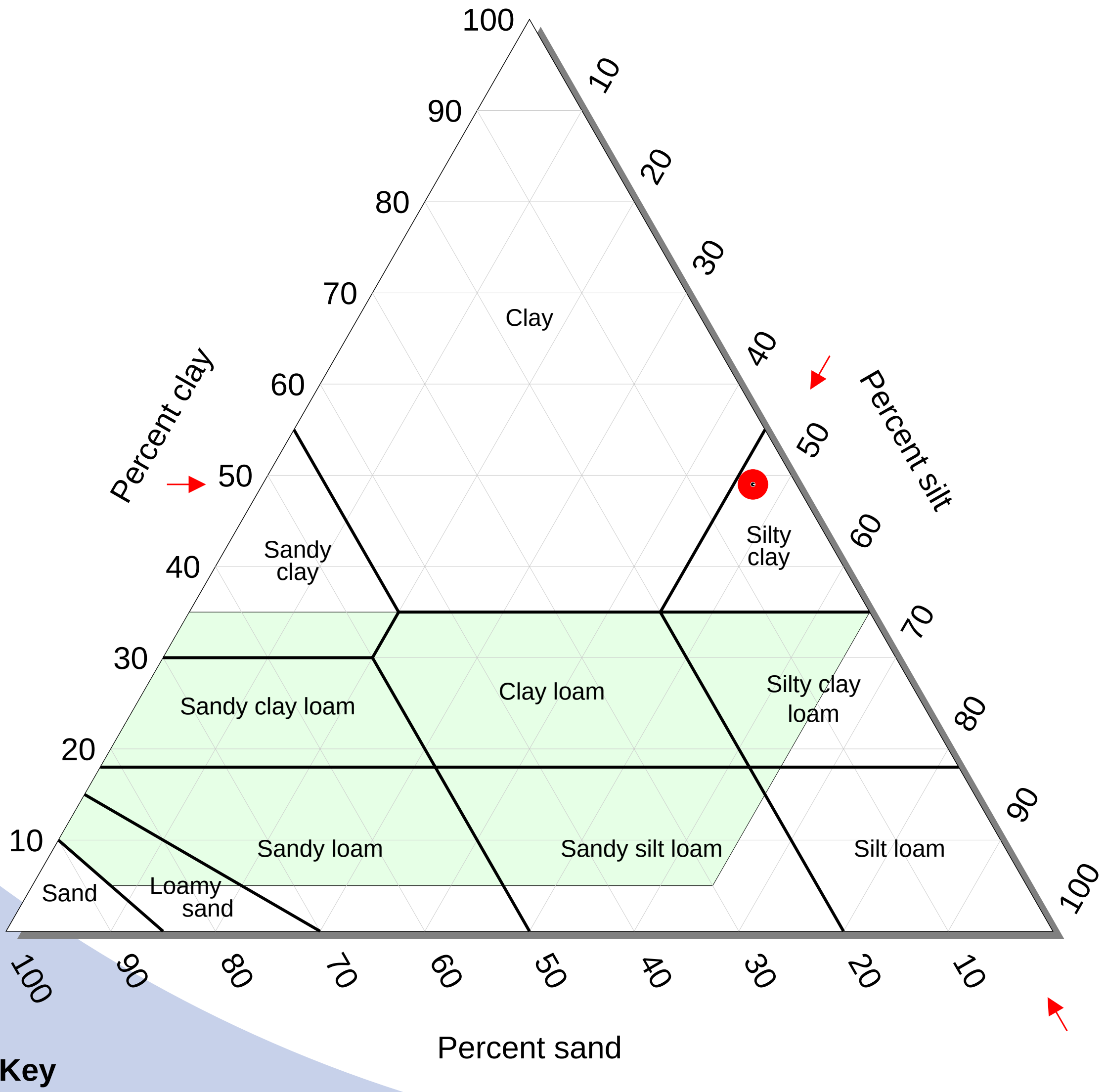
Client: JANET JONES
(K920) JONES ENVIRONMENTAL LAB
UNIT 3 DEESIDE
ZONE 3
DEESIDE IND EST
DEESIDE CH5 2UA

Originator: 11014
EMT 177411
EMT 177411

Lab ID: 61881 - 441958
Sample ID: AUK-TP-28 0.20
Sample Weight: 414g

Date Received: 11/07/2019
Date Reported: 18/07/2019

Fig. 1. Textural Class: Organic Silty Clay (non-compliant)



Key

🟩 Area within which texture of topsoil is required to fall.

Certificate of Analysis

Client:	JANET JONES	**Originator:**	11014
(K920)	JONES ENVIRONMENTAL LAB		EMT 177411
	UNIT 3 DEESIDE		EMT 177411
	ZONE 3		
	DEESIDE IND EST		
	DEESIDE CH5 2UA		

Lab ID:	61881 - 441959	**Date Received:**	11/07/2019
Sample ID:	AUK-TP-16 0.00-0.10	**Date Reported:**	18/07/2019
Sample Weight:	469g		

BS 3882 : 2015 SPECIFICATION FOR TOPSOIL

Fails BS 3882

					Compliant with range (Y/N)					
		Unit	**Result**		**Multi-P**	**Acid**	**Calc**	**Low-F**	**Low-F Acid**	**Low-F Calc**
Texture:	Clay	% w/w	15							
	Silt	% w/w	14				*See area of permitted soil textural classes in Fig. 1.*			
	Sand	% w/w	71							
	Textural Class		Sandy Loam		Y	Y	Y	Y	Y	Y
Organic Matter:		% w/w	7.2		Y	Y	Y	Y	Y	Y
Coarse Fragment Content:	>2 mm	% w/w	3.6		Y	Y	Y	Y	Y	Y
	>20 mm	% w/w	2.1		Y	Y	Y	Y	Y	Y
	>50 mm	% w/w	0.0		Y	Y	Y	Y	Y	Y
Soil pH:			7.9		Y	N	Y	Y	N	Y
Carbonate:		% w/w	2.0				Y			Y
Available Plant Nutrients:	Nitrogen	% w/w	0.273		Y	Y	Y			
	Phosphorus	mg/l	50.8	(4)*	Y	Y	Y	N	N	N
	Potassium	mg/l	183.3	(2+)*	Y	Y	Y			
	Magnesium	mg/l	95.1	(2)*	Y	Y	Y			
Carbon:Nitrogen Ratio:		:1	15.3		Y	Y	Y	Y	Y	Y
Exchangeable Sodium Percentage:		%	0.4							
Phytotoxic Contaminants:	Total Zinc	mg/kg	55.2		Y	Y	Y	Y	Y	Y
	Total Copper	mg/kg	24.1		Y	Y	Y	Y	Y	Y
	Total Nickel	mg/kg	12.0		Y	Y	Y	Y	Y	Y
Visible Contaminants:	> 2mm	% w/w	0.52		N	N	N	N	N	N
	Plastics	% w/w	0.00		Y	Y	Y	Y	Y	Y
	Number of Sharps		0		Y	Y	Y	Y	Y	Y
Additional Analysis:	Available Sodium	mg/l	9.2							
	Available Calcium	mg/l	1565.9							
	Conductivity	uS/cm	2148		Y					
Compliancy:					**N**	**N**	**N**	**N**	**N**	**N**

Results are expressed on a dry matter basis.
* Soil indices from RB209

Released by: Joe Cherrie **Date: 18/07/2019**

DECLARATION: I certify that this sample has been analysed by NRM in accordance with BS 3882 Specification for Topsoil (2015).

Analytical Report

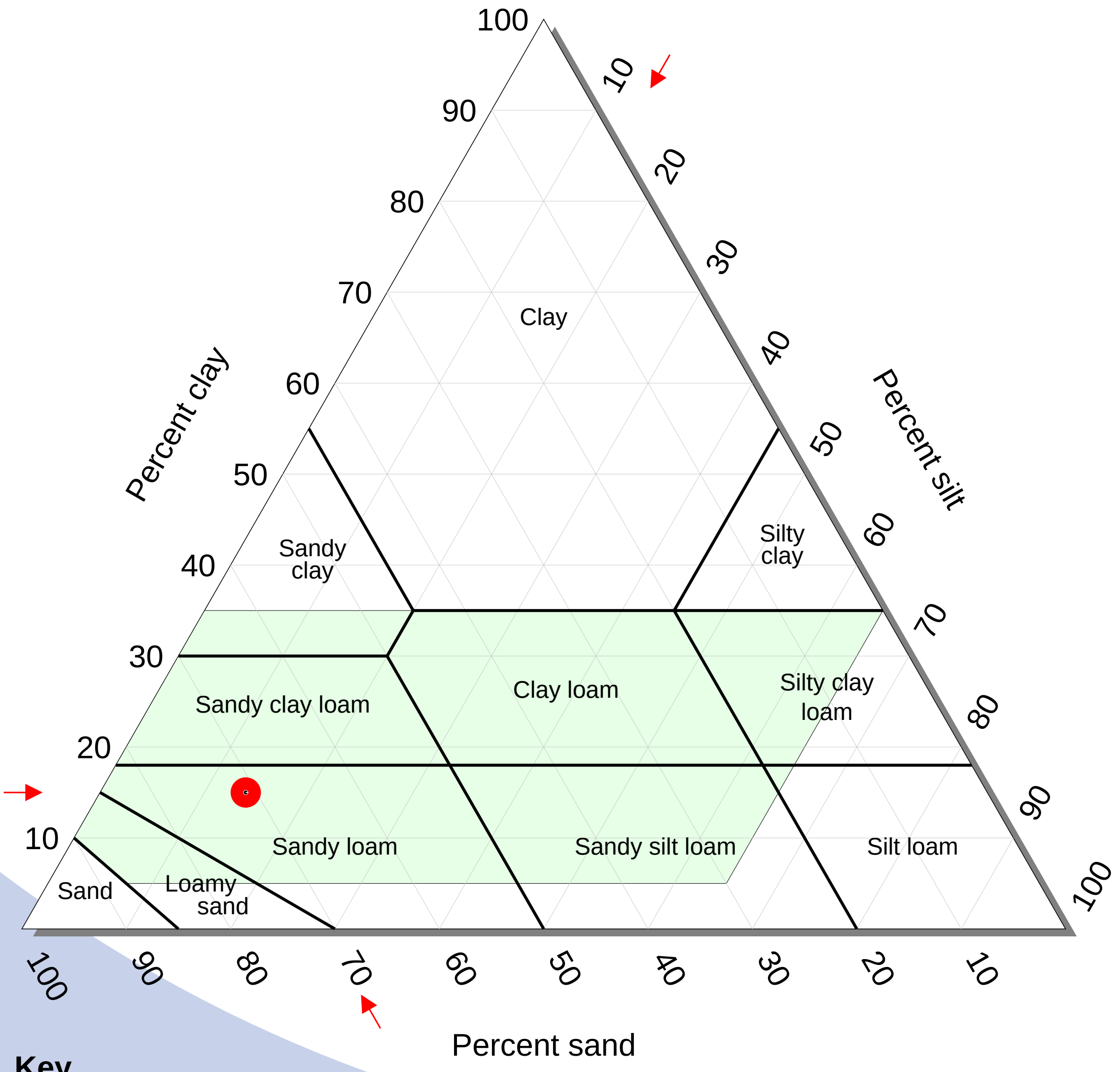
Client: JANET JONES
(K920) JONES ENVIRONMENTAL LAB
UNIT 3 DEESIDE
ZONE 3
DEESIDE IND EST
DEESIDE CH5 2UA

Originator: 11014
EMT 177411
EMT 177411

Lab ID: 61881 - 441959
Sample ID: AUK-TP-16 0.00-0.10
Sample Weight: 469g

Date Received: 11/07/2019
Date Reported: 18/07/2019

Fig. 1. Textural Class: Sandy Loam (compliant)



Key

🟩 Area within which texture of topsoil is required to fall.

Certificate of Analysis

Client: JANET JONES
(K920) JONES ENVIRONMENTAL LAB
UNIT 3 DEESIDE
ZONE 3
DEESIDE IND EST
DEESIDE CH5 2UA

Originator: 11014
EMT 177411
EMT 177411

Lab ID: 61881 - 441960
Sample ID: AUK-TP-04 0.00-0.10
Sample Weight: 495g

Date Received: 11/07/2019
Date Reported: 18/07/2019

BS 3882 : 2015 SPECIFICATION FOR TOPSOIL

Specific Purpose: Low Fertility

					Compliant with range (Y/N)					
		Unit	**Result**		**Multi-P**	**Acid**	**Calc**	**Low-F**	**Low-F Acid**	**Low-F Calc**
Texture:	Clay	% w/w	9							
	Silt	% w/w	10			*See area of permitted soil textural classes in Fig. 1.*				
	Sand	% w/w	81							
	Textural Class		Loamy Sand		Y	Y	Y	Y	Y	Y
Organic Matter:		% w/w	3.5		Y	Y	Y	Y	Y	Y
Coarse Fragment Content:	>2 mm	% w/w	4.1		Y	Y	Y	Y	Y	Y
	>20 mm	% w/w	1.8		Y	Y	Y	Y	Y	Y
	>50 mm	% w/w	0.0		Y	Y	Y	Y	Y	Y
Soil pH:			8.2		Y	N	Y	Y	N	Y
Carbonate:		% w/w	2.5				Y			Y
Available Plant Nutrients:	Nitrogen	% w/w	0.156		Y	Y	Y			
	Phosphorus	mg/l	18.0	(2)*	Y	Y	Y	Y	Y	Y
	Potassium	mg/l	89.8	(1)*	N	N	N			
	Magnesium	mg/l	37.9	(1)*	N	N	N			
Carbon:Nitrogen Ratio:		:1	13.0		Y	Y	Y	Y	Y	Y
Exchangeable Sodium Percentage:		%	0.3							
Phytotoxic Contaminants:	Total Zinc	mg/kg	95.5		Y	Y	Y	Y	Y	Y
	Total Copper	mg/kg	25.4		Y	Y	Y	Y	Y	Y
	Total Nickel	mg/kg	15.7		Y	Y	Y	Y	Y	Y
Visible Contaminants:	> 2mm	% w/w	0.00		Y	Y	Y	Y	Y	Y
	Plastics	% w/w	0.00		Y	Y	Y	Y	Y	Y
	Number of Sharps		0		Y	Y	Y	Y	Y	Y
Additional Analysis:	Available Sodium	mg/l	5.0							
	Available Calcium	mg/l	1381.9							
	Conductivity	uS/cm	2110		Y					
Compliancy:					**N**	**N**	**N**	**Y**	**N**	**Y**

Results are expressed on a dry matter basis.
* Soil indices from RB209

Released by: Joe Cherrie **Date: 18/07/2019**

DECLARATION: I certify that this sample has been analysed by NRM in accordance with BS 3882 Specification for Topsoil (2015).

Analytical Report

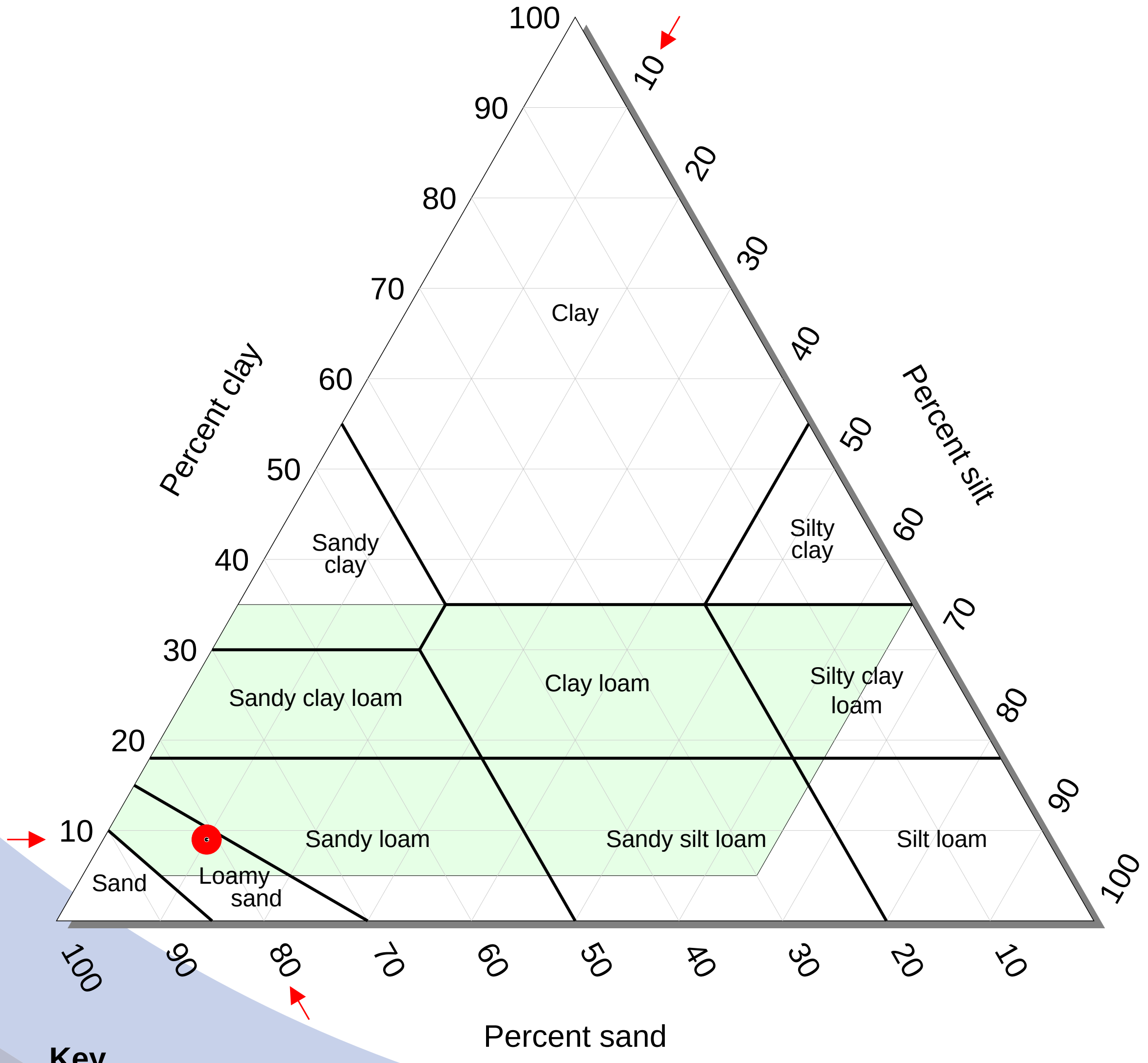
Client: JANET JONES
(K920) JONES ENVIRONMENTAL LAB
UNIT 3 DEESIDE
ZONE 3
DEESIDE IND EST
DEESIDE CH5 2UA

Originator: 11014
EMT 177411
EMT 177411

Lab ID: 61881 - 441960
Sample ID: AUK-TP-04 0.00-0.10
Sample Weight: 495g

Date Received: 11/07/2019
Date Reported: 18/07/2019

Fig. 1. Textural Class: Loamy Sand (compliant)



Key

🟩 Area within which texture of topsoil is required to fall.

