Mick George Limited

Hydrogeological Risk Assessment

Wakerley Quarry, Northamptonshire

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1 Introduction

1.1 Report Context

1.1.1 WYG Environment (WYG) have been commissioned by Mick George Limited (the client) to undertake a Hydrogeological Risk Assessment (HRA) to support an environment permit variation (Application No. EPR/HB3300HY/A001) for the rolling restoration programme of a mineral extraction site through the importation of inert material (Planning Application Reference: 19/00060/WASFUL) at Wakerley Quarry, Northamptonshire.

1.1.2 Planning for the mineral extraction site (for ironstone and overlying minerals) was granted in December 2015 (reference 08/00026/MIN), it is understood that the extraction activities started in c. 2019.

1.1.3 The sites operator, Mick George Limited, are seeking to allow for the importation of inert waste to restore the former mineral extraction void progressively over five phases to a mixture of agricultural use and conservation uses including calcareous grassland, herb-rich grassland and tree and shrub planting areas to provide habitat diversity. The permit application and this HRA relates to the proposed infilling of Phase A and Phase B only.

1.1.4 An HRA is required to demonstrate that the proposed landfill will be compliant with Environment Agency (EA) Groundwater Protection Positions Statement 'E', Landfill Location Policy and the Environmental Permitting Regulations 2016 (as amended) including the Landfills for inert waste Guidance (2020). These regulations & guidance documents require that certain substances (Hazardous Substances) are not discharged to groundwater such that they are discernible, and that the discharge of other substances (Non-Hazardous Pollutants) is limited to prevent pollution of the water environment.

1.1.5 This version of the HRA includes the following changes as required by the EA Schedule 5 Notice 3 dated 09 November 2020 (attached in Appendix D):

- An update to the conceptual site model to include;
  - Revisions of groundwater contour plots from August 2020 to include information from new boreholes, W05S and W05D. Groundwater flow maps for November 2020 have also been produced and historical maps reviewed;
  - Clarify the proposed basal depth and site engineering;
  - Revision of inert waste acceptance criteria to be used;
  - Clarify effective rainfall value applied;

  - Update Inset one with details of borehole installation screening depths;
  - Clarify the saturated thickness depths of the Lincolnshire Limestone;
  - Discuss potential hydraulic connections to the springs and surface watercourses to the north of the site;
  - Revise groundwater contour plots to account for a potential groundwater divide;
- An update to the hydrogeological risk assessment to include:
  - Clarify long term expected leachate head;
  - Revision of Environmental Assessment Levels including use of MRV for Lead;
- Update to quantitative hydrogeological risk assessment using LandSim software version 2.5 to explore a single lifetime phase. Existing models to be updated with conservative retardation value ranges, suitable head of 'leachate' breakout and potential impact to receptors to the north.
- Revise proposed compliance limits for the borehole including an explanation of how the compliance limits have been calculated.
- Our response to the individual Schedule 5 comments is provided at Appendix K.

1.2 Objectives

1.2.1 The HRA has been undertaken in accordance with the EA guidance on Landfill developments: groundwater risk assessment for 'leachate'[1] which replaced the EA guidance document Horizontal guidance Note H1 – '*Annex J3: Additional guidance for hydrogeological risk assessment for landfills and the derivation of groundwater control levels and compliance limits v 2.1 (2011)* [2]' on the 1st February 2016; and, EA guidance on '*Waste recovery plans and permits' (2016)* [3].

1.2.2 The principal objective of this HRA is to characterise the hydrological and hydrogeological site setting through the development of a robust Conceptual Site Model (CSM) so that the potential impacts of the proposed development on the surrounding controlled waters can be fully assessed.

1.2.3 Further objectives of this study are to:

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[1] Department for Environment, Food & Rural Affairs and Environment Agency, 'Landfill developments: groundwater risk assessment for leachate', 1 February 2016 - https://www.gov.uk/guidance/landfill-developments-groundwater-risk-assessment-for-leachate [Accessed 26th June 2019]

[2] Environment Agency, 'Horizontal guidance Note H1 – Annex J 3. Additional guidance for hydrogeological risk assessments for landfills and the derivation of groundwater control levels and compliance limits v 2.1, December 2011, www.gov.uk/government/publications/h1-annex-j3-hydrogeological-risk-assessment-for-landfills-and-derivation-of-groundwater-levels-and-compliance

[3] Environment Agency, 'Waste recovery plans and permits - How to apply for a waste recovery environmental permit to permanently deposit waste on land. 18th October 2016, https://www.gov.uk/guidance/waste-recovery-plans-and-permits

- Determine baseline conditions in relation to the water environment at Phases A and B at Wakerley Quarry and in the wider surrounding area;
- Establish compliance with the Water Framework Directive, Groundwater Daughter Directive (GWDD) and the Environment Agency's Groundwater Protection Policy Landfill positional statement E;
- Develop a hydrogeological conceptual model for the site including source term, pathway receptor relationship and to define groundwater levels and direction beneath the site;
- Identify the likely risk to identified groundwater dependant receptors due to the proposed restoration of the site as an inert landfill; and,
- Run a model using the Environment Agency approved LandSim software (Version 2.5) to quantitatively model the risk from the proposed infilling of the eastern quarry void with imported inert waste.

1.2.4 A detailed conceptual hydrogeological model for the proposed development is presented on Figure 5 for the site its current condition and Figure 6 in its restored phase. The CSMs provide a graphical representation of the hydrological and hydrogeological environments both at the site and potential groundwater receptors identified beyond the site boundary.

1.2.5 The CSM has been used to inform the risk screening exercise and subsequent quantitative assessment. As part of the quantitative assessment we have considered the potential for 'leachate' to discharge from the site and we have quantified the risk to controlled waters, and justified whether further, more detailed assessment is required.

1.3 Regulatory Context

1.3.1 The Water Framework Directive (WFD) (2000/EC/60) came into force in December 2000. The Water Framework Directive establishes an integrated approach to the protection, improvement and sustainable use of Europe's surface waters and groundwater.

1.3.2 The WFD and Groundwater Daughter Directive (GWDD) have superseded the former Groundwater Directive (80/68/EEC) in December 2013 with EU member states ensuring an equal level of protection to groundwater quality under the WFD measures. The two main objectives for groundwater in the WFD are 'No deterioration in status' and 'Good quantitative status' of groundwater bodies by 2027 (WFD Cycle 2). Objectives for groundwater quality are subject to a more detailed description and criteria under the Groundwater Daughter Directive (GWDD).

1.3.3 The EA framework for the regulation, protection and management of groundwater is set out in their approach to groundwater protection guidance document[4] which replaces 'Groundwater Protection: Policy and Practice (GP3)' which was withdrawn in March 2017. The guidance documents detail the technical framework to the EA approach to the management and protection of groundwater, the tools used in the assessment of groundwater, and the policy and legislation.

1.3.4 Groundwater can be at serious risk of pollution unless landfills are located in the right place and subject to the right operational controls. The EA's approach is to steer the development of landfills into less sensitive hydrogeological locations such as unproductive strata. The aim is to protect existing water supplies and to avoid the situation where the presence of a landfill constrains future development of the most important groundwater resources for future generations.

