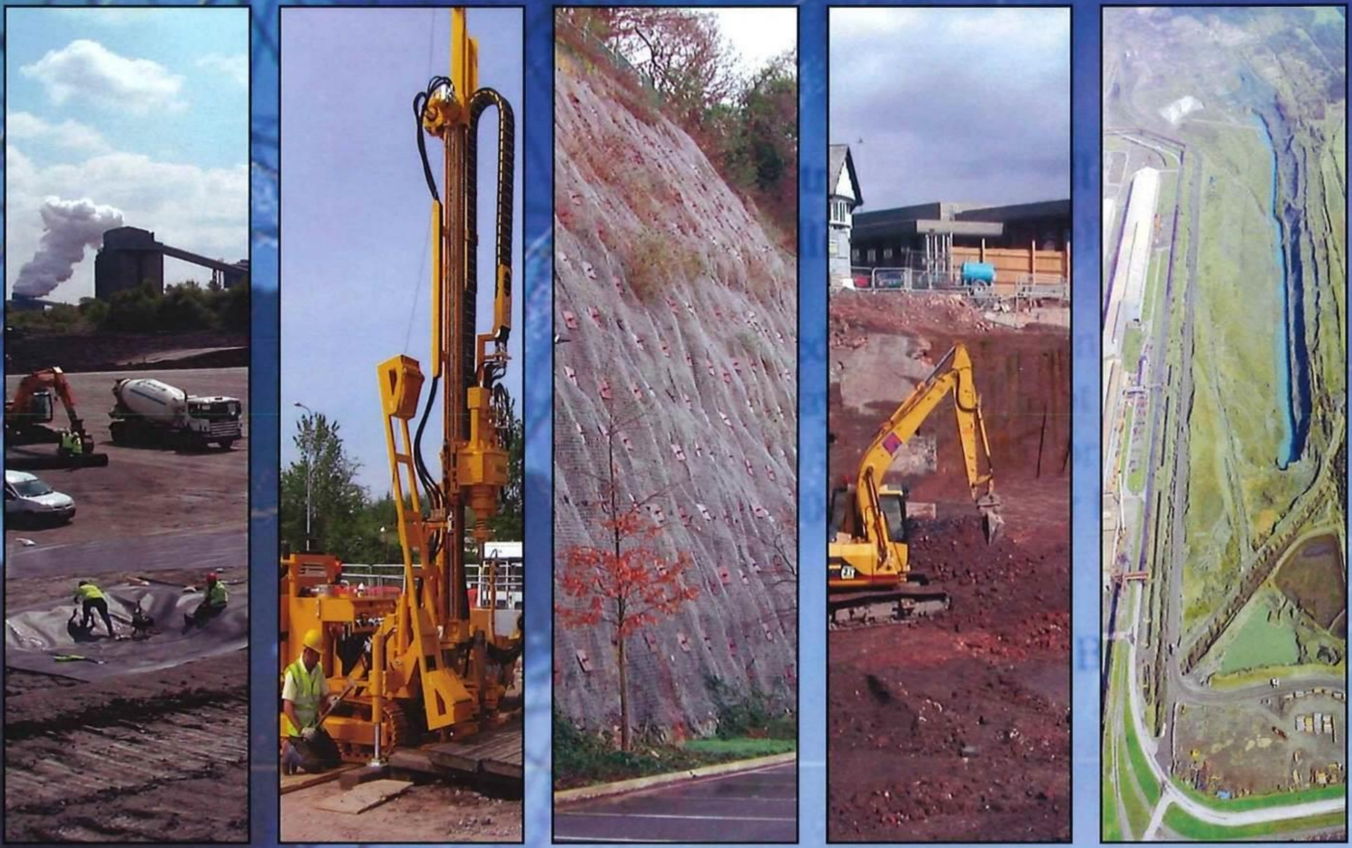

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June 2021
Report No 5192/R/007/01

ELSTOW SOUTH LANDFILL SITE

HYDROGEOLOGICAL RISK ASSESSMENT

Prepared for:

Anti-Waste Limited

ELSTOW SOUTH LANDFILL SITE

HYDROGEOLOGICAL RISK ASSESSMENT

Date: June 2021

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ELSTOW SOUTH LANDFILL SITE

HYDROGEOLOGICAL RISK ASSESSMENT

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APPENDICES

1. INTRODUCTION

1.1 Report Requirements

This technical appraisal supports a permit application to infill the voids at Elstow South (relevant for the discharge of planning condition application and associated Environmental Statement (ES) chapter), as part of the site's originally intended scheme of restoration by landfilling.

Applications for both Planning and Environmental Permit propose to utilise a supply of waste materials associated with excavation and construction works which may include material from the HS2 development. These wastes are of lower polluting potential than those infilled at the adjacent landfill, Elstow North, operated by Bedford Borough Council (BCC). It is proposed to infill the existing quarry voids (currently flooded) as a restoration activity.

The infill material comprising only of wastes which are considered suitable and which are specified by Her Majesty's Revenue and Customs (HMRC) in The Landfill Tax (Qualifying Material) Order 2011 (as amended) (i.e. Qualifying Materials (QMs). This is a change from the consented scheme, which consented the infilling with biodegradable wastes, as per the adjacent Elstow North site.

The infilling of the current voids will be completed to a level coincident with surrounding / perimeter ground and shaped to facilitate surface water drainage. Further supporting information on the design and operation of the site is provided within the Environmental Installation Design (ESID) report and is not reproduced in full here, this includes stability, and gas assessment. This report provides an appraisal on the infilling scheme with regard to hydrogeological system.

1.2 Site Location and Description

The Elstow South site is located to the southwest of Bedford, Bedfordshire (National Grid Reference (NGR) TL 048 456) adjacent to the A6 (Figure 1). The development site was formerly used for clay extraction, with the majority of the site now dominated by the flooded, unrestored voids. For the purposes of development, the site is classified as brownfield, previously developed land. London Brick extracted clay from the site between 1949 and 1979. Elstow North was infilled with waste between 1964 and 1988. Elstow North is operated and owned by Bedford Borough Council (BBC) and is partly restored. The southern flanks of Elstow North are bounded to the south by the flooded voids of the Elstow South site, Figure 2.

The topography of the land surrounding the site is relatively flat at ~35 - 31mAOD and dominated in the north east and south by agriculture, the closest residential properties to the north east is the Village of Elstow (~0.6km) and Wixams to the south east (~0.3km), Figure 2.

The perimeter of the site is at ~29mAOD in the east, 32mAOD on the south and south west falling to a low point of 25mAOD near the north east corner. A bathymetric survey in combination with recent intrusive Ground Investigation (GI) data indicates the western void is steep sided (slopes of 30°) with a flat base at 14 – 15mAOD.

Figure 1 Site Location – Elstow South

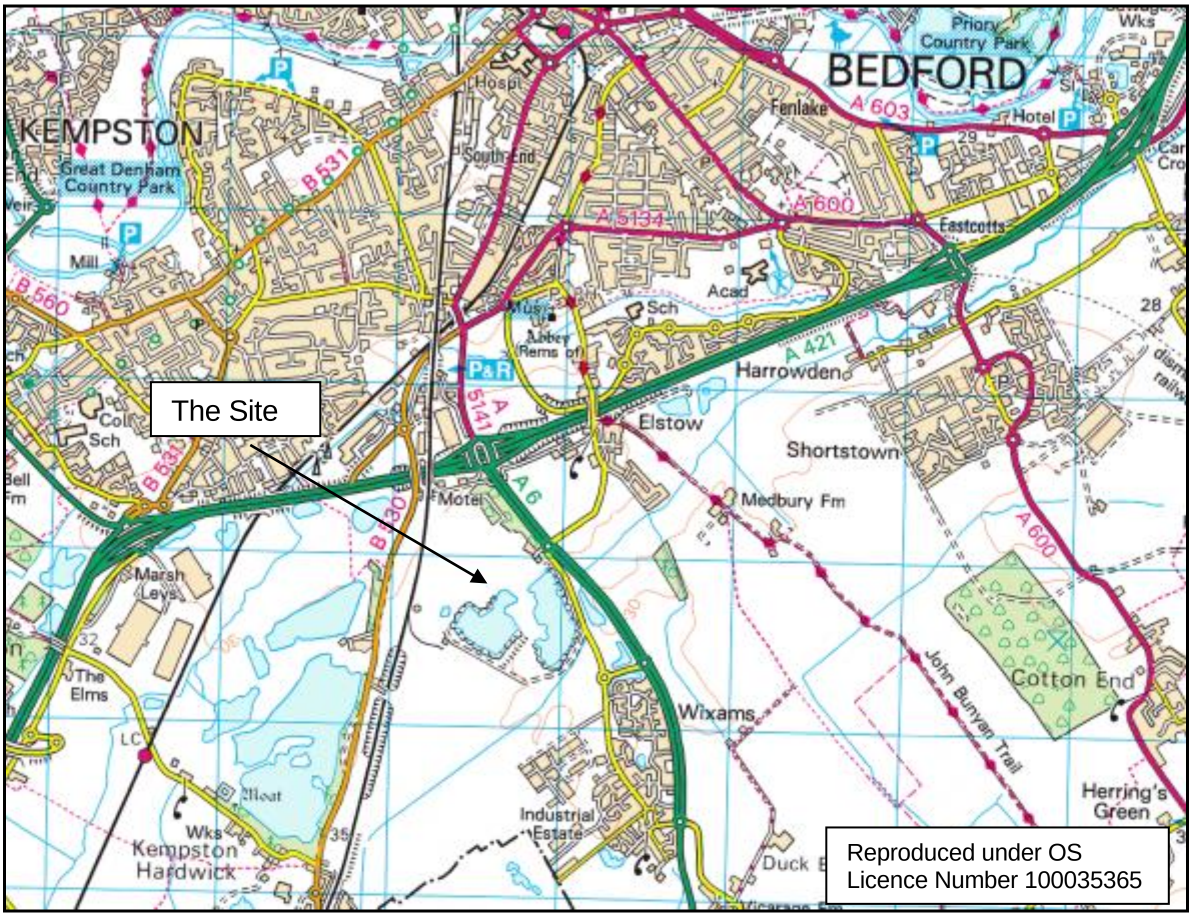

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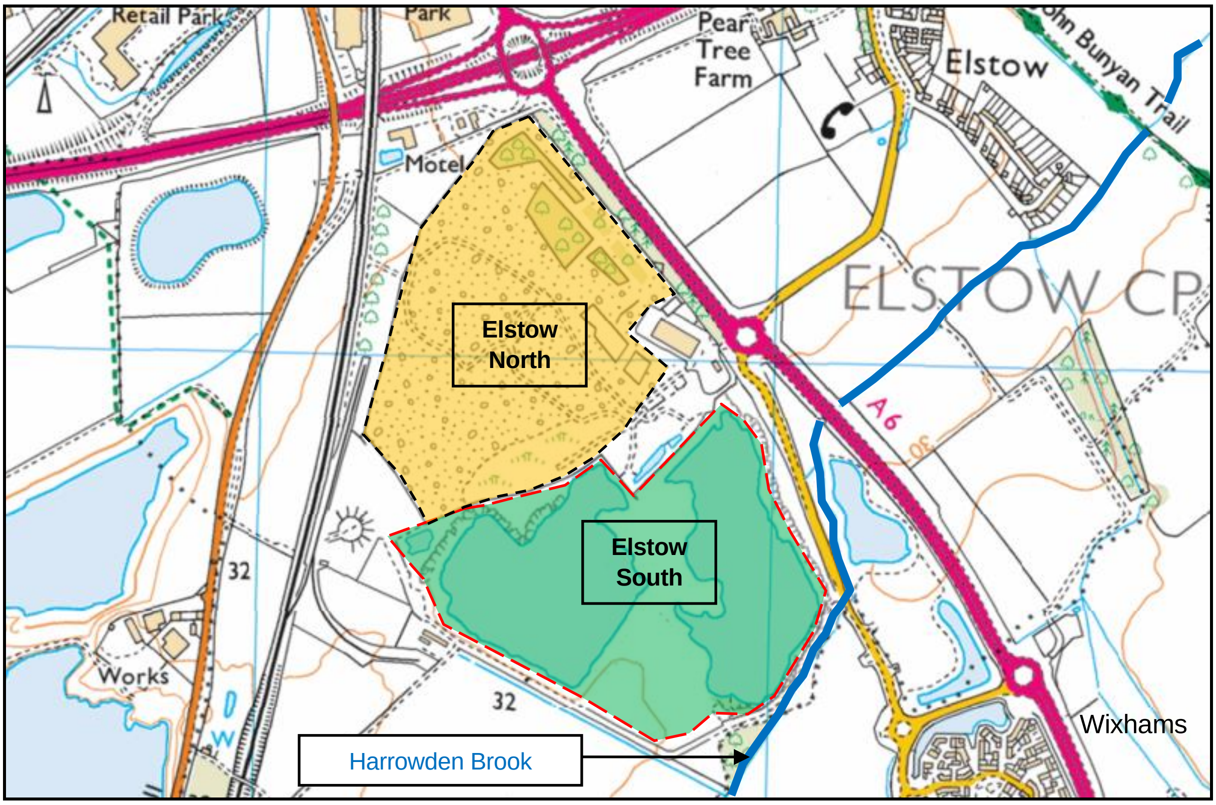
Figure 2 Site Areas



The eastern void is not as steep sided (15-20°) however there is a greater range of basal elevations. The base in the southern area is at 16mAOD and between 17 and 22mAOD in the central and northern areas.

Recent water levels in the partially flooded voids are at ~25mOAD, the entire site is located within low permeability Oxford Clay bedrock (a natural geological barrier). The nearest watercourse is the Harrowden Brook adjacent to the south eastern perimeter (Figure 2).

1.3 Proposed Development

It is proposed to complete the infilling of the eastern and western voids with wastes which are listed as qualifying materials[1]. The infilling of the voids (green shaded area on Figure 3) will provide final restoration contours for the site to be commensurate with the surrounding land surface (as far as is reasonably practical).

The proposed wastes will consist of excavation, construction/demolition wastes and similar industrial wastes that have a low-level pollution potential. Therefore, it is not expected that the waste will generate landfill gas or that active management of landfill gas will be required. Such a restriction will also prevent the generation of the primary soluble landfill leachate pollutant (*i.e.* ammonium) as well as the organic degradation by-products, namely hydrolysis products such as the phenols and hazardous substances such as BTEX compounds.

The proposed wastes will have a negligible pollution potential, thus the voids are highly likely to rapidly stabilise to a state where the permitted area could be surrendered upon or shortly after cessation of disposal activities. Hence, final surrender is likely to be undertaken far in advance of the adjacent biodegradable waste landfill, Elstow North.

Notwithstanding the negligible pollution potential of the wastes proposed for the voids, an appropriately “risk based” network of perimeter boreholes will be installed and monitored routinely around the perimeter of the infill area which will be used throughout the site’s operational and post-closure phases to assess whether the voids are operating as intended.

2. SOURCE TERM

2.1 Site Engineering

There is not a risk-based requirement to engineer the *in-situ* surrounding / underlying Oxford Clay, as it naturally achieves the Landfill Directive requirement of a geological barrier equivalent to 1m at a hydraulic conductivity at <1x10^{-7}m/s (inert waste).

Investigations have demonstrated that the underlying (upper surface contact) between the Kellaways Sand and Oxford Clay rises in elevation from south west to north east, with a contact boundary at ~13m – 14mAOD under the footprint of the western void and an elevation of ~15m - 16AOD under the eastern void.

Both voids will be dewatered and infilled, the eastern void will be infilled first, commensurate with dewatering of the western void. The base design for the eastern void slopes from ~20mAOD in the east to ~17mAOD in the west in the southern area (Figure 3). The void is to be subdivided into 4 sub-cells (ESID 6B). The base design for the western void slopes from

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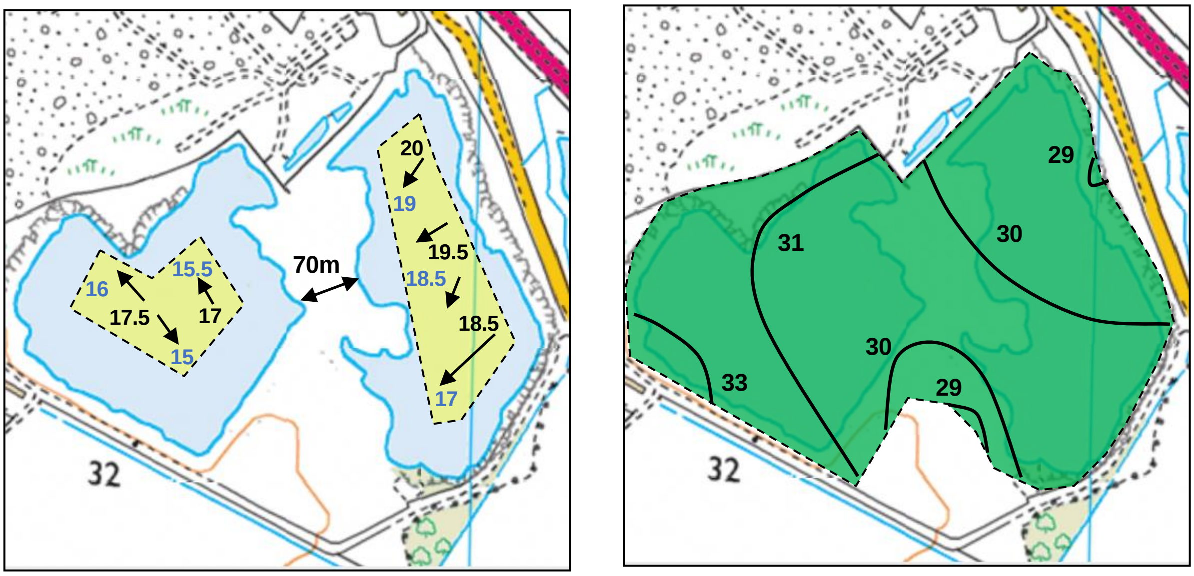
[1] The Landfill Tax (Qualifying Material) Order 2011 (as amended) - https://www.legislation.gov.uk/uksi/2011/1017/contents/made

17.5mAOD to a low point of 15mAOD (Figure 3), the void is to be divided into 3 sub-cells (ESID 6C).