Certificate of Analysis

Client: JANET JONES
(K920) JONES ENVIRONMENTAL LAB
UNIT 3 DEESIDE
ZONE 3
DEESIDE IND EST
DEESIDE CH5 2UA

Originator: 11014
EMT 177411
EMT 177411

Lab ID: 61881 - 441961
Sample ID: AUK-TP-01 0.00-0.20
Sample Weight: 464g

Date Received: 11/07/2019
Date Reported: 18/07/2019

BS 3882 : 2015 SPECIFICATION FOR TOPSOIL
Specific Purpose: Low Fertility

					Compliant with range (Y/N)					
		Unit	**Result**		**Multi-P**	**Acid**	**Calc**	**Low-F**	**Low-F Acid**	**Low-F Calc**
Texture:	Clay	% w/w	7							
	Silt	% w/w	6			*See area of permitted soil textural classes in Fig. 1.*				
	Sand	% w/w	87							
	Textural Class		Loamy Sand		Y	Y	Y	Y	Y	Y
Organic Matter:		% w/w	3.0		Y	Y	Y	Y	Y	Y
Coarse Fragment Content:	>2 mm	% w/w	4.4		Y	Y	Y	Y	Y	Y
	>20 mm	% w/w	1.4		Y	Y	Y	Y	Y	Y
	>50 mm	% w/w	0.0		Y	Y	Y	Y	Y	Y
Soil pH:			7.0		Y	N	N	Y	N	N
Carbonate:		% w/w	<1				N			N
Available Plant Nutrients:	Nitrogen	% w/w	0.116		N	N	N			
	Phosphorus	mg/l	17.6	(2)*	Y	Y	Y	Y	Y	Y
	Potassium	mg/l	55.0	(0)*	N	N	N			
	Magnesium	mg/l	83.3	(2)*	Y	Y	Y			
Carbon:Nitrogen Ratio:		:1	15.0		Y	Y	Y	Y	Y	Y
Exchangeable Sodium Percentage:		%	0.5							
Phytotoxic Contaminants:	Total Zinc	mg/kg	38.9		Y	Y	Y	Y	Y	Y
	Total Copper	mg/kg	15.3		Y	Y	Y	Y	Y	Y
	Total Nickel	mg/kg	<10		Y	Y	Y	Y	Y	Y
Visible Contaminants:	> 2mm	% w/w	0.00		Y	Y	Y	Y	Y	Y
	Plastics	% w/w	0.00		Y	Y	Y	Y	Y	Y
	Number of Sharps		0		Y	Y	Y	Y	Y	Y
Additional Analysis:	Available Sodium	mg/l	6.1							
	Available Calcium	mg/l	850.5							
	Conductivity	uS/cm	2061		Y					
Compliancy:					**N**	**N**	**N**	**Y**	**N**	**N**

Results are expressed on a dry matter basis.
* Soil indices from RB209

Released by: Joe Cherrie **Date: 18/07/2019**

DECLARATION: I certify that this sample has been analysed by NRM in accordance with BS 3882 Specification for Topsoil (2015).

Analytical Report

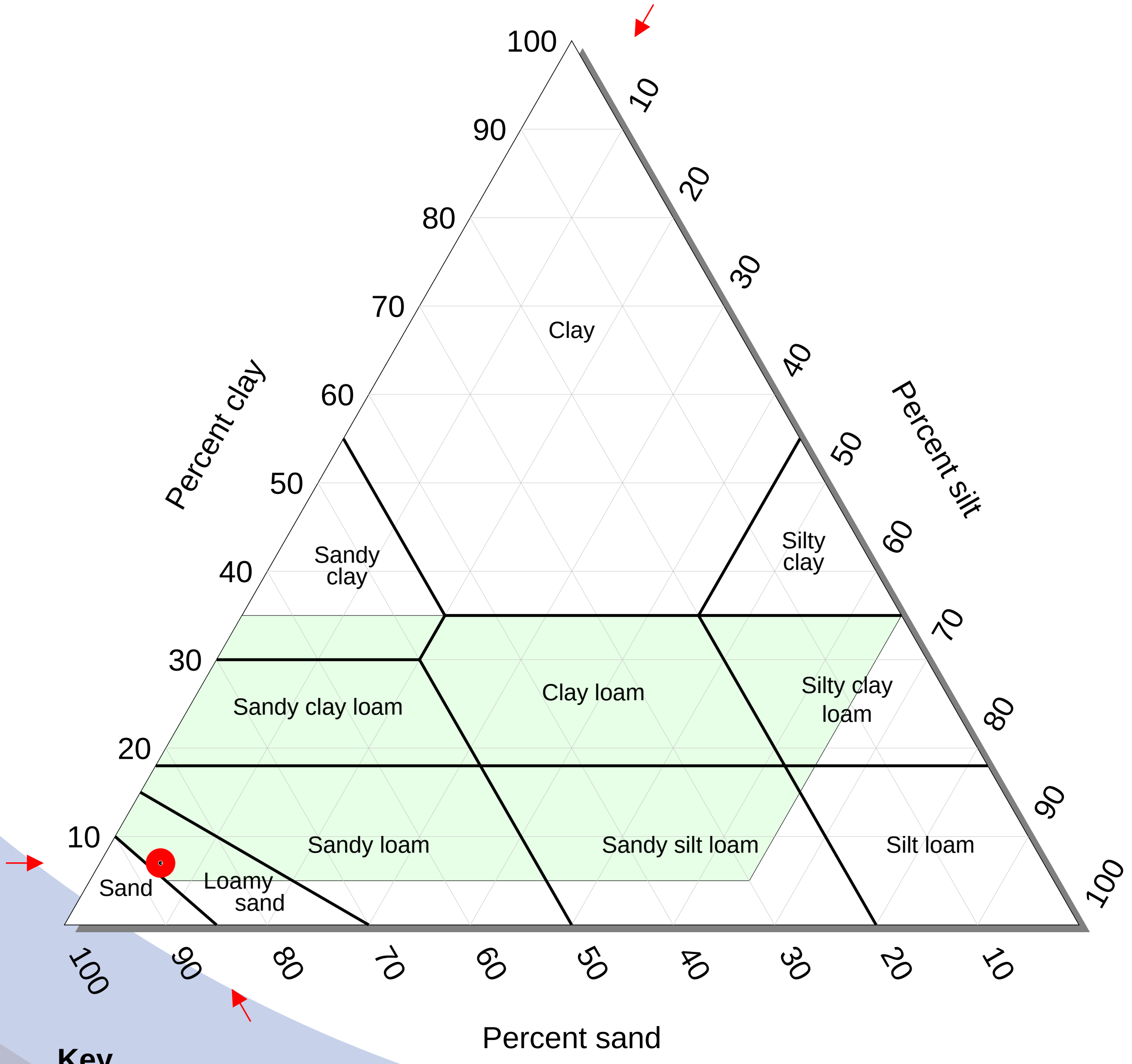
Client: JANET JONES
(K920) JONES ENVIRONMENTAL LAB
UNIT 3 DEESIDE
ZONE 3
DEESIDE IND EST
DEESIDE CH5 2UA

Originator: 11014
EMT 177411
EMT 177411

Lab ID: 61881 - 441961
Sample ID: AUK-TP-01 0.00-0.20
Sample Weight: 464g

Date Received: 11/07/2019
Date Reported: 18/07/2019

Fig. 1. Textural Class: Loamy Sand (compliant)



Key

🟩 Area within which texture of topsoil is required to fall.

Certificate of Analysis

Client: JANET JONES
(K920) JONES ENVIRONMENTAL LAB
UNIT 3 DEESIDE
ZONE 3
DEESIDE IND EST
DEESIDE CH5 2UA

Originator: 11014
EMT 177411
EMT 177411

Lab ID: 61881 - 441962
Sample ID: AUK-TP-32 0.00-0.30
Sample Weight: 484g

Date Received: 11/07/2019
Date Reported: 18/07/2019

BS 3882 : 2015 SPECIFICATION FOR TOPSOIL

Fails BS 3882

					Compliant with range (Y/N)					
		Unit	**Result**		**Multi-P**	**Acid**	**Calc**	**Low-F**	**Low-F Acid**	**Low-F Calc**
Texture:	Clay	% w/w	9							
	Silt	% w/w	12			*See area of permitted soil textural classes in Fig. 1.*				
	Sand	% w/w	79							
	Textural Class		Loamy Sand		Y	Y	Y	Y	Y	Y
Organic Matter:		% w/w	4.2		Y	Y	Y	Y	Y	Y
Coarse Fragment Content:	>2 mm	% w/w	8.1		Y	Y	Y	Y	Y	Y
	>20 mm	% w/w	7.1		Y	Y	Y	Y	Y	Y
	>50 mm	% w/w	0.0		Y	Y	Y	Y	Y	Y
Soil pH:			5.9		Y	N	N	Y	N	N
Carbonate:		% w/w	<1				N			N
Available Plant Nutrients:	Nitrogen	% w/w	0.160		Y	Y	Y			
	Phosphorus	mg/l	37.2	(3)*	Y	Y	Y	N	N	N
	Potassium	mg/l	73.7	(1)*	N	N	N			
	Magnesium	mg/l	31.0	(1)*	N	N	N			
Carbon:Nitrogen Ratio:		:1	15.3		Y	Y	Y	Y	Y	Y
Exchangeable Sodium Percentage:		%	0.8							
Phytotoxic Contaminants:	Total Zinc	mg/kg	50.1		Y	Y	Y	Y	Y	Y
	Total Copper	mg/kg	24.9		Y	Y	Y	Y	Y	Y
	Total Nickel	mg/kg	<10		Y	Y	Y	Y	Y	Y
Visible Contaminants:	> 2mm	% w/w	0.00		Y	Y	Y	Y	Y	Y
	Plastics	% w/w	0.00		Y	Y	Y	Y	Y	Y
	Number of Sharps		0		Y	Y	Y	Y	Y	Y
Additional Analysis:	Available Sodium	mg/l	8.1							
	Available Calcium	mg/l	816.3							
	Conductivity	uS/cm	2062		Y					
Compliancy:					**N**	**N**	**N**	**N**	**N**	**N**

Results are expressed on a dry matter basis.
* Soil indices from RB209

Released by: Joe Cherrie **Date: 18/07/2019**

DECLARATION: I certify that this sample has been analysed by NRM in accordance with BS 3882 Specification for Topsoil (2015).

Analytical Report

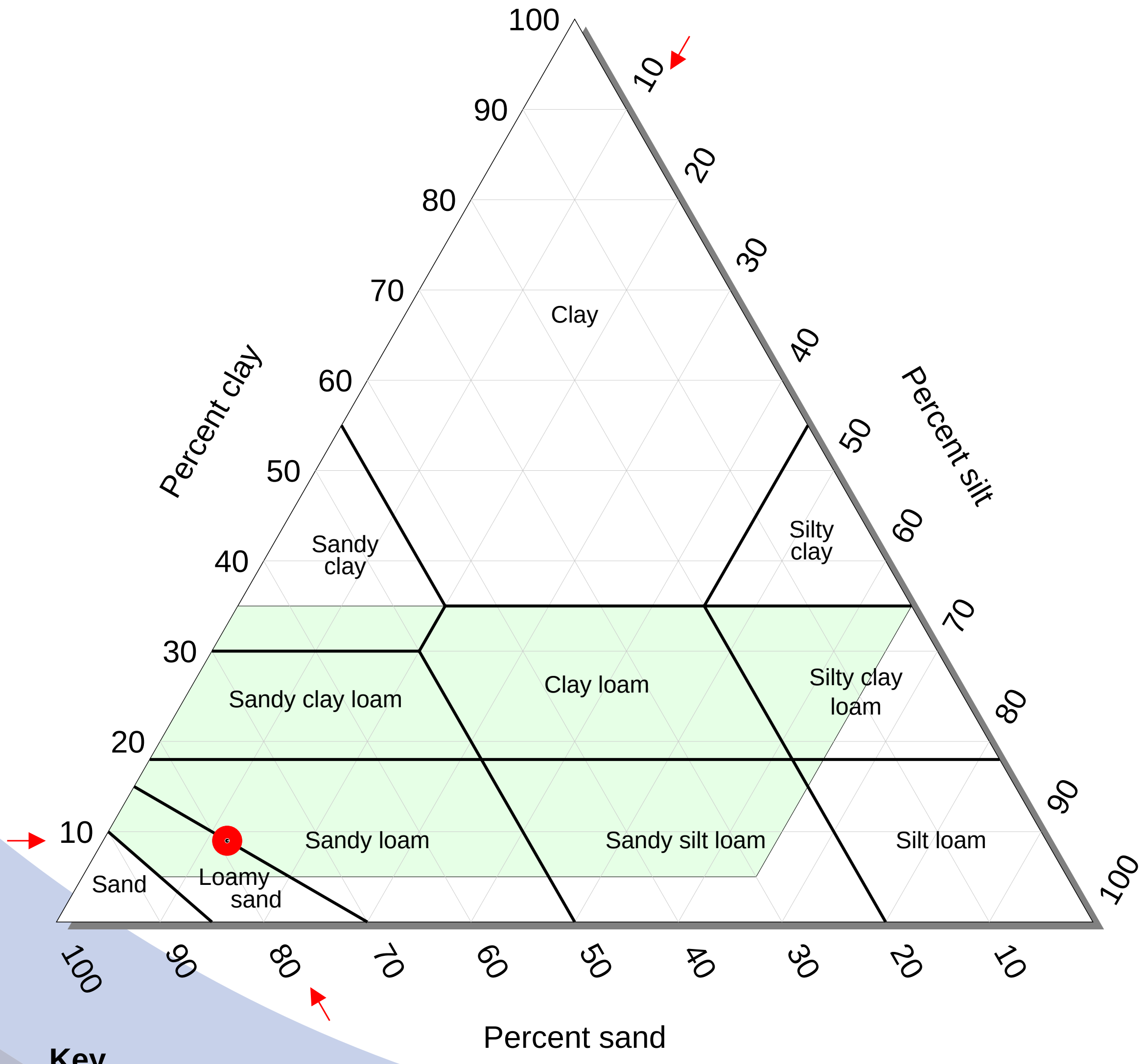
Client: JANET JONES
(K920) JONES ENVIRONMENTAL LAB
UNIT 3 DEESIDE
ZONE 3
DEESIDE IND EST
DEESIDE CH5 2UA

Originator: 11014
EMT 177411
EMT 177411

Lab ID: 61881 - 441962
Sample ID: AUK-TP-32 0.00-0.30
Sample Weight: 484g

Date Received: 11/07/2019
Date Reported: 18/07/2019

Fig. 1. Textural Class: Loamy Sand (compliant)



Key

🟩 Area within which texture of topsoil is required to fall.