1.3.5 The EA will apply the E1 Landfill Location Positional Statement, as outlined in 'The Environment Agency's approach to groundwater protection (February 2018), in its consultee role under the Town & Country Planning Act 1990 and in its permitting role. The EA positional statement is as follows:

(i) We will object to any proposed landfill site in groundwater source protection zone 1;

(ii) For all other proposed landfill site locations, a risk assessment must be conducted based on the nature and quantity of the wastes and the natural setting and properties of the location; and,

(iii) Where this risk assessment demonstrates that active long-term site management is essential to prevent long-term groundwater pollution, we will object to sites:

- *Below the water table in any strata where the groundwater provides an important contribution to river flow or other sensitive surface waters;*
- *Within source protection zones 2 and 3;*
- *On or in a Principal Aquifer.*

1.3.6 The controls to protect groundwater quality formerly dealt with under the transitory Groundwater Regulations 2009 (which superseded the Groundwater Regulations 1998) came within phase 2 of environmental permitting regime via the Environmental Permitting (England & Wales) Regulations (EPR) 2016 (as amended). The regulations were introduced on 06 April 2010 and replaced the 2007 regulations which combined the Pollution Prevention and Control (PPC) and Waste Management Licencing (WML) regulations. The EPR regulations implements the requirements for the control of discharges to groundwater imposed by the WFD and GWDD.

1.3.7 The Landfill Directive (99/31/EC) for the purposes of the EPR (2016) applies to waste destined for

[4] The Environment Agency's approach to groundwater protection. Environment Agency. Version 1.2. February 2018, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/692989/Envirnment-Agency-approach-to-groundwater-protection.pdf

disposal onto or into land (article 2(g)). The management of waste at a mineral extraction site needs to be covered by environmental permits. There are two principal activities that need a permit. Firstly, the management of extractive waste, and secondly where applicable, the disposal/recovery of waste. These activities can be covered by a single permit or two permits each covering a different activity.

1.3.8 A geological barrier is a fundamental requirement for all landfills according to the Landfill Directive (1999/31/EC) and must provide sufficient attenuation to prevent a risk to soil and groundwater. Condition 2.6 of the permit templates for landfills for inert waste disposal requires the operator of the site to submit construction proposals for the development of new cells to the Environment Agency. At landfills for inert waste, this requirement will cover the construction and quality assurance (CQA) of the geological barrier across the base and sides of the landfill. The importance of the geological barrier in the prevention of long-term groundwater pollution is emphasised in the Landfill Directive, Annex I, paragraph 3.1; that groundwater is to be protected by the artificial geological barrier combined with a top liner (i.e. a cap or restored soils) during the aftercare period.

1.3.9 The landfills for inert waste guidance – 'The environmental permitting requirements for landfills for inert waste and how to comply with your permit' has now replaced withdrawn EA guidance document 'Waste acceptance at landfills – Guidance on waste acceptance procedures and criteria' [withdrawn 30 January 2020]. This guide describes the requirements for landfills for inert waste. Inert waste is waste that does not undergo any significant physical, chemical or biological transformations. The total leachability and pollutant content of the waste and the ecotoxicity of the 'leachate' must be insignificant and not endanger the quality of surface water or groundwater. This HRA has been prepared in accordance with this guidance and in accordance with:

- Landfill Developments: groundwater risk assessment for leachate. DEFRA/EA. Published 01 February 2016; and,
- Groundwater risk assessment for your environmental permit. DEFRA/EA. Published 01 February 2018.

1.4 Report Structure

1.4.1 The remainder of this report is structured as follows:

- Section 2 – Environmental Site Setting;
- Section 3 – Proposed Landfill Engineering;
- Section 4 – Hydrogeological Conceptual Model;
- Section 5 – Risk Screening & Hydrogeological Risk Assessment;

- Section 6 – Proposed Monitoring Scheme; and,
- Section 7 – Conclusions.

1.4.2 The report and content within are subject to the conditions presented at Appendix A

2 Environmental Setting

2.1 Introduction

2.1.1 This section of the report summarises available information collected during the desk-based study of the geology and hydrogeology of the site and surrounding area.

2.1.2 Details on the current scheme, proposed restoration and the environmental setting of the site are set out in the following reports and resources which should be referred to during the review of this HRA;

- Groundsure Enviro Data - http://groundsure.io/ (Accessed 05 May 2020);
- British Geology Survey GeoIndex Onshore Viewer - http://www.bgs.ac.uk/data/mapViewers (Accessed 05 May 2020);
- The physical properties of major aquifers in England and Wales. British Geological Survey in partnership with the Environment Agency. Technical Report WD/97/34. Publication 8;
- The physical properties of Minor aquifers in England and Wales. British Geological Survey in partnership with the Environment Agency. Technical Report WD/00/04. Publication 68;
- Investigation of the Hydrology and Hydrogeology in the Vicinity of Wakerley Quarry, Northamptonshire. Hafren Water. Dated May 2007;
- Hydrogeological Impact Assessment for Revised Restoration of permitted mineral extraction, Wakerley Quarry, Northamptonshire. Hafren Water. Ref 2107/HIA, Version F2. Dated October 2016 (Appendix E);
- Monitoring borehole completion report, Wakerley Quarry, Northamptonshire. Hafren Water. Ref. 2107/CR, Version D1. Dated July 2016 (Appendix E);
- Planning Application Supporting Statement, Wakerley Quarry, Northamptonshire. Mineral Surveying Services Limited. Version 2. Dated August 2019;
- Planning Application Non-Technical Summary. Wakerley Quarry, Northamptonshire. Mineral Surveying Services Limited. Version 1. Dated August 2019, and;
- Borehole logs drilled by Site Investigation Services in 2017 (Appendix B.2).

2.2 Site Location

2.2.1 Wakerley Quarry is located 1.5km south of Wakerley Village, and 7km east of Uppingham as shown in Figure 1. The A43 is located approximately 3km to the south-east of the site.

2.2.2 The site is bounded on all sides by mixed forestry and agricultural land. This assessment comprises the areas 'Phase A' and 'Phase B' of a larger development plan shown in the MGL-A099077-PER-01; and will be known hereafter as "the site". The larger quarry site for all 5 No. Phases covers an area of 60.9 hectares. The quarry will extract limestone of the Lower Lincolnshire Limestone for the manufacture of aggregate for general construction uses.

2.2.3 The quarry is centred at National Grid Reference (NGR) SP 94394 97719.

2.3 Current Site Setting

2.3.1 The site is currently a disused airfield, with the landing strip approximately south west to north east across the site. The remainder of the site is shown to be grass covered land with areas of trees and hedges near the northern boundary and in the southern portion of the site.

2.3.2 OS mapping indicates that the site is located on the brow of a hill, with contours decreasing from c.101mAOD at the disused airfield in the centre of the site, decreasing to c.95mAOD towards the northeast of the site, in the direction of Wakerley Village.

2.4 Proposed Development

2.4.1 The currently approved Proposed Restoration Scheme for the site is depicted in Figure 2 (Ref. W4 18 02) and shows the site to be restored to a mix of agricultural land and various other uses following mineral extraction. Land along the western boundary and south eastern boundary is indicated to be restored and managed as calcareous grassland. Two sink points are included for surface water drainage. The Proposed Restoration Scheme is to include screening bunds to the north (Bund 4), east (Bund 4a) and south (Bund 5). The plan shows the general direction of infilling to occur from west to east.

2.5 Site History

2.5.1 Historical mapping indicates that the site remained as agricultural land from the 1880s to the mid-1960s whereupon the airfield became active onsite. Beyond the immediate site boundary, significant changes are apparent over this period. Historical mapping from the mid-1880s shows the site and its immediate environs as undeveloped farmland and woodland, however the presence of quarrying to the south and north of the proposed permit boundary from the 1940s suggests significant working of the land around the site. Extraction of both Limestone and Ironstone is noted in the land between Wakerley and Harringworth.