The voids are separated by a *“made ground”* bund (Figure 3) with a crest width ranging between ~70m and 140m. The *in-situ* Oxford Clay is ~1m in thickness above the Kellaways Sand in the north area of the bund, 0.6m in the centre and ~11m in the south. The bund is comprised predominately of mudstone with brick, sandstone, gravel and shell fragments. The proposed permit boundary is depicted on drawing ESID 4.

Figure 3 Engineering Design Schematic



Base (mAOD) & direction of fall

Restoration Surface (mAOD)

Although the bathymetric survey indicates some areas of the western void may be lower than 14mAOD, where present these areas appear localised and are within the central area of the basal area of the void. These areas (if identified post dewatering) will be infilled with clay taken from the sidewall batters that are surplus to the requirement in void preparation.

GI boreholes including “overwater drilling”, online BGS borehole logs[2], drill core analysis and geological appraisals have enabled the upper surface of the Kellaways Sand (the upper part of the Kellaways Formation) to be contoured. This is the base level of the Oxford Clay.

The interface appears highest (topographically) at 14mAOD in the western void (borehole log WLO 19-09 and WLO 19-05, drawing 3393.1.001), with a highest level of 16.2mAOD (borehole log ELW 19-02) within the eastern void. The base design liner formation levels have been set accordingly to include a 1m separation above this contoured interface as a minimum.

The position of borehole ELW 19-02 cross referenced with the base design formation level indicates an *in-situ* thickness of Oxford Clay of 2.1m.

At the periphery of the western void, (northern margin WLO 19-06) the base of Oxford Clay is deeper than 13.8mAOD relative to design formation level of 16.9mAOD (therefore greater than 2m of *in-situ* material). The thinnest designed thickness of Oxford Clay relates to the southern area of the western void, a sump level of 15mAOD relative to boreholes WLL 19-03 and WLO

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[2] https://mapapps.bgs.ac.uk/geologyofbritain/home.html

19-09 would indicate a thickness of clay between 1 and 1.6m. Overall, the range in thickness in Oxford Clay at the base of the voids is estimated with a triangular distribution of 1m, 1.5m, 2.8m.

Notwithstanding the above, the basal engineering will utilise re-worked Oxford Clay to the specification of 500 mm of engineered clay to a maximum permeability of $1x10^{-8}$m/s. It has been demonstrated by the Hydrogeological Risk Assessment and through experienced gained at other similar sites that by controlling the nature of the waste inputs, leachate collection will not be necessary.

However, if present leachate monitoring will be undertaken utilising monitoring chambers and basal drains. Where natural clay deposits are not present on the sides of the dewatered void (e.g. the flanks of the central ‘made ground’ bund) these will be lined with re-worked Oxford Clay won from other areas of the site and placed to the same specification as the basal engineering. For steeper sections of the side slope the re-worked clay will be placed in lifts commensurate to the rising waste fill deposits to ensure stability. On completion of the filling a cap will be placed using selected cohesive materials to limit infiltration.

Requirement for Leachate Collection

Previous permit applications at sites with equivalent environmental settings (also operated by FCC Environment) included an appraisal of soil / water mobility by “*Preene Groundwater Consulting (PGC)*”. Key considerations from these identical applications included the following discussion (accepted by the Environment Agency as permits have been granted accordingly):

- *……… laboratory test results of four samples from another site permitted to accept non-hazardous Qualifying Material in previous applications for similar sites. The four samples all show well-graded particle size distributions (PSDs) with vertical permeability values reported in the range $1x10^{-10}$ to $3x10^{-10}$m/s from laboratory testing in a 100 mm diameter triaxial cell.*
- *PGC also did not expect the placed waste to generate significant volumes of ‘leachate’ (i.e. mobile water). The fill is of very low permeability; once placed, any water falling on the exposed surfaces at working level will be prone to ponding at the surface (and removal by surface water control measures in place at the time). Based on the expected waste materials little water will infiltrate into the waste.*
- *It is considered improbable that all liquid within the significant thickness of overlying soils can be removed or that the upper level of saturated soil could be lowered by extraction of liquid at the base of the site.*
- *The water entering the void will be dominated by water derived from rainfall during wet weather. Due to the nature of the waste materials, PGC expected during previous technical reviews that the majority of the water falling onto the waste during placement will become run-off and, subject to water quality, will be pumped away as part of surface water management. Over the operational period of the Site very little water is anticipated to soak into the waste and contribute to ‘leachate’.*

The reasons above justify why leachate level limits are meaningless within QM infill schemes. In this regard, permitted QMs infill sites do not, and are not required to include leachate control limits.

In simple terms water contained within the waste mass cannot be controlled by underdrainage extraction and hence any proposed limit of control is unachievable. Consequently, no artificial sealing liner is proposed or required.

For consistency with similar applications however, a separation geotextile layer will be placed above the formation layer with a “notional leachate collection chamber” in each void cell installed above a concrete target pad for the collection of pore-water.

Spine drains will connect to the chamber, overlain by stone haunching (20/40mm aggregate). Disposal operations will be below ground level for the majority of the operational lifespan apart from the final stages and capping.

The restored surface slopes gently from the western area of the western void at ~33mAOD to between 31 and 30mAOD in the centre, to a low point of 29mAOD in the east and south (Figure 3, ESID 5A). This restoration profile will assist in surface water control and will allow surface water to shed to the discharge points.

2.2 Engineering Properties

The site is located entirely within non-productive strata (a geological barrier), permeability of the Oxford Clay is low. Information relating to the engineering properties has been detailed in previous reviews e.g. Parry 1972[3], Reeves et al. 2006[4]. Hydraulic conductivity is typically $<1x10^{-10}$m/s. CQA test data for the engineered clay at other FCC sites demonstrated that the compacted clay liner are typically constructed to a hydraulic conductivity of between $1.6x10^{-11}$ and $3.6x10^{-10}$m/s.

2.3 Waste Types and Quantities

The void area combined has a projected capacity of ~2.5Mm^3 and comprises an area of approximately 14ha (base) and 27ha (upper surface).

The proposed design is to restore the voids using QMs. QMs are a list of waste types in which Her Majesty’s Revenue and Customs (HMRC) has made specific allowance for quarry restoration identifying a very limited list of suitable wastes in accordance with The Landfill Tax (Qualifying Material) Order 2011 (as amended).

The QM Order lists a series of wastes with limited to negligible pollution potential with respect to the production of landfill gas or leachates. The qualifying materials include wastes in the following groups:

Group 1	Rocks and soils
Group 2	Ceramics or concrete materials
Group 3	Minerals, processed or prepared
Group 4	Furnace slags
Group 5	Ash

Of these the majority of the materials to be landfilled are expected to be:

- Soil (including mixed clays, silts and sands);
- Stones; and
- Concrete based construction materials from development schemes

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[3] PARRY, R.H.G. 1972. Some properties of heavily over-consolidated Oxford Clay at a site near Bedford. Géotechnique, 22, 485-507.

[4] REEVES, G.M, SIMS, I. & CRIPPS, J.C. (eds) 2006. Clay Materials Used in Construction. Geological Society London, Engineering Geology Special Publication, 21.

2.4 Leachate Chemistry

Any leachate generated from the QMs will differ significantly from a typical Municipal Solid Waste (MSW) leachate as there is not a putrescible component to the waste stream. Consequently, the significant ammoniacal-N and dissolved organic matter (as represented by the COD) as well as other soluble salts will not be present as readily degradable organic matter and soluble salts are specifically excluded from the list of wastes described as QMs. Given that the proposed waste types are unlikely to contain a degradable organic content, elevated ammoniacal-N and BOD is not expected to be associated with site. Similarly, solvents, refined petroleum fuels or other chemical sources will be excluded.

A source term has been derived based on the leaching limits set within the Landfill Directive for Inert Waste (Table 1). When comparing the inert WAC limits against observed leachate concentrations TerraConsult have compiled from hazardous soil landfills over a 10year period, as well as other leaching data, it is evident that the inert WAC limits are significantly greater than the observed concentrations from the hazardous soils sites.

Given the proposed waste inventory, the leachate from the wastes will primarily be below the Drinking Water Standard (DWS) at source and therefore be of a low to negligible risk to the environment. Consequently it is considered that a leachate source term based on inert WAC limitations is a conservative representation of the expected leachate composition from the bulk inert wastes.

Table 1 Inert Waste Leaching Limits and Typical Observed Leaching Concentration from Hazardous Soil Landfills

Determinand	Source (Inert WAC limits)		Typical Soil**	DWS	Inert Leachate* Compared to DWS	Comment
	Soil	Leachate*				
	mg/kg	mg/l	mg/l	mg/l		
Hazardous Metals						
Cadmium	0.04	0.004	0.0003	0.005	80%	Below DWS at source
Mercury	0.01	0.001	0.00004	0.001	100%	At DWS at source
Non-hazardous Metals						
Lead	0.5	0.05	0.002	0.01	500%	Above DWS at source
Nickel	0.4	0.04	0.008	0.02	200%	
Chromium	0.5	0.05	0.003	0.05	100%	At DWS at source
Copper	2	0.2	0.006	2	10%	Below DWS at source
Zinc	4	0.4	0.045	5	8%	
Non-Hazardous Oxyanions						
Arsenic	0.5	0.05	0.005	0.01	500%	Above DWS at source
Molybdenum	0.5	0.05	0.023	0.07	71%	Below DWS at source
Antimony	0.06	0.006	<0.001	0.05	12%	
Selenium	0.1	0.01	0.004	0.01	100%	At DWS at source
Matrix and Minor ions						
Chloride	800	80	295	250	32%	Below DWS at source
Sulphate	1000	100	1,400	250	40%	
Fluoride	10	1		1.5	67%	

*based on 10:1 Liquid to soil leaching ratio

**TerraConsult soil leaching database – accepted as representative at the Calvert, Sutton Courtenay, Dix Pit, Dogsthorpe and Thurcroft landfill sites (accepted within associated permit variation applications)

The exception to the above is for sulphate which is observed at concentrations higher than the inert WAC limit at the hazardous soils sites.

Notwithstanding the above, elevated sulphate concentrations have, for the purposes of conservative modelling, been considered within this risk assessment.

Leachate chemistry from FCC's QMs site at Calvert Pit 6 (an equivalent environmental setting and similar waste input) will also be used in deriving appropriate source term ranges for subsequent hydrogeological modelling.

3. PATHWAYS

3.1 Geological Succession

The British Geological Survey (BGS) generally describe the Jurassic succession in the area as forming under marine conditions which continued throughout the period of deposition of the Lias.

The geological succession is as follows[5]:

- Fluvioglacial sand and gravel / limited areas of alluvium (Course of Harrowden Brook)
- Oxford Clay (Peterborough and Stewartby Member)
- Kellaways Sand (2.5 to 5.5m)
- Kellaways Clay (0.7 to 2m)
- Cornbrash Limestone (0 to 3m)
- Blisworth Clay (0 to 7m)
- Blisworth Limestone (8 to 14m)
- Great Oolite Group / Rutland Formation (4-22m)

The fluvioglacial deposits are stratigraphically above the Oxford Clay and physically separate from the sediments which underlie the clay. The extent of the superficial deposits in relation to the site are given in Figure 4.

The thickness of the alluvium in the area is variable and is within the course of the Harrowden Brook local to the site. It is noted however that the winning of the Oxford Clay has removed all superficial deposits within the site area, this also incudes the area to the north associated with Elstow North landfill.

The Lower Oxford Clay is a fissile mudstone interbedded with pale grey blocky mudstone. The underlying Kellaways Beds (also termed Formation in some literature sources) comprise the Kellaways Sand (upper) and the Kellaways Clay (lower).

The sequence below the Kellaways Beds forms the Great Oolite Group and comprises of the Cornbrash, Blisworth Clay / Limestone and Upper Estuarine Series. The Kellaways Sand and Blisworth Limestone are water bearing.

The Cornbrash Formation, an intensely bioturbated limestone containing numerous clay field burrows. The limestone units comprise fine shell debris in a microcrystalline calcite matrix. The Blisworth Clay consists of mudstones with some interbedded silty layers which grade between marls and shelly limestones. Ironstones also occur at several levels within the formation. The Blisworth Clay transitions from a shelly marl into the underlying Blisworth Limestone, a shelly limestone with beds of shelly marl and laminated shelly mudstone.

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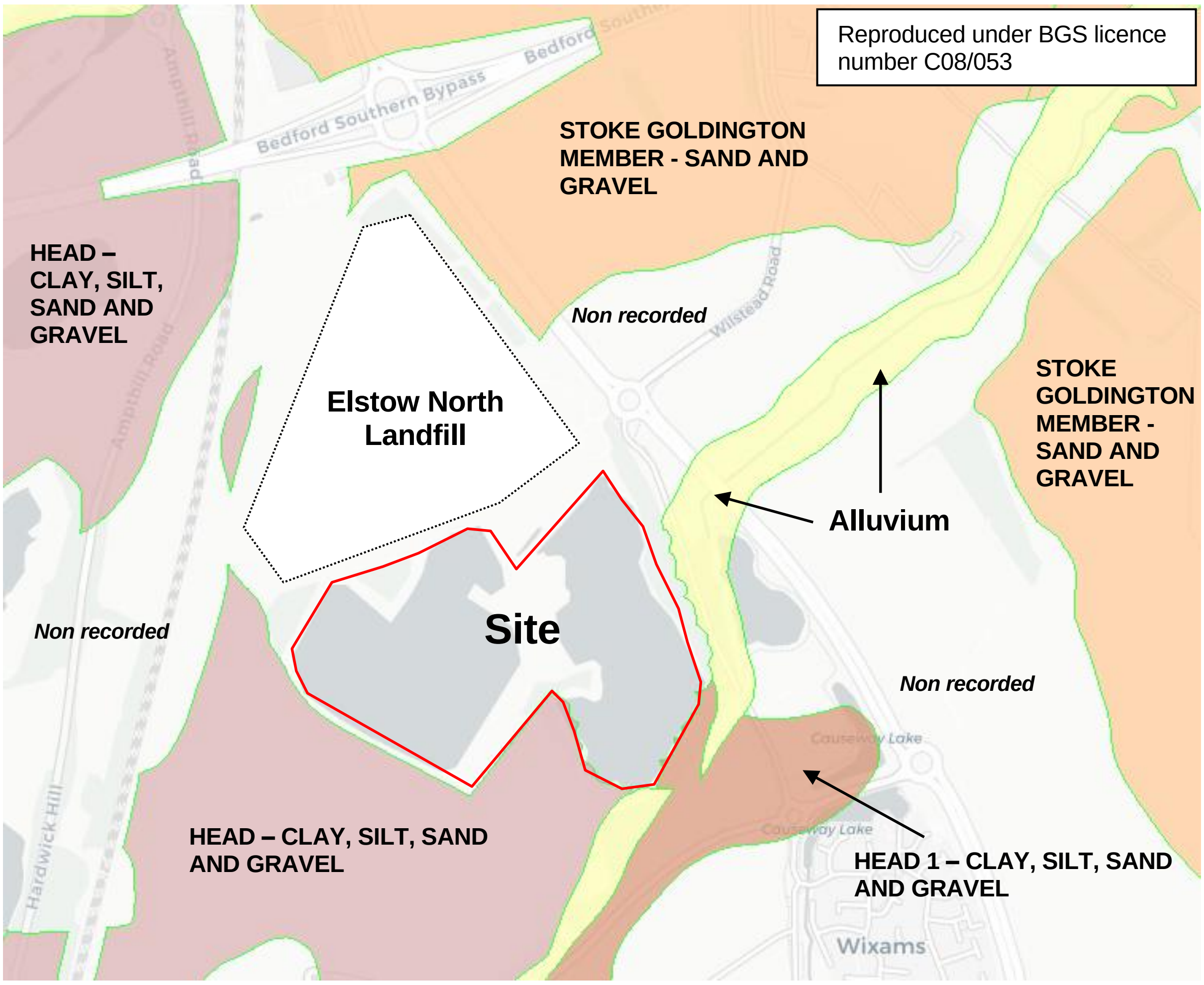
[5] Geology of the Bedford District, A brief explanation of Sheet 203, 1:50 000, BGS, 2010

Figure 4 **Local Geology – Superficial Deposits**



- Extract taken from BGS Viewer - http://mapapps.bgs.ac.uk/geologyofbritain/home.html
- Figure shows limited connection between the site and the adjacent superficial strata

Linkage from the void to the alluvium on the east is through in-situ Oxford Clay / glacial strata

The Jurassic strata were gently folded and faulted during the subsequent period up to the end of the Tertiary.