Certificate of Analysis

Client: JANET JONES
(K920) JONES ENVIRONMENTAL LAB
UNIT 3 DEESIDE
ZONE 3
DEESIDE IND EST
DEESIDE CH5 2UA

Originator: 11014
EMT 177411
EMT 177411

Lab ID: 61888 - 441963
Sample ID: AUK-TP-03 0.00-0.30
Sample Weight: 464g

Date Received: 11/07/2019
Date Reported: 18/07/2019

BS 3882 : 2015 SPECIFICATION FOR TOPSOIL

Fails BS 3882

						Compliant with range (Y/N)				
		Unit	**Result**		**Multi-P**	**Acid**	**Calc**	**Low-F**	**Low-F Acid**	**Low-F Calc**
Texture:	Clay	% w/w	13							
	Silt	% w/w	14			*See area of permitted soil textural classes in Fig. 1.*				
	Sand	% w/w	73							
	Textural Class		Sandy Loam		Y	Y	Y	Y	Y	Y
Organic Matter:		% w/w	5.0		Y	Y	Y	Y	Y	Y
Coarse Fragment Content:	>2 mm	% w/w	1.2		Y	Y	Y	Y	Y	Y
	>20 mm	% w/w	0.0		Y	Y	Y	Y	Y	Y
	>50 mm	% w/w	0.0		Y	Y	Y	Y	Y	Y
Soil pH:			8.2		Y	N	Y	Y	N	Y
Carbonate:		% w/w	5.7				Y			Y
Available Plant Nutrients:	Nitrogen	% w/w	0.239		Y	Y	Y			
	Phosphorus	mg/l	56.0	(4)*	Y	Y	Y	N	N	N
	Potassium	mg/l	120.3	(1)*	N	N	N			
	Magnesium	mg/l	19.9	(0)*	N	N	N			
Carbon:Nitrogen Ratio:		:1	12.1		Y	Y	Y	Y	Y	Y
Exchangeable Sodium Percentage:		%	0.3							
Phytotoxic Contaminants:	Total Zinc	mg/kg	55.5		Y	Y	Y	Y	Y	Y
	Total Copper	mg/kg	26.1		Y	Y	Y	Y	Y	Y
	Total Nickel	mg/kg	<10		Y	Y	Y	Y	Y	Y
Visible Contaminants:	> 2mm	% w/w	0.10		Y	Y	Y	Y	Y	Y
	Plastics	% w/w	0.00		Y	Y	Y	Y	Y	Y
	Number of Sharps		0		Y	Y	Y	Y	Y	Y
Additional Analysis:	Available Sodium	mg/l	4.7							
	Available Calcium	mg/l	1516.9							
	Conductivity	uS/cm	2110		Y					
Compliancy:					**N**	**N**	**N**	**N**	**N**	**N**

Results are expressed on a dry matter basis.
* Soil indices from RB209

Released by: Joe Cherrie **Date: 18/07/2019**

DECLARATION: I certify that this sample has been analysed by NRM in accordance with BS 3882 Specification for Topsoil (2015).

Analytical Report

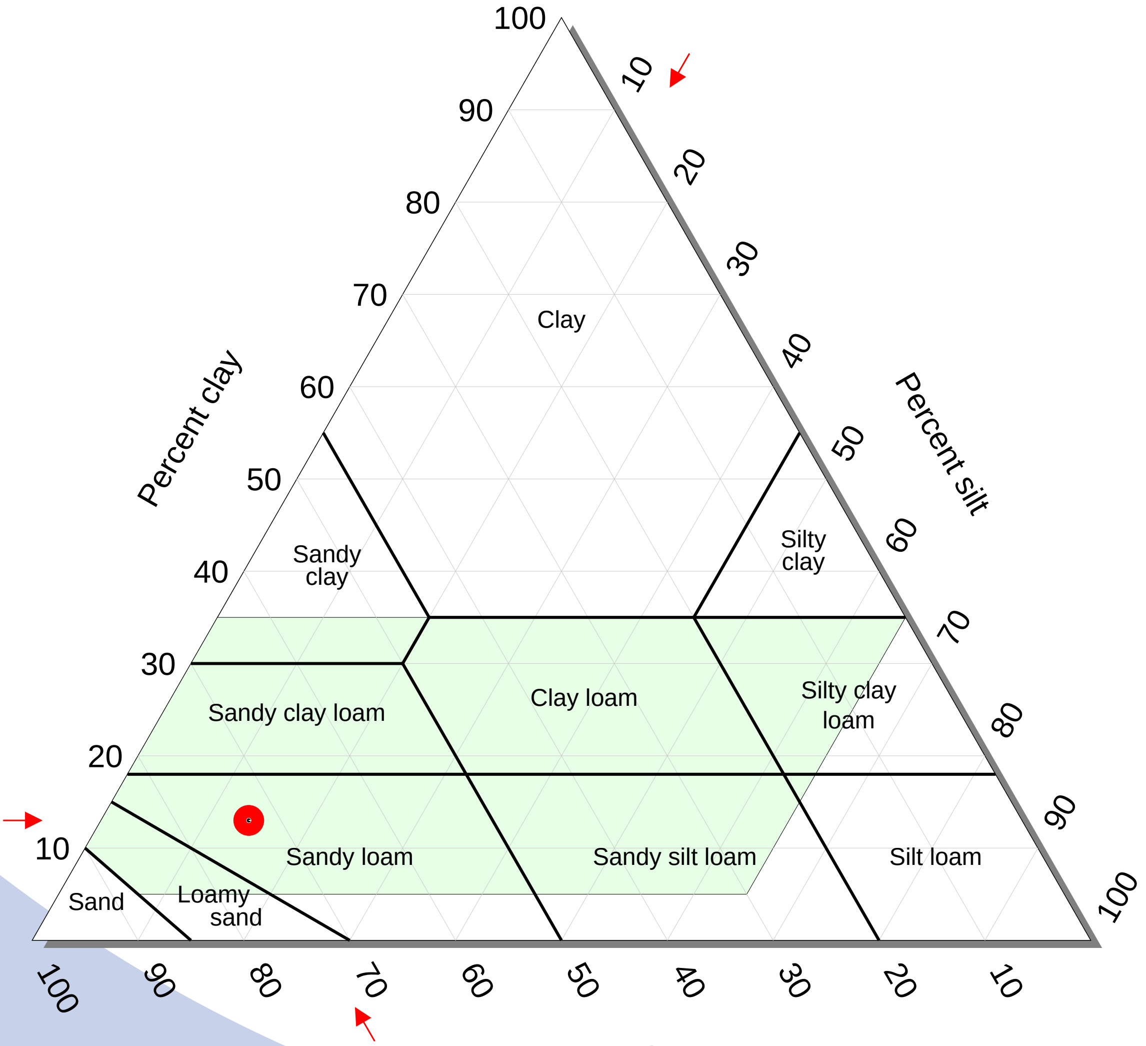
Client: JANET JONES
(K920) JONES ENVIRONMENTAL LAB
UNIT 3 DEESIDE
ZONE 3
DEESIDE IND EST
DEESIDE CH5 2UA

Originator: 11014
EMT 177411
EMT 177411

Lab ID: 61888 - 441963
Sample ID: AUK-TP-03 0.00-0.30
Sample Weight: 464g

Date Received: 11/07/2019
Date Reported: 18/07/2019

Fig. 1. Textural Class: Sandy Loam (compliant)



Key

🟩 Area within which texture of topsoil is required to fall.

APPENDIX D

Stabilisation Trials, Laboratory Bench Scale Mix Design Study

Geochem
Cutting-Edge Geochemistry

British Sugar Stabilisation Trials

Laboratory Bench Scale Mix Design Study

Report A190504
November 2019

Prepared for

ARCADIS

Revision Schedule

Report
December 2019

Rev	Date	Details	Prepared by	Reviewed by	Approved by
1	11/2019	Draft	**Thomas Beaver / Dr Jamie Cutting**	**Dr Jamie Cutting / Dr Vanessa Appleby**	**Dr Jamie Cutting**
2	12/2019	Final	**Dr Jamie Cutting**	**Dr Jamie Cutting**	**Dr Jamie cutting**

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Tel +44 (0)1629 584 416

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Limitations

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The interpretations and recommendations contained in this Report are based upon information generated from samples provided by others. For all intents and purposes, samples are assumed to be representative. CE Geochem have tested samples as instructed, without influence or prejudice on samples selection.

The methodology adopted and the sources of information used by CE Geochem in providing its services are outlined in the original Proposal [P190504]. 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.

Where assessments of works or costs identified in this Report are made, such assessments are based upon the information available at the time and where appropriate are subject to further investigations or information which may become available during the performance of scheduled tasks.

CE Geochem disclaim any undertaking or obligation to advise any person of any change in any matter affecting this test work, which may come or be brought to CE Geochem attention after the date of submission of the Final Report.

Certain statements made in this document may constitute estimates, projections or other forward-looking statements and even though they are based on reasonable assumptions as of the date of this document, such forward-looking statements by their nature involve risks and uncertainties that could cause actual results or programmes to differ materially from those predicted. CE Geochem specifically does not guarantee or warrant any estimate or projections contained in this document.

Unless otherwise stated in this Report, the assessments made assume that the sites and facilities will continue to be used for their current purpose without significant changes.

Where field sampling has been conducted by others, CE Geochem have assumed that samplers provided are suitable to meet the stated objectives of the services. The inherent variability of real samples may affect the results of any laboratory test works detailed herein, in such a manner that cannot be resolved using the proposed methodologies. Such variability is beyond the control of CE Geochem and no warranties or assurances are offered or implied, as to appropriateness of results or the applicability of laboratory data to site conditions.

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Table of Contents

1 Executive Summary

CE Geochem have been commissioned by Arcadis to undertake an independent mix design study laboratory study and prepare an interpretive laboratory report for bench scale stabilisation trials. Stabilisation trials were conducted on specimens prepared from soil samples provided by Arcadis representing 6 No. discrete material types on site, including; granular MADE GROUND, cohesive MADE GROUND, organic rich soil, Limex waste, lagoon sediments and natural cohesive geology.

This report details the findings of a geochemical and geotechnical test work programme that has included;

- Source term characterisation
- Geotechnical classification testing for OMC-MDD, lime demand, particle size distribution, plasticity index, BRE-SD1 and MCV mellowing curves
- Geotechnical performance testing by UCS strength gain curves, quick undrained triaxial shear strength, CBR and CBR swell
- Geochemical performance was confirmed by semi-dynamic tank testing and leaching assessments in accordance with EA NEN 7375 / ASTM D308 Methodologies

This study has demonstrated that stabilisation techniques may be regarded as suitable for improving the geotechnical performance of materials. Lime based stabilisation provided geotechnical improvement for all trialled soils, whilst the application of cement based mass stabilisation was found to produced satisfactory strength gain for lagoon sediments.

The geochemical study has identified ammoniacal nitrogen as the key remedial driver. Detailed leaching assessments demonstrate mass flux for this compound is under depletion control leading to declining source term leaching behaviour. Where detailed design requires forward predictive modelling to estimate the leaching trajectories associated with stabilised soil masses on site, we recommend that diffusive flux simulation are completed to allow the impact on groundwater to be quantitatively assessed using the derived effective diffusion coefficients presented herein.

Gas evolution studies for ammonia were completed to provide an indication of the possible rate of ammonia gas release from heavily impacted materials subjected to lime addition. Mass transfer rates and % release are presented to allow suitable working methodologies to be developed.

Analytical results support source mass reduction in ammoniacal nitrogen concentrations for the organic rich sample. These results may be indicative of biologically mediated nitrification processes, operating under aerobic conditions. Further investigation is recommended as potential source term depletion remedial technique that may assist with lower ammonia mass flux rates from both gas liberation during ex situ mixing and leaching when placed as a hydraulically bound soil mass.

Verification strategies should be agreed with the regulatory authorities prior to the construction phase. In addition, field trials are strongly recommended to finalise detailed design and materials processing routes prior to full scale site works.

2 Introduction

2.1 Project Appreciation

2.1.1 Arcadis have commissioned CE Geochem to undertake bench-scale stabilisation trials to assess geotechnical and geochemical performance of stabilised materials as part of a mix soil stabilisation study.

2.1.2 This test work programme has been conducted 6 No. test work samples identified as;

- Granular MADE GROUND (composite 1)
- Cohesive MADE GROUND (composite 2)
- Organic rich soils (composite 3)
- Limex waste (composite 4)
- Lagoon sediments (composite 5)
- Natural cohesive site soils (composite 6)

2.1.3 The test work programme has included the following scope of works;

- Geochemical source term characterisation and BRE-SD 1 analysis
- Geotechnical assessment of unbound soils by UCS and CBR with classification testing inclusive of particle size distribution and plasticity index
- Lime demand and MCV mellow curves for lime stabilisation to assess the improvement in soil densification
- UCS strength gain curves for lime stabilisation trial mixes and cement based dry mix mass stabilisation systems
- Quick undrained triaxial shear strength assessments for lime and cement based systems
- CBR analysis for lime and cement based systems
- CBR swell testing to confirm mix designs were not subject to volumetric expansion and deterioration in the soaked state
- Ammonia gas diffusion cell testing to evaluate the rate of ammonia flux from lime stabilised materials
- Semi-dynamic tank testing to assess the rate of contaminant flux from hydraulically bound mix designs.
- Interpretation of mass flux profiles to determine leaching mechanisms by EA NEN 7375 and derivation of effective diffusion coefficients by ASTM C1308 methodologies

- Separate study on Magnesium Phosphate Cement (MPC) based stabilisation systems, including an assessment of the influence of zeolites for ammoniacal nitrogen retention. Geochemical assessments were undertaken by semi-dynamic tank testing and geotechnical performance by UCS strength gain analysis.

2.2 Mix Design Strategy

2.2.1 The mix design strategy was initially predicated on lime only based soil stabilisation technologies to improve the workability through moisture conditioning of materials, which are currently present on site significantly above optimum moisture content, and provide a mechanism for geochemical retention of contaminants. Lime based mix designs were originally proposed by Arcadis with subsequent refinements through discussions with CE Geochem.

2.2.2 During the execution of the test work programme, it became apparent that the high Natural Moisture Content (NMC) and fine grained nature of lagoon sediments would lead to poor compactability, geotechnically incompatible with lime based soil stabilisation techniques that relies on the application of an external compactive effort. To overcome these restrictions, a cement based mass stabilisation approach was trialled based on a dry mix (as opposed to grout mix) mass stabilisation approach that utilises self-weight compaction as opposed to external compactive effort.

2.2.3 Magnesium based low pH binder systems, employing MPC technologies were also trialled in a separate investigation to assess the potential incompatibility of lime and cement based mix designs for treating the high ammoniacal nitrogen concentrations within organic rich soils. The hyper-alkaline environment created by lime and cement (>pH 12) leads to deprotonation of ammonium (NH_4^+) forming ammonia (NH_3) within the hydraulically bound stabilised matrix. Ammonia shows very poor geochemical retention in such matrices, hence MPC trial mixes were investigated with a view to fixing ammoniacal nitrogen as ammonium. The pKa for ammonium-ammonia equilibrium is 9.25, which means that at pH 9.25, these species are in equi-molar equilibrium, and at pH's below 9.25 ammonium becomes the predominant specie.

2.2.4 MPC formulations were initialled trialled by varying the Mg : P ratio to assess the influence on equilibrium pH. The optimum Mg:P ratio was used to achieve a low pH binder system (pH <8) without excess phosphate. Boric acid was employed as a set retardant at a fixed addition rate of 3 wt.%.

2.2.5 MPC mix designs also investigated the influence of clinoptilolite, a naturally occurring zeolite, as a sorbent to retard ammoniacal nitrogen flux through its high ion exchange capacity of for ammonium.

2.2.6 All mix designs investigated in this study are presented in section 3.3 of this report.

2.3 Nominated Third-Party Analytical Laboratory Accreditation and Quality Assurance

2.3.1 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.

2.3.2 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.

2.3.3 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.

2.3.4 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.

2.3.5 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 6 No. test work samples were supplied by Arcadis for use in this study which include: Granular Made Ground (composite 1), Cohesive Made Ground (composite 2), Organic Rich Soil (composite 3), Limex Waste (composite 4), Lagoon Sediment (composite 5) and Natural Cohesive Geology (composite 6).

3.1.2 The preparation of homogeneous test work samples is critical for any test work programme that requires comparison between independent samples / specimens. All bulk sample were homogenised using a forced action horizontal pan mixer, following sieving to 100% passing 20mm.

3.1.3 Optimum Moisture Content Maximum Dry Density (OMC-MDD) relationships were determined by BS EN 13286-4. OMC-MDD relationships were determined for each of the 6 No. test work samples, apart from Composite 5, used for mass stabilisation trials.

3.1.4 Classification testing was conducted on homogenised test work soils for plasticity index and Particle Size Distribution (PSD), conducted in accordance with BS 1377-2.

3.1.5 Total Potential Sulphates (TPS) were determined for each test work sample 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)

3.1.6 Unconfined Compressive Strength (UCS) by BS EN 13286-41 and Californian Bearing Ratio (CBR) by BS EN 13285-47 determinations were also undertaken on all test work samples at Optimum Moisture Content (OMC) in their unvbound state (no hydraulic binder), with the exception of composite 5.

3.2 Source Term Characterisation

3.2.1 Source term determinations were undertaken in triplicate on composited test work samples produced from the homogenised test work matrix. Composite analytical splits were formed from 5 No. randomly selected 100g 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, Cd, Cr, Cu, Hg, Ni, Pb, At, Se, S, V, Zn
- Ammoniacal N
- Ca, Na, SO_4, Cl
- 8-band TPH
- USEPA 16 Priority PAHs

- Organic Matter in accordance with BS1377

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

3.3 Mix design formulations

3.3.1 22 No. mix designs were manufactured in total using the 6 No. homogenised test work samples. Information regarding mix design formulations are listed in Tables 3.1 and 3.2.

Mix Design	Test work sample	CaO addition (%)	CEM I addition (%)
1	Granular Made Ground (Comp 1)	1.5	
2	Granular Made Ground (Comp 1)	3	
3	Granular Made Ground (Comp 1)	6	
4	Cohesive Made Ground (Comp 2)	3	
5	Cohesive Made Ground (Comp 2)	6	
6	Cohesive Made Ground (Comp 2)	10	
7	Organic Rich Soil (Comp 3)	3	
8	Organic Rich Soil (Comp 3)	6	
9	Organic Rich Soil (Comp 3)	10	
10	Limex Waste (Comp 4)	1.5	
11	Limex Waste (Comp 4)	3	
12	Limex Waste (Comp 4)	6	
13	Lagoon Sediment (Comp 5)		3
14	Lagoon Sediment (Comp 5)		6
15	Lagoon Sediment (Comp 5)		10
16	Natural Ground Cohesive (Comp 6)	2.5	

Table 3.1 Mix design 1 – 16. Binder addition expressed as % dry wt.