2.6 Surrounding Land Use

2.6.1 The immediate surroundings of the site comprise agricultural land to the north and west with extensive woodland (Wakerley Great Wood) to the east and south. The nearest residential dwellings to the application site are situated approximately 500m north of the site at Wakerley. A review of available mapping indicates there is 1 No. historic landfill within 2km of the site and no authorised landfills.

2.7 Geology

2.7.1 Geology information for the site and the surrounding area has been reviewed using the British Geological Survey (BGS) Geological Map Stamford (1978), Sheet 157 (England & Wales) and the BGS Onshore viewer[5].

Made Ground

2.7.2 The BGS does not identify Made Ground deposits on site. However, Made Ground is anticipated on-site associated with the former development of the site as an airfield.

Superficial Deposits

2.7.3 Superficial deposits are shown to be present across the majority of the site. The BGS generally describe these deposits as "*Till – Mid Pleistocene – Diamicton*". These superficial deposits are glaciogenic in origin and can form a wide range of deposits and geomorphologies associated with glacial and inter-glacial periods.

Solid Geology

2.7.4 The Rutland Formation (formerly the Upper Estuarine Series) is part of the Great Oolite Group and is shown to outcrop in the southern and eastern extent of the site on geological maps. The formation was deposited 166 to 170 million years ago in the Jurassic Period. The BGS describes the Rutland Formation as a "*succession of shallowing upward, delta-type rhythms, comprising ideally of a grey marine mudstone passing up into non-marine mudstone and siltstone, with a greenish-grey rootlet bed at the top. The basal beds comprise mainly fluviatile and lacustrine sandstones, designated the Stamford Member in the south, passing north in central Lincolnshire into the Thorncroft Sand Member. Subordinate sandstone beds occur higher in the sequence locally, as well as typically shelly and shell-detrital marine limestones and calcareous mudstones, notably in the mid part, the Wellingborough Limestone Member, in Northamptonshire.*" A maximum thickness of up to 15m is

[5] British Geology Survey GeoIndex Onshore Viewer - http://www.bgs.ac.uk/data/mapViewers

recorded for the formation, but thicknesses typically range between 8 -12m.

2.7.5 The Lower Lincolnshire Limestone Member forms part of the Lincolnshire Limestone Formation and Inferior Oolite Group, outcropping in the northern and western area of the site. The Member formed approximately 168 to 170 million years ago in the Jurassic Period. The BGS describes the Lower Lincolnshire Limestone Member as *"Limestones, dominated by low-energy calcilutite, and peloidal wackestone and packstone. Commonly includes sandy limestone or calcareous sandstone in basal part (locally known as Collyweston Slate) and contains substantial units of mudstone, particularly from the Lincoln area northwards."* Thicknesses of between 0 - 20m are recorded for the Lincolnshire Member.

2.7.6 BGS maps indicate a regional dip of strata to the east, south-east at a very shallow to sub-horizontal angle. This shallow dip results in the distribution of the outcrops being largely governed by elevation; a small valley formed by the River Welland to the north east cuts down through the following strata within the Inferior Oolite Group.

2.7.7 Therefore, the Grantham Formation, which underlies the Lower Lincolnshire Limestone Member, outcrops to the east, south-east of the site. The Grantham Formation (formerly the Lower Estuarine Series) is described as consisting of *'mudstones, sandy mudstones and argillaceous siltstone-sandstone […] comprising several shallowing-upwards, delta-type rhythms'.* The formation is sometimes labelled as 'black clays' due to dark carbonaceous shaly clay bed. Thicknesses of the formation are highly variable, but are generally between 2 – 5m, but can be up to 15m in thickness locally.

2.7.8 Further to the east, south- east of the site, outcrops the Northampton Sand Formation which underlies the Grantham Formation. The formation consists of a greenish *'Sandy, berthierine-ooidal and sideritic ironstone […containing] lenses of mudstone and limestone in places'.* Thicknesses are typically between 4 – 8m but can be up to 21m regionally.

2.7.9 At the lowest elevation furthest to the east, south-east, mapping indicates the Whitby Mudstone Formation (formerly the Upper Lias Clay) outcrops, forming part of the Lias Group and unconformably underlying the Northampton Sand Formation. Thicknesses are c.120m regionally, with the formation consisting of *'medium and dark grey fossiliferous mudstone and siltstone […] with thin siltstone or silty mudstone beds and rare fine-grained calcareous sandstone beds'.*

Structural Geology

2.7.10 A fault is shown on geological maps located within the north-west of the site. The fault runs approximately north, north-west to south, south-east off-setting the Lincolnshire Limestone, Grantham Formation and Northampton Sand Formation.

2.7.11 Three faults have been identified on the site as shown on drawing Ref. 2107/CR/02 within the Hafren Water Monitoring Borehole Completion Report (2016). The faults are shown to run approximately north-east, south-west traversing the site; and are downthrown to the south-east by 1.50m to 5.00m. Further discussion on the faults is included in Section 2.8.13.

Borehole Records

2.7.12 Twenty one BGS borehole records are shown to be present on site within the Phase A and Phase B areas. Borehole records which present clear and obvious thicknesses of the Glacial Till and the Lower Lincolnshire Limestone are summarised in Table 2-1.

2.7.13 Glacial Till deposits have largely been encountered in all BGS boreholes records, except for borehole records SP/99NW/392, SP/99NW/348, SP/99NW/467 and SP/99NW/118. These boreholes are located in the western extent of the site, where till is found in boreholes within the same area.

2.7.14 The Rutland Formation (previously the Upper Estuarine Series) is not distinctly identified in the BGS borehole logs present. The formation is described as a series of muds, silts and limestone, it is likely that the unit has been included in the surface clays or the upper portion of the Lincolnshire Limestone Member.

2.7.15 The Lower Lincolnshire Limestone Member was encountered in all exploratory boreholes summarised in Table 2-1, with the full thickness of the Limestone proven in all records: ranging between 8.53m and 17.98. Generally, the Lower Lincolnshire Limestone Member was found to comprise of interbedded soft and hard limestone, with yellow sand horizons.

2.7.16 The depth to the base of the Lower Lincolnshire Limestone Member was encountered between 77.75m AOD to 96.80 m AOD in boreholes drilled across Phases A and B of the site. BGS records (SK/41SW/97 and SK41SW/64) located further to the west of the site encountered the base of the Lower Lincolnshire Limestone Member between 89mAOD and 94mAOD, whereas the base of the unit at the west of the site is located between 77mAOD and 81mAOD indicating that the geological strata are regionally dipping to the east. Within the BGS records, the Lower Lincolnshire Limestone Formation across Phases A and B is between 8.5m and 18m in thickness.

2.7.17 Beneath the Limestone the Grantham Formation is encountered in all BGS borehole, with a thickness of between 1.8m and 7m.

2.7.18 A band of ironstones associated within the Northampton Sand Formation are encountered below the Grantham Formation. These deposits are encountered in all boreholes except SP/99NW/467 which does not extend deep enough. The unit is found to range in thicknesses between 5.3m and 6.4m.

2.7.19 The last unit present in the borehole logs, underlying the Northampton Sand is the Whitby Mudstone Formation. These deposits are encountered in all boreholes except SP/99NW/467 which does not extend deep enough, terminating in the Northampton Sand Formation. The thickness of Whitby Mudstone cannot be determined as the base of the unit was not reached.