Most of the folds appear to be associated with the faulting and are superimposed on a very gentle regional dip to the south-east. There are faults, both upgradient and downgradient of the site.

3.2 Pathway Properties and Hydrogeology

As a result of the extensive detail provided in the ESID (5192/R/003/01) obtained from literature accounts and field investigations, it is apparent that the Kellaways Sand is mis-classified as a receptor within previous assessments in the region, i.e. nearby Stewartby, Brogborough, Bletchley in addition to Calvert (Buckinghamshire) and Dogsthorpe (Cambridgeshire).

As such, and for completeness, the following section outlines the regulatory framework / background to provide context as to this conclusion.

Aquifer Classification – Regulatory Background

The classification of water resources is determined by the terminology and objectives of the Water Framework Directive. This directive was adopted with the specific purpose of establishing a framework for the protection of inland surface waters (rivers and lakes), transitional waters (estuaries), coastal waters and groundwater. It will ensure that all aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands meet 'good status' by 2015.

With regards to groundwater, Article 7 (of 2000/60/EC) states that for *"Waters used for the abstraction of drinking water"*

1. Member States shall identify, within each river basin district:

- all bodies of water used for the abstraction of water intended for human consumption providing more than 10 m^3 a day as an average or serving more than 50 persons, and
- those bodies of water intended for such future use.

Member states shall monitor, in accordance with Annex V, those bodies of water which according to Annex V, provide more than 100m^3 a day as an average.

Annex III (assessment of groundwater chemical status) of the Groundwater Daughter Directive (Directive 2006/118/EC) also states in Paragraph 4

4. For the purposes of investigating whether the conditions for good groundwater chemical status referred to in Article 4 (2)(c)(ii) and (iii) are met, Member States will, where relevant and necessary, and on the basis of relevant monitoring results and **of a suitable conceptual model of the body of groundwater, assess**:

(a) the impact of the pollutants in the body of groundwater;

(b) **the amounts and the concentrations of the pollutants being, or likely to be, transferred from the body of groundwater to the associated surface waters or directly dependent terrestrial ecosystems;**

(c) **the likely impact of the amounts and concentrations of the pollutants transferred to the associated surface waters and directly dependent terrestrial ecosystems;**

(d) the extent of any saline or other intrusions into the body of groundwater; and

(e) **the risk from pollutants in the body of groundwater to the quality of water abstracted, or intended to be abstracted, from the body of groundwater for human consumption.**

Groundwater is considered to have a good chemical status when:

- measured or predicted nitrate levels do not exceed 50 mg/l, while those of active pesticide ingredients, their metabolites and reaction products do not exceed 0.1 µg/l (a total of 0.5 µg/l for all pesticides measured);
- the levels of certain high-risk substances are below the threshold values set by Member States; at the very least, this must include ammonium, arsenic, cadmium, chloride, lead, mercury, sulphate, trichloroethylene and tetrachloroethylene;

- the concentration of any other pollutants conforms to the definition of good chemical status as set out in Annex V to the Water Framework Directive;
- if a value set as a quality standard or a threshold value is exceeded, **an investigation confirms, among other things, that this does not pose a significant environmental risk.**

The Water Framework Directive (WFD) also defines an “aquifer” as

> “*a subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater”.*

and defines a “Body of groundwater” as

> “*a distinct volume of groundwater within an aquifer”*

The directive therefor quantifies an aquifer as a rock bearing a sustainable useable quantity of water in excess of 10m^3/d on average. The Environment Agency have further classified the status of an aquifer into Principal and Secondary Aquifers defined as:

Principal Aquifers: These are layers of rock or drift deposits that have high intergranular and/or fracture permeability - meaning they usually provide a high level of water storage. They may support water supply and/or river base flow on a strategic scale. In most cases, principal aquifers are aquifers previously designated as major aquifer.

Secondary Aquifers include a wide range of rock layers or drift deposits with an equally wide range of water permeability and storage. Secondary aquifers are subdivided into two types:

- **Secondary A** - permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers. These are generally aquifers formerly classified as minor aquifers;
- **Secondary B -** predominantly lower permeability layers which may store and yield limited amounts of groundwater due to localised features such as fissures, thin permeable horizons and weathering. **These are generally the water-bearing parts of the former non-aquifers.**

There is a third type of rock classification “Unproductive Strata”. These are rock layers or drift deposits with low permeability that have negligible significance for water supply or for river base flow.

The classification exercise undertaken for the purposes of the WFD was based on a simple assumption presented by the Environment Agency to the British Geological Survey (BGS) that rocks characterised as mudstones are unproductive strata and that all other strata (including potentially permeable bands and lenses) are classified as an aquifer, and hence considered as a high priority receptor within risk assessment irrespective of whether there is a viable sustainable recharge or not.

As a first stage high level screening exercise this is a useful starting point to focus on the key water resource strata and ensuring that important baseflow contributors to the surface water ecosystems are identified.

With regards to the aquifer status, the WFD defines two criteria, namely a requirement to monitor those bodies which provide more than 100m^3/day as well as bodies of water used for the abstraction of more than 10m^3 a day as an average. These abstraction figures therefore provide a benchmark or threshold for assessing and classifying aquifers as either Principal or Secondary Aquifers.

Where there is the requirement for site specific clarification is associated with how a water body is assessed when sustainable recharge rates approach or are below 10m^3/day, but do not have a geological description as a mudstone. Under this condition, the groundwater resource value cannot be associated with abstraction, as there is clearly too little recharge to sustain abstraction. However, this does not prevent a need to assess such a geological strata as a pathway towards either a more permeable strata or its net base-flow contribution to surface water.

Regional Hydrogeological Properties

The Kellaways Sand only provides yields of local significance from shallow to moderate depth wells within the south western section of the Cotswolds area; elsewhere in the country the yield is low to negligible. Consequently, the Kellaways Sand is specifically not identified as part of the Jurassic minor aquifers identified within Table 1.2 ("Reference table of aquifer /formation/unit names for which entries exist in the Aquifer Properties Database") of "The physical properties of minor aquifers in England and Wales"[6], which describes strata with aquifer potential nationally. It is only within the discussion of "The Jurassic sequence on the East Midlands Shelf, the Worcestershire Basin/Cotswolds and the Wessex Basin" Table 6.5 - 6.7 that the Kellaways Sands is identified as a potential Minor Aquifer.

The yields and quality obtained from the Kellaways Sand in the west (*i.e*. the Cotswolds) or towards Humberside are significantly different to that obtained from the Kellaways Sand Formation associated with the East Midlands Shelf, where no springs issue from the Kellaways Sand at outcrop. The yield is also so low that where clay pits are excavated into the Kellaways Sand, the associated discharge into the pits is below evaporative losses and there is not a requirement to manage the discharge. Studies by Mather *et al.* (1998)[7] also concluded that at the low hydraulic conductivities and minimal thickness that the Kellaways Sand could not yield a useful abstraction rate.

The Cornbrash Limestone is described as providing small, perched groundwater supplies which tend to dry out during drought periods, especially if hydraulically separated from the underlying Great Oolite Limestone, which is the case within the East Midlands Shelf, where the underlying Blisworth Clay provides the hydraulic separation from the Blisworth Limestone (lateral equivalent of the Great Oolite Limestone). Within the East Midland Shelf, the Blisworth Limestone is reported to feed springs in Lincolnshire, however, in the Midlands area, where the thin useable zone is exploited, it is at the expense of river recharge fed by springs. Furthermore the Cornbrash and Blisworth Limestone quickly tend to become saline with depth and distance from the recharge zone.

Local Hydrogeological Properties

The hydrogeological properties of the strata underlying the site have been established by rising head tests within the groundwater monitoring infrastructure installed as part of the SI program. Aquifer status is discussed in Section 4.

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[6] British Geological Survey (2000). The Physical Properties of Minor Aquifers in England and Wales. Environment Agency R&D Publication 68, BGS Technical Report WD/00/04

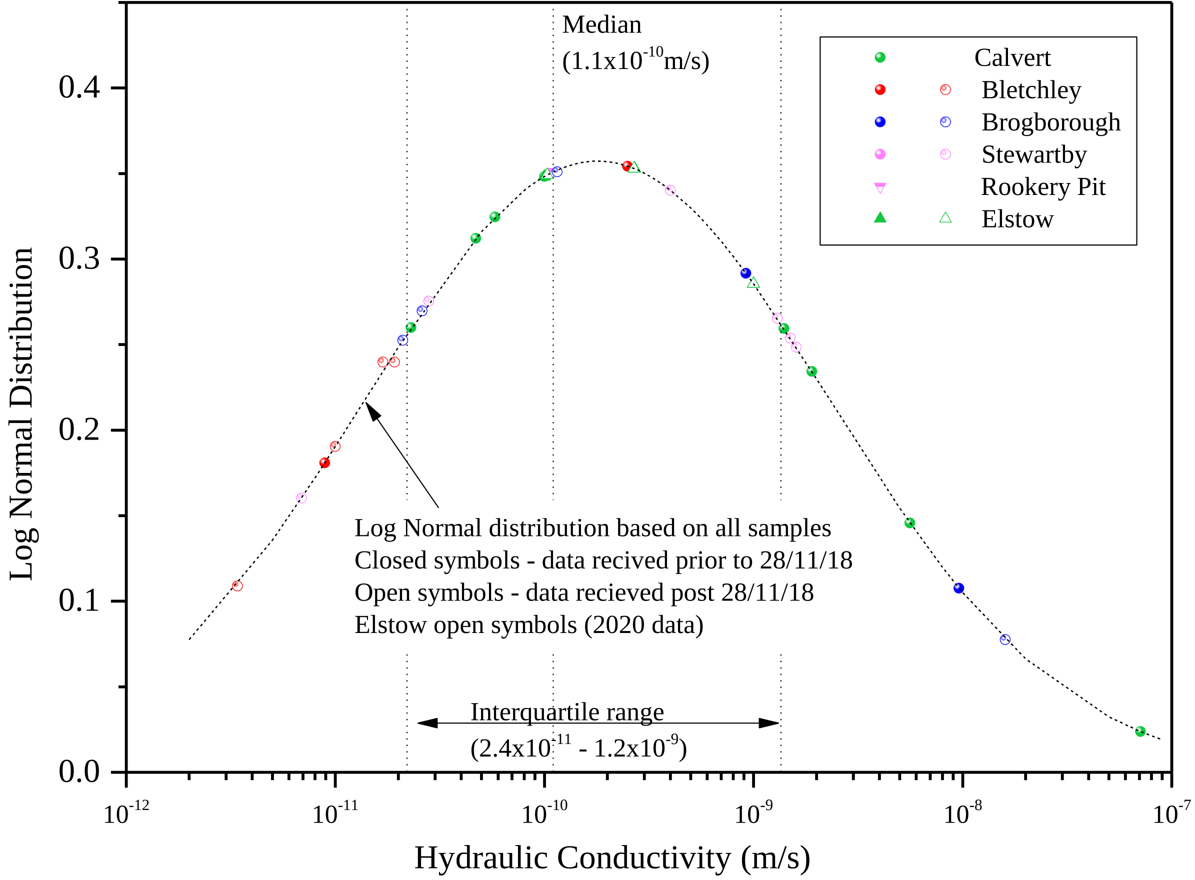
[7] Mather, J., Halliday, D. & Joseph, J.B. (1998). Is all the groundwater worth protecting? The example of the Kellaways Sand. *In: Robins, N.S. (eds) Groundwater Pollution, Aquifer Recharge and Vulnerability.* Geological Society, London, Special Publication, **130**, 211-217.

A recent extensive literature review however of the Kellaways Sand (all known available data) was conducted by Rick Brassington (Consultant Hydrogeologist)[8] in association with ongoing works at FCC's Calvert Landfill (Buckinghamshire) and the determination of bulk hydraulic properties. The low bulk hydraulic conductivity (median value) of the formation of 0.00259m/d (3x10^{-8}m/s) for 56 measurements was consistent with the observations made at all Oxford Clay sites with identical conceptualisation to Elstow (i.e., at Dogsthorpe, Calvert, Bletchley, Brogborough, Stewartby). The bulk hydraulic conductivity (all data) was also similar to the 90th%ile value previously attained from site boreholes at Dogsthorpe.

Laboratory hydraulic conductivity testing has been undertaken on multiple samples from boreholes at Calvert, Bletchley, Brogborough and Stewartby and Elstow to further understand the hydraulic properties of this stratum.

The recent data collected from Elstow and across all companion sites follows a log normal distribution would imply a median of 1.1x10^{-10} m/s, and an interquartile range of 2.4x10^{-11}m/s to 1.2 x10^{-9}m/s (Figure 5), *i.e.* the upper range of this interquartile is approximate to the prior BGS published median conductivity (of 4x10^{-9}m/s).

Figure 5 Kellaways Sand Laboratory Hydraulic Conductivity



The laboratory determinations on 3 Kellaways Sand drill core samples from Elstow returned hydraulic conductivity results of 1x10^{-9}m/s and 1.03x10^{-10}m/s (BH18/01); 2.68x10^{-10}m/s (BH18/02). The average of the three Elstow laboratory tests is 4.6x10^{-10}m/s. Variance is attributed to particle size distribution (PSD), the 1x10^{-9}m/s conductivity result was obtained from a sample with a sand/silt/clay % ratio of 40,24,27.

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[8] The Kellaways Sand - Aquifer Designation & Definition of Pollution (Brassington) June 2017

There are no corresponding PSD's for the other two triaxial tests. Consistent with previous observations if the strata is to be classified based on the laboratory hydraulic properties the conclusion drawn would be that the Kellaways Sand has a typically hydraulic conductivity of 4.6×10^{-10}m/s at site which is an order of magnitude below that required for a mineral liner and an artificial geological barrier.

With respect to this "*low permeability*", of important note are the results of a recent detailed investigation regarding geotechnical properties at Coronation Pit[9] (located ~2km to the southwest). Atterberg limits tests on 7 samples indicated a moisture content of 14-19%, liquid limit 33&34%, plastic limit 14-16% and plasticity indices of 17-19 resulting in the material classification of "*a low plasticity clay*". This does not fit the description of an aquifer but corroborates previous investigations and assumptions that the Kellaways Sand in certain areas of the UK is more akin to an aquiclude or aquitard[12].

Field investigations however from the nearby Coronation Pit recorded *in-situ* permeability constant head packer test results of 9.48×10^{-8}, 1.17×10^{-6}, 1.98×10^{-7}, 1.23×10^{-7} and 2.74×10^{-7}m/s compared to variable falling head test results of 2.31×10^{-7}, 5.3×10^{-8}, 4.29×10^{-7},1.06×10^{-7} and 9.09×10^{-8}m/s. The laboratory investigations from the same study reported hydraulic conductivities of 1 - 3 orders of magnitude lower than the field data at 2.7×10^{-10} - 1.6×10^{-7}m/s even when tests were undertaken on sand grade samples (i.e. >75% sand, <25% clay and silt).

On-site rising head testing has provided further detail on the differences reported in literature between site derived information compared to that obtained from laboratory analysis. Some consolidation effects from laboratory analysis can be expected however miss-representation of the formation's hydraulics are apparent if only short-term field recharge tests are performed.

This has been verified by comparing a short-term test on BH18/03 (conducted over 110 minutes) compared to the results of recharge after the sustained pumping trial conducted over 1.7 days (2435 seconds). The comparative results (k) were 1.05×10^{-7}m/s and 7.55×10^{-9}m/s respectively. The results are informative and demonstrate that "full recovery" of water levels pre- and post-pumping must be obtained before testing is finalised.

The rising head test permeability (k) for BH18/01 is reported at 4.08×10^{-9}m/s (trial duration of 1270 seconds) and BH18/02 at 3.37×10^{-9}m/s (trial duration 2840 seconds).

The rising head test observations (low bulk permeability) are supported by the evidence from pump test trials performed at Elstow (see below) and previously at Calvert in 2017[10] and laboratory data.

Hydraulic testing of the Cornbrash Limestone at the Stewartby landfill site and Coronation Pit has however returned permeability's of 8×10^{-10}m, 2×10^{-8} and 2×10^{-9}m/s which is consistent with that of the Blisworth Clay at 2.5×10^{-10}m/s also at the Stewartby site.

Such a low hydraulic conductivity is unsurprising for a cemented limestone, with intervening clay and mudstone layers. It is therefore considered that the Kellaways Clay, Cornbrash Limestone and the Blisworth Clay form a continuous low permeability geological barrier between the Kellaways Sand and the Blisworth Limestone.