Mix design	MgO addition (%)	MPC addition (%)	Zeolite addition (%)
17	10		
18		5	
19		10	
20		10	2.5
21		10	5
22		10	10

Table 3.2 Mix design 17-22. Binder and admixture addition expressed as % dry wt.

3.3.2 Mix designs 17 – 22 represent candidate low pH magnesium based binder systems, employing magnesium phosphate cements (MPC) as potential alternatives to conventional lime and Ordinary Portlandite Cement (OPC) systems. MPC mix designs were trialled exclusively on organic rich soils (composite 3), exhibiting very high ammoniacal nitrogen source term concentrations.

3.3.3 Magnesium phosphate cements are formed through an acid base reaction between magnesium oxide (MgO) and potassium phosphate monobasic (KH_2PO_4) with a simplified reaction sequence shown below:

$$KH_2PO_4 \rightarrow 2H^+ + KPO_4{}^{2-}$$

$$MgO \rightarrow Mg(aq)^{2+} + O^{2-}$$

$$Mg(aq)^{2+} + \; KPO_4{}^{2-} \rightarrow MgKPO_4$$

$$2H^+ + O^{2-} \rightarrow H_2O$$

3.3.4 The initial dissolution of KH_2PO_4 forms H^+ ions providing a lowering the mixture pH and encouraging dissociation of MgO. Mg^{2+} and KPO_4^{2-} react to form an insoluble $MgKPO_4$ polymeric structure.

3.3.5 MgO and KH_2PO_4 were mixed as dry powder with 1.5 wt. % of Boric acid (H_3BO_3). With addition of water MgO and KH_2PO_4 initially forms an orange paste that rapidly undergoes an exothermic cementation reaction. Boric acid is used as a set retardant to increase workability.

3.3.6 Previous published studies suggest an excess of phosphate is required where low pH cementation reactions are favoured, however noting the cost of phosphate reagents, this study has focussed on optimising M:P ratios for soil stabilisation systems.

3.3.7 Preliminary experiments were performed on MPCs with varying M:P ratios. The progress of the MPC cementation reaction was monitored through observing shifts in pH over time (up to 7 days).

3.3.8 Table 3.3 below lists the recorded MPC pH over 7 days. A lower M:P ratio results in a lower initial pH, M:P ratios 0.25, 0.33 and 0.5 retain the lower pH values over 7 days, indicating sufficient KH_2PO_4 to control pH for continual MgO dissociation.

M:P ratio	pH (initial)	pH (2 hours)	pH (24 hours)	pH (7 days)
1	7.31	8.308	12.013	N/A
0.5	7.09	7.307	7.445	7.57
0.33	6.92	6.853	6.846	6.85
0.25	6.70	6.654	6.639	6.66

Table 3.3 pH data for M:P ratios tested over 7 days.

3.3.9 Based on the results of these preliminary investigations, an optimum M:P ratio of 0.4 has been employed for the production of dry MPC powder mixtures, used exclusively for monolithic specimen manufacture, providing a compromise between cost and pH control.

3.4 Geochemical Specimen Manufacture

3.4.1 12 No. nominal 50 mm monolithic specimens were formed for semi-dynamic tank testing; corresponding to lime (soil stabilisation) and cement (mass stabilisation) based mix designs: MD 3, MD 6, MD 9, MD 10, MD 15, MD 16 and magnesium (soil stabilisation) based mix designs; MD 17, MD 18, MD 19, MD 20, MD 21, MD 22.

3.4.2 All soil stabilisation specimens for lime and magnesium based systems were formed by vibrating hammer compaction to refusal in 50 mm stainless steel moulds (BS EN 13286-53).

3.4.3 Mass stabilisation specimens representing MD 13, MD 14 and MD 15 were formed for composite 5 at NMC (approximately 4% above the samples liquid limit) using a CEM I dry mix. Specimens were produced with the aid of a vibrating table to induce self-weight compaction and expel entrained air.

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

3.5 Geotechnical Specimen Manufacture

3.5.1 Specimens were produced by vibrating hammer compaction at OMC for all mix designs with the exception of MD7, MD8 & MD9 that were manufactured above OMC[1] and MD13, MD 14 and MD15, which were formed at NMC by vibrating table compaction as discussed above.

3.5.2 Geotechnical test work specimens were produced as either 100mm (cement & lime) or 50mm (MPC) specimens for UCS testing at axial : diametric ratio of 1, whilst all CBR and CBR swell specimens were formed as 150mm specimens with axial : diametric ratio = 1. Triaxial specimens for undrained shear strength analysis were formed as 100mm diameter cylindrical specimens at axial : diametric ratios of 2.

3.5.3 All specimens were cured at 95%+ relative humidity at 20°C prior to extrusion and testing.

3.6 Geotechnical Characterisation

3.6.1 Strength gain curves were generated from UCS analysis (BS EN 13286-41) at curing times (t) = 1, 7, 14 and 28 days for MD 1 - 16 investigated in this study. MPC specimens, formed as 50mm monoliths were tested at 7, 14 and 28 days.

3.6.2 Moisture condition value (MCV) testing was performed at 2, 4, 24 and 48 hours (BS EN 13286-46) for all 13 No. lime based mix designs, MD 1 – 12 and MD 16.

3.6.3 Lime demand testing was initially performed (BS 1924-2 Clause 5.4 : 1990) for the 6 No. test work samples through addition of CaO at 0.5%, 1%, 2% additions followed by increments of 2 % dry wt. up to 10 %. Lime demand curves were generated to find the

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[1] Target moisture content for composite 3 was 45 %. Following soil moisture conditioning @ 30°C over 2-3 days, the moisture content of the test work matrix was determined by microwave drying to be 46.71%. Subsequent moisture determinations undertaken on test work specimens however, by oven methods at 105°C, produced consistently higher, but more variable moisture contents ranging from 51-63%. Following a thorough review of data, the reason for these discrepancies / variability remains unclear.

minimum CaO addition to achieve the equilibrium pH of 12.4- 12.6 representative of system saturation by portlandite.

3.6.4 Undrained shear strength was determined using a triaxial cell setup without measurement of pore pressure (BS-1377-7 clause 8), at an axial strain rate of 1 % per minute until failure or plateau beyond 10% axial strain. Triaxial tests were operated using a confining pressure of 60 kPa.

3.6.5 Californian Bearing Ratio (CBR) testing was determined using an automatic electromechanical compression tester with force and displacement transduction sensors. Testing was conducted in general accordance with BS EN 1377-4.

3.6.6 CBR analyses were conducted on specimens cured for 7 days and 28 days. All 16 No. lime and cement based stabilisation mix designs were subjected to CBR analysis. MPC mix designs were not analysed for CBR.

3.6.7 CBR swell monitoring was conducted on the 2 No. optimum mix designs, as directed by Arcadis. CBR Swell monitoring was undertaken in general accordance with BS 1377-4, over a 28 day immersion period following an initial 4 day cure. Terminal CBR values were determined for specimens in the soaked state.

3.7 Semi-dynamic Diffusion Based Tank Testing

3.7.1 3D semi-dynamic diffusion based tank testing was undertaken in general accordance with EA NEN 7375 using a 8 No. fraction sampling protocol based on the square of time over an initial total cumulative leaching period of 2.25 days.

3.7.2 2 No. optimum mix designs, were selected by Arcadis based on the observed leaching trajectories from F1-F4, for extension to 16 day leaching assessments in fulfilment of EA NEN 7375 protocols by inclusion of F5 – F8 sampling.

3.7.3 All 22 No. monolithic specimens used for semi-dynamic tank testing were allowed to cure for a minimum of 14 days prior to commencement of leaching trials.

3.7.4 Gas tight glass tanks were employed throughout to avoid gaseous exchange with the atmosphere. In particular, this approach is used to reduce the potential for carbonation reactions that are responsible for the onset of calcite precipitation and lowering of leachant pH, which may otherwise compromise the stability of test specimens.

3.7.5 All tank testing employed a leachant solution of 18.2 MΩ deionised water, which was exchanged at cumulative time points t= 0.083, 0.25, 1, 2.25, 4, 6.25, 9 and 16 days.

3.7.6 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.

3.7.7 Semi-dynamic tank testing analytical suites comprised; basis suite for assessing matrix stability (Ca, Na, SO_4, Cl, pH, Eh, EC), trace metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Sb, Se, V, Zn) and ammoniacal nitrogen only. No organic contaminants were included due to the low source term concentrations encountered.

3.8 Ammonia Gas Evolution Study

3.8.1 Evolution of ammonia (NH_3) gas was monitored from 6 No. 550 cm^3 gas diffusion cells. Table 3.4 below presents the experimental matrix for gas diffusion testing with estimated soil volumes based on a soil density of 1.6g/cm^3.

3.8.2 A Biogas 5000 portable gas monitor (QED Environmental Systems Ltd), with calibration span up to 1000 ppm vol/vol, was used to record NH_3 gas at time intervals (t) = 1.5, 6, 24, 60, 96, 150, 216, 384, 1536, 3072 and 4685 minutes. A square root of time ($t^{1/2}$) sampling protocol was observed to allow fitting of diffusive flux parameters.

Sample	Soil mass (g)	Binder addition (g)	Solid volume (cm3)
0% CaO	200	0	125
3% CaO	194	6	121.25
6% CaO	188	12	117.5
10% CaO	180	20	112.5
5% Mg3(PO4)2	190	10	118.75
10% Mg3(PO4)2	180	20	112.5

Table 3.4 Experimental samples with the corresponding soil and binder additions

3.8.3 Gas analysis was performed in hermetically sealed gas diffusion cells by fully evacuating the chamber with 2 No. volumes of air under negative pressure whilst completing analysis cycles.

3.8.4 NH_3 gas concentrations were recorded in ppm (v/v) where 1ppm is measured as 1 µl of NH_3 in a litre of gas (units of µl/l). Analysis is presented in units of flux as mg/m^3/min.

4 Source Term Characterisation

4.1.1 Statistical analyses of source characterisation datasets for the 6 No. test work samples (composite 1-6) are presented in Tables 4.1 and 4.2, 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 and 4.2. Note that CoV analysis will be influenced where determinations are near limits of analytical detection, and by the rounding of analytical results to 2 significant figures (format issued by the contract analytical laboratory). This specifically influences the reported CoV for TPH and PAH datasets.

4.1.3 The following analytes were determined at concentrations below the analytical limits of detection, therefore source term concentrations for these components are deemed negligible and are hence unlikely to demonstrate a leaching potential that would present a risk to controlled waters.

- Hg (test work samples 1, 4 – 6)
- CWG TPH (all bands for aro and ali for all test work samples)
- Sb (all test work samples)
- Se (test work samples 1, 4 – 6)
- PAHs (apart from Pyrene and Benzo[a]anthracene for test work samples 1, 2 and 6. Phenanthrene and Anthracene for test work sample 2.)

	Determinand	Units	Composite 1 Source term concentrations								Composite 2 Source term concentrations								Composite 3 Source term concentrations							
	Determinand	Units	N	N<LOD	Min	Max	Ave	σ	NUB95	CoV	N	N<LOD	Min	Max	Ave	σ	NUB95	CoV	N	N<LOD	Min	Max	Ave	σ	NUB95	CoV
INORGANICS	Arsenic	mg/kg	3	0	9.4	12	10	1.4	12	14.0%	3	0	12	12	12	0	0	0.0%	3	0	19	21	20	1.2	22	6.0%
	Cadmium	mg/kg	3	0	0.19	0.26	0.23	0.035	0.29	15.2%	3	0	0.34	0.35	0.34	0.0058	0.35	1.7%	3	0	0.84	0.89	0.87	0.026	0.91	3.0%
	Chromium	mg/kg	3	0	14	18	16	2.1	20	13.1%	3	0	16	18	17	1	19	5.9%	3	0	38	42	41	2.3	45	5.6%
	Copper	mg/kg	3	0	21	29	25	4	32	16.0%	3	0	54	61	57	3.6	63	6.3%	3	0	33	36	35	1.5	38	4.3%
	Mercury	mg/kg	3	0	0.1	0.1	0.1	1.7E-17	0.1	0.0%	3	0	0.1	0.13	0.12	0.017	0.15	14.2%	3	0	0.19	0.21	0.2	0.012	0.22	6.0%
	Nickel	mg/kg	3	0	13	16	14	1.5	17	10.7%	3	0	17	18	17	0.58	18	3.4%	3	0	29	32	31	1.7	34	5.5%
	Lead	mg/kg	3	0	28	32	30	2.1	34	7.0%	3	0	43	46	45	1.5	48	3.3%	3	0	69	75	73	3.2	78	4.4%
	Antimony	mg/kg	3	0	2	2	2	0	0	0	3	0	2	2	2	0	0	0.0%	3	0	2	2	2	0	0	0.0%
	Selenium	mg/kg	3	0	0.2	0.2	0.2	3.4E-17	0.2	0.0%	3	0	0.2	0.38	0.27	0.099	0.44	36.7%	3	0	0.42	0.56	0.51	0.076	0.64	14.9%
	Total Sulphur	%	3	0	0.045	0.075	0.06	0.015	0.085	25.0%	3	0	0.059	0.066	0.063	0.0038	0.069	6.0%	3	0	0.14	0.16	0.15	0.01	0.17	6.7%
	Vanadium	mg/kg	3	0	16	19	17	1.7	20	10.0%	3	0	18	19	19	0.58	20	3.1%	3	0	45	50	48	2.6	52	5.4%
	Zinc	mg/kg	3	0	61	68	65	3.6	71	5.5%	3	0	77	86	80	5.2	89	6.5%	3	0	130	140	130	5.8	140	4.5%
	Sulphate (2:1 Water Soluble) as SO4	g/l	3	0	0.27	0.41	0.34	0.07	0.46	20.6%	3	0	0.1	0.11	0.11	0.0058	0.12	5.3%	3	0	0.01	0.01	0.01	0	0	0.0%
	Chloride (Water Soluble)	g/l	3	0	0.014	0.019	0.017	0.0026	0.021	15.3%	3	0	0.019	0.19	0.11	0.086	0.25	78.2%	3	0	0.058	0.062	0.06	0.0021	0.064	3.5%
	Sodium	mg/l	3	0	60	85	72	13	94	18.1%	3	0	75	75	75	0	0	0.0%	3	0	240	350	300	55	390	18.3%
	Ammoniacal Nitrogen	mg/kg	3	0	2.9	4	3.3	0.59	4.3	17.9%	3	0	7.2	9.3	7.9	1.2	9.9	15.2%	3	0	610	780	720	98	890	13.6%
	Calcium (Total)	mg/kg	3	0	47000	51000	49000	2100	53000	4.3%	3	0	61000	63000	62000	1000	64000	1.6%	3	0	25000	29000	27000	2100	31000	7.8%
	Sulphate (Total)	%	3	0	0.16	0.18	0.17	0.01	0.19	5.9%	3	0	0.087	0.1	0.096	0.0075	0.11	7.8%	3	0	0.2	0.23	0.21	0.015	0.24	7.1%
	Sulphate (Acid Soluble)	%	3	0	0.17	0.21	0.19	0.02	0.22	10.5%	3	0	0.15	0.16	0.16	0.0058	0.17	3.6%	3	0	0.4	0.42	0.41	0.01	0.43	2.4%
TPH	Aliphatic TPH >C5-C6	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aliphatic TPH >C6-C8	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aliphatic TPH >C8-C10	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aliphatic TPH >C10-C12	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aliphatic TPH >C12-C16	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aliphatic TPH >C16-C21	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aliphatic TPH >C21-C35	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aliphatic TPH >C35-C44	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Total Aliphatic Hydrocarbons	mg/kg	3	0	5	5	5	0	0	0.0%	3	0	5	5	5	0	0	0.0%	3	0	5	5	5	0	0	0.0%
	Aromatic TPH >C5-C7	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aromatic TPH >C7-C8	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aromatic TPH >C8-C10	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aromatic TPH >C10-C12	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aromatic TPH >C12-C16	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aromatic TPH >C16-C21	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aromatic TPH >C21-C35	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aromatic TPH >C35-C44	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Total Aromatic Hydrocarbons	mg/kg	3	0	5	5	5	0	0	0.0%	3	0	5	5	5	0	0	0.0%	3	0	5	5	5	0	0	0.0%
	Total Petroleum Hydrocarbons	mg/kg	3	0	10	10	10	0	0	0.0%	3	0	10	10	10	0	0	0.0%	3	0	10	10	10	0	0	0.0%
PAH	Naphthalene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Acenaphthylene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Acenaphthene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Fluorene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Phenanthrene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	1.4	0.47	0.8	1.8	170.2%	3	0	0.01	0.01	0.01	0	0	0.0%
	Anthracene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.43	0.15	0.24	0.55	160.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Fluoranthene	mg/kg	3	0	0.01	0.28	0.18	0.15	0.43	83.3%	3	0	0.01	2.3	0.77	1.3	3	168.8%	3	0	0.01	0.01	0.01	0	0	0.0%
	Pyrene	mg/kg	3	0	0.01	0.28	0.17	0.14	0.41	82.4%	3	0	0.01	2.1	0.71	1.2	2.7	169.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Benzo[a]anthracene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Chrysene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Benzo[b]fluoranthene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Benzo[k]fluoranthene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Benzo[a]pyrene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Indeno(1,2,3-c,d)Pyrene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Dibenz(a,h)Anthracene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Benzo[g,h,i]perylene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Total Of 16 PAH's	mg/kg	3	0	0.2	0.56	0.42	0.19	0.74	45.2%	3	0	0.2	6.2	2.2	3.5	8.1	159.1%	3	0	0.2	0.2	0.2	3.4E-17	0.2	0.0%
ORGANIC	Organic Matter BS1377	%	3	0	0.4	1	0.73	0.31	1.3	42.5%	3	0	0.6	1.1	0.77	0.29	1.3	37.7%	3	0	7.7	8.2	7.9	0.26	8.3	3.3%

Table 4.1 Statistical summary for test work samples: composite 1, 2 and 3 source term characterisation datasets. All statistical analysis presented to 2 significant figures. CoV analysis is presented as a percentage (1dp).