Table 2-1 – BGS Borehole Records

BGS Reference	Name	NGR	Made Ground / Soil		Glacial Till		Lower Lincolnshire Limestone	
			Thickness (m)	Unit Base (mAOD)	Thickness (m)	Unit Base (mAOD)	Thickness (m)	Unit Base (mAOD)
SP99NW392	Wakerley	494081, 297939	0.46	100.23	ne	ne	11.13	89.11
SP99NW348	Wakerley Great Wood 7654	494171, 297935	0.61	97.56	ne	ne	10.06	87.50
SP99NW394	Wakerley	494282, 297987	ne	ne	0.91	97.97	12.50	85.47
SP99NW396	Wakerley	494365, 298026	ne	ne	3.96	95.89	12.19	83.70
SP99NW347	Wakerley Great Wood 7639	494453, 298080	0.61	99.49	0.91	98.58	17.98	80.59
SP99NW349	Wakerley Great Wood 7604	494791, 297984	0.61	102.18	5.79	96.39	15.24	81.15
SP99NW350	Wakerley Great Wood 7614	494527, 297853	0.61	103.23	7.01	96.22	12.50	83.72
SP99NW390	Wakerley	494447, 297813	ne	ne	4.57	99.14	14.02	85.12
SP99NW384	Wakerley	494417, 297759	ne	ne	3.66	99.85	13.72	86.14
SP99NW386	Wakerley	494372, 297740	ne	ne	3.05	100.40	12.80	87.60
SP99NW352	Wakerley Great Wood 7631	494278, 297693	0.61	102.92	0.91	102.01	10.67	91.34
SP99NW467	Wakerley	494188, 297654	0.61	103.17	ne	ne	9.14	94.03
SP99NW388	Wakerley	494125, 297631	ne	ne	0.91	103.23	9.45	93.78
SP99NW118	Shotley East LXXXV1 No.6250YY/6844	494020, 297600	ne	ne	ne	ne	8.53	96.80
SP99NW385	Wakerley	494330, 297425	ne	ne	2.44	101.34	13.11	88.24
SP99NW395	Wakerley	494372, 297471	ne	ne	3.35	100.59	12.5	88.09
SP99NW393	Wakerley	494470, 297526	ne	ne	4.88	99.18	12.80	86.38
SP99NW354	Wakerley Great Wood 7586	494569, 297562	0.10	103.99	6.60	97.38	15.54	81.84
SP99NW378	Harrington Notification No. SN7040	494675, 297652	ne	ne	9.45	93.62	13.41	80.21
SP99NW353	Wakerley Great Wood 7592	494787, 297727	0.30	101.05	8.84	92.21	14.63	77.58
SP99NW355	Wakerley Great Wood 7682	494677, 297443	ne	ne	7.62	95.33	13.11	82.22

Ne = Not Encountered

2.8 Hydrogeology

Aquifer Classification

2.8.1 The EA classify the Lincolnshire Limestone as a Principal Aquifer. 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".

2.8.2 The EA classify the Northampton Sand as a Secondary A aquifer. These are 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;

2.8.3 The Rutland Formation, which is not distinctly recorded on BGS borehole records reviewed as part of this assessment, is classified as a Secondary A Aquifer by the EA. These are 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.

2.8.4 The Grantham Formation and superficial Glacial Till deposits are classified as Secondary Undifferentiated which are assigned where it has not been possible to attribute either category A or B to a rock type. In most cases, this means that the layer in question has previously been designated as both minor and non-aquifer in different locations due to the variable characteristics of the rock type.

2.8.5 The Whitby Mudstone Formation is classified as unproductive strata (non-aquifers). These are rock layers or drift deposits with low permeability that have negligible significance for water supply or river base flow.

Groundwater Source Protection Zones

2.8.6 The site is not located within an Environment Agency designated groundwater Source Protection Zone (SPZ) for potable water supply.

Aquifer Properties

Lincolnshire Limestone Formation

2.8.7 The Lincolnshire Limestone outcrops between Humber Estuary in the north and Peterborough and

Kettering in the south. The Lincolnshire Limestone, as one of six principle aquifers across England and Wales, is characterised by high transmissivities and low storage coefficients. Groundwater movement is almost entirely by fracture flow along well-developed bedding plane fractures and joints[6]. Groundwater flows eastwards downdip from the outcrop to the confined area. The aquifer dips to the east, ranging from 3° north of Lincoln to 1° in the south. It has a maximum thickness of over 40 m in south Lincolnshire, becoming thinner to the north and south. It also thins from west to east, eventually 'pinching out'.

2.8.8 The BGS Major Aquifer Properties Manual[6] reports the large range of hydraulic conductivity of the Lincolnshire Limestone due to the presence of very low intergranular permeability. Ranges are between 2x 10^{-6} m/d and 0.17m/d. The mean is found to generally be 10^{-4} m/d. A similar large range is present in values of Transmissivity for the unit with values recorded between 100m^2/d up to 10,000m^2/d. Values are generally between 265m^2/d and 2,265m^2/d, with an average transmissivity of 665m^2/d.

2.8.9 Porosity values for the Lincolnshire Limestone have also been defined following review of existing literature. Porosities are reported to typically range between 2.5 and 51.1%[7].

2.8.10 Further information on the groundwater levels, preferential flow paths and recharge mechanisms within the Lincolnshire Limestone Formation is outlined in Section 3.5.

Northampton Sand Formation

2.8.11 The Northampton Sand Formation is a minor aquifer present across the East Midlands Shelf. The aquifer is characterised by a combination of matrix and fracture flow, but generally intergranular flow is dominant.

2.8.12 Yields from the aquifer unit are varied, with yields up to 1,000m^3/d recorded. In comparison, there are also wells that have been drilled into the rock unit that have been unsuccessful in delivering a water supply. Transmissivity of the unit is recorded as 60m^2/d where the unit is 6m thick and fully saturated which equates a hydraulic conductivity value of 10m^2/d. Where there is hydraulic continuity between the Northampton Sand Formation and the Lincolnshire Limestone, the transmissivities are higher due to the highly transmissive, overlying limestone aquifer. On site, the presence of the Grantham Formation between the two units is likely to restrict hydraulic continuity between the two units.

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[6] The physical properties of major aquifers in England and Wales. British Geological Survey in partnership with the Environment Agency. Technical Report WD/97/34. Publication 8.
[7] The physical properties of Minor aquifers in England and Wales. British Geological Survey in partnership with the Environment Agency. Technical Report WD/00/04. Publication 68.

2.8.13 The historic mining and extraction of the ironstones of the Northampton Sand Formation has disrupted natural hydrogeological conditions of the unit by creation of open shafts and disused mine workings and by producing fractures. Prior to mining, due to the overlying units, recharge to the unit was limited and water levels were low. During the period of mining natural recharge was supplemented by anthropogenically-induced recharge. This became the principle mechanism for recharge (Stanyer, 1982). Although the mines have now been largely backfilled, recharge to the unit remains higher than before the mining period due to increased infiltrated through the backfill material. This has resulted in more water being available in the unit in areas where the unit did not previously hold water (Stanyer, 1982).