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[9] GroundSolve Ltd. (2013). Coronation Pit, Stewartby, Investigation of the Kellaways Sand
[10] TerraConsult 2017, Calvert Landfill – Sustainable Groundwater Yield Test. Ref: 2077/R/102/1

Groundwater Yield

Sustainable yield trials have not been undertaken with the Kellaways Sand since the early 20th century because the initial conclusions demonstrated a negligible yield of a non-potable water. However, a sustainable yield can be extrapolated from the Kellaways Sand hydrogeological properties for a theoretical abstraction point using the following methodology:

(Equations 1 & 2):

Radius of influence

$$R_0 = \sqrt{2.25.T.\frac{t}{S}}$$

Equation 1

Where

- R_0 Radius of influence (m)
- T Transmissivity (assuming 10^{-7}m/s, over a continuous 3m aquifer thickness)
- S Storativity[11]
- t Time (days)

and the borehole yield, at Time t can be estimated from

$$Q = \frac{k(H^2 - h^2)}{C.\log(^{R_0}/_{r})}$$

Equation 2

Where:

- k Hydraulic conductivity (m/d), calculated at the expected conductivity of the Kellaways Sand of 10^{-7}m/s)
- H Aquifer thickness (typical thickness of 3m) – from regional information
- h Height water in well (assumed as 0.25m, during abstraction, *i.e.* the pump height)
- R_0 Radius of influence (from equation 1)
- r Radius of well (assumed as 0.15m, *i.e.* from a 300mm diameter well)

Drawdown curves and yield calculations even for a 300mm diameter borehole indicate that the steady-state yield would be between 30 – 40 litres per day after a few weeks of abstraction, which would reduce further to 20 - 30 litres per day over time. The radius of influence of an abstraction borehole would increase over time to a radius of between 0.1 and 1km within the first two years of sustained abstraction from a single well abstraction point (Figure 6 and Figure 7).

It should be noted that the yield estimation is based on an aquifer hydraulic conductivity (of 1×10^{-7}m/s) which is 2 orders of magnitude higher than the hydraulic conductivity from boreholes BH18/01, BH18/02 and BH18/03 hence the drawdown predictions are overly conservative.

Sensitivity analysis demonstrates that the Kellaways Sand has a low to negligible yield and that thicknesses would have to be in excess of 20m before a yield in excess of 1m^3/day could be generated and given that thicknesses are generally in the 2.5 – 5.5m range (locally), such a yield could not be generated (Figure 8).

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[11] Brassington, (1988). Field Hydrogeology. John Wiley & Sons, Chichester

Figure 6 Groundwater Drawdown Curve and Yield Depletion Over Time

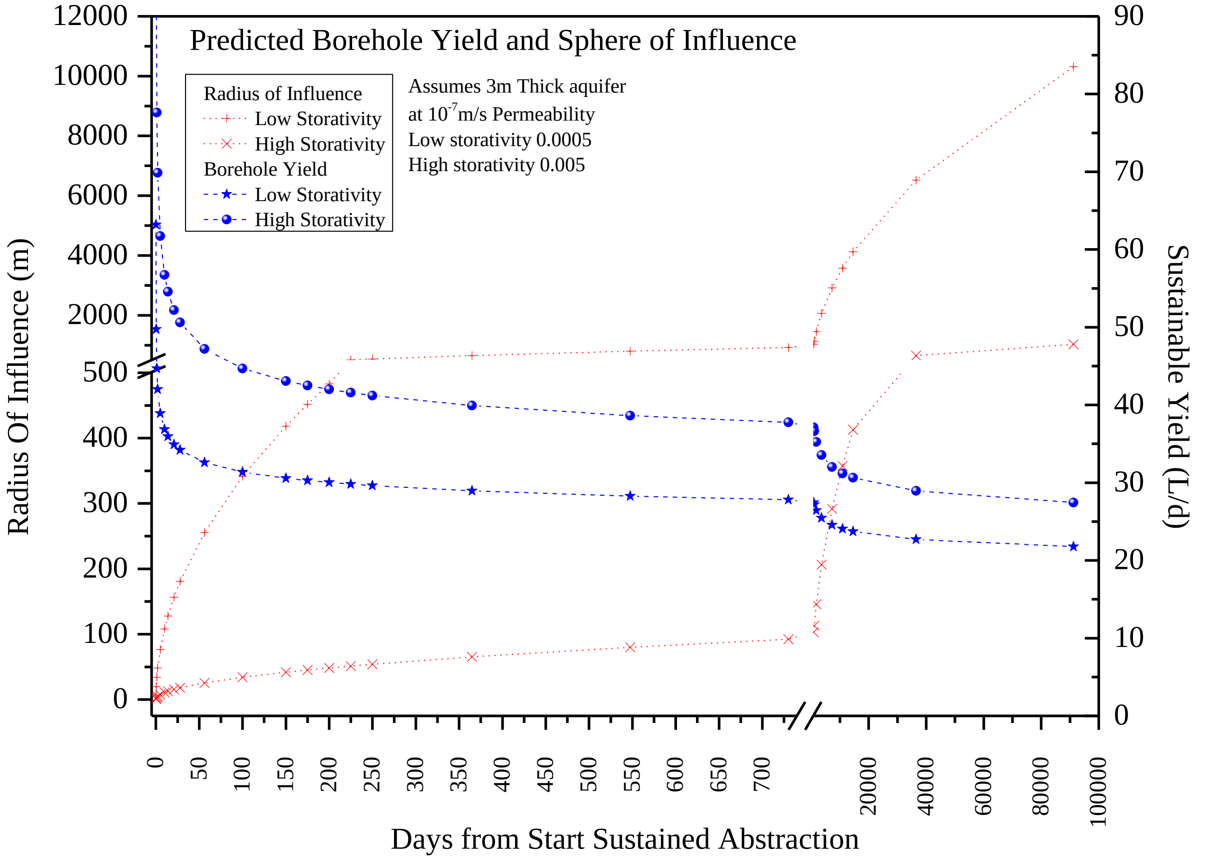


Figure 7 Groundwater Drawdown Curve and Yield Depletion Over Time

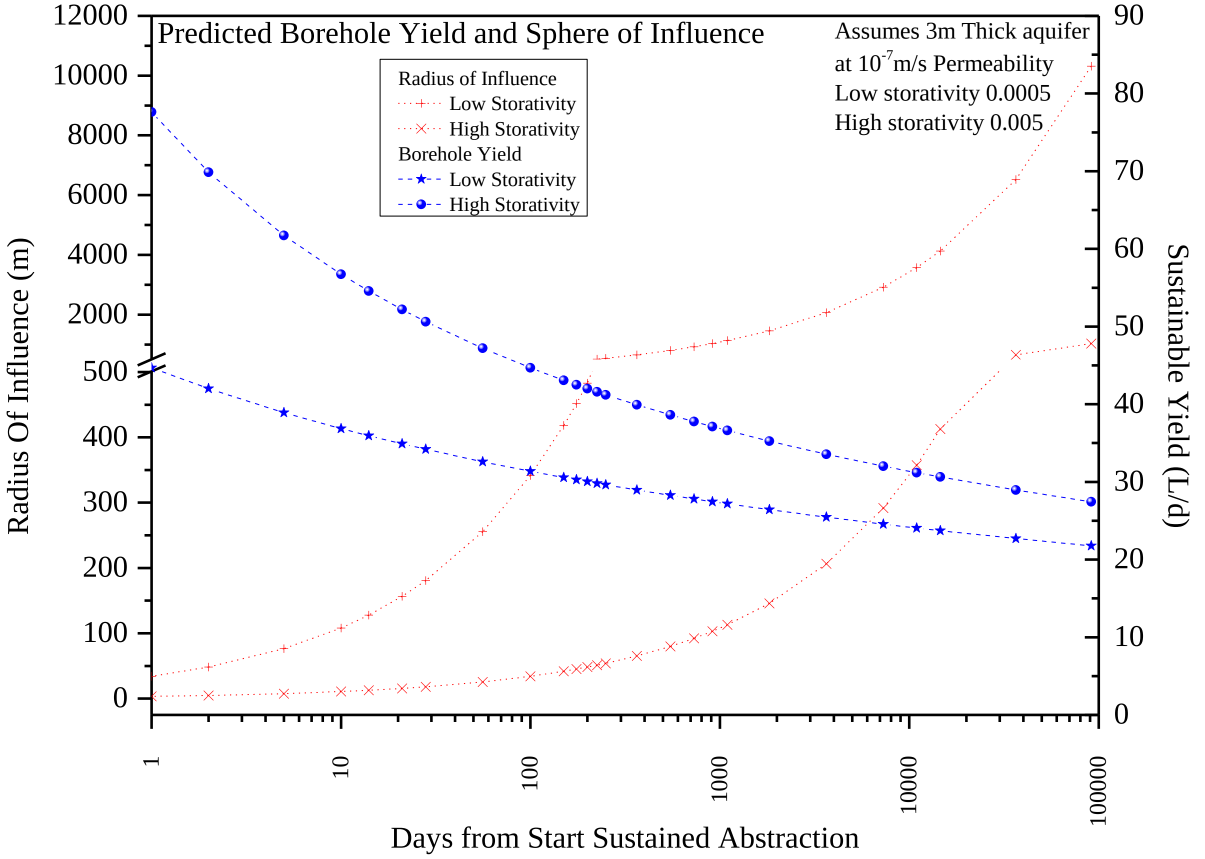


Figure 8 Predicted Borehole Yield at Various Kellaway Sand Thicknesses

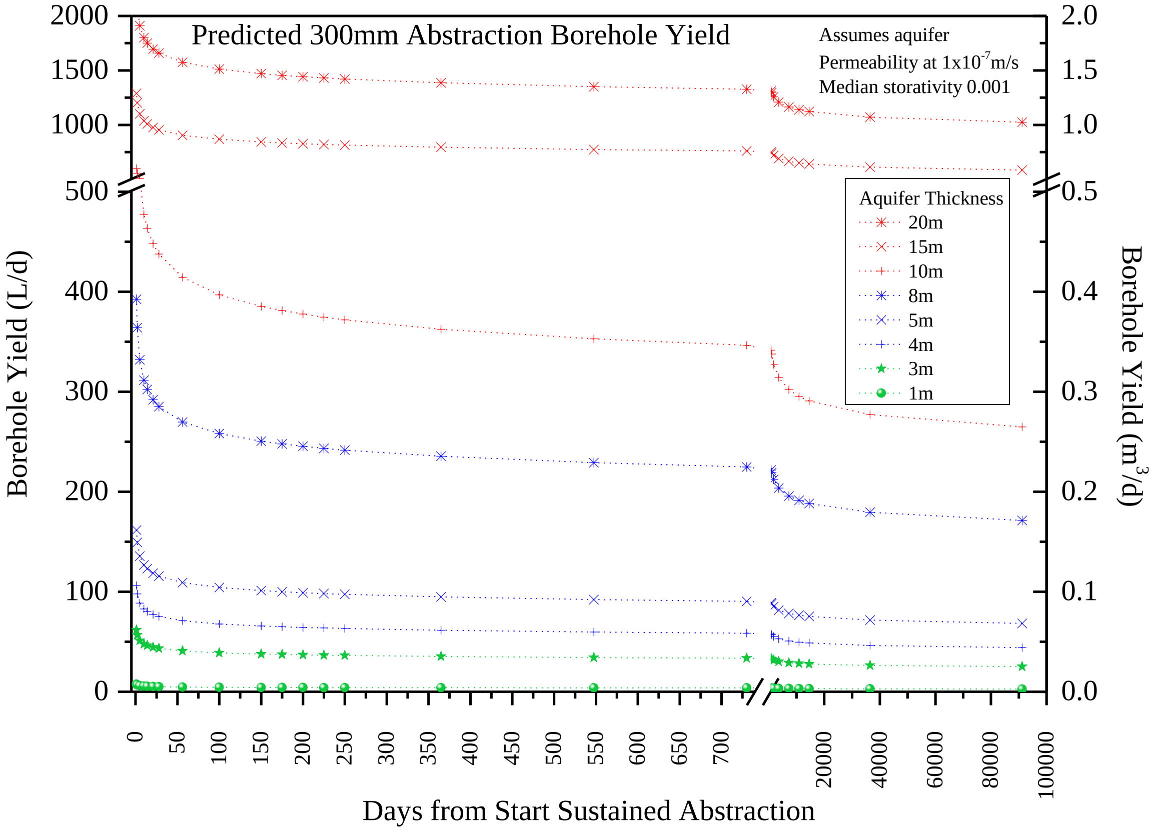
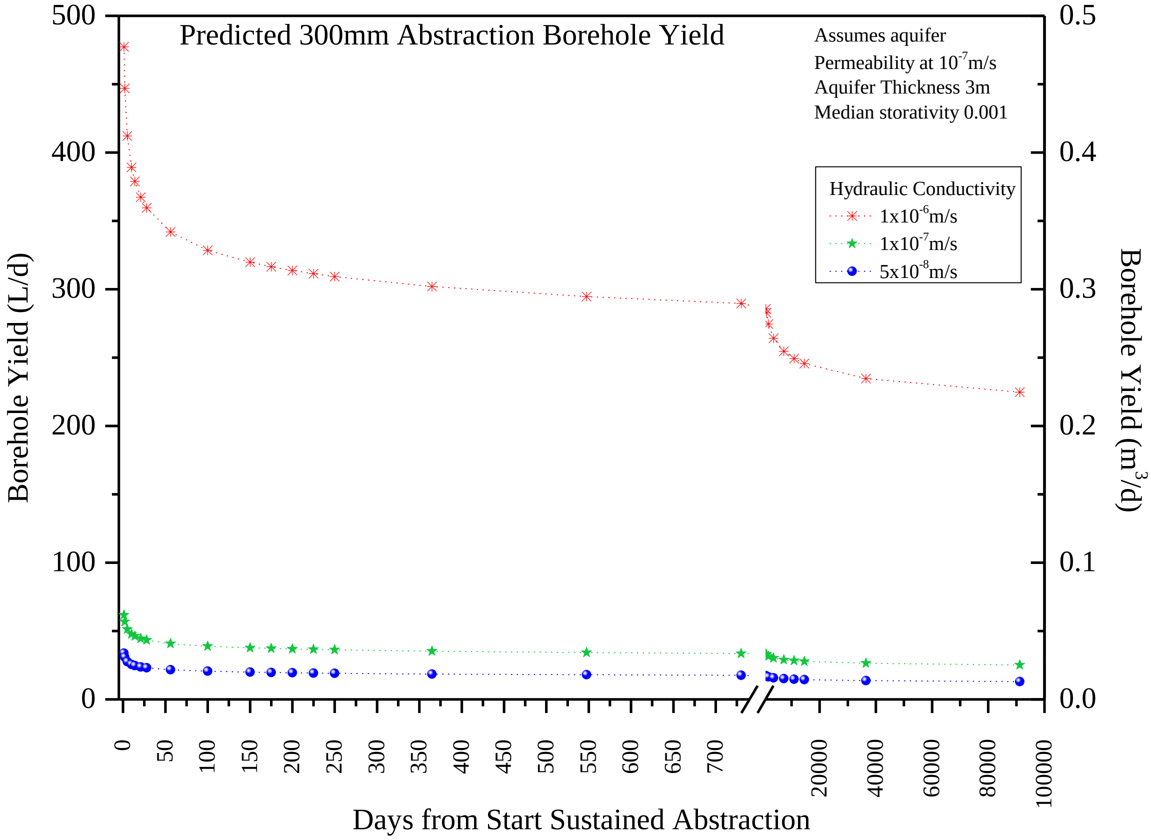


Figure 9 Predicted Borehole Yield at Various Hydraulic Conductivities



Similarly sensitivity analysis also demonstrates that even at the outlier hydraulic conductivity range (*i.e.* ~10^{-6}m/s- recorded at Coronation Pit); it would not be possible to obtain a significant yield (Figure 9).

Although at the upper hydraulic conductivity range sustained yields would be in the 1 Population Equivalent (PE) range, *i.e.* 0.2 - 0.3m^3/day.

Such a yield is highly unlikely to be sustainable, previous works have established and documented this point, Halliday et al 1997[12] stated that at Bletchley *"the transmissivity of the formation is in the order of 1.7x10^{-6}m/s, so low that it could neither be expected to yield useful supplies of water nor be considered as even a very local water supply source".*

This was confirmed by field trials where boreholes can be pumped dry in a few minutes but take more than 24 hours to recharge. Halliday et al. (1997) also documented[12] that during clay extraction:

> *"it was necessary to cut drainage channels into the base of the pit to control surface water on the pit base "some of which broke through onto the top of the Kellaways Sand. Even though the piezometric head in the formation outside the pit usually remained several meters above its base within a very few metres of its edge (i.e. the hydraulic gradient was very steep close to the pit edge), no dry weather flow was ever seen in the channels. In other words, the formation failed to yield any water even when exposed in the side of a channel and when there was a substantial piezometric head in the same formation only a few metres away laterally".*

The regional low flow / hydraulic movement of the Kellaways Sand groundwater (of circa 18mm / year[12]) in the Marston Vale is further supported by recent studies by Westaway et al (2015)[13] at Stewartby. The negligible flux has preserved a thermal gradient within the groundwater whereby one of the overlying brick kilns has thermally heated the ground for a period of circa 56 years.