			Composite 4 Source term concentrations								Composite 5 Source term concentrations								Composite 6 Source term concentrations							
	Determinand	Units	N	N<LOD	Min	Max	Ave	σ	NUB95	CoV	N	N<LOD	Min	Max	Ave	σ	NUB95	CoV	N	N<LOD	Min	Max	Ave	σ	NUB95	CoV
INORGANICS	Arsenic	mg/kg	3	0	21	26	23	2.5	27	10.9%	3	0	7.2	8.4	7.8	0.6	8.8	7.7%	3	0	8.1	9.1	8.4	0.58	9.4	6.9%
	Cadmium	mg/kg	3	0	0.7	0.93	0.79	0.13	1	16.5%	3	0	0.18	0.27	0.22	0.046	0.3	20.9%	3	0	0.21	0.22	0.22	0.0058	0.23	2.6%
	Chromium	mg/kg	3	0	3.4	4.2	3.8	0.4	4.5	10.5%	3	0	13	21	17	4	24	23.5%	3	0	13	18	16	2.5	20	15.6%
	Copper	mg/kg	3	0	2.6	3.2	2.9	0.31	3.4	10.7%	3	0	10	11	10	0.58	11	5.8%	3	0	20	22	21	1	23	4.8%
	Mercury	mg/kg	3	0	0.1	0.1	0.1	1.7E-17	0.1	0.0%	3	0	0.1	0.1	0.1	1.7E-17	0.1	0.0%	3	0	0.1	0.1	0.1	1.7E-17	0.1	0.0%
	Nickel	mg/kg	3	0	2.9	3.4	3.2	0.25	3.6	7.8%	3	0	8.8	14	11	2.8	16	25.5%	3	0	12	16	14	2.1	18	15.0%
	Lead	mg/kg	3	0	25	34	29	4.6	37	15.9%	3	0	18	22	20	2.1	24	10.5%	3	0	26	30	28	2	31	7.1%
	Antimony	mg/kg	3	0	2	2	2	0	0	0.0%	3	0	2	2	2	0	0	0.0%	3	0	2	2	2	0	0	0.0%
	Selenium	mg/kg	3	0	0.2	0.2	0.2	3.4E-17	0.2	0.0%	3	0	0.2	0.2	0.2	3.4E-17	0.2	0.0%	3	0	0.2	0.2	0.2	0	0.2	0.0%
	Total Sulphur	%	3	0	0.023	0.027	0.025	0.002	0.028	8.0%	3	0	0.06	0.072	0.065	0.0062	0.075	9.5%	3	0	0.062	0.077	0.068	0.0079	0.081	11.6%
	Vanadium	mg/kg	3	0	5	5	5	0	0	0.0%	3	0	13	13	13	0	0	0.0%	3	0	14	20	17	3.1	22	18.2%
	Zinc	mg/kg	3	0	63	69	67	3.2	72	4.8%	3	0	34	39	36	2.5	40	6.9%	3	0	56	64	61	4.6	69	7.5%
	Sulphate (2:1 Water Soluble) as SO4	g/l	3	0	0.034	0.04	0.037	0.0031	0.042	8.4%	3	0	0.096	0.16	0.13	0.033	0.19	25.4%	3	0	0.3	0.35	0.33	0.029	0.38	8.8%
	Chloride (Water Soluble)	g/l	3	0	0.012	0.11	0.047	0.054	0.14	114.9%	3	0	0.014	0.14	0.059	0.07	0.18	118.6%	3	0	0.025	0.027	0.026	0.001	0.028	3.8%
	Sodium	mg/l	3	0	29	40	35	5.7	45	16.3%	3	0	50	55	53	2.9	58	5.5%	3	0	75	80	78	2.9	83	3.7%
	Ammoniacal Nitrogen	mg/kg	3	0	1.5	6.7	3.3	2.9	8.2	87.9%	3	0	21	32	27	5.6	36	20.7%	3	0	3.6	10	7	3.2	12	45.7%
	Calcium (Total)	mg/kg	3	0	70000	75000	72000	2500	76000	3.5%	3	0	41000	42000	41000	580	42000	1.4%	3	0	39000	40000	39000	580	40000	1.5%
	Sulphate (Total)	%	3	0	0.041	0.057	0.048	0.0081	0.062	16.9%	3	0	0.05	0.078	0.063	0.014	0.087	22.2%	3	0	0.13	0.14	0.13	0.0058	0.14	4.5%
	Sulphate (Acid Soluble)	%	3	0	0.06	0.065	0.062	0.0026	0.066	4.2%	3	0	0.15	0.17	0.16	0.012	0.18	7.5%	3	0	0.16	0.18	0.17	0.01	0.19	5.9%
TPH	Aliphatic TPH >C5-C6	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aliphatic TPH >C6-C8	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aliphatic TPH >C8-C10	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aliphatic TPH >C10-C12	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aliphatic TPH >C12-C16	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aliphatic TPH >C16-C21	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aliphatic TPH >C21-C35	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aliphatic TPH >C35-C44	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Total Aliphatic Hydrocarbons	mg/kg	3	0	5	5	5	0	0	0.0%	3	0	5	5	5	0	0	0.0%	3	0	5	5	5	0	0	0.0%
	Aromatic TPH >C5-C7	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aromatic TPH >C7-C8	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aromatic TPH >C8-C10	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aromatic TPH >C10-C12	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aromatic TPH >C12-C16	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aromatic TPH >C16-C21	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aromatic TPH >C21-C35	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Aromatic TPH >C35-C44	mg/kg	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%	3	0	1	1	1	0	0	0.0%
	Total Aromatic Hydrocarbons	mg/kg	3	0	5	5	5	0	0	0.0%	3	0	5	5	5	0	0	0.0%	3	0	5	5	5	0	0	0.0%
	Total Petroleum Hydrocarbons	mg/kg	3	0	10	10	10	0	0	0.0%	3	0	10	10	10	0	0	0.0%	3	0	10	10	10	0	0	0.0%
PAH	Naphthalene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Acenaphthylene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Acenaphthene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Fluorene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Phenanthrene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Anthracene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Fluoranthene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	3	1	1.7	3.9	170.0%
	Pyrene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	2.9	0.97	1.7	3.8	175.3%
	Benzo[a]anthracene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Chrysene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Benzo[b]fluoranthene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Benzo[k]fluoranthene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Benzo[a]pyrene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Indeno(1,2,3-c,d)Pyrene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Dibenz(a,h)Anthracene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Benzo[g,h,i]perylene	mg/kg	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%	3	0	0.01	0.01	0.01	0	0	0.0%
	Total Of 16 PAH's	mg/kg	3	0	0.2	0.2	0.2	3.4E-17	0.2	0.0%	3	0	0.2	0.2	0.2	0	0	0.0%	3	0	0.2	5.9	2.1	3.3	7.7	157.1%
ORGANIC	Organic Matter BS1377	%	3	0	0.1	0.1	0.1	1.7E-17	0.1	0.0%	3	0	1.6	2	1.8	0.21	2.2	11.7%	3	0	0.9	1	0.97	0.058	1.1	6.0%

Table 4.2 Statistical summary for test work samples: composite 4, 5 and 6 source term characterisation datasets. All statistical analysis presented to 2 significant figures. CoV analysis is presented as a percentage (1dp).

4.1.4 Readily measurable inorganic determinands; zinc, copper and lead all demonstrate low CoV values consistent with a well homogenised test work matrix for all test work composites. 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.

4.1.5 All test work samples contain > 10 mg/kg arsenic, with Composite 4 the highest concentration at 23 mg/kg average. Cadmium, mercury and selenium concentrations for all test work samples have been reported at < 1 mg/kg. Most inorganic contaminants do not exceed 100 mg/kg for any test work samples with the exception of zinc, and ammoniacal nitrogen for composite 3.

4.1.6 Composite 3 contains the highest average concentrations for chromium (41 mg/kg), lead (71 mg/kg), vanadium (48 mg/kg), zinc (130 mg/kg) and ammoniacal nitrogen (720 mg/kg).

4.1.7 Based on the source characterisation datasets presented above, ammoniacal nitrogen, especially for composite 3 (average = 720 mg/kg, n=3), is identified as the main remedial driver, recognised as potentially producing problematic mass flux rates in hyper-alkaline stabilised matrices such as those considered in this study.

4.1.8 CWG TPH compounds were not detected above analytical detection limits (1 mg/kg) for any of the individual components analysed.

4.1.9 In addition, PAH compounds were generally low, with Pyrene and Benzo[a]anthracene detected marginally above analytical reporting limits in test work samples 1, 2 and 6. Phenanthrene and Anthracene concentrations were also found to be present at low concentrations for test work sample 2. All other compounds were not detected above LOD. Elevated CoV statistics originate from the influence of LOD on the variability of reported analytical results.

5 Geotechnical Performance

5.1 Unbound Soils

Test work sample	UCS (MPa)	CBR (%)
Composite 1	0.34	24.15
Composite 2	0.38	11.74
Composite 3	0.21	5.53
Composite 4	0.31	35.27
Composite 5	U/S	U/S
Composite 6	0.18	12.25

Table 5.1 UCS and CBR data for unbound material, U/S is unsuitable for testing as the specimen stiffness of bearing capacity was below the seating force required to initiate testing.

5.1.1 In the absence of geotechnical compliance criteria, comparison of strength for unamended unbound soils against stabilised materials provides a metric for assessing geotechnical performance. Geotechnical bench-marking for unbound soils is presented in Table 5.1.

5.1.2 As can be seen from inspection of Table 5.2, the moisture content of materials recovered from site in their natural state (NMC), is significantly higher than optimum (OMC) with the exception of samples identified as Limex waste (composite 4). Note that OMC data is not available for composite 5 as these materials were used exclusively for mass stabilisation mix designs.

Sample	OMC (%)	NMC (%)	MDD (Mg/m^3)	Moisture range (%)
Composite 1	13.29	18.58	1.870	4-16
Composite 2	12.36	22.92	1.856	2-18
Composite 3	31.59	79.93	1.308	22-39
Composite 4	14.34	13.74	2.008	2-14
Composite 5		33.90		
Composite 6	11.87	15.74	1.886	4-16

Table 5.2 Summary for OMC-MDD determinations.

5.1.3 All OMC-MDD results relate to test work soils only in the absence of any binder addition.

5.1.4 Particle Size Distribution (PSD) and Plasticity Index (PI) analyses for all test work samples are presented in Appendix A.

5.2 MCV Mellowing Curves

5.2.1 MCV mellowing curves were constructed for MD1 – MD12 and MD16 to investigate the influence of lime on moisture condition values over 48 hour mellowing period with testing at time intervals (t) = 2, 4, 24 and 48 hours. Test certificates are presented in Appendix A.

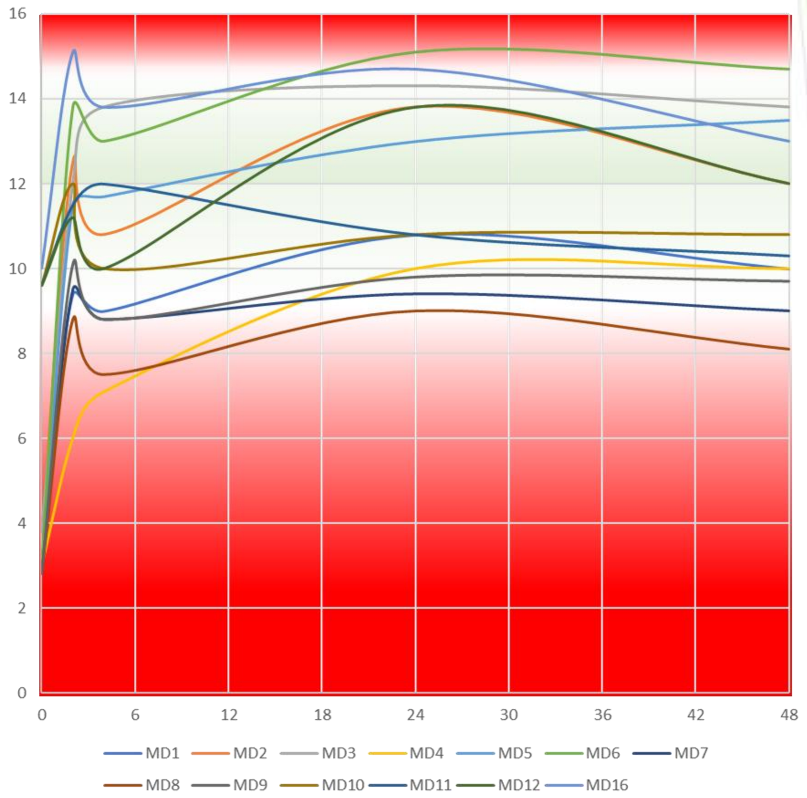

Table 5.1 MCV mellowing curves showing optimum compaction range in green, acceptable ranges for compaction in white and unacceptable ranges in red.

	MCV Values				
	0	**2**	**4**	**24**	**48**
MD1	3.8	9.4	9	10.8	10
MD2	3.8	12.5	10.8	13.8	12
MD3	3.8	12	13.8	14.3	13.8
MD4	3	6	7.1	10	10
MD5	3	11.5	11.7	13	13.5
MD6	3	13.8	13	15.1	14.7
MD7	2.8	9.5	8.8	9.4	9
MD8	2.8	8.8	7.5	9	8.1
MD9	2.8	10.1	8.8	9.8	9.7
MD10	9.6	12	10	10.8	10.8
MD11	9.6	11.5	12	10.8	10.3
MD12	9.6	11.2	10	13.8	12
MD16	10	15.1	13.8	14.7	13

Table 5.3. MCV data for mellowing curves.

5.2.2 As can be seen in Table 5.3 and Figure 5.1, all samples with the exception of Limex waste (MD7-9) have a natural MCV between 2.8 and 3.8, considerably below the minimum acceptable MCV of 8 for compaction. The influence of lime is observed to improve the densification of all samples leading to an almost immediate improvement in MCV performance. All mix designs achieve satisfactory MCV vales at 48 hours (between 10-15, with optimum generally regarded to be 12-13). A slight improvement is seen with increasing lime addition rates.

5.2.3 Limex waste shows no significant improvement in compatibility with respect to lime addition rate or mellowing times and hence the use of lime conditioning to improve the compactability of these materials is not necessarily required.

5.1 Lime Demand Curves

5.1.1 Lime demand was determined for all test work samples in accordance with BS 1924-2 Clause 5.4 : 1990, with results listed below in Table 5.4. Lime demand relates to the minimum addition rate of lime required to maintain equilibrium with portlandite ($Ca(OH)_2$ at circa. pH 12.6. All test work matrices investigated required between 1.5-2.2% lime addition with the exception of Limex waste, which only required 1.0% due to native high pH of this matrix.

5.1.2 Lime demand datasets may be used to establish the minimum lime addition rate required for stabilisation, below which Calcium Alumino-Silicate Hydrates (CASH) gels are unlikely to form through the alkaline dissolution-reprecipitation of phyllosilicate clay minerals, and hence pozzolanic strength gain reactions are unlikely to occur to any significant extent. Soil conditioning however, at lower lime addition rates, may still be possible whereby the improved friability of soils may be attributed to the flocculation of clay particles rather than CASH gel formation.

Test work sample	Equilibrium pH	Lime Demand (%)
Composite 1	12.689	1.5
Composite 2	12.694	1.8
Composite 3	12.645	2.2
Composite 4	12.680	1.0
Composite 5	12.677	2.0
Composite 6	12.660	1.6

5.1.3 **Table 5.4** Equilibrium pH and lime demand data for each test work sample

5.2 Quick Undrained Triaxial Shear Strength

5.2.1 Quick Undrained Triaxial (QUT) shear strength determinations were performed in accordance with BS1377 for MD 1 – 16 at a confining pressure of 60 kPa.

Mix Design	Undrained Shear Strength (kPa) 7 day	28 day
MD1	210	312
MD2	489	676
MD3	462	734
MD4	306	263
MD5	426	574
MD6	677	402
MD7	39	36
MD8	42	37
MD9	76	77
MD10	1134	522
MD11	1220	571
MD12	416	369
MD13	U/S	88
MD14	136	144
MD15	398	533
MD16	419	472

Table 5.5 Undrained shear strength values for MD 1 – 16 at 7 day and 28 day curing times. MD 13 (7 days) has been classed as unsuitable for testing (U/S) due to a specimen manufacturing fault (void) within the monolithic specimen.