2.8.14 A review of the Hafren (2016) Report (Section 2.10) reveals that ironstone has been worked extensively in the surrounding area, with the closest known workings shown on the Geological Map (Sheet 157) to be approximately 150m to the north-west of Phase A. The ironstone present in the exposed Northampton Sand Formation in this area is understood to have been worked from the surface i.e. traditional quarrying methods. The report does not indicate that underground mines were advanced to extract the mineral or that any workings underlie the site. A review of the Coal Authority Interactive Viewer does not show any mine entry or mine shaft records at the site or within the surrounding area however, it should be noted that the records held by the Coal Authority are for coal mining rather than ironstone working.

2.9 Hydrology

2.9.1 The presence of surface water features, including streams, rivers, drainage ditches and ponds have been determined from the Ordnance Survey (OS) Maps. The Wakerley Quarry site is located in the River Welland catchment. The River Welland flows 65km from near Market Harborough in Leicestershire to the Wash. The closest watercourse to the site is a stream located 400m south of the quarry. This stream flows eastwards and is a tributary of the Fineshade Brook. The Fineshade Brook has been classified of 'Moderate' ecological and 'Good' chemical quality under The Water Framework Directive (2016). The Fineshade brook is a tributary of the River Welland.

2.9.2 The River Welland is located 1km north-west of the site, within the Welland Valley, which flows eastwards towards Stamford. This section of the Welland River has also been classified of Moderate Ecological and Good Chemical quality under The Water Framework Directive (2016).

2.9.3 Streams, which are thought to be spring fed, emerge on the southern flank of the Welland Valley to the north of the site. Groundwater emerges from the springs either at the contact between the Lincolnshire Limestone aquifer and the less permeable mudstone layers of the overlying Rutland Formation or underlying Grantham Formation. These springs contribute to flows in the River Welland which is present at the base of the valley.

2.9.4 Additional spring features are expected to provide a source of water to streams to the south and south-west of the site. The Hafren Report (2016) reports that these springs are seasonal. These springs are thought to emerge at the contact between the overlying clays of the Rutland Formation / Glacial Till and the Lincolnshire Limestone.

2.10 Previous Site Investigations

Hafren Water Monitoring Borehole Completion Report (July 2016)

2.10.1 Hafren Water completed groundwater monitoring in 4No. borehole locations each with a shallow well 'S' installed into the Lincolnshire Limestone and a deeper well 'D' installed into the underlying Northampton Sand Formation. The borehole logs and results of the monitoring are presented in a Borehole Completion Report (Reference: 2107/CR, Version D1. Dated July 2016). The relevant information contained within the report is presented throughout this section and summarised in Table 2.2 below. The reader is referred to the original report for further information which is attached in Appendix E.

2.10.2 Site investigation works were completed in 2016 around the perimeter of Phase A and Phase B of Wakerley Quarry. These were installed as a condition of the Planning Permission to extract limestone from the area. This report presents details of the 4No. borehole location, construction, water levels and water quality.

2.10.3 The boreholes were drilled between 14.5mbgl to 32mbgl through the Superficial Clay cover, Lincolnshire Limestone, Grantham Formation (estuarine sands and clays), Northampton Sands (ironstone) and into the top of the 'Lias Clay' (Whitby Mudstone Formation). The encountered horizons are presented on borehole logs attached in Appendix B.1 and summarised in the below table.

Table 2-2 – Summary of Borehole Logs W01-W04 (2016)

ID	NGR	Made Ground / Soil		Glacial Till		Lower Lincolnshire Limestone		Grantham Formation		Northampton Sands	
		Thickness (m)	Unit Base (mAOD)	Thickness (m)	Unit Base (mAOD)	Thickness (m)	Unit Base (mAOD)	Thickness (m)	Unit Base (mAOD)	Thickness (m)	Unit Base (mAOD)
W01S	493916.3 297857.0	ne	ne	0.40	100.90	11.80	89.10	0.4	88.70	np	np
W01D	493916.2 297854.5	ne	ne	0.40	100.98	11.60	89.38	0.6[a]	88.78	5.4	83.38
W02S	494284.3 297495.2	ne	ne	4.00	99.79	10.20	89.59	np	np	ne	ne
W02D	494285.1 297491.3	ne	ne	2.50	101.37	11.50	89.87	4.2	85.67	6.6	79.07
W03S	494646.2 297454.6	0.3	102.57	7.50	95.07	13.30	81.77	np	np	ne	ne
W03D	494642.3 297454.7	0.3	102.66	7.50	95.16	13.20	81.96	3.90	78.06	6.50	71.56
W04S	495032.0 297952.2	0.9	99.86	7.20	92.66	13.30	79.36	np	np	ne	ne
W04D	495035.9 297952.9	0.9	99.82	7.20	92.62	13.30	79.32	3.70	75.62	5.40	70.22

[a] Hafren Water infer the Grantham Formation to be 0.60m within a table attached in Appendix 2107/CR/A3 of the 2016 report. A review of the log reveals that there is clay materials between 6.00m bgl to 9.40m bgl (3.00m thickness) which is likely to be the Grantham Formation overlying the top of the Northampton Sands at 9.40mbgl (91.08mAOD). *ne = Not Encountered; np = Not Proven*

2.10.4 As shown above in Table 2-2, the full thickness of the Lower Lincolnshire Limestone was proven in all eight boreholes with thickness between 10.2m (W02S) to 13.3m (W03S). The unit was encountered at between 101.37mAOD and 92.62mAOD. The Grantham Formation was encountered in all eight boreholes to underlie the Lower Lincolnshire Limestone Formation between 79.32mAOD to 89.87mAOD. The full thickness of the Grantham Group was proven in five boreholes and was between 0.4m (W01S) and 4.2m (W02D). The Northampton Sand Formation was encountered in five boreholes, and its full thickness was proven in four boreholes. The unit was encountered between 88.78mAOD and 75.62mAOD, with a thickness of 3.4m (W01S) to 6.6m (W02D). The top of the Whitby Mudstone Formation (Lias Clay) was encountered in four boreholes between 83.38mAOD and 70.22mAOD.

2.10.5 Water strikes recorded during drilling are summarised in Table 2.3 below.

Table 2.3 – Borehole Groundwater Strikes

Borehole ID	Water Strike		Strata Descriptions
	mbgl	mAOD	
W01S	5.80	95.50	Lower Lincolnshire Limestone Formation
	16.00	85.30	Northampton Sand
W01D	6.00	95.38	Lower Lincolnshire Limestone Formation
W02S	12.50	91.29	Lower Lincolnshire Limestone Formation
W02D	none	none	-
W03S	18.40	84.47	Lower Lincolnshire Limestone
W03D	none	none	-
W04S	19.00	81.76	Lower Lincolnshire Limestone
W04D	none	none	-

2.10.6 Groundwater strikes were generally recorded within the Lower Lincolnshire Limestone Formation between 81.8m AOD to 95.5m AOD. Only a single water strike is recorded in the deeper Northampton Sand Formation at 85.3mAOD.

2.10.7 Upon the completion of drilling, the wells were screened in either the Lincolnshire Limestone, or the Northampton Sands. The wells ending with the letter 'S' are installed into the Limestone and the wells ending with the letter 'D' are installed into the Northampton Sands. Water level monitoring was completed by Hafren Water within the Lincolnshire Limestone and the Northampton Sand between April and June 2016.

2.10.8 Further discussion on groundwater levels and flow directions within the underlying aquifers is presented in Section 3.4.