Although the low thermal conductivity of the Oxford Clay minimized the heat that was transported into the subsurface, other local rock properties and fault offsets, notably low hydraulic conductivity (with limited/zero recharge) have evidently facilitated the preservation of, and assisted our ability to recognize this subsurface thermal anomaly.

The theoretical yields and sensitivity analyses are confirmed by recent site testing. The pump test trials at Calvert (2017) indicated that after the initial volume of water was removed from the borehole annulus, and surrounding disturbed strata, the yields diminished incrementally each hour of the test. The best yields returned 3.48m^3/day, and the worse was at 1.66m^3/day.

Sustained pumping trials were undertaken at site between the 26th and 30th November 2020. Three boreholes appropriate for the pumping trials at site are those located within the land bridge that separate the two lakes (BH18/01, BH18/02 and BH18/03). Initial head volumes removed equated to between 3.9 and 5.4m^3/day to reach steady state recharge.

- Borehole BH18/01 reduced from 3.86m^3/day after the first hour and incrementally reduced to 3.6m^3/day after a 5hr pumping test (total volume of 840 ltr removed during the trial)

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[12] Halliday, D, Joseph, J.B, and Mather (1997). Engineered Landfill containment - Lessons from the Oxford Clay

[13] Westaway, R, Scotney, PM, Younger, P.L, Boyce, A (2015). Subsurface absorption of anthropogenic warming of the land surface: The case of the world's largest brickworks (Stewartby, Bedfordshire, UK). Science of the Total Environment 508 (2015) 585–603

- BH 18/02 reduced from 3.66m^3/day after the first hour and incrementally reduced to 2.98m^3/day after a 6hr pumping test (total volume of 895 ltr removed during the trial)
- BH 18/03 (test 1) reduced from 3.74m^3/day after the first hour and incrementally reduced to 2.92m^3/day after a 6hr pumping test (total volume of 850 ltr removed during the trial)
- BH 18/03 (test 2, conducted the following day) reduced from 3.61m^3/day after the first hour and incrementally reduced to 2.76m^3/day after a 4hr pumping test (in total this borehole was pumped for 10hrs)

The three boreholes yield on average 3.3m^3/day with a maximum and minimum of 3.86m^3/day and 2.76m^3/day respectively, similar to the *"best case"* results obtained at Calvert.

The results at both sites (one third to one tenth of the Water Framework Directive requirement useable water requirement threshold) confirm BGS observations reported within their Physical Properties of Minor Aquifers[14] that

- the Kellaways Sand yields small supplies of groundwater, however there are no springs issuing from the outcrop, and that
- groundwater from the Kellaways Sand does not fill pits dug above, as the volumes of groundwater involved are small compared to the evaporative losses.

The BGS note[5] that exposure of the Kellaways Sand is sometime visible in drainage ditches and sumps in the bottom of brick pits in the Marston Vale, reference is given to Quest Pit at Stewartby (~2km to the southwest, opposite Coronation Pit) and photographic evidence of the stratigraphic succession is provided at Plate 3, page 14. There does not appear to be any water ingress or standing present from this exposure of the uppermost surface of the Kellaways Sand.

The picture is not reproduced due to copyright restrictions however it can viewed on page 14 at: http://pubs.bgs.ac.uk/publications.html?pubID=B06908, if the exposure is the top of the Kellaways Sand (at Quest Pit) it is evident that there is no water ingress or ponding.

Groundwater Bodies

The Kellaways Sand beneath the Elstow landfill site forms a limited hydraulic unit, as the body is restricted by a series of faults which juxtapose the Kellaways Sand against low permeability strata which prevents there being a hydraulically continuous connection to a surface or sub-cropping recharge zone (Figure 10).

If the groundwater within the Kellaways Sand is considered as an aquifer under the definition of the WFD, then the Kellaways Sand must form a single groundwater body downgradient of the site. With recharge potential restricted to a small area of outcrop to the northeast, the recharge potential to the Kellaways Formation is indirect either via a downwards gradient through the increasing thicknesses of overlying mudstone, or from an upwards gradient from the Blisworth Limestone as discussed by Mackay and Cooper (1996)[15] which would result in any dissolved constituents migrating into the Oxford Clay. Figure 10 demonstrates that the formation is not only hydrogeologically off-set upgradient (flow direction discussed in section4) it is also off-set immediately downgradient.

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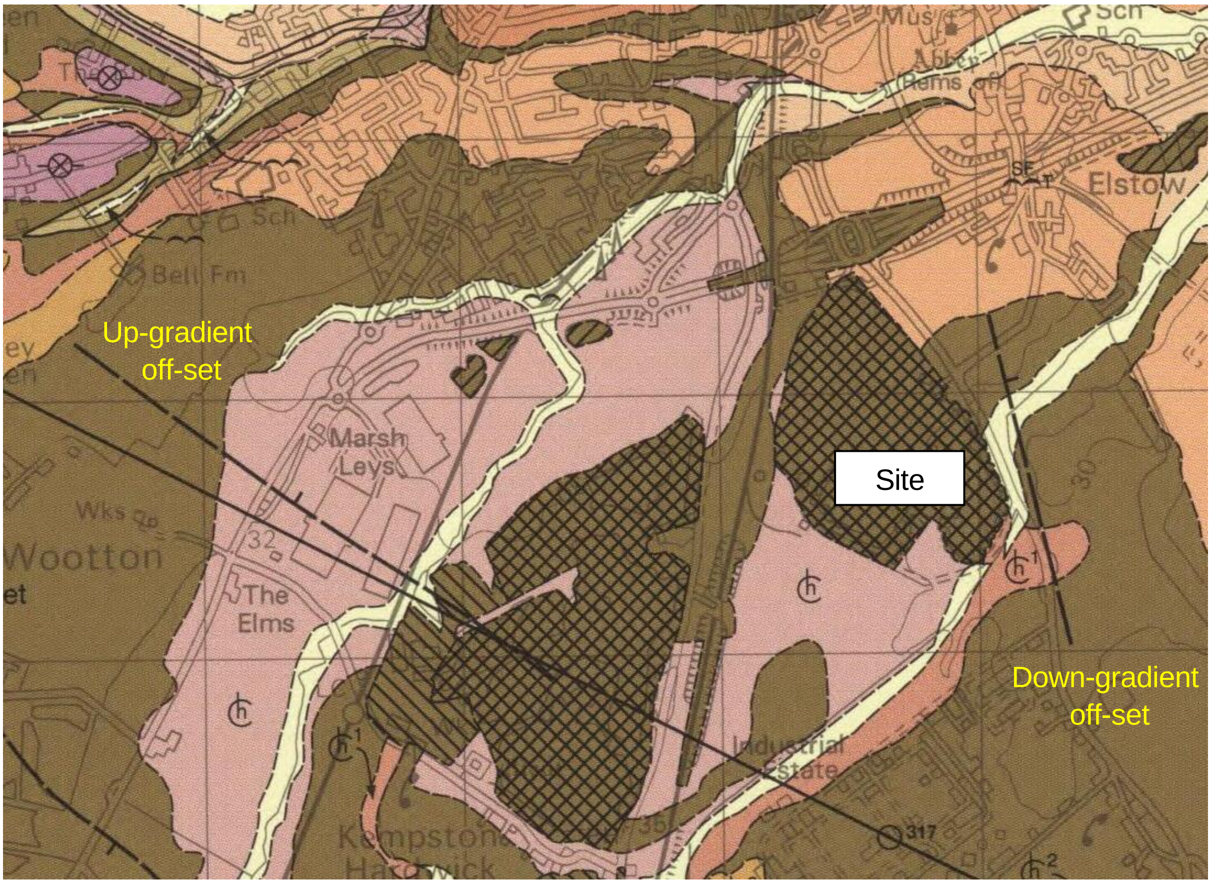
[14] British Geological Survey 2000, The physical properties of minor aquifers in England and Wales, Technical report WD/00/4. Environment Agency R&D Publication 68, Jones et al.

[15] Mackay, R., and Copper, T.A. (1996). Contaminant transport in heterogeneous media: a case study. 1. Site characterisation and deterministic modelling. *Journal of Hydrology* Vol. 175, *383-406*

Figure 10 Local Geology and Fault Off-sets



Groundwater Mineralisation

Groundwater within the Kellaways Sand has been reported as saline since the original investigations in water resources were undertaken in the later 19th and early 20th centuries and formally published in aquifer reviews by 1909, when Woodward and Thompson[16] reported that for the Kellaways Sand *"this water is simply an impossible one to contemplate using as a regular water supply, either for drinking or general domestic use. The amount of salt is enormous."*

The formation was laid down offshore in the latitude of the modern Mediterranean Sea, when the structure of Britain was still taking shape. At this stage, the coal swamps of the north-western shore of the island had subsided below the sea so that the Kellaways Clay was formed in fairly deep water and the Kellaways Sand was blown and washed from what had become the hot desert land. Under such conditions, evaporite minerals would be expected, particularly $CaSO_4$ and NaCl based, which could account for the inherent natural salinity.

Groundwater in the Kellaways Sand is reported[14] as being of a poor quality, often saline, water however does issue from springs and shallow wells in the Cotswolds over 50km to the west. However, even in this area, this is restricted to locations where the Kellaways Sand is topographically elevated and the base is exposed at the surface and can form spring lines. Such salinity is indicative of an elevated inherent salt content (primarily $CaSO_4$ and NaCl) within the strata over and above that expected from the mineralisation of connate waters, even when not confined. Increased $CaSO_4$ concentrations associated with the mineral Selenite

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[16] Woodward, H.B. & Thompson, B (1909). The water supply of Bedfordshire and Northamptonshire from underground sources with records of sinkings and borings. *Memoir of the Geological Survey.*

($CaSO_4 \cdot 2H_2O$) which is prevalent throughout the Oxford Clay. Chloride however does not have a similar range solubility limit; hence chloride concentrations increase with distance away from a surface recharge zone under low permeability conditions. This is a natural process which results in a stratification of the groundwater chloride concentrations increasing with the distance from the recharge zone. The distance to the saline interface is relatively short at Stewartby and Elstow due to the low permeability strata, with minimal thickness encapsulated within a host marine mudstone (i.e. the Oxford Clay).

This conclusion is consistent with observations from Loomis et al (1998)[17] who studied the same stratigraphic units within the Marston Vale, including at the Stewartby landfill using chloride isotope investigations. They concluded that:

> *"Both stable isotope chloride compositions and plots of elements and element ratios from the groundwater and leachate samples indicate that the groundwaters are distinctly different from the landfill leachates".*

This conclusion is consistent with the geochemical expectations for the strata at the base of the Oxford Clay and other similar marine clays and is not a localised phenomenon. The elevated salinity is also reported for the Bedford area[7,12] (as well as the Milton Keynes area to the southwest) with the expected trend of increasing salinity with distance from the recharge area and increasing overlying thickness of marine clays (*i.e*. the Oxford Clay then the Ampthill and Kimmeridge Clays).

4. RECEPTORS

4.1 Aquifers and Abstraction Points

Nationally and regionally the confined strata underling the Oxford Clay is at best a very poor water resource on both recharge and salinity grounds. The groundwater is not potable (section 4.2) and the volume that could be sustainably recharged is low to negligible (less than Water Framework threshold requirements). Such a low recharge typically 1-4m^3/day is consistent with the lack of groundwater abstraction points from either the Kellaways Sand or Blisworth Limestone within 4km of the site. Consequently the site is not within a designated Source Protection Zone (SPZ) and there are no SPZs associated with the Kellaways or Blisworth Formations.

The SPZ designations are related to the exposure of the Great Oolite Group in the west of Bedford and Lower Greensand Group to the south east (Figure 11). A limited area of Kellaways Sand has been exposed by the River Great Ouse to the north east (Priory Park), with a lateral exposure width of ~250 - 300m. This limited exposure in addition to the lack of springs recorded at outcrop suggest base flow contributions to surface water features are negligible.

Both the Kellways Sand and Blisworth Limestone are classified as Secondary A aquifers (at outcrop, northeast of the site, Figure 11). The host rock Oxford Clay is non-productive strata, the Oxford Clay and Blisworth Limestone are not receptors at the site. Where groundwater abstraction does occur, it is related to strata overlying the Oxford Clay, namely localised areas of Gravels, the Great Oolite Group and Lower Greensand Group. Two groundwater abstraction licences are noted in the Groundsure report (Appendix A) at a distance of ~500 to

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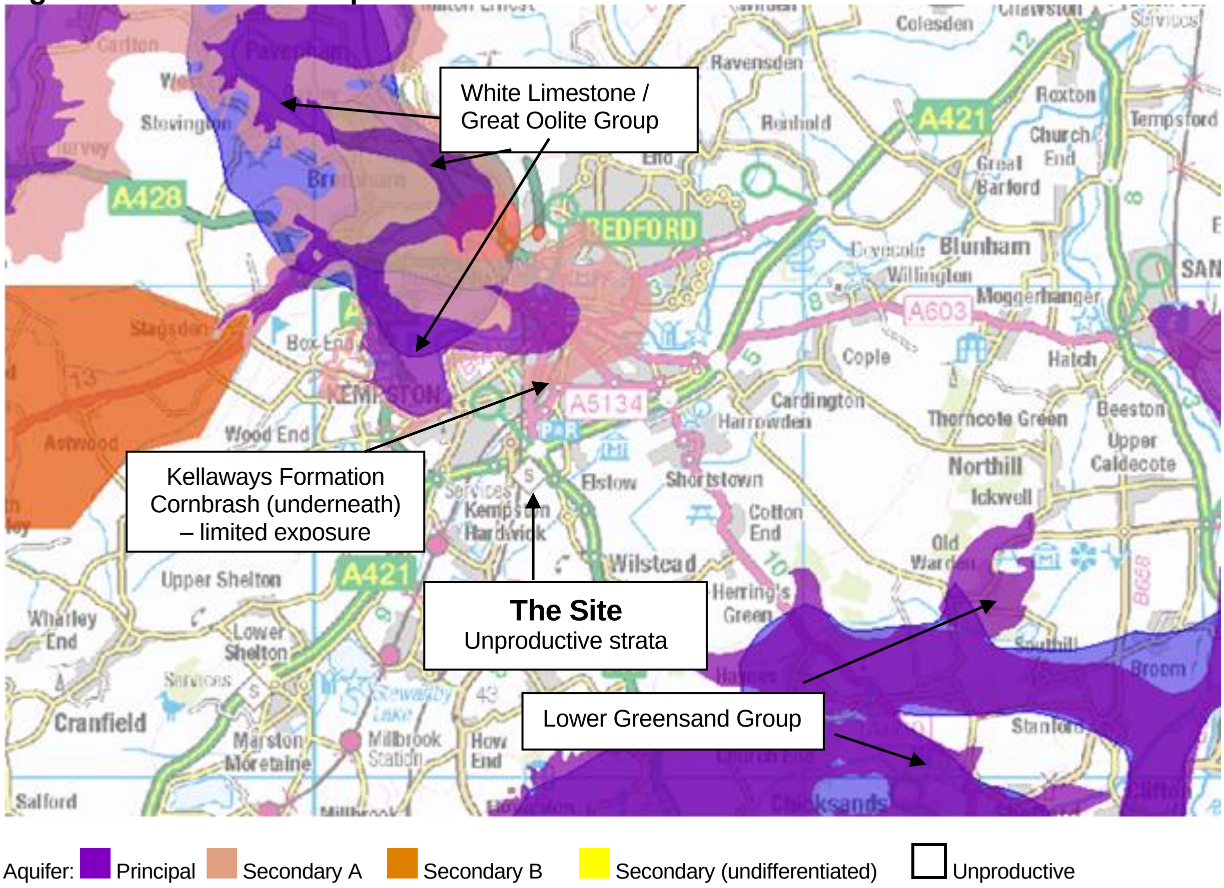
[17] Loomis, J.L. Coleman, M. & Joseph, J. (1998). Use of stable chlorine isotopes to evaluate the origin of a Cl-rich plume in the Oxford Clay, England. Goldschmidt Conference, Toulouse, 1998 Conference Proceedings 901 - 902

the west of site, no details are available but it is expected that any water used is from the Great Oolite Formation sequence below the Kellaways Formation.

Figure 11 Bedrock Aquifer Status



Hydraulically, both boreholes are “upgradient” to the site (section 4.2). This limited distribution and complete lack of abstractions from the Kellaways to Blisworth Formations confirms previous observations[5] in that confinement beneath the Oxford Clay (relatively thin units) dictate both poor quality and yield.

The over-arching characteristics of the Kellaways Sand are a low permeability, highly saline strata which contains insufficient yield to sustain a meaningful abstraction volume whilst the natural salinity makes the groundwater unpotable without significant treatment. The potential for significant pollution transmission through the Kellaways Sand is considered to be low to negligible.