5.2.2 It is immediately apparent from inspection of Table 5.5 that lime based stabilisation mix designs for organic rich soil (composite 3) provided poor strength development with QUT shear strengths (Cu) between 36-77 kPa and no notable strength gain over the 28 day curing period. These mix designs also showed no significant improvement in Cu with respect to binder addition rates. We tentatively ascribe the poor performance of these mix designs to the high water content (circa. 65%) present within the matrix and the potential for adverse binder phase reactions with the high organic load.

5.2.3 It should be also noted that CE Geochem have experienced delayed strength gain in a number of high ammonium containing stabilised soil matrices in the past, which may have also contributed to the poor performance observed for the organic rich test work soils in this study.

5.2.4 Both granular and cohesive MADE GROUND test work samples show a general improvement in shear strength within increasing binder content and curing time. By comparison with UCS datasets produced on unbound soils, both MADE GROUND matrices show notable improvements in shear strength, for example 1.5% lime in MD1 provides a 184% improvement in Cu whereas 3% and 6% lime addition produce improvements of 398% and 432% respectively based on the relationship UCS = 2Cu. Similar improvements are note for the cohesive made ground matrix, with the exception of MD6 (10% lime) which may be due to the increased friability of this mix design at high lime addition rates.

5.2.5 Limex mix design specimens show a reduction in Cu over time and at the highest binder ratio (6% CaO) compared with lower lime addition rates. Loss of strength over time and at higher binder ratios may both be related to loss of inter-particulate cohesion within this matrix whereby the low Al-Si content does not promote pozzolan development, whilst increased lime content leads to higher friability.

5.2.6 Cement based dry-mix mass stabilisation systems show a generally positive correlation in Cu with binder ratio and time. When compared to UCS data for unbound soils, there is a significant improvement in shear strength, as was also reported for composite 6, identified as cohesive natural ground.

5.2.7 QUT shear strength determinations are broadly consistent with UCS datasets presented in section 5.3 below.

5.3 Strength Gain Curves by UCS

5.3.1 Unconfined Compressive Strength testing was undertaken in general accordance with BS EN 13286-41.

5.3.2 The rate of strength gain for each of the 22 No. mix designs investigated in this study has been assessed by unconfined compressive strength. UCS determinations were undertaken on specimens manufactured at axial : diametric ratio of either = 1, cured at 95%+ RH for curing times (t) = 1, 7, 14 and 28 for MD 1 - 16, (t) = 7, 14 and 28 days for MD 17 - 22.

5.3.3 Strength gain curves are presented in Figures 5.2 – 5.6 for lime and cement based stabilisation systems identified as MD1 - MD16, whilst Figure 5.7 displays the UCS strength gain curves for Magnesium Phosphate Cements (MPC) identified as MD 17 – 22.

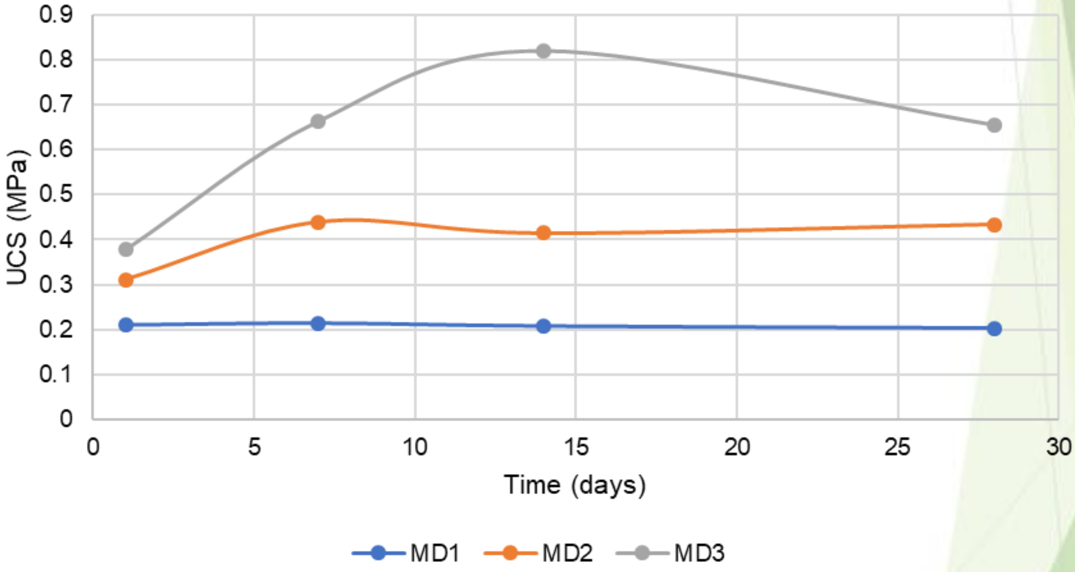

Figure 5.2. UCS strength gain curves for MD1-3, Granular MADE GROUND (Composite 1).

5.3.4 Candidate mix designs manufactured using Composite 1 show a terminal strength dependency on lime addition rates. MD1 shows no appreciable strength gain beyond 1 day curing time. MD2 and MD3 show initial strength development up to 7 and 14 days respectively followed by a slight plateauing up to 28 days, usually more common in cement based systems.

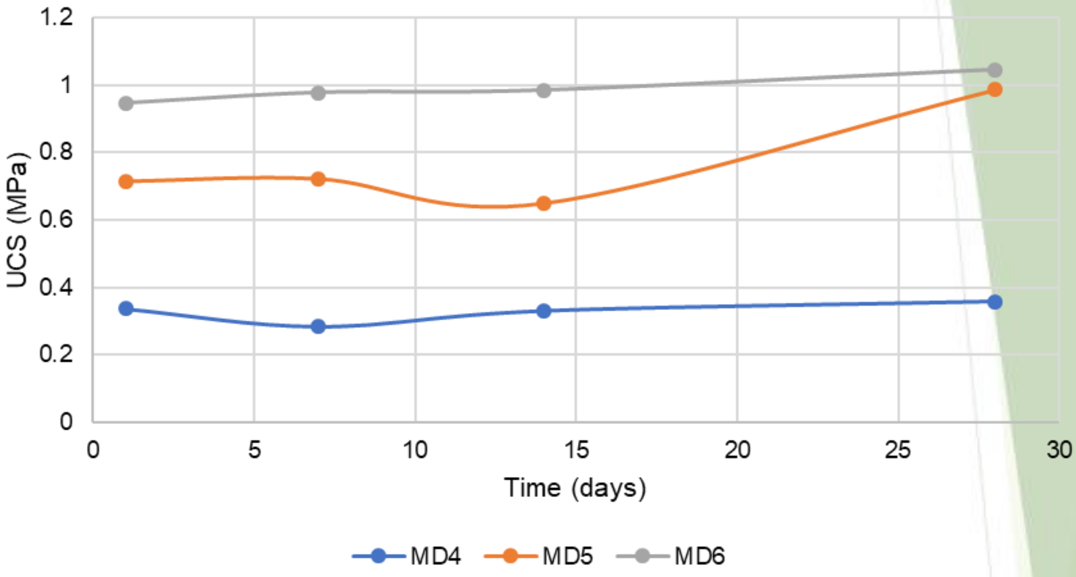

Figure 5.3. UCS strength gain curves for MD4-6, cohesive MADE GROUND (Composite 2).

5.3.5 Candidate mix designs manufactured using cohesive MADE GROUND (Composite 2) show initial strength increase with increasing binder addition, although the application rate of 3% dry wt. of CaO in MD4 appears to have very little or no effect on UCS compared to the unbound material, possibly due to incomplete activation for pozzolan components. Higher application rates of CaO correlate to higher UCS. Strength gain curves appear more typical of lime based systems, showing relatively consistent strength development over time.

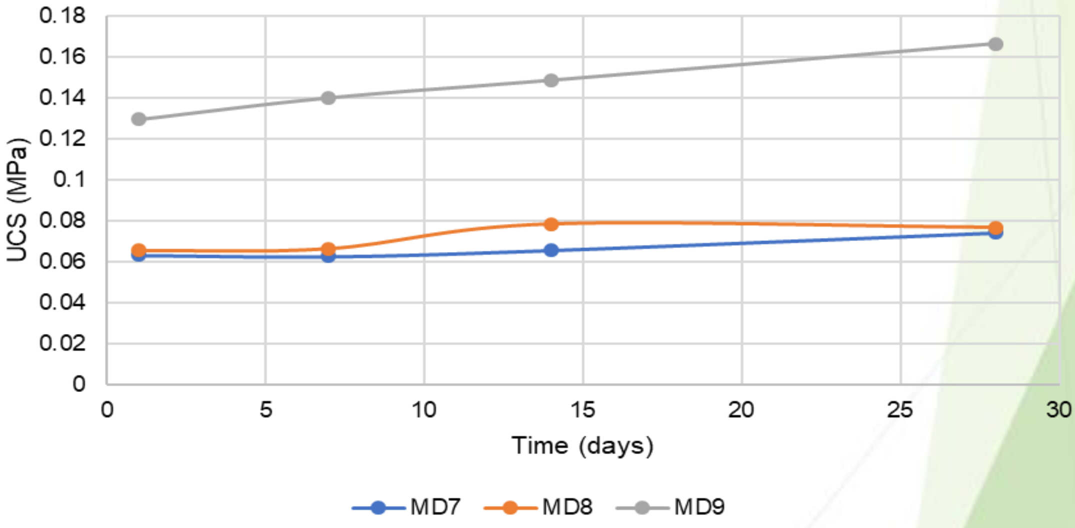

Figure 5.4. UCS strength gain curves for MD7-9, organic rich soil (Composite 3).

5.3.6 Strength gain within the organic rich soil system shows possible evidence of pozzolan development, particularly at the highest binder addition rate, however as discussed above for shear strength determinations, strength development in this system is typically low due to the high water content of this soil matrix.

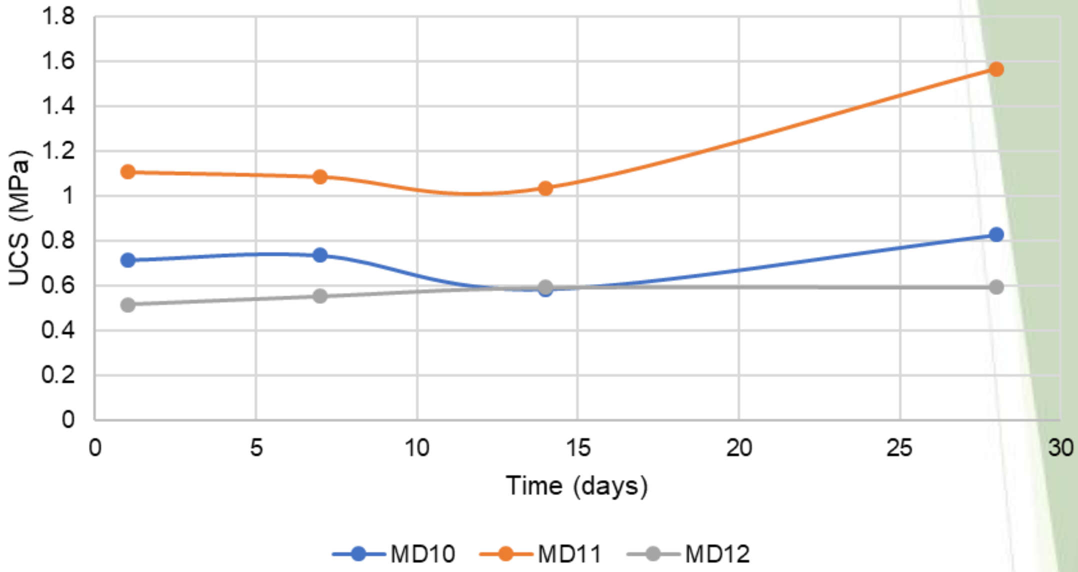

Figure 5.5. UCS strength gain curves for MD10-12, limex waste (Composite 4).

5.3.7 Poor strength development for MD12 at 6% lime addition likely relates to the chemically induced drying of this sample below OMC caused by high lime addition rates. Results from MD11 suggest 3% lime may be optimal for this matrix, achieving good strength development over time, producing terminal UCS values which are generally consistent with 28 days Cu values.

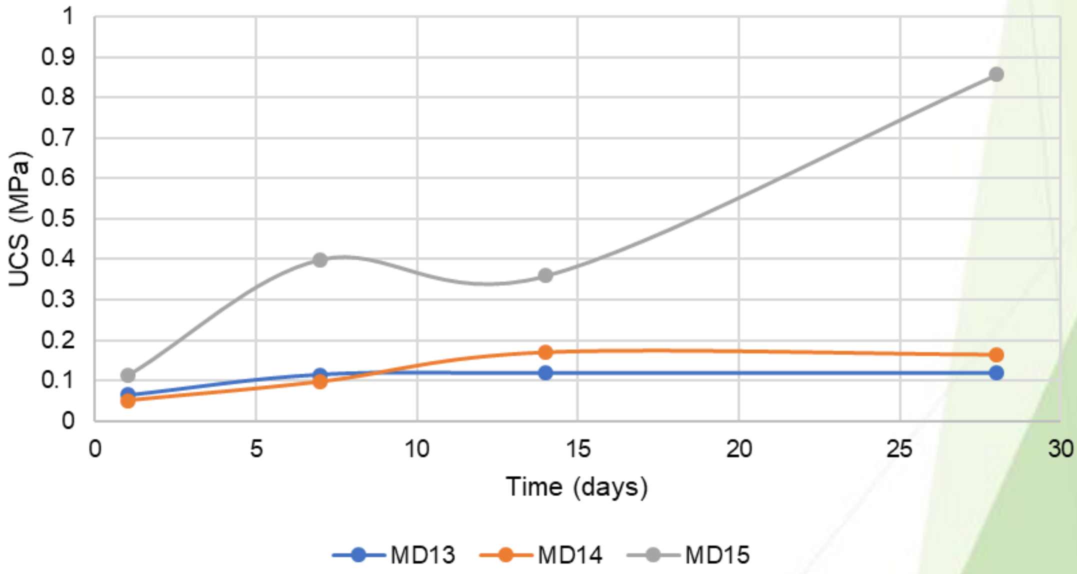

Figure 5.6 UCS strength gain curves for MD13-15, organic rich soil (Composite 5).

5.3.8 Candidate mass stabilisation mix designs manufactured by dry-mix incorporation of CEMI 52.5N into lagoon sediments (Composite 5) display minimal strength gain at binder application rates below 6%, however these mix designs still provide significant improvement over unbound soils. 10% application rates produce good strength development. Results are in good agreement with shear strength datasets presented in the previous section.

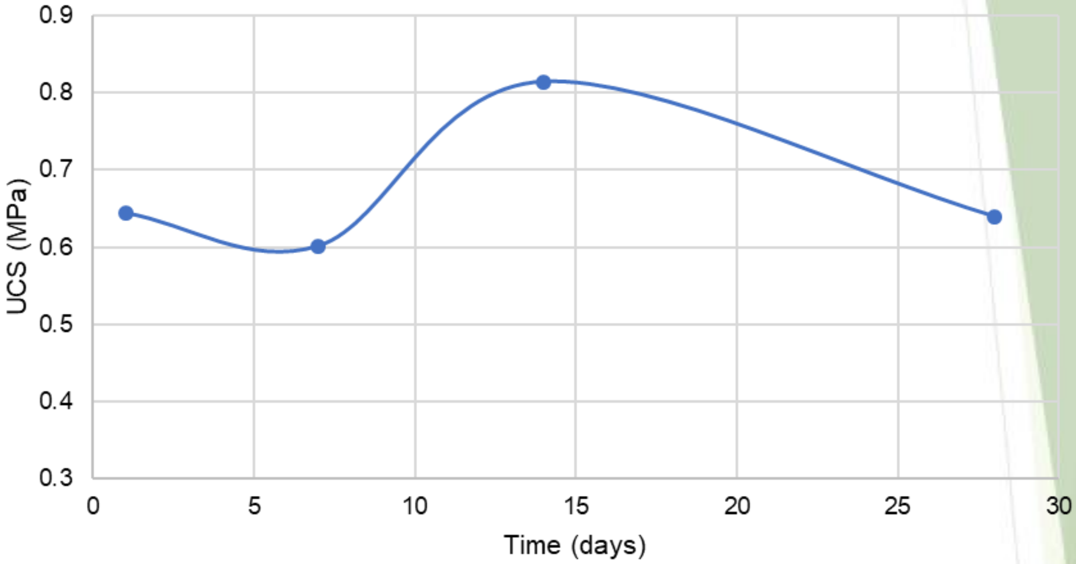

Figure 5.6. UCS strength gain curve for MD16, natural ground (Composite 6).

5.3.9 The addition of 2.5 % CaO produces significant strength gain improvement for natural ground relative to unbound specimens. There is however, no evidence of strength development beyond 1 day, with subsequent data points oscillating around circa. 700 kPa. This is again broadly consistent with shear strength determinations from QUT testing.