Site Investigation Services Water Well Record (2017)

2.10.9 WYG have been provided with borehole (drillers) logs for 4No. boreholes drilled by Site Investigation Services between the 04 and 12 May 2017 using the Beretta T44 drilling rig. The location of these boreholes is illustrated in Figure 3. Borehole logs are presented at Appendix B.2. The boreholes were drilled to depths of between 23 and 35 mbgl through the Superficial Clay Cover, Lincolnshire Limestone, possible Grantham Formation (sands not containing ironstone), Northampton Sands (ironstone) and into the top of the 'dense blueish grey' clay and mudstone of the Whitby Mudstone Formation.

2.10.10 As shown below in Table 2-2.4, glacial till was encountered in 2No. boreholes (R3 and R4) to a depth of 2.4 and 3.4 mbgl. A 2.3m thick layer of siltstone was encountered at R4 which could represent the base of the Rutland Formation or as discussed in Section 2.7, a mudstone unit associated with the Lincolnshire Limestone Formation. The full thickness of the Lower Lincolnshire Limestone was proven in all four boreholes with thickness between 11.6 m and 13.5 m. A bed of dense yellow sandstone not containing iron stone was encountered in three boreholes and has been interpreted as The Grantham Formation. The unit ranged in thickness from 1.5 to 3.5 m. It is possible that this is the top of the Northampton Sand Formation and that the Grantham formation is absent across all boreholes. Ironstone interpreted as the Northampton Sand Formation was encountered in all four boreholes. The unit ranged in thickness from 2.1m to 8.5 m (or 10 m if the assumed Grantham Formation is included). The top of the Whitby Mudstone Formation (Lias Clay) was encountered in four boreholes between 25.6 and 77.6 mAOD.

Groundwater was not encountered in borehole R2 and R3. Water was struck in the Northampton sand formation at 18.0 mbgl in R1 and 19.5 mbgl in R4 rising to and resting at 13.1 and 18.0 mbgl respectively.

2.11 Additional Site Investigations

SIS Drill (UK) Ltd Borehole Completion Log (August 2020)

2.11.1 The client instructed SIS Drill (UK) Ltd to advance additional investigative boreholes (W05D and W05S) along the northern boundary of the site. The boreholes were advanced on 06 August 2020 to a depth of 27mbgl and 10 August 2020 to a depth of 17mbgl. A negligible groundwater seep was encountered at W05D at a depth of 23mbgl within the consolidated Northampton Sands. A summary of the geological logs is provided in Table 2.5 below. Borehole logs are presented at Appendix B.3.

Table 2.4 Summary of 2017 borehole logs R1 – R4

ID	NGR	Elevation* (mAOD)	Total Depth (mbgl)	Soil		Glacial Till		Lower Lincolnshire Limestone		Grantham Formation		Northampton Sands	
				Thickness (m)	Unit Base (mAOD)	Thickness (m)	Unit Base (mAOD)	Thickness (m)	Unit Base (mAOD)	Thickness (m)	Unit Base (mAOD)	Thickness (m)	Unit Base (mAOD)
R1	497714, 299696	44	23	0.5	43.5	ne	ne	13.5	30.0	1.8	28.2	2.6	25.6
R2	495849, 299075	72	27	0.4	71.6	ne	ne	12.1	59.5	3.5	56.0	2.1	53.9
R3	495761, 298970	76	30	0.4	75.6	2.0	73.6	11.6	62.0	1.5	60.5	8.5	52.0
R4	494636, 298154	101	35	0.4	100.6	3.0	97.6	15.3^	82.3	np	np	4.7	77.6

*Estimated from Ordnance Survey (OS) Terrain 50 DEM through OS OpenData; ^ Siltstone bed 2.3 m thick could represent the base of the Rutland Formation; ne indicates geological unit not encountered; np indicated geological unit not proven

Table 2.5 – Summary of Borehole Logs W05D and W05S (2020)

ID	NGR	Made Ground / Soil		Glacial Till		Lower Lincolnshire Limestone		Grantham Formation		Northampton Sands	
		Thickness (m)	Unit Base (mAOD)	Thickness (m)	Unit Base (mAOD)	Thickness (m)	Unit Base (mAOD)	Thickness (m)	Unit Base (mAOD)	Thickness (m)	Unit Base (mAOD)
W05D	494510, 298123	0.9	99.76	0.8	98.96	16.3	82.66	np	np	5.6	77.06
W05S	494510, 298123	0.6	99.81	2.4	97.41	14*	83.51	np	np	np	np

ne indicates geological unit not encountered; np indicates geological unit not proven. *0.5m thick damp clay layer which could represent Grantham Formation located between 13 and 13.5mbgl

2.12 Regulatory Consultation

Regulatory Consultation

2.12.1 WYG contacted the EA on Thursday 22 June 2018 in order to gain an understanding of the current site setting. WYG asked the Environment Agency to provide details on surface water and groundwater abstractions, discharge consents, and pollution incidents within a 2km radius of Leicester Quarry. The EA response on 12 September 2018 and their response is attached in Appendix C and summarised below.

Discharge Consents

2.12.2 The consultation response indicates 5No. discharge consents within 2km of the site. The discharge type for 3No. of the consents is for Domestic Property (single) including farmhouse, 1No. is for WwTW/Sewage Treatment Works (water company) and 1No. for Dentist / Hospital / Nursing Home / Human Health.

Pollution Incidents

2.12.3 The consultation response indicates 3No. pollution incidents within 2km of the site dated from 2001-2003. The cause for 2No. of the incidents was reported as "Unauthorised Waste Management Activity" with identified pollutants of Construction and Demolition Materials and Waste and "other". The cause of the remaining incident is listed as "Fly-Tipping" with an identified pollutant of other general biodegradable materials or waste. All 3No. incidents are listed as Land Category 3 (Minor).

Surface Water Abstractions

2.12.4 The response states there are no surface water abstractions within 2km of the site.

Groundwater Abstractions

2.12.5 The response states there are no live groundwater abstraction licences within 2km of the site. However, in drawing 2107/HIA/02 within the 2016 Hafren Water report (ref. 2107/HIA) a licensed abstraction located c.700m to the south of the site is annotated at Town Wood Farm. Therefore, it is assumed that the licensed abstraction has either ceased, or is de-regulated i.e. abstracts less than 20m^3 per day, thus not requiring an abstraction licence from the EA. The Hafren Water report states that *"The Environment Agency record for the licensed abstraction at Town Wood, Upper Laxton identifies the abstraction from the Lincolnshire Limestone. It is unclear whether this is correct."*

Private Water Supplies

2.12.6 A private water supply borehole was previously identified to be located approximately 700m south of the site at Town Wood Farm within the Hafren Water Hydrological Assessment Report (ref. 2107/HIA) dated October 2016. It is understood that the supply draws groundwater from the Northampton Sand aquifer which supplies water to a few surroundings residential properties.

2.12.7 An information request was submitted to Northamptonshire County Council (NCC) to investigate the potential for the presence of private water supplies within 2km of the site. NCC responded to explain that they did not hold this information and suggested contacting East Northamptonshire District Council (ENDC). The ENDC were contacted on Tuesday 25 September 2018 for details of any private water supplies within 1km of the site boundary. The ENDC responded on 02 October 2018 and their response is attached in Appendix C confirming that one PWS exists at 494638,296716 NGR which is located at Town Wood Farm, Upper Laxton; approximately 790m south of the southern site boundary.

3 Proposed Landfill Engineering

3.1 Operation Phasing

3.1.1 The proposed phasing plan is detailed on Figure 1 (Ref. MGL-A099077-PER-01) and Figure 4 (Ref. W4 18 02). As detailed in these plans, the site will be restored over 5 No. phases (A-E); however, the permit application and this report focuses on Phases A and B only.