The regional strata properties outlined in Section 3.2 has been demonstrated for all equivalent FCC Oxford Clay hosted sites, key conclusions in this regard are:

1) the Kellaways Sand has no resource value due to the negligible yield.

2) There is no downgradient receptor which could be considered at risk, such as a base-flow to a surface water / ecological feature or a connecting groundwater aquifer body.

3) hydrogeological modelling from the adjacent landfill demonstrates that any “contamination” which could be hypothesised would be restricted to the immediate vicinity of the site; and

4) the Kellaways Sand is not potable due to its natural salinity, whilst there is insufficient yield to enable any treatment process to be implemented

At Elstow, the potential for a connection to the River Great Ouse is recognised, albeit it is noted that there is an exposure face with the River Great Ouse at a distance of 3.8km to the northeast. However quantitative modelling at "biodegradable waste sites" (of a greater pollution potential than the proposed scheme) has indicated no risk beyond the confines of the site boundaries. Notwithstanding these previous conclusions at companion sites, the outcrop of the River Great Ouse is not directly "hydraulically downgradient" and any flow north-easterly is disrupted by the adjacent fault (down throw to the east). If the northerly extent of the fault termination is as depicted in Figure 10, groundwater flow towards the receptor is primarily from Elstow North Landfill.

The Kellaways Sand is not considered to be a receptor in its own right or a risk pathway capable of transmitting pollutants to a receptor, the aquifer status is miss-classified on the basis of both yield and quality, however it is modelled in this document for completeness for risk assessment purposes.

The glacial superficial strata (at the site periphery) are classified as Secondary undifferentiated aquifers, there is no direct linkage from the majority of the void area to these deposits. The alluvium is a Secondary A aquifer and is only present in the course of the Harrowden Brook (c.f. Figure 2 with Figure 4). In a wider context the superficial strata is clay dominated and glacial in origin, any groundwater flow is anticipated to be dictated by local drainage and the River Great Ouse valley and associate tributaries.

4.2 Groundwater Monitoring, Levels and Groundwater Quality

Groundwater Level

Groundwater is monitored over the wider area in boreholes associate with the Elstow North Landfill.

Groundwater data has been obtained previously in the following boreholes:

- Kellaways Sand - EM2B, EM3B, EM7B, EM9B, EM10B, EM28B and EM30B) and;
- Blisworth Limestone - EM2A, EM3A, EM7A, EM9A, EM10RA, EM28RA and EM30RA

Piezometric levels are summarised below (Figure 12), groundwater flow is towards the north east.

The piezometric surface within the Kellaways Sand decreases north eastwards (towards outcrop and the River Great Ouse), from some 27mAOD to around 24mAOD across the Elstow North site. Hydraulic gradient is calculated at 0.005.

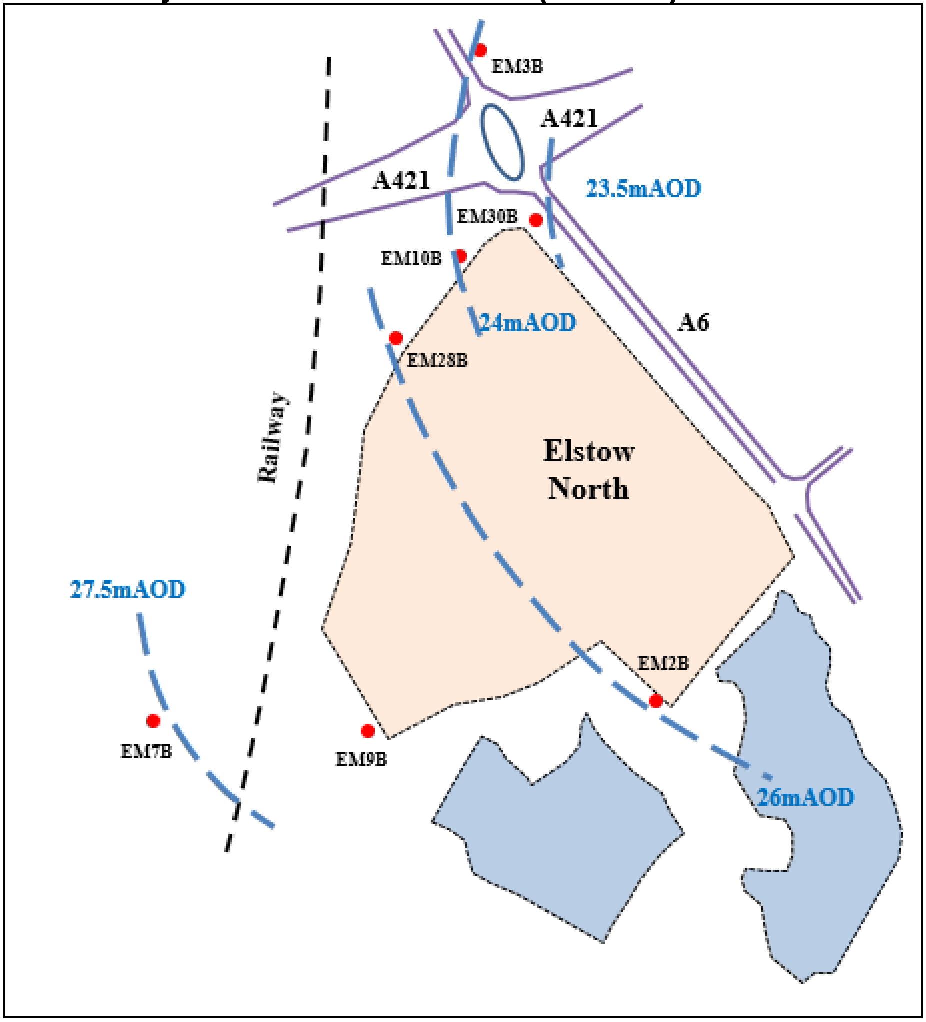
Groundwater Quality

The primary control on groundwater salinity is the saline interface in which chloride levels increase from low to negligible concentrations at the recharge zone towards concentrations in excess of 5,000mg/l.

In most aquifers, where there is a large recharge zone, and groundwater is primarily dominated by surface recharge, this saline interface can be observed at depths below 500m in larger aquifers. The limited thickness of the Kellaways Sands (i.e. <4m, combined with frequent calcified concretions / cementation which restrict water movement) is contained between marine deposited clays, the saline interface is significantly closer to the surface and this effect can be observed at depths of <20m and a distance of <2km from the recharge zone.

These effects are evident at all sites contained within the Oxford Clay with increasing chloride concentrations with increasing distance from the upgradient recharge zone is illustrated in Table 2.

Figure 12 Kellaways Sand Piezometric levels (end 2017)



Lake levels (2020) consistent with long term groundwater level at 25-26mAOD, and recent data from BH 18/01, BH18/02 and BH18/03 (24.5 – 25.8mAOD, Sept to Oct 2020)

Data obtained from the adjacent Elstow North site indicates consistency with this assumption (Table 3) and proximity to outcrop.

With regards to the natural chemistry, the formation at Site does not meet potable water quality criteria (which it clearly cannot meet for a number of substances, including chloride, sulphate and sodium) consistent with the regional quality determinations.

The groundwater is primarily a calcium sulphate solution with secondary calcium bicarbonate and an increasing proportion of sodium chloride with increasing distance from the recharge zone (evident at the nearby Stewartby Site and Coronation Pit to the southwest). The monitoring data confirms the high background sulphate salinity reported historically for the Kellaways Sand within literature sources. Sulphate is within the 500 - 1500mg/l range with a high bicarbonate concentration (Table 3).

Table 2 Kellaways Sand Regional Groundwater Quality (2011 to March 2017) mg/l

Site		NH_4-N	Ca	Mg	Na	K	Cl	SO_4	Alk
	Regulatory Standard	*0.39*	*none*	*none*	*200*	*none*	*250*	*250*	*none*
Calvert	**Max**	3.5	650	127	1240	44	2130	1770	654
	Average	0.88	250	46	581	22	437	1135	327
	85%ile	1.50	347	79	1050	33	765	1503	466
	25%ile	0.08	145	22	156	16	128	951	245
Dogsthorpe	**Max**	3.50	551	110	618	24	310	1600	660
	Average	1.21	250	42	214	13	136	641	359
	85%ile	2.00	346	81	391	17	179	1130	422
	25%ile	0.50	205	20	93	9	105	290	315
Stewartby	**Max**	5.30	364	69	1300	33	1330	1590	450
	Average	0.75	107	25	609	22	681	492	296
	85%ile	1.34	169	32	925	27	1130	789	336
	25%ile	0.06	47	16	286	19	313	249	255
Brogborough	**Max**	1.50	381	85	1340	42	1300	1150	524
	Average	0.53	157	36	706	27	694	710	307
	85%ile	1.20	332	57	1082	34	1140	1016	332
	25%ile	0.09	66	25	454	21	145	558	282
Coronation Pit	**Max**	1.30	446	105	847	48	1320	2020	697
	Average	0.39	153	30	530	23	517	784	258
	85%ile	0.90	233	56	809	30	1167	1119	383
	25%ile	0.03	58	18	178	18	125	389	171
Bletchley	**Max**	6.10	189	66	290	28	151	550	401
	Average	0.88	161	30	105	13	63	280	366
	85%ile	1.52	179	50	169	18	91	507	391
	25%ile	0.14	155	15	30	7	26	118	344
Marston Vale BH Series	**Max**	2.00	57	34	1300	33	1500	629	440
	Average	0.64	32	18	928	24	1062	308	312
	85%ile	1.29	55	21	1026	27	1355	602	343
	25%ile	0.20	8	14	850	22	897	85	291
Marston Vale BH Series	**Max**	4.80	-	-	990	82	1100	-	-
	Average	2.12	-	-	618	32	646	-	-
	85%ile	2.99	-	-	832	44	795	-	-
	25%ile	1.28	-	-	466	22	513	-	-

Shaded Cells exceed regulatory standards; Marston Borehole Series are remote monitoring points in the area between Stewartby and Brogborough Landfill ~ 5 – 8km to the southwest

Table 3 Elstow Kellaways Sand Groundwater Quality (2016 to 2017) mg/l

	Max	Min	Ave
Electrical Conductivity (µS/cm)	3500	1400	2446
Dissolved Oxygen	15	5	8
Alkalinity (Total $CaCO_3$)	690	18	375
Chloride	530	61	200
Ammoniacal Nitrogen (NH_4-N)	17	0.02	3
Nitrite	2.00	0.02	0.23
Nitrate	19	1	5
Sulphate	1500	550	919
Calcium	1300	55	330
Potassium	47	4	19
Magnesium	200	12	57
Sodium	700	53	302

Shaded cells denote exceedance of MAC or typical water quality standards, Limits: EC (2500µS/cm); Chloride & SO_4 (250mg/l); Na (200mg/l); NH4-N (0.39mg/l or 0.5mg/l DWS)
- from https://www.legislation.gov.uk/uksi/2016/614/pdfs/uksi_20160614_en.pdf

This type of profile is consistent with the dissolution of $CaSO_4$ and $CaCO_3$ minerals, a process that is dominated by equilibrium with the host rock, whilst the increasing sodium chloride is a legacy of connate water chemistry.

The chloride and sodium concentrations are greater for the underlying Blisworth Limestone and sulphate concentrations are equivalent. Ammoniacal-N varies in both the Kellaways Sand and Blisworth Limestone but is ~3mg/l as an average concentration in both formations between 2016 and 2018.

Recent site data is comparable to that of Elstow North, however with lower concentrations of chloride, it is also noted that concentrations of Pb are apparent within the Kellaways Sand groundwater at concentrations approximate to the DWS of 5µg/l (0.005mg/l), see ESID 5192/R/003/01.

Table 4 Elstow Blisworth Limestone Groundwater Quality (2016-2017) mg/l

	Max	Min	Ave
Electrical Conductivity (µS/cm)	4100	2000	3168
Dissolved Oxygen	13	5	8
Alkalinity (Total $CaCO_3$)	610	17	352
Chloride	970	69	433
Ammoniacal Nitrogen (NH_4-N)	12	0.04	3
Nitrite	1	0.02	0.28
Nitrate	54	1	7
Sulphate	1500	220	910
Calcium	1100	29	321
Potassium	38	7	17
Magnesium	130	15	51
Sodium	1500	70	489

4.3 Surface Water Monitoring and Quality

The adjacent Harrowden Brook forms the closest receptor. The main reach of this watercourse runs parallel with a limited section of the site boundary (Figure 2).

The watershed catchment contributing drainage flows to this watercourse subsequently form part of the Upper and Bedford Ouse drainage catchment.

At its closest, the brook is ~30m from the site boundary, flows north easterly and is culverted under Wilstead Road. The brook flows northerly (almost parallel with Wilstead Road) before turning north easterly via culverts under the A6.

Surface water quality is not monitored around the site.

4.4 Receptor Summary

The potential receptors at site have been qualitatively assessed as:

1) Kellaway Sand - Not considered as a receptor below or downgradient of the site based on:

- Considered as Unproductive Strata based on natural high salinity and low yield
- Chloride concentrations up to 530mg/l, Sulphate concentrations up to 1,500mg/l
- Primary recharge via Oxford Clay with limited to negligible surface recharge
- Low to negligible thickness (1.3 – 4.3m)

- Low to negligible effective porosity, i.e. high content of ferroan-calcified concretions limit both conductivity and storage (PSD test data indicates clay component can vary from 27% to 43%)
- No downgradient exposure at surface (only cross gradient exposure at Bedford)
- Not considered as a receptor below or downgradient of the site – modelled for completeness only.

2) Blisworth Limestone and other non-clay strata below Kellaways Clay - Not considered as a receptor below or downgradient of the site based on:

- Potential higher hydraulically yielding body than Kellaways Sand, only if not cemented and flow is via an extensive fissure network, consistent with Karst limestone
- Larger recharge zone compared to Kellaways Sand
- Elevated salinity due to natural mineralisation (greater than Kellaways Sand)
- Recharge via Kellaways Clays (i.e. expected high salinity)
- No exposure at surface downgradient of the site (only cross gradient)
- No known pathway linkages from the site due to the intervening and confining Kellaways Clay
- Not considered as a receptor below or downgradient of the site.

3) Harrowden Brook (alluvium)

Potentially a surface water receptor adjacent to the south eastern perimeter of the site:

- Pathway for lateral migration through the *in-situ* Oxford Clay / glacial strata for leachate (pore-water) where levels are in excess of invert to the Brook
- Minimum distance of 30m from the site boundary
- Not considered as a receptor as the restoration (topographic) profile falls to the north, with a low point of 25mAOD (Figure 3) hence pore water (see section 5) cannot exceed the invert level of the brook at ~30mAOD.

5. CONCEPTUAL SITE MODEL

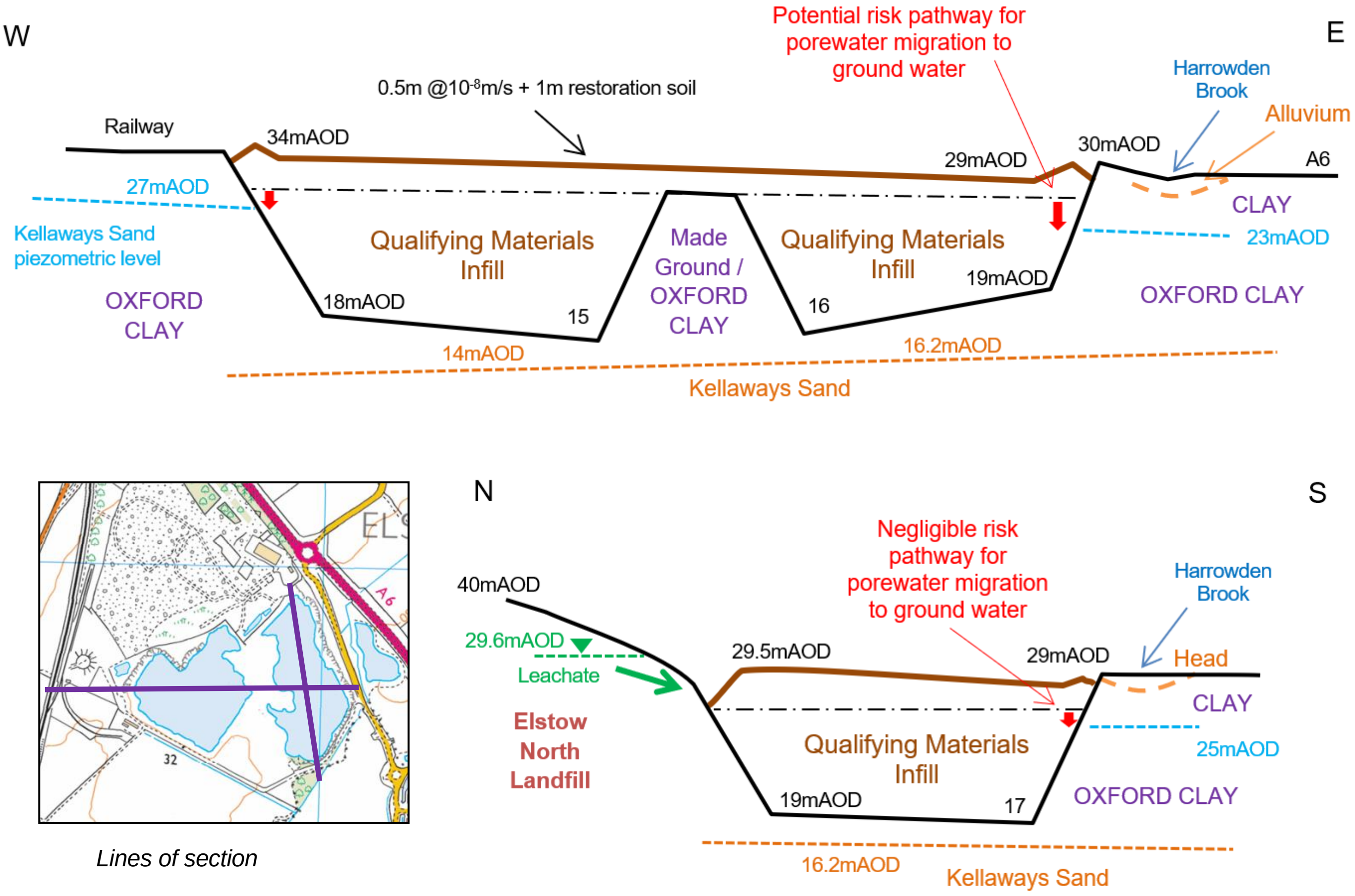
A conceptual hydrogeological model has been developed for the site, based on the proposed infilling scheme (Figure 13). The site is a “sub water table” site.