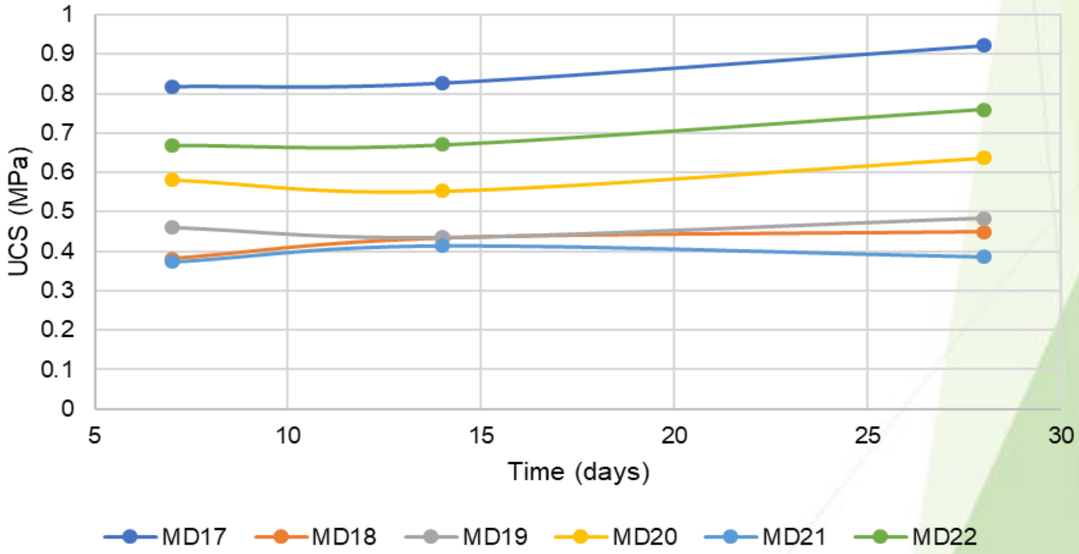

Figure 5.7. UCS strength gain curves for alternative binders using Composite 3.

5.3.10 The series of MPC mix designs manufactured using Composite 3 all show relatively low rates of strength development following an initial rapid stiffening over the first 24 hours curing. MgO provides the highest terminal strength development in comparison to magnesian phosphate cements, however all achieve good strength improvement over the unbound soil comparator. The addition of clinoptilolite (a naturally occurring zeolite with high ion exchange capacity for ammonium) appears to provide some additional strength improvement.

5.3.11 The geotechnical improvements seen for MPC mix designs are of a similar magnitude to those reported for the CEMI mass stabilisation mix design MD10.

5.1 BRE-SD1 Assessment.

5.1.1 BRE-SD1 analysis was conducted in triplicate on the 6 No. test work samples in order to assess aggressive chemical environments that may influence the behaviour of cementitious binders, and more specifically identify the potential risk of sulphate attack as detailed in Table 5.6 – 5.11.

5.1.2 With the exception of Composite 3, all test work samples contain < 0.24 % Total Potential Sulphate (TPS), categorising these materials as Design Class DS-1. Excluding organic rich soils, materials at the subject sites are classified as containing a low potential for producing aggressive ground conditions, and are henceforth not expected to adversely effect soil stabilisation using cementitious binders.

5.1.3 Composite 3 returned an average TPS of 0.45%, classified as Design Class DS-2, which may produce mildly aggressive ground conditions, that could affect soil stabilisation using cementitious binders, such as those investigated in this mix design study.

BRE-SD1 Assessment - Composite 1			
	ST1	ST2	ST3
TPS (%)	0.183	0.135	0.225
WSS (mg/l)	270	330	410
ASS (%)	0.17	0.19	0.21
OS (%)	0.013	-0.055	0.015

Table 5.6 BRE-SD1 for composite 1. TPS = Total Potential Sulphate; WSS = Water Soluble Sulphate (2:1 as SO_4); ASS = Acid Soluble Sulphate; OS = Oxidisable Sulphates.

BRE-SD1 Assessment - Composite 2			
	ST1	ST2	ST3
TPS (%)	0.177	0.198	0.195
WSS (mg/l)	110	110	100
ASS (%)	0.16	0.16	0.15
OS (%)	0.017	0.038	0.045

Table 5.7 BRE-SD1 assessment for composite 2. TPS = Total Potential Sulphate; WSS = Water Soluble Sulphate (2:1 as SO_4); ASS = Acid Soluble Sulphate; OS = Oxidisable Sulphates.

BRE-SD1 Assessment - Composite 3			
	ST1	ST2	ST3
TPS (%)	0.42	0.48	0.45
WSS (mg/l)	10	10	10
ASS (%)	0.42	0.4	0.41
OS (%)	0	0.08	0.04

Table 5.9 BRE-SD1 assessment for composite 3. TPS = Total Potential Sulphate; WSS = Water Soluble Sulphate (2:1 as SO_4); ASS = Acid Soluble Sulphate; OS = Oxidisable Sulphates.

BRE-SD1 Assessment - Composite 4			
	ST1	ST2	ST3
TPS (%)	0.069	0.075	0.081
WSS (mg/l)	40	36	34
ASS (%)	0.06	0.061	0.065
OS (%)	0.009	0.014	0.016

Table 5.10 BRE-SD1 assessment for composite 4. TPS = Total Potential Sulphate; WSS = Water Soluble Sulphate (2:1 as SO_4); ASS = Acid Soluble Sulphate; OS = Oxidisable Sulphates.

BRE-SD1 Assessment - Composite 5			
	ST1	ST2	ST3
TPS (%)	0.216	0.189	0.18
WSS (mg/l)	96	160	140
ASS (%)	0.17	0.17	0.15
OS (%)	0.046	0.019	0.03

Table 5.11 BRE-SD1 assessment for composite 5. TPS = Total Potential Sulphate; WSS = Water Soluble Sulphate (2:1 as SO_4); ASS = Acid Soluble Sulphate; OS = Oxidisable Sulphates.

BRE-SD1 Assessment - Composite 6			
	ST1	ST2	ST3
TPS (%)	0.186	0.195	0.231
WSS (mg/l)	300	350	350
ASS (%)	0.18	0.17	0.16
OS (%)	0.006	0.025	0.071

Table 5.12 BRE-SD1 assessment for composite 6. TPS = Total Potential Sulphate; WSS = Water Soluble Sulphate (2:1 as SO_4); ASS = Acid Soluble Sulphate; OS = Oxidisable Sulphates.

5.1.4 These classifications are based on the average of triplicate sub-samples from homogenised test work samples, considered to be representative of general site conditions. As well as varying TPS loads across the site, analysis suggests the presence of oxidizable sulphur loadings are generally low. Notwithstanding this, areas may exist with a higher risk of sulphate attack or variable sulphur speciation at the subject site. We 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 validation CBR specimens, produced for CBR swell monitoring at a frequency not less than 1 No. specimen per 500 m^3.

5.1.5 Certificates of analyses are included in Appendix B.

5.2 Californian Bearing Ratio (CBR)

5.2.1 CBR testing was conducted on 150mm diameter monoliths, as described in section 3.6. Specimens were cured at 95%+ RH prior to CBR analysis following curing for 7 days and 28 days, in order to assess the rate of strength development and terminal bearing capacity, as an indicator of long-term performance. CBR analyses are presented in Table 5.12 for each of the 16 No. mix designs investigated.

5.2.2 Test certificates for CBR determinations are available in Appendix A.

Specimen ID	CaO addition (%)	CEM I addition (%)	CBR Value (%)	
			7 Day	28 Day
MD1	1.5		6.26	6.36
MD2	3		27.11	34.83
MD3	6		121.17	120.4
MD4	3		9.03	12.12
MD5	6		45.48	49.95
MD6	10		115.92	83.84
MD7	3		U/S	U/S
MD8	6		U/S	U/S
MD9	10		2.61	2.97
MD10	1.5		54.08	35.98
MD11	3		134.68	163.73
MD12	6		206.8	164.31
MD13		3	5.45	7.09
MD14		6	6.56	10.83
MD15	0	10	28.75	79.88
MD16	2.5		63.08	73.01

Table 5.12 CBR indices for 16 No. test specimens for 7 and 28 day tests. U/S is unsuitable for testing as the bearing capacity of the specimen was below the seating force required to initiate the test.

5.3 CBR Swell Testing

5.3.1 CBR Swell testing was undertaken specifically to monitor the potential for sulphate heave and binder deterioration under soaked conditions.

5.3.2 No significant heave following 21 days immersion was observed for the specimen analysed. CBR swell monitoring was undertaken on mix designs selected by Arcadis; MD 3, 6, 9,10, 14 and 16.

5.3.3 Table 5.13 shows interim 21 day datasets for CBR.

Specimen ID	Volumetric Swell (%)	Vertical Swell (mm)
MD3 - Composite 1	0.086	0.13
MD6 - Composite 2	0.105	0.16
MD9 - Composite 3	0.039	0.06
MD10 - Composite 4	0.026	0.04
MD14 - Composite 5	0.013	0.02
MD16 - Composite 6	0.039	0.06

Table 5.13 CBR Swell Analysis Summary Table.

5.3.4 Terminal CBR in their final soaked state at 28 days immersion will be reported under separate cover.

6 Geochemical Performance

6.1.1 Prepared monolithic specimens for 12 No. mix designs were subjected to semi-dynamic leaching trials. All leaching trials were conducted on monolithic specimens in 3D unconfined configuration. Lime and cement based mix designs; MD3, MD6, MD9, MD10, MD14 and MD16 were observed to retain complete structural integrity throughout the entire immersion period of the test, up to 16 days for optimum mix designs MD9 & MD14, however MPC based stabilisation systems showed evidence of volumetric expansion and surface cracking, with a complete loss of structural integrity observed for MD21.

6.1.2 Leaching assessments are presented below, including determination of leaching mechanisms, partition coefficients, Upper Leaching Limits (ULL) and the experimentally derived effective diffusion coefficients (De).

6.1.3 All 12 No. mix designs were initially assessed using a 4 fraction, 2.25 day semi-dynamic tank testing protocol with analysis for inorganic determinands: As, Cd, Cr, Cu, Hg, Ni, Pb, Sb, Se, V, Zn, Cl, Ammoniacal N, SO4, Ca, Na. These interim leaching datasets were used to select 2 No. optimum mix designs for continuation to 16 days cumulative leaching time by inclusion of Fractions (F) 5 - 8.

6.1.4 Due to high As, Pb, Zn and PO_4 leaching in the initial 4 No. fractions, MD18 – 22 tank testing was discontinued at fraction 4 (fraction 3 for MD 21 due to loss of structural integrity). A summary of cumulative contaminant leaching for MD 18 – 22 is shown below in Table 6.1.

	Units	MD 18	MD 19	MD 20	MD 21	MD 22
As	ug/l	243	588	593	350	491
Pb	ug/l	3490	3910	4250	2570	3710
Zn	ug/l	2654	2900	3050	1990	2600
$(PO_4)^{3-}$	mg/l	465	1830	1540	950	1210

Table 6.1 Sum of leachate concentrations from initial fractions 1 – 4 (1 – 3 for MD 21).

6.1.5 Unexpectedly high mass transfer rates for As, Pb and Zn may be due to ion pair formation with phosphate, irrespective of the mechanism of contaminant mobilisation, the observed mass flux rendered MPC based mix designs unsatisfactory.

6.1.6 2 No. optimum mix designs (MD9 & MD14) were selected by Arcadis with the aid of interim leaching trajectory plots presented in appendix C, for completion of 16 day semi-dynamic leaching trials. This has enabled the evaluation of leaching mechanisms and diffusive flux rates (with parameterisation of De). Only optimum mix designs; MD9 and MD14, are discussed in this section, for which a complete assessment is presented.

6.1.7 Further details of the modelling framework and assumptions based on diffusive flux are presented in the following sections.

6.2 Semi-dynamic Diffusion Based Tank Testing

6.2.1 The interpretation of semi-dynamic leaching trials, such as the 16 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 leach rates such as those determined through EA NEN 7375. The effective diffusion coefficient (De) 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:

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

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

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

- pDe >12.5 low mobility
- 11.0< pDe <12.5 average mobility
- pDe <11.0 high mobility

6.2.6 It should be noted that the methodology employed in EA NEN 7375 requires the determination of the Maximum Availability in accordance with EA NEN 7371. However, we have adopted the mathematical approach described in ASTM C1308, by 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 high mass transfer occurs in intervals that include initial fractions, data may be influenced by initial surface wash off events.

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 (SDrc) 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 the majority of fractions during 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 De parameters.

6.2.11 Where analytical concentrations for all fractions are reported below Method Reporting Limits (MRL), CE Geochem suggest that any evaluation of effective diffusion coefficient parameters should be regarded as conservative.

6.2.12 Due to the aforementioned constraints imposed by analytical detection limits, the accurate interpretation of leaching behaviour, and derivation of effective diffusion coefficient is not possible for the following components; Cadmium, Mercury, Lead, Antimony and Selenium.

6.2.13 Based on the aforementioned restrictions, in particular the lack of measurable concentrations, we conclude that the above compounds are unlikely to present a risk to controlled waters, however, for completeness we provide leaching interpretations for all compounds analysed.

6.3 Leaching Mechanisms and Upper Leaching Limits

6.3.1 Leaching trajectories for all components, irrespective of whether detected at measurable concentrations, are provided graphically as incremental and cumulative dissolved phase concentrations in Appendix C, as well as cumulative mass flux (mg/m^2) plots for the derivation of De in EA NEN 7375 Interpretive reports, which are also provided in the same appendix.

6.3.2 The predicted leaching mechanisms for all mix designs are presented in the Table 6.2. Full details are presented in Appendix C along with estimated upper leaching limits, graphical interpretations for leaching trajectories and experimentally derived effective diffusion coefficients (De) and partition coefficients (Kd).

6.3.3 Leaching under diffusion control was demonstrated for at least 1 No. leaching interval for the majority of the compounds reported below (Table 6.2). It should be noted that for Na and Cl, although demonstrating initial diffusion control, later intervals show depletion based released, with a notable plateau developing beyond fraction 5.

6.3.4 Where a large spread in datasets is observed or the component is typically determined to be below the MRL, no direct determination of leaching mechanism is possible / is not technically justifiable. However, for the purpose of mass flux leaching projections reported in section 7, we have assumed that the release of these compounds are under diffusional based mass transfer control.

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 are presented in Table 6.3. 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 applications. The most appropriate framework for longer term leaching predictions is to apply a diffusion based leaching model using effective diffusion coefficients, particularly for contaminants identified as demonstrating diffusive flux.

6.3.7 Table 6.3 presents ULLs with colour coding to provide a visual indication of the relative efficacy of each stabilisation mix design, whereby green signifies comparatively good geochemical retention, red signifies comparatively poorer geochemical retention, based on the observed mass transfer. This table is not meant to provide any indication of performance with respect to environmental compliance criteria, such as drinking water or environmental quality standards or indeed any site specific leachate acceptance criteria.

6.3.8 Where it has been possible to determine a leaching mechanism, it can be seen that the majority of contaminants of interest are under diffusive flux control for most mix designs. 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.

6.3.9 Although sulphate, sodium and ammoniacal nitrogen are all identified as diffusional release mechanisms, further inspection of leaching trajectory plots reveals that later fractions show strong depletion behaviour and linear diffusive flux is relatively short-lived due to the high rate of mass flux encountered for these components. See latter discussion of ammoniacal nitrogen mass flux mechanisms.

	Leaching Mechanisms for Mix Designs	
Contaminant	**MD9**	**MD14**
Arsenic (Dissolved)	Diffusion	Diffusion
Chromium (Dissolved)	Depletion	Depletion with Surface wash-off
Copper (Dissolved)	Diffusion	NPTDLM
Nickel (Dissolved)	Diffusion	NPTDLM
Vanadium (Dissolved)	Diffusion	Diffusion
Zinc (Dissolved)	Diffusion	NPTDLM
Chloride	Depletion with Surface wash-off	Depletion with Surface wash-off
Ammoniacal Nitrogen	Diffusion with Surface wash-off	Diffusion with Surface wash-off
Sulphate	Diffusion	Depletion with Surface wash-off
Calcium	Diffusion	Diffusion
Sodium	Diffusion	Depletion

Table 6.2 Leaching mechanisms for Optimum Mix Designs. Where the determination of leaching mechanisms was not possible this is typically due to measurands being reported below the MRL (NPTDLM). Note later stage depletion was identified for sulphate, sodium and ammoniacal nitrogen.

	Upper Leaching Limit (mg/m2)	
Contaminant	**MD9**	**MD14**
Arsenic (Dissolved)	2.58	1.01
Chromium (Dissolved)	8.07	14.4
Copper (Dissolved)	16.2	18.1
Nickel (Dissolved)	11.4	26.3
Vanadium (Dissolved)	1.27	1.83
Zinc (Dissolved)	0.76	0.628
Chloride	1060	6600
Ammoniacal Nitrogen	1650	507
Sulphate	1450	18800
Calcium	130000	64100
Sodium	3860	1880

Table 6.3 Upper Leaching Limits (ULL) for Optimum Mix Designs, calculated from semi-dynamic tank test leaching datasets. 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). All data presented to 3 significant figures.

6.4 Derived Effective Diffusion Coefficients (D_e)

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, however we report the effective diffusion co-efficient for all inorganic compounds assuming diffusion-based leaching in order to provide predictive modelling capabilities for all determinands.

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 De parameters from mix designs employing different mix ratios.

6.4.3 The effective diffusion coefficients presented in Table 6.3 may be used for forward predictive modelling of mass transfer rates by leaching over defined time periods. Please refer to Table 6.2 for identification of components identified as being under diffusion control, noting also changes in mechanisms discussed for some components over extended leaching periods. Where depletion based release is observed however, the implementation of a diffusive flux leaching assessment should provide conservative estimates of mass transfer rates, or in circumstances where datasets are influence by MRLs.