3.1.2 Mineral extraction began in c. 2019 starting in Phase A with topsoil strip and placement to the south to establish screening bund number 5 whilst subsoils (Glacial Till) have been placed within the landscaped screening mounds to the north and west of the application site (Bunds 4 and 4a).

3.1.3 Following the topsoil strip, mineral extraction has then commenced at the western end of Phase A and has progressed eastwards towards Phase B. As works have progressed across these two phases, the overburden and imported inert waste will be subsequently utilised to facilitate the restoration of the worked-out phases of the quarry. Extraction is anticipated to be completed in c.2028.

3.1.4 It is understood that all limestone is to be removed within Phase A and B, leaving any residual existing clay layers at the base. A 1m thick geological barrier with a permeability no greater than $1x10^{-7}$m/s or equivalent will then be installed across the base and sides of the quarry as outlined below. The proposed basal depth is detailed with the Environmental Site Setting and Design Report.

3.1.5 Should groundwater be encountered within the Lincolnshire Limestone Formation during the extraction process, groundwater control measures will be put in place to control the ingress of groundwater into the site. Dewatering is not anticipated to be required during the infilling stage.

3.2 Site Engineering

<u>Artificial Geological Barrier</u>

3.2.1 An artificial geological barrier is a fundamental requirement for all landfills according to the Landfill Directive and must provide sufficient attenuation to prevent a risk to soil and groundwater. An artificial geological barrier will be installed on top of the Grantham Formation across the base of the site. The barrier will be constructed using suitable imported materials consisting of non-waste materials which will either be 1m in thickness with a permeability no greater than $1x10^{-7}$m/s or its EA approved equivalent of 0.5m with a permeability of no greater than $5x10^{-8}$m/s.

3.2.2 In situ testing and sampling will be undertaken to ensure that the imported material is suitable for this purpose. The method and testing of the material will be pre-agreed with the Environment

Agency and subsequently demonstrated to ensure that the quality of installation is to the required standards.

Sidewall Artificial Geological Barrier

3.2.3 An engineered side wall barrier is to be constructed along the sidewall of the quarry and is to have a thickness of 1m and a permeability of no greater than 1×10^{-7}m/s or its EA approved equivalent.

3.2.4 The proposed construction of the barrier would be to the specification detailed in the Construction Quality Assurance (CQA) Plan that will be produced for the site. The method and testing of the material will be pre-agreed with the Environment Agency and subsequently demonstrated to ensure that the quality of installation is to the required standards (i.e. no greater than 1×10^{-7}m/s).

Capping Layer

3.2.5 In accordance with the requirements of the Landfill Directive, an engineered cap (clay or plastic) is not required. However, on completion of filling to final levels, the site will be restored with 1m of previously stripped low permeability subsoils comprising not less than 0.3m of topsoil. High moisture content materials will be avoided to minimise the risk of consolidation.

Restoration

3.2.6 The application site was formerly used for agricultural purposes prior to mineral extraction and it is the intention of Mick George to restore the site back to agricultural land with additional features that will enhance the biodiversity of the site as detailed in the approved restoration scheme.

Leachate Management

3.2.7 An engineered leachate drainage / collection system will not be installed at Wakerley Quarry. The restoration of the site is anticipated to reduce effective infiltration in Phases A and B by c.90%. The quality of the 'leachate' generated by the inert material is expected to pose a negligible risk to the receiving environment. Therefore, no management of leachate levels will be necessary.

Leachate Monitoring

3.2.8 Adherence to the Waste Acceptance Criteria (WAC) under the Environmental Permitting Regime will ensure that the material inputs remain within the inert classification, thereby mitigating any risk to groundwater. The monitoring of the inert waste stream negates the requirement for 'leachate' monitoring.

4 Conceptual Site Model

4.1 CSM Overview

4.1.1 This section sets out a Conceptual Site Model (CSM), which qualitatively describes the potential contaminant sources / ground conditions of the proposed inert landfill site, receptors upon which contaminants could potentially have an impact and also pathways that may exist to allow contaminants to impact upon the identified receptors.

4.1.2 The Conceptual Site Model development has focussed on characterising the Hydrogeological Model for groundwater beneath the site, both in its current condition and post restoration of the site. A conceptual understanding of the hydrogeological regime in the vicinity of Wakerley Quarry and the proposed restoration has been derived from an assessment of published and site-specific information.

4.1.3 To assess the potential impact of any contamination identified at the site on groundwater receptors, a risk assessment has been progressed. In order for a risk to be present at the site three components must exist:

- Contaminant(s) must be present at concentrations capable of causing adverse effects on groundwater (Source);
- A groundwater dependent receptor must be present, (Receptor); and
- There must be exposure migration pathway by which the receptor comes into contact with the contaminant (Pollutant Linkage).

4.1.4 The source-pathway-receptor scenario is a useful means to generate a conceptual model, which can be used to identify critical pathways to inform the decision whether a more detailed quantitative analysis of risk is required. The source term is considered to be potentially contaminating components of the 'leachate' that will be generated by the inert wastes, followed by the most likely pathways that these contaminants would take in the environment and finally the potential receptors of concern.

4.2 Source Term Characteristics

4.2.1 It is proposed to restore Wakerley Quarry with inert material as outlined in the Planning Application Supporting Statement (dated August 2019). The site will be restored on a phased basis as shown in Figure 4. The Permit Application (Ref. EPR/HB3300HY/A001) includes Phases A and B only at this stage. Inert waste is defined in Article 2 of the Landfill Directive 1999/31/EC as follows:

4.2.2 *'Inert waste' means waste that does not undergo any significant physical, chemical or biological transformations. Inert waste will not dissolve, burn or otherwise physically or chemically react, biodegrade or adversely affect other matter with which it comes into contact in a way likely to give rise to environmental pollution or harm to human health. The total leachability and pollutant content and the ecotoxicity of its leachate are insignificant and, in particular, do not endanger the quality of any surface water and/or groundwater.'*

4.2.3 Table 4.1 below lists those wastes that may be accepted at the site which do not require Waste Acceptance Criteria (WAC) testing under Council Decision (2003/33/EC), provided that they are inert and from a single source only (mixed loads from more than one site cannot be accepted without testing).

Table 4.1 – Permitted Waste Types

EWC Code	Description	Restriction
10	**WASTES FROM THERMAL PROCESSES**	
10 11	**Wastes from manufacture of glass and glass products**	
10 11 03	Waste glass-based fibrous materials	Only without organic binders
15	**WASTE PACKAGING; ABSORBENTS, WIPING CLOTHS, FILTER MATERIALS AND PROTECTIVE CLOTHING NOT OTHERWISE SPECIFIED**	
15 01	**Packaging (including separately collected municipal packaging waste)**	
15 01 07	Glass packaging	
17	**CONSTRUCTION AND DEMOLITION WASTES (INCLUDING EXCAVATED SOIL FROM CONTAMINATED SITES)**	
17 01	**Concrete, bricks, tiles and ceramics**	
17 01 01	Concrete	Selected C&D waste only*
17 01 02	Bricks	Selected C&D waste only*
17 01 03	Tiles and ceramics	Selected C&D waste only*
17 01 07	Mixtures of concrete, bricks, tiles and ceramics other than those mentioned in 17 01 06	Selected C&D waste only*
17 02	**Wood, glass and plastic**	
17 02 02	Glass	
17 05	**Soil (including excavated soil from contaminated sites), stones and dredging spoil**	
17 05 04	Soil and stones other than those mentioned in 17 05 03	Excluding topsoil, peat; excluding soil and stones from contaminated sites
19	**WASTES FROM WASTE MANAGEMENT FACILITIES, OFF-SITE WASTE WATER TREATMENT PLANTS AND THE PREPARATION OF WATER INTENDED FOR HUMAN CONSUMPTION AND WATER FOR INDUSTRIAL USE**	
19 12	**Wastes from the mechanical treatment of waste (for example sorting, crushing, compacting, pelletising) not otherwise specified**	
19 12 05	Glass	
20	**MUNICIPAL WASTES (HOUSEHOLD WASTE AND SIMILAR COMMERCIAL, INDUSTRIAL AND INSITUTIONAL WASTES) INCLUDING SEPARATELY COLLECTED FRACTIONS**	
20 01	**Separately collected fractions (Except 15 01)**	

20 01 02	Glass	Separately collected glass only
20 02	**Garden and park wastes (including cemetery waste)**	
20 02 02	Soil and stones**	Only from garden and parks waste; excluding topsoil, peat.