The conceptual model has been based on the Source → Pathway → Receptor relationship where the:

- Source is the Qualifying Materials used to restore the void
- The Pathway is the sidewall engineering and the geological pathway towards a water resource; and
- The Receptor is an underlying or adjacent water resource

It is considered that the underlying hydrogeological system (Kellaways Sand) does not constitute a justifiable receptor, however as a matter of completeness it is incorporated within this assessment. The majority of the porewater (that will be contained within the qualifying materials infill) will be hydraulically contained by the piezometric level of the Kellaways Sand groundwater.

Figure 13 Schematic Conceptual Model



Lines of section

The potential for porewater levels to exceed the piezometric surface is limited, hence the potential for downward migration is negligible (Figure 13).

The invert level of the Harrowden Brook on the south boundary of the site is at ~31mAOD (30mAOD on the eastern boundary). Any porewater contained within the infill (Qualifying materials) has the potential to seep from within the site toward the brook if levels rise above 30 - 31mAOD.

Pore-water movement however is likely to be vertical (through the basal liner) and lateral flow through the liner and containing sidewall of *in-situ* Oxford Clay it is not envisaged to be significant. Drainage is towards the separation bund between the east and west voids (Figure 3) and not the external east and west margins of site periphery hence base flow contribution to the brook to the south east or east is therefore discounted.

Any seepages of porewater from the Elstow South site into the separating land between the Elstow North site at ~26mAOD will be insignificant in both volume and concentrations compared to the leachate quality, volume and contributing surface water run-off water volumes from the Elstow North site. As such, no further assessment is required.

However, the design of the restoration profile falls to a low point of ~29mAOD on the east of the eastern void area and ~29mAOD at the south. With a sloped gradient that falls from the west and north of the infilled voids it is not be possible for pore-water to exceed a level of 31mAOD hence there is no further requirement for quantitative modelling.

6. RISK ASSESSMENT METHODOLOGY

6.1 Justification for Modelling Approach and Software

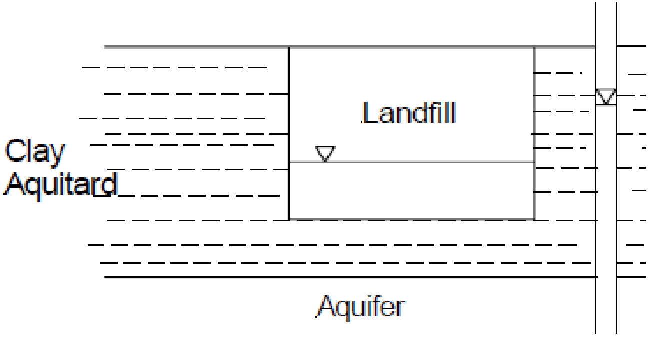
There are two modelling approaches that can be taken for the Elstow site in regard to the groundwater system.

The first is to consider the site as a hydraulically contained landfill, in which the water levels (pore-water) within the site are below the external groundwater level. The Environment Agency has produced a model calculation programme to assess contaminant fluxes from hydraulically contained landfills[18], which is supported by a technical review[19]. This model was produced because mass transport models, including programmes such as LandSim, are based on substance migration which is proportional to the hydraulic gradient. Under hydraulic containment this flux is into the landfill site and the hydraulic models would return a zero value.

The hydraulic containment model has been produced to assess the chemical diffusion flux through the sides and / or base of a landfill in the context of how diffusion is affected by the inwards hydraulic gradient and landfill liner properties. The Hydraulic Containment Model (HCM) is a steady-state model, which calculates the diffusion of contaminants through a geological strata or liner that does not take leachate depletion into account. Therefore, unlike models such as LandSim, the effects of the source depletion as contaminants are removed, such as by abstraction, are not considered within the model conclusions and any conclusions drawn are therefore conservative with regards to the intermediate and long term.

Given that the site is located within a mudstone (*in-situ* clay), there is no risk with regards to lateral migration and the only potential migration route is vertically through the base of the site. Under this scenario, then Hydraulic Containment Model Scenario 1 (Figure 14) would usually be considered as the most appropriate scenario.

Figure 14 Hydraulically Contained Landfill: Scenario 1, Landfill Located Wholly within a Clay Aquitard / Geological Barrier



A second approach would be to consider the potential impact of a leachate head in excess of the underlying groundwater piezometric head acting on the site (illustrated schematically on Figure 13 – red arrows).

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[18] Environment Agency (2004) Contaminant fluxes from hydraulic containment landfills spreadsheet v1.0 User Manual. Science Report SC0310/SR

[19] Environment Agency (2004) Contaminant fluxes from hydraulic containment landfills spreadsheet - a review. Science Report SC0310/SR

The LandSim model[20] developed on behalf of the Environment Agency by Golder Associates is the preferred model for assessing risks to groundwater from above groundwater landfill sites by each of the UK's Environment Agency bodies.

This strategy was adopted in previous HRA's in the justification for higher leachate levels relative to adjacent groundwater, an approach recently accepted by the Environment Agency at Calvert, Bletchley, Stewartby, Brogorough and Dogsthorpe.

Considering a restoration profile of 1m in thickness, and low point of 26mAOD to the north of the eastern void, pore-water will only exceed the piezometric level in the Kellaways Sand on the eastern boundary by some 1 – 2m.

The LandSim model is a Monte Carlo simulator, which is a probabilistic simulator to assess contaminant migration from a source through a barrier system which underlies the potential polluting source, vertically through an unsaturated zone beneath the barrier, and a saturated pathway before entering an aquifer.

The Monte Carlo Simulator allows for a stochastic approach to be taken for the model. Stochastic models allow a range of values to be input for each parameter. The model then selects a value for each parameter when running a simulation. Thus the model overcomes difficulties associated with deterministic models which take a single value for each parameter when a series of end member scenarios are run without understanding how each parameter interacts or their relative importance.

The model also performs multiple simulation runs and the simulation programme compiles the results as a statistical probability of a particular result occurring. When the results are statistically combined, the likelihood of each of the 'worst-case' parameters occurring simultaneously can be compared with the general case which is actually expected to happen. The impact of each of these cases and that of intervening probabilities can then be compared with relevant water standards and the background geochemistry to determine if the risk is acceptable.

Regarding surface water, the conceptualisation considers that there is no requirement for modelling.

6.2 Preliminary Screening & Source Term

The first screening stage in any hydrogeological risk assessment is the identification of the types of substances within a potential leachate which could cause harm. For harm to occur, the leachate within a site contained by a significant artificial and / or geological barrier must contain sustained concentrations of hazardous or non-hazardous substances above background concentrations. In addition, where dissolved substance concentrations are above background concentrations the concentrations within the leachate should exceed the relevant DWS for assessments where the primary receptor is groundwater, or the EQS where the primary receptor is a surface water feature.

Where substance concentrations are likely to be above these threshold levels, then attenuation processes should be considered to establish whether an impact on the receiving waters is likely to occur.

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[20] Golder Associates (UK) Ltd (2003) LandSim. Landfill Performance Simulation by Monte Carlo Method. *Environment Agency R&D Publication 120*

The proposed waste types all conform to the requirements of The Landfill Tax (Qualifying Material) Order 2011 (as amended). Source characterisation will preclude any significantly contaminated soils.

It is therefore considered highly unlikely that there will be sufficient putrescible organic matter or xenobiotic organic substances present to produce a sustained leachate at concentrations of concern for organic substances to pose a risk to water resources. The resultant risk is therefore likely to be associated with the presence of substances which could persist through the combustion process and / or are likely to be present within the received waste types which include:

1) The soluble salts, e.g. chloride and sulphate; and
2) Non-hazardous and hazardous metals.

The presence of soluble salts can be of concern where a site is located above a low salinity hydrogeological system. However, at Elstow, the expected leachable sulphate and chloride concentrations are consistent with background. Therefore, soluble salts within the QMs proposed for the void (in this case sulphate and chloride) cannot have a discernible or adverse impact on receiving water quality. Background salinity has been discussed earlier within this appraisal.

The source term data reviewed includes recently obtained source term (pore-water) from Calvert (Pit 6) which is an equivalent site to the geological & hydrogeological setting at Elstow.

The current infill materials at Calvert however include an Incinerator Bottom Ash (IBA) component from the adjacent Greatmoor EfW hence salts are expected to be elevated compared to the proposed excavation and construction wastes to be utilised at Elstow.

In fact, wastes that would have been deposited at Calvert will be diverted to Elstow making the Calvert source term a relevant comparator for Elstow. Based on the Waste Leaching Limits and Observed Leaching Concentration from Hazardous Soil Landfills presented at Table 1 it is applicable to model:

- Lead
- Nickel
- Arsenic

Similar sites (with equivalent waste inputs) have allowed the collation of the following data presented in Table 5 hence the following would also be considered for modelling:

- Cadmium
- Ammoniacal-N
- Chloride
- Sulphate

The modelled source term for this appraisal is provided in Table 6.

Given the high attenuation factor expected for the metals to the Oxford Clay, breakthrough is considered unlikely. Ammoniacal-N has been included within this list of substances because of its perceived sensitivity.

Table 5 Leachate Source Term Comparison (mg/l)

Substance	DWS	Eardswick Hazardous			Site 2 (Non-Haz Soils)			Calvert Pit 6		
		Min	Ave	Max	Min	Ave	Max	Min	Ave	Max
pH	6 - 9	7.0	7.7	8.6	7.0	7.6	8.6	6.1	7.3	8.3
NH_4-N	0.39	<0.02	1.9	17	0.18	5	11	0.01	5	20
Nitrate-N	11	0.3	2	9	0.3	1	5	-	-	-
TOC	none	1	12	39	7	65	140	19	50	200
BOD	none	1	5	48	9	7	14	3	24	77
COD	none	26	110	259	91	170	264	28	107	378
Chloride	250	9	139	728	154	283	404	16	338	684
Sulphate	250	14	411	1,300	1,380	1,510	1,720	11	1,068	1,990
Alkalinity	none	153	442	785	62	403	1,010	8	86	202
Potassium	none	7	16	28	27	32	40	22	50	94
Cadmium	0.005	0.00006	0.0025	0.062	<0.0001	0.0001	0.0002	0.00001	0.00006	0.0002
Mercury	0.001	<0.00001	0.0002	0.001	<0.0002	0.0001	0.0002	<0.0003	<0.0003	<0.0003
Arsenic	0.01	0.001	0.005	0.072	0.005	0.013	0.023	0.002	0.011	0.048
Lead	0.01	0.002	0.006	0.020	<0.001	<0.001	<0.001	0.0005	0.0008	0.013
Chromium	0.05	0.001	0.006	0.019	<0.001	0.003	0.006	0.0005	0.0028	0.05
Copper	2	0.002	0.008	0.024	<0.001	0.005	0.016	0.001	0.013	0.119
Nickel	0.02	0.002	0.009	0.042	0.012	0.022	0.037	0.003	0.017	0.089
Zinc	5	0.003	0.079	1.591	0.002	0.010	0.019	0.002	0.020	0.27

Shaded cells exceed Drinking Water Standards (DWS), units are mg/l, Calvert Pit 6 Data – FCC, 2018-2020 (Aug), outliers removed. Chloride and sulphate potentially elevated as a result of IBA inclusion

Table 6 Modelled Leachate Source Term

Substance	Concentration (mg/l)
Lead	0.002-0.007-0.02
Nickel	0.002-0.017-0.089
Arsenic	0.001-0.007-0.072
Cadmium	0.00001-0.003-0.062
Ammoniacal-N	0.01-3-20

*sulphate and chloride not modelled as average (most likely values) are equivalent to background groundwater concentrations in the Kellaways Sand

7. RISK ASSESSMENT

7.1 Hydraulic Containment

The hydraulic containment model is a spreadsheet model published by the Environment Agency and default values proposed in the accompanying review document have been utilised where material or site-specific properties cannot be sourced. The hydraulic containment model is based on the assumption that leachate levels are below the external piezometric level. The model itself is insensitive to the absolute levels used, but is dependent on the relative difference in water levels and the barrier properties. A leachate height set as 0.1m below the external groundwater level has been assessed to demonstrate the diffusion potential for a substance from the site.

For sensitivity purposes the model has been run in “List I” mode for all substances to the edge of the Oxford Clay barrier, *i.e.* prior to entering the Kellaways Sand so that a direct comparison can be made with the underlying groundwater quality. The model uses single input parameters and assumes a constant source concentration; therefore the model has been run for a fixed period of 1,000years. Model parameters are shown in Table 7 for the pathway specific parameters using ammoniacal-N as an example.

The substance specific parameters are presented in Table 8. The diffusion coefficients modelled are derived from the Hydraulic Containment supporting documentation[18] for cadmium and ammoniacal-N. However, there are no readily available diffusion coefficients for the remaining metals modelled and therefore it is considered appropriate that the diffusion coefficient for cadmium is used for lead, nickel and arsenic.

The source concentrations are taken as the maximum concentrations observed within the leachate for these substances as illustrated in Table 6.Attenuation coefficients have been derived from testing[21] of the Oxford Clay from Oxfordshire and supplementary information[22].

Table 7 Hydraulic Containment Model Parameterisation

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION	Parameter	Units	Justification / Reference / Notes
Scenario	1		Landfill constructed into Oxford Clay pit
Basal width perpendicular to groundwater flow	330	m	Void dimensions (combined)
Basal length parallel to groundwater flow	420	m	Void dimensions (combined)
Elevation of base of landfill	17.5	mAOD	Design
Elevation of top of aquifer	16	mAOD	Borehole data
Maximum thickness of underlying aquifer	4	m	Aquifer thickness range 1.4 – 4.3m
Leachate head inside landfill	23.9	mAOD	Sensitivity analysis - below modelled groundwater level
Groundwater head outside landfill	24.0	mAOD	Site monitoring data
CONTAMINANT PARAMETERS			
Contaminant name	Ammoniacal-N	-	Sensitivity analysis
Contaminant type	Inorganic	-	
Contaminant classification	List I	-	Modelled to edge of liner for conservatism
Concentration in landfill leachate	20	mg/l	Maximum concentration expected
Free water diffusion coefficient	1.96E-09	m2/s	HCM Table 3.1
Partition coefficient in clay	3	l/kg	Fannin, 2006 QJEGH, Vol 39, 267 - 281
Half-life in clay (0 for no decay)	0	days	
Decay in sorbed phase?	No	-	
MINERAL BARRIER / LINER			
Thickness of mineral barrier is calculated as 1.5m	1.5	m	minimum thickness likely to be constructed ($1x10^{-8}$) + in-situ barrier ($1x10^{-11}$) – combined appraisal
Hydraulic conductivity	1E-10	m/s	Un-weathered Oxford Clay
Average pore radius	1E-5	m	Adapted from Burke et al (1988)
Effective porosity	0.15	-	Assumed continuity through ancient marine clay
Dry bulk density	2100	kg/m3	
Tortuosity	10	-	HCM Table 3.3, De Marsily (1986)

In reality, the sloping / undulating nature of the existing sidewall dictates that the thickness of clay “to the site boundary” varies between 6m and 21m (in addition to the reworked liner)

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[21] Fannin, C. A. (2006). An evaluation of the chemical attenuation capacity of UK mineral liner and geological barrier materials for landfill leachate components. *Quarterly Journal of Engineering Geology and Hydrogeology.* **39** 267 - 281

[22] Science Report SC050021 / Arsenic SGV, Science Report SC050021 / Arsenic supplementary report

Table 8 Hydraulic Containment Model Substance Specific Parameters

Parameter	Modelled Source Concentration	Background Kellaways Sand Concentration (2018-2019)	Attenuation Coefficient (K_d)	Diffusion Coefficient
	mg/l	(max mg/l)	m/g	m^2/s
Lead	0.02	No data	1000	$0.717x10^{-9}$
Nickel	0.09	No data	>863	$0.717x10^{-9}$
Arsenic	0.07	No data	500	$0.717x10^{-9}$
Cadmium	0.06	No data	1,947	$0.717x10^{-9}$
Ammoniacal-N	20	17	3	$1.96x10^{-9}$

Chloride and sulphate not included as per background groundwater concentrations, Table 3

7.2 Hydraulic Containment Diffusion Model Results

The hydraulic containment model predicts that after 1,000 years, ammoniacal-N concentrations would be at 0.086mg/l prior to mixing with groundwater through the Oxford Clay barrier.