Effective Diffusion Coefficient De (m2/s)			pDe	
Contaminant	**MD9**	**MD14**	**MD9**	**MD14**
Arsenic (Dissolved)	2.29E-15	2.18E-15	14.64	14.66
Chromium (Dissolved)	7.46E-16	9.70E-15	15.13	14.01
Copper (Dissolved)	3.57E-14	1.56E-14	13.45	13.81
Nickel (Dissolved)	1.87E-14	4.93E-15	13.73	14.31
Vanadium (Dissolved)	1.01E-16	1.59E-15	15.99	14.80
Zinc (Dissolved)	3.51E-18	2.70E-17	17.45	16.57
Chloride	7.93E-12	1.15E-11	11.10	10.94
Ammoniacal Nitrogen	6.02E-13	2.80E-11	12.22	10.55
Sulphate	8.20E-14	1.70E-12	13.09	11.77
Calcium	4.64E-12	3.90E-13	11.33	12.41
Sodium	7.58E-11	4.34E-10	10.12	9.36

Table 6.3 Effective diffusion coefficients and pDe values for Optimum Mix Designs.

6.4.4 Alternatively, ULLs may be used to provide simple estimates of total mass flux over the time periods of the leaching trials (16 days). Linear extrapolation of ULL's over longer periods will be conservative for all leaching mechanisms, particularly diffusion based, and is not advised.

6.4.5 Contaminant release expressed as mass transfer per unit surface area with respect to a defined time interval can be calculated for diffusional control using the following equation;

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

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).

6.4.6 The above equation enables site specific assessment to be undertaken for stabilised materials based on source term contaminant mass and the dimensions of proposed stabilisation zone based on a consideration of geometric surface area.

6.4.7 Furthermore, this approach allows source-term leaching (a declining source-term model), 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.

6.4.8 Tortuosity, as referenced in EA NEN 7375, is a measurement of physical retardation, that gives an indication of the path length that a diffusing ion must cover in a porous matrix. This calculation assumes no chemical interaction with the matrix, so the component must be relatively inert so that the only impedance to diffusion is by physical retardation. Due to it's conservative nature, the sodium cation is traditionally used to calculate tortuosity using the equation below:

$$T = \frac{D_{Na}}{D_{e,Na}}$$

where De_{Na} is the effective diffusion coefficient of sodium as presented above and D_{Na} is the diffusion coefficient of sodium in pure water (1.32×10^{-9} m^2s^{-1}).

	MD9	MD14
Na^+	17.39	3.04

Table 6.4 Tortuosity values for sodium and ammonium for MD 9 and 14.

6.5 Partition Co-efficient (Kd)

6.5.1 As an alternative approach, experimentally derived partition coefficients (Kd) for stabilised sediments are presented in Table 6.5. 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 standard 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 using effective diffusion coefficients for assessing diffusive flux from stabilised materials. In particular, the De approach better describes the declining source term leaching observed for low permeability stabilised materials (i.e. mass transport under diffusive flux over time) rather than an application of distribution coefficients which tends 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 MRLs in either the source, leachate or both.

6.5.4 Particular care should also be taken when applying either Kd or De parameters from this study to materials that different 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.

Average Partition Coefficient Kd (L/Kg)		
Contaminant	**MD9**	**MD14**
Arsenic (Dissolved)	5900	6260
Chromium (Dissolved)	17300	2600
Copper (Dissolved)	4860	7240
Nickel (Dissolved)	4540	5190
Vanadium (Dissolved)	25400	5550
Zinc (Dissolved)	110000	32700
Chloride	67.7	74.5
Ammoniacal Nitrogen	529	93.5
Sulphate	977	132
Calcium	282	2350
Sodium	31.2	22

Table 6.5 Distribution coefficients for optimum mix designs, presented in units of L/kg. Data represents average values from 8 No. fractions. Minimum, maximum and median statistics for Kd parameters are presented within EA NEN 7375 interpretive report.

6.6 Release of Ammoniacal Nitrogen

6.6.1 Special attention is given to the release of ammoniacal nitrogen for optimum mix designs as this component is recognised as the main remedial driver for assessing the geochemical performance of stabilised materials.

6.6.2 From a geochemical perspective, high flux rates are to be anticipated when using conventional hydraulic binders due to the elevated pH associated with cement and lime based stabilisation systems. This shift in pH will deprotonate charged ammonium (NH_4^+) cations to form zero-valent ammonia (NH_3). Ammonia is poorly retarded in stabilised matrices due to the loss of electrostatic interaction that leads to expulsion from interlayer gallery sites within phyllosilicate clay minerals, and release from organic ligands such as carboxylate groups associated with organic matter.

6.6.3 Both MD9 and MD14 show initial high rates of mass transfer from semi-dynamic tank tests with later stage depletion dominating longer leaching intervals. As can be seen from inspection of Figure 6.1, both systems appear to plateau after F4/F5. It is interesting to note that MD14, 6% CEMI addition to lagoon sediments shows 100% mass release of ammoniacal nitrogen at the point of plateaux. Conversely for MD9, 10% lime addition to organic rich soil, only reports 16.5% mass release at the point of plateauing.

6.6.4 Two potential explanations arise for MD9. Either, only 16.5% of the ammoniacal nitrogen present within this test work sample is labile and the remainder is bound/immobilised within the matrix, or, source term determinations have over-estimated the source term mass present within this test work sample.

6.6.5 As presented in Table 4.1, initial source term characterisation datasets determined ammoniacal nitrogen was present in the homogenised organic rich test work sample at average concentrations of 720 mg/kg. Assuming these initial characterisation datasets are in error and the true concentration present in composite 3 relates to 100% of the observed release, we calculate a possible adjusted source term mass for ammoniacal nitrogen in this sample of 119 mg/kg.

6.6.6 Irrespective of the aforementioned possible discrepancy, the results from semi-dynamic leaching assessments clearly demonstrate ammoniacal nitrogen will be liberated from the stabilised matrix at initially high rates of mass flux which is likely to lead to spiking of peak soil pore water concentrations shortly after installation as a hydraulically bound soil mass. Porewater within the interfacial exchange zone near to the surface of the stabilised soils are likely to maintain alkaline conditions. Where pore water or groundwater pH remains above pH 9.25, ammonia will be favoured over ammonium, however depending on the buffering capacity and native pH of the local groundwater, reversion of ammonia to ammonium below pH 9.25 would be favoured.

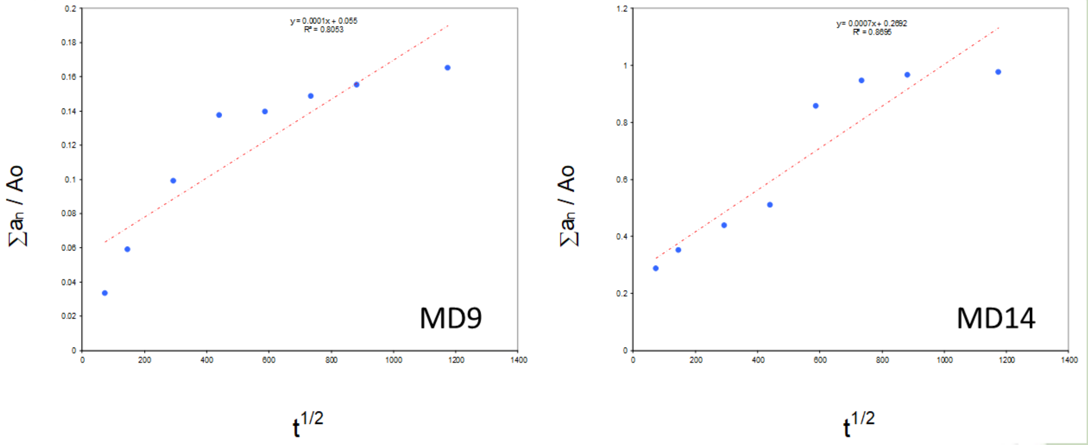

Figure 6.1. Mass transfer rates for ammoniacal nitrogen (predominantly ammonia at the prevailing pH) for MD9 and MD14. Note the plateau in transfer rates over longer leaching fractions demonstrating deletional based leaching mechanism.

6.6.7 Due to the aforementioned depletion based leaching controls on ammoniacal nitrogen mass transfer rates, we would not expect ammoniacal nitrogen to produce long-term elevated groundwater concentrations, although initial spiking in groundwater concentrations should be anticipated.

6.7 Ammonia gas evolution

6.7.1 Test work certificates from the ammonia gas evolution study can be found in Appendix D, with key information summarised below. Test work composite 3 was used exclusively for this test work with a perceived high ammoniacal source term concentration of 720 mg/kg. Subsequent reanalysis of composite 3 determined a much lower source term mass of ammoniacal nitrogen of just 34 mg/kg.

6.7.2 The reason for this discrepancy was not fully explained as samples were retrieved from the homogenised test work mass used for both source characterisation, semi-dynamic tank testing and the gas evolution study. Samples were stored in sealed HDPE bags following homogenisation and prior to subsequent test work.

6.7.3 We tentatively assume the high ammoniacal nitrogen loading may be associated with organic matter within this sample which may be subject to biological nitrification processes during storage. This may explain the reduction in source term ammoniacal nitrogen initially reported at 720 mg/kg on 13th August and reanalysed at 34 mg/kg on 21st October.

6.7.4 Source term reduction of ammoniacal nitrogen may be a viable pre-treatment phase for organic rich soils on site, to assist in reducing the potentially high initial mass transfer rates. Collection of samples will have inevitably exposed organic rich soils (which are likely to be under reducing / anaerobic conditions in situ) to oxygen, possibly initiating nitrification processes.

6.7.5 We recommend that this is investigated further by collecting fresh organic rich soils and exposing these to aerobic conditions with monitoring for ammoniacal nitrogen, nitrite and nitrate.

6.7.6 Table 6.6 below displays the total ammonia ($NH_{3(g)}$) released presented in absolute terms (mg) and as a percentage released relative to the initial source term concentration (34 mg/kg).

6.7.7 MPC mix designs and control soils showed 0% ammonia release with no detectable ammonia reported in the gas diffusion cell headspace through the completion of testing. This was expected for MPC mix designs, and one of the driving motivations to trial MPC based stabilisation systems, which retain the low pH of the initial soil material through retaining ammoniacal nitrogen mass ad ammonium (NH_4^+) as production of ammonia remains unfavourable at pH <8.

Lime Addition (%)	3%	6%	10%	Units
Cum. NH3 Measured	270	293	382	*v/v ppm*
Measured Volume of NH3	270	293	382	*ul/l*
Absolute Volume of NH3	1.15E-04	1.25E-04	1.62E-04	*L*
No. moles	4.66E-06	5.05E-06	6.59E-06	*moles*
Mass of NH3	7.91E-05	8.59E-05	1.12E-04	*g released*
Mass of NH3	7.91E-02	8.59E-02	1.12E-01	*mg released*
Initial Soil NH3 mass	2.9682	2.8764	2.754	*mg*
% Released	2.666%	2.986%	4.066%	%

Table 6.5: Summary of ammonia gas diffusion for composite 3 at 3%, 6% and 10% lime addition (uncompacted).

6.7.8 As can be seen from Table 6.5 the percentage NH_3 released from composite 3 increases with CaO added as expected. In Figure 6.1 the cumulative NH_3 concentration for all 3 experiments remains relatively linear over the time course of the experiments.

6.7.9 Experimental datasets were used to derive mass transfer rates for each of the trialled lime stabilisation systems demonstrating measurable mass flux. These parameters are reported in Appendix D and may be used (with caution) to predict ammonia concentrations liberated from as dug stockpiles on site.

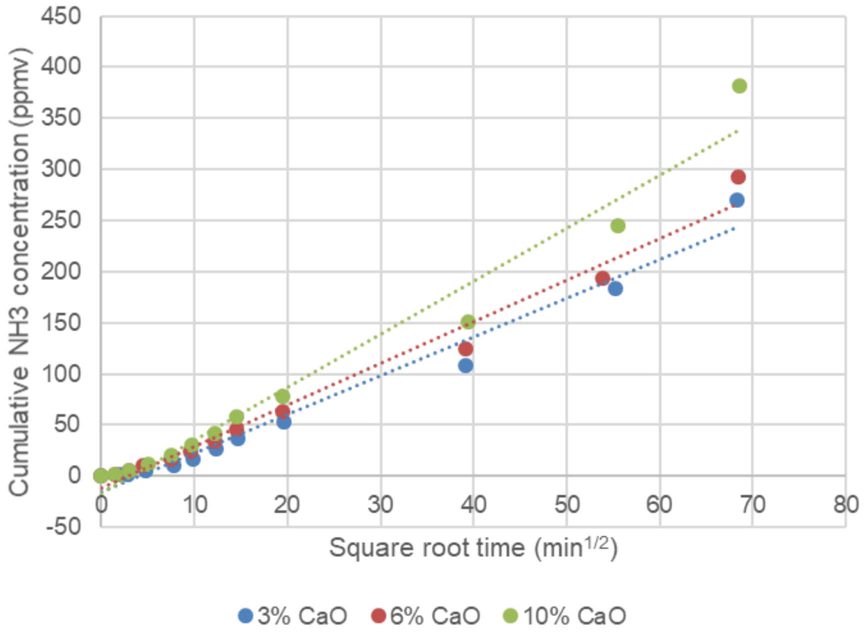

Figure 6.1: Cumulative NH_3 concentration plotted as a function of the square root of time for the 3 CaO added experiments.

7 Conclusions & Recommendations

7.1.1 This test work programme has shown good geotechnical improvement of site materials can be achieved by conventional lime stabilisation or cement based mass stabilisation for lagoon sediments. The application of lime to Limex waste materials gave neglibible improvement and is not considered necessary for reuse of these materials should it remain possible to place Limex waste near its OMC.

7.1.2 The results from geotechnical and geochemical test work packages are presented to allow selection of appropriate candidate mix designs for subsequent field trials. We strongly recommend that field trials are undertaken to confirm the suitability of plant and materials processing routes for achieving the desired end specification for materials placement and compaction.

BRE-SD1 assessments revealed low risk of sulphate induced heave when using the candidate hydraulic binders trialled in this study which was supported by CBR swell testing (interim results enclosed). We recommend a watching brief is maintained in line with best practice employing daily BRE-SD1 testing and CBR swell validation testing.

7.1.3 Geochemical test work has identified ammoniacal nitrogen as the key remedial driver. Leaching trajectory analysis for optimum mix designs MD 9 and 14 have enable leaching mechanisms and diffusion data has been extracted from experimental leaching datasets. These support a depletion based leaching control mechanism for ammonia from both lime and cement based systems.

7.1.4 Effective diffusion coefficients (De) for optimum mix designs are presented in section 6. If required in detailed design, these parameters may be used to simulate diffusive flux for as built stabilised soil masses on site and predict the likely change in groundwater concentrations for contaminants of concern.

7.1.5 Ammonia gas evolution experiments reveal lime based mix designs would be expected to release ammonia, for example where pre-mixing of lime in stockpiles is undertaken. A 10% CaO addition (equivalent to MD 9) liberated approximately 4 % of ammonia by weight over 80 hours.

7.1.6 Semi-dynamic tank testing performed on magnesium phosphate cement based mix designs resulted in unexpectedly high leachate concentrations for As, Pb, Zn. We doi not recommend MPC mix design be considered further in the context of these stabilisation works.

7.1.7 With specific reference to organic rich soils, CE Geochem recommend that further test work be completed to assess the potential for aerobic nitrification of ammoniacal nitrogen. These high source term samples appear to have shown circa. 95% depletion in source term ammoniacal nitrogen from 720 mg/kg to 34 mg/kg in approximately 2 months. We tentatively scribe this top potential biological nitrification processes upon exposure to aerobic conditions during homogenisation.

7.1.8 For the purpose of verifying the remedial efficacy of site works, CE Geochem recommend that a validation strategy be implemented based on verification semi-dynamic leaching assessments from moulded specimens taken from as-placed materials. This is considered preferential to granular leaching tests such as BS EN 12457 parts 1-4. The results from semi-dynamic tank testing should be in integrated with observed ammoniacal nitrogen concentrations in groundwater to confirm a declining source term leaching model is appropriate. Such observations may be calibrated with diffusive flux simulations from De parameters presented in this report to demonstrate validation works are appropriately captured by conceptual design models.

7.1.9 The frequency of testing employed should be commensurate with the variability of materials to be treated. Where material processing (excavation, stockpiling, ex situ binder mixing, deposition) will create a relatively well mixed homogeneous treated sediment, a sampling frequency of 1 specimen per 1000 m^3 is likely to be appropriate.

7.1.10 CE Geochem strongly recommend that site control testing is implemented throughout the stabilisation works programme by an experienced independent laboratory. This may include;

- Moisture content and in situ density by core cutter or sand replacement for monitoring as placed materials with reference to OMC-MDD relationships and to quantify % compaction
- Degree of pulverisation, which should ideally be >60% to ensure adequate binder incorporation
- Spread checks and depth checks to calibrate and verify binder addition rates
- Daily BRE-SD1 and CBR swell specimen manufacture to provide on going monitoring for the potential for sulphate attack and volumetric expansion

7.1.11 Additional geotechnical validation testing may also be undertaken by either;

- In Situ CBR or plate bearing testing on the as built finished surface.
- Light Weight Deflectometry on the as built finished surface

7.1.12 The most suitable validation method for geotechnical compliance is likely to be defined by the end-product specification and associated geotechnical design criteria.

Appendix A Geotechnical Assessment

Appendix B Chemical Analysis

Appendix C EA NEN 7375 Reports

Appendix D Ammonia Gas Evolution Studies

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