Table Notes:
*Selected construction and demolition waste with low contents of other types of materials (like metals, plastic, soil, organics, wood, rubber etc). The origin of the waste must be known.
- No C&D waste from construction, polluted with inorganic or organic dangerous substances e.g. because of production processes in the construction, soil pollution, storage and usage of pesticides or other dangerous substances etc., unless it is made clear that the demolished construction was not significantly polluted.
- No C&D waste from constructions treated, covered or painted with materials, containing dangerous substances in significant amounts.
- The origin of the wastes must be known and they will have low contents (<5% by mass per load of other types of materials (like metals, plastics, soil, organics, wood, rubber, etc).

4.2.4 Permitted wastes accepted at the site will be strictly inert as classified under the Landfill Directive (1999/31/EC) and Council Decision (2003/33/EC) of 19 December 2002 'establishing criteria and procedures for the acceptance of waste landfills'.

4.2.5 The total quantity of waste materials that will be used to restore the quarry is anticipated to be 2.50Mm^3 which equates to approximately 4M tonnes when using a bulk density conversion factor of 1.6 tonnes/m^3. Importation rates for waste will be 100,000m^3 per annum (approximately 160,000 tonnes per annum). It is expected that filling of Phases A and B will take approximately 12 years.

Leachate Generation

4.2.6 Due to the inert nature of the material to be used to restore the quarry, it is considered highly unlikely that water coming into contact with the material at the restored site will generate high concentrations of pollutants. It is proposed to screen incoming waste under Council Decision (2003/33/EC) Inert waste acceptance criteria. It is recognised that hazardous substances and non-hazardous pollutants are present in these criteria and could occur from rogue loads of non-inert waste. However, to mitigate this, the operator would restrict the source of waste materials allowed on to the site and all waste would be subject to stringent Waste Acceptance Procedures (as detailed in the Operating Techniques, Appendix B of the Environmental Permit Application). It is therefore considered that hazardous substances are not expected to be present and non-hazardous substances are expected to be low with respect to the background groundwater quality.

4.2.7 The decline in leachate concentrations is controlled by water inputs to the fill material at the site. The limestone mineral (Lincolnshire Limestone Formation) is to be extracted in phases, starting within Phase A and rolling eastwards into Phase B as discussed in Section 3.1. Therefore, the site will be restored in a phased manner and will be open to rainfall infiltration to the waste which will either run-off over the waste and be subject to evapotranspiration or, infiltrate through waste mass as effective rainfall.

4.2.8 The annual average rainfall (1981 to 2010) has been obtained from a weather station located at Wittering[8] c. 11.5km northeast of the site and is reported at a value of 609mm/year. This annual rainfall value has been compared against the Centre for Ecology & Hydrology (CEH) and BGS UK Hydrological Review report for Anglian catchment in 2010[9]. The annual rainfall for the Anglian area was 666mm/year in 2009 into 2010. The average annual rainfall for the Anglian area between 1971 and 2000 is c. 601mm/year. Therefore, the annual rainfall reported by the nearby weather station is within the annual rainfall range for the region.

4.2.9 During rainfall events, rainwater will fall onto the ground where a proportion will infiltrate through the top of soils and the balance will run off. The remaining water will seep into the underlying Glacial Till/ restoration soils (upon restoration of the site) where it will be subject to evaporation and use by plants (transpiration). These two processes are known as evapotranspiration. The CEH & BGS UK Hydrological Review report for 2009[10] provides actual evapotranspiration rates for that year and totals for 1971 to 2000 as a percentage. The actual evapotranspiration totals for the Anglian area are shown to be between 490 - 529mm/year, with the average between 1971 to 2000 shown to be as much as 10% lower than this.

4.2.10 The approximate area of Phases A and B are approximately 455,000m^2 and the estimated effective rainfall to the site is anticipated to be 119 to 80mm/year which is based on the annual rainfall (609mm/year) recorded at the Wittering rainfall station minus the average evapotranspiration rates (490 - 529mm/year). Based on this, the current infiltration is estimated to be c. 36,400 to 54,145m^3/year.

4.2.11 Following the infilling of the void with inert materials, the site will be restored with 1m of previously stripped low permeability Glacial Till clay soils comprising not less than 0.3m of Topsoil. High moisture content materials will be avoided to minimise the risk of consolidation. It is known that the soils are to comprise of low permeability clay rich Glacial Till soils. This restoration soil profile will promote surface water run-off and limit effective rainfall infiltration and leachate migration from existing waste into the underlying inert materials. Therefore, the effective rainfall at the site, following restoration, is anticipated to be similar to that for the current site setting.

4.2.12 Effective rainwater which does infiltrate through the restoration layer will migrate vertically through the inert waste materials. 'Leachate' generated will be subject to attenuation and retardation processes as it migrates through the geological barrier and the unsaturated zone of the limestone aquifer.

[8] Wittering Weather Station: https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-averages/gcrem99cb
[9] UK Hydrological Review, 2010: http://nora.nerc.ac.uk/id/eprint/15942/1/Hydrological_Rev2010.pdf
[10] UK Hydrological Review, 2009: http://nora.nerc.ac.uk/id/eprint/13677/1/Hydrological_Rev2009.pdf

4.2.13 LandSim model runs with a non-fixed leachate head have been conducted to determine the level to which the leachate within the waste is likely to rise to. Additional calculations have also been undertaken using hydraulic containment worksheets to quantify the flux of water into the landfill from the Lincolnshire Limestone, through the low permeability sidewall liner. The modelling of the predicted maximum leachate head and a discussion of the water balance at the site is presented in Section 5.4.9 of this report.

4.3 Pathways

4.3.1 A conceptual understanding of the hydrogeological regime in the vicinity of Wakerley Quarry and the proposed restoration has been derived from an assessment of both published and site-specific information.

4.3.2 The site is underlain by low permeability clays of the Glacial Till which overlies limestone layers of the Lower Lincolnshire Limestone which is designated a Principal Aquifer by the EA. The Glacial Till deposits are to be stripped at the site and temporarily stockpiled for later use to restore the quarry. Limestone is anticipated to be extracted to or close to the base of the Lincolnshire Limestone which is underlain by mudstone layers of the Grantham Formation (non-aquifer). The low permeability mudstone layers of the Grantham Formation will provide retardation and attenuation to any generated 'leachate' contaminants within the waste mass following the removal of the limestone; offering protection to