In a worst-case scenario, if the geological barrier had a thickness of 0.5m at $1x10^{-8}$m/s as designed, (i.e. removing the *in-situ* component of the Oxford Clay, assumed 1m as a minimum) this would result in ammoniacal-N concentrations of less than $3.4x10^{-14}$mg/l at the edge of liner hence there is no potential impact on groundwater quality from ammoniacal-N.

The priority metals, cadmium, arsenic, nickel and lead are not predicted to impact the Kellaways Sand groundwater, (Table 9) at maximum source term concentrations when leachate levels (qualifying material pore-water) are 0.1m below adjacent groundwater.

Table 9 Hydraulic Containment Model Results

	Source	Edge of Oxford Clay Liner	DWS
	mg/l	mg/l	mg/l
Lead	0.02	No breakthrough	0.01
Nickel	0.09	No breakthrough	0.02
Arsenic	0.07	No breakthrough	0.01
Cadmium	0.06	No breakthrough	0.005
Ammoniacal-N	22	0.08	0.39

7.3 Longer term scenarios – Basal Leakage

The next stage of assessment addresses the potential impacts if leachate levels in the site raise above adjacent groundwater levels of the Kellaways Sand.

A LandSim model has been constructed to assess the potential impact in accordance with previously accepted applications. The LandSim model follows the same methodology as the hydraulic containment model to estimate substance concentrations exiting the Oxford Clay.

The model has been run assuming that basal containment is provided for by the Oxford Clay.

The Oxford Clay will act as a continuous hydraulic barrier / liner between the Qualifying Materials and the underlying groundwater system. The model was carried out assuming an operational period consistent with the estimated period of operations (i.e. 10 years), after which infiltration will be limited by the placement of a cap.

The cell dimensions and materials properties are based on the proposed restoration scheme.

The LandSim model has an advantage over models such as the hydraulic containment model in that the model uses a stochastic approach and therefore a probability density function can be used to give a statistical based interpretation of the likelihood that the site could impact the environment.

The summarised design parameters used within the model are presented within Table 10.

Table 10 LandSim Model Parameters for Assessing Impact at Base of Oxford Clay

Parameter		**Elstow East and West Void**
Operational	Yrs	10
Aftercare	Yrs	60
Infiltration to open waste	mm/yr	575
Capped infiltration	mm/yr	50
Thickness Waste	m	5-16
Waste Porosity		0.1-0.2
Waste Field Capacity		0.15
Waste Dry Density		1.2
Basal Liner Type	type	Clay
Liner & Geological Barrier Thickness	m	0.5
Permeability	m/s	$1x10^{-8}$
Unsaturated Zone	m	1 - 1.5 – 2.1
Permeability (in-situ Oxford Clay)	m/s	$1.6e^{-11}$,$1e^{-10}$,$3e^{-10}$
Length Base	m	420
Width Base	m	330

The maximum head of leachate “above piezometric level” (*as porewater levels are not expected to exceed 26mAOD*) is calculated between 1 and 2m. Simulation undertaken with a 1.5m “overall average” leachate head (SIM A). Liner modelled at extremely conservative 0.5m.

7.4 LandSim Model Results

The maximum breakthrough concentrations for the metals have no environmental significance as they are all less than their associated DWS’s (Table 11), the hazardous metals lead and arsenic are predicted at a concentrations below or equivalent to their respective MRV’s of 0.0002mg/l (0.2µg/l) and 0.005mg/l (5µg/l).

A similar conclusion can be drawn for ammoniacal-N as the predicted 95%ile concentration exiting the Oxford Clay is less than the average observed concentration within the local groundwater, 3mg/l (Table 3). Consequently, there will be no impact on the groundwater system. The results demonstrate acceptable low concentrations in a status where leachate levels (pore water within the soil infill) exceed adjacent groundwater. As such, there is no requirement for additional plume migration / dispersion modelling within the framework of the Remedial Targets worksheet for the modelled substances exiting the clay barrier.

A sensitivity analysis has been undertaken (SIM B), increasing the leachate head to 3m. The simulated results did not indicate any exceedance of DWS, changes to the 95%ile concentrations were de minims (including ammoniacal-N).

Table 11 LandSim Predicted Concentration at the Base of the Oxford Clay, Prior to Groundwater Mixing

Parameter	DWS	Modelled Concentration (mg/l)	Predicted Concentration Existing Oxford Clay		Years to peak concentration
	mg/l		Most Likely (50th%ile)	Maximum (95th%ile)	
Lead	0.01	0.002-0.007-0.02	0.0009	0.001	9,720
Nickel	0.02	0.002-0.017-0.089	0.002	0.003	8,400
Arsenic	0.01	0.001-0.007-0.072	0.004	0.005	6,000
Cadmium	0.005	0.00001-0.003-0.062	0.0001	0.002	20,000
Ammoniacal-N	0.39	0.01-3-20	0.4	1.8	39

7.5 Lateral Migration to Surface Waters

As described in section 5, this is only possible if pore-water levels exceed 30 - 31mAOD, this is not considered possible based on the restoration profile, hence no further modelling is required. There is no plausible risk to adjacent surface water (Harrowden Brook).

8. REVIEW OF TECHNCIAL PRECAUTIONS

The primary technical precaution implemented for the void restoration scheme is through restricting the restoration materials to the QMs. These materials have negligible organic content and a resulting negligible leachate generating potential. This hydrogeological risk assessment has demonstrated that technical precautions are not required for the restoration of Elstow South using QMs.

Protection is provided for by the properties of a significant thickness of *in-situ* Oxford Clay, which acts as a natural geological barrier beneath and to the side of the landfill, in combination with the hydraulic containment potential provided for by groundwater.

The assessment has demonstrated that leachate level (pore-water) control is not necessary and that any substances exiting the Oxford Clay either under a concentration gradient (*i.e.* chemical diffusion) or a mass flux under a hydraulic gradient would not lead to a change in groundwater quality. In addition, in all likelihood the diffusion gradient could be in the direction of the waste materials driven by a higher concentration within the groundwater system compared to that expected within the site. It is however, considered possible that a proportion of the incidental rainfall will not infiltrate into the deposited materials and will run-off as surface water.

Therefore, some surface water management will be required during the first phase of operations when the quarry floor has been partially restored.

9. REQUISITE SURVEILLANCE

A monitoring schedule is based on the risk assessment which has demonstrated that provided that the robust waste acceptance control procedures are implemented, monitoring of the leachate and groundwater is unlikely to be necessary.

However, as per previously determined permit applications for equivalent schemes, a monitoring network for off-waste and in-waste monitoring will be proposed (5192/R/006/01).

10. CONCLUSIONS

The site is located within a low-risk area, namely a clay pit within Oxford Clay. A natural geological barrier, compliant with the requirements of the Groundwater Directive is present at the site.

It is considered that given the natural salinity of the groundwater and the attenuation capacity of the geological barrier that it is highly unlikely that the proposed restoration scheme could discernibly impact on groundwater quality. Consequently, the requirements of the Groundwater Directive (1998) have been met.

The nature of the proposed materials and the associated hydrogeological risk is consistent with that for an inert site.

Such sites do not require active management controls and there is not a sensitive underlying water resource. There is not a risk-based justification for implementing active management controls for leachate within the site. However, a monitoring schedule has been proposed in the permit application which will enable the design assumptions to be validated. This monitoring schedule will however include infrastructure capable of being utilised for leachate abstraction should a condition arise where active leachate management is required.

Appendix A

Diffusion Spreadsheet & LandSim Files

Contaminant Fluxes from Hydraulic Containment Landfills Worksheet Version 1.0

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Produced under Science Group: Air, Land & Water Project SC0310

Statement of Use

This worksheet has been prepared to help assessors quantify the contaminant flux from a hydraulic containment landfill constructed to the specifications in the Landfill Regulations (2002). It has been prepared to allow Agency staff to assess third party calculations of the diffusive contaminant flux from hydraulic containment landfills.

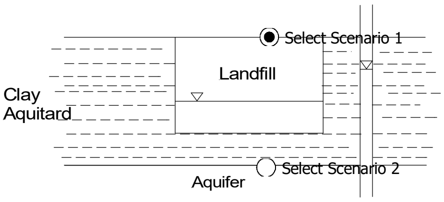
Data needs to be entered only in YELLOW cells. Assessors have to specify a preferred option from a pull-down menu in BLUE cells, interim calculation results are presented in GREY cells and final results in GREEN cells.
Only data in YELLOW or BLUE cells may be changed.

Site name
Elstow
Assessor's name
TerraConsult
Date
22 October 2020

Liability: The Environment Agency does not promise that the worksheet will provide any particular facilities or functions.
You must ensure that the worksheet meets your needs and you remain solely responsible for the competent use of the worksheet.
You are entirely responsible for the consequences of any use of the worksheet and the Agency provides no warranty about the fitness for purpose or performance of any part of the worksheet. We do not promise that the media will always be free from defects, computer viruses, software locks or other similar code or that the operation of the worksheet will be uninterrupted or error free.
You should carry out all necessary virus checks prior to installing on your computing system.

SELECT LANDFILL CONSTRUCTION SCENARIO

Scenario 1

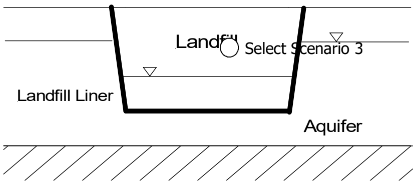


● Select Scenario 1

○ Select Scenario 2

The landfill is constructed in a clay pit, underlain by a confined aquifer.
Water and contaminant fluxes occur across the bottom of the landfill only.

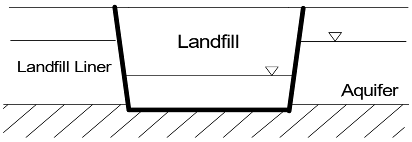
Scenario 2



○ Select Scenario 3

The landfill is lined and located in a permeable formation
a finite distance above an impermeable layer. The water and
contaminant fluxes can occur through the base and sides of the landfill.

Scenario 3



The landfill is lined and located in a permeable formation
a finite distance below an impermeable layer. The water and
contaminant fluxes can occur through the sides of the landfill only.

Elstow 22 October 2020

NH4-N

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION

Conceptual model of landfill construction	CM	1	-
Basal width perpendicular to groundwater flow	Width_LF	330	m
Basal length parallel to groundwater flow	Length_LF	420	m
Basal area	Base_Area	138600	m2
Elevation of base of landfill	LFbase_elev	17.5	maOD
Elevation of top of aquifer	Aqbound_elev	16	maOD
Maximum thickness of underlying aquifer	Aq_max	4	m
Leachate head inside landfill	Head_inLF	23.9	maOD
Groundwater head outside landfill	Head_outLF	24	maOD
Area of liner below the water table	Area_contact	138600	m2

CONTAMINANT PARAMETERS

Contaminant name	Cont_Nme	NH4-N	-
Contaminant type	Cont_Type	Inorganic	-
Contaminant classification	Cont_Class	List I	-
Concentration in landfill leachate	Conc_LF	20	mg/l
Free water diffusion coefficient	Dw_cl	1.96E-09	m2/s
Partition coefficient in clay	Kd_cl	3	l/kg
Retardation factor in clay	R_cl	43	-
Half life in clay (0 for no decay)	thalf_cl	0	days
Decay in sorbed phase?	Decay_sorb	No	-
Decay constant in clay	Decay_cl	0	1/s

MINERAL BARRIER / LINER

Thickness of mineral barrier is calculated as 1.5m

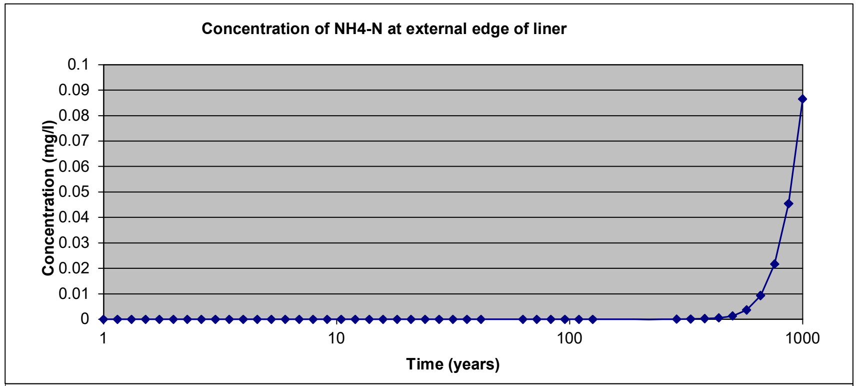
Hydraulic conductivity	k_cl	1.00E-10	m/s
Average pore radius	pore_radius	1.00E-05	m
Effective porosity	n	0.15	-
Dry bulk density	rho	2100	kg/m3
Tortuosity	tau_cl	10	-

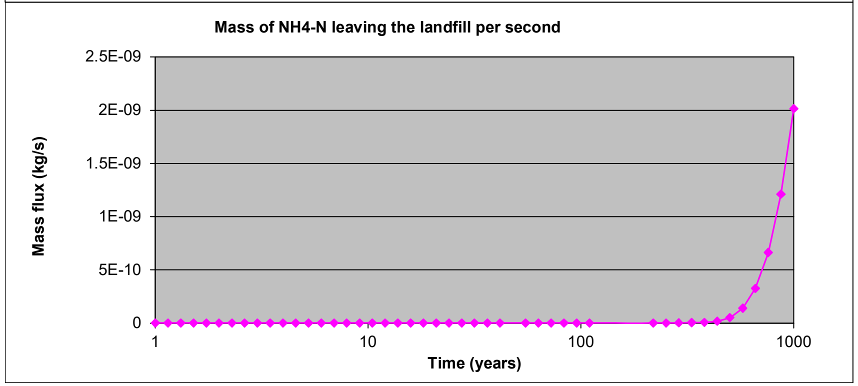
CONTAMINANT AND WATER FLUXES

Groundwater flux into landfill		1.848E-06	m3/s
Maximum contaminant concentration at compliance point at tmax	C_comp	0.08656704	mg/l

CHART PARAMETERS

Minimum axis display	tmin	1	years
Maximum axis display	tmax	1.00E+03	years


Concentration of NH4-N at external edge of liner


Mass of NH4-N leaving the landfill per second

Elstow **22 October 2020**
TerraConsult

CONCEPTUAL MODEL AND LANDFILL CONSTRUCTION				Justification / Reference / Notes
Scenario		1		Landfill constructed directly in Oxford Clay
Basal width perpendicular to groundwater flow	Width_LF	330	m	Void dimnsions (combined)
Basal length parallel to groundwater flow	Length_LF	420	m	Void dimnsions (combined)
Elevation of base of landfill	LFbase_elev	17.5	maOD	Site detail - design (to model at 1.5m barrier)
Elevation of top of aquifer	Aqbound_elev	16	maOD	Site Investigation - BH logs (east void)
Maximum thickness of underlying aquifer	Aq_max	4	m	2003 ESID
Leachate head inside landfill	Head_inLF	23.9	maOD	Assumed - 0.1m below GW
Groundwater head outside landfill	Head_outLF	24	maOD	Adjacent BH data - GW levels on eatern boundary

CONTAMINANT PARAMETERS				
Contaminant name	Cont_Nme	NH4-N	-	
Contaminant type	Cont_Type	Inorganic	-	
Contaminant classification	Cont_Class	List I	-	Modelled as list I - to simulate edge of liner
Concentration in landfill leachate	Conc_LF	20	mg/l	Max concentration for source term
Free water diffusion coefficient	Dw_cl	1.96E-09	m2/s	HC Manual - Table 3.1
Partition coefficient in clay	Kd_cl	3	l/kg	Fannin 2006 QJEGH
Half life in clay (0 for no decay)	thalf_cl	0	days	
Decay in sorbed phase?	Decay_sorb	No	-	

MINERAL BARRIER / LINER				
Thickness of mineral barrier is calculated as 1.5m	thick_clbr	0	m	minimum thickness likely to be constructed
Hydraulic conductivity	k_cl	1E-10	m/s	Conservative value from site data
Average pore radius	pore_radius	0.00001	m	HC Model Manual - Adapted from Burke et al 1988
Effective porosity	n	0.15	-	Typical Value
Dry bulk density	rho	2100	kg/m3	Typical Value
Tortuosity	tau_cl	10	-	HC Model Review _ EA_Typical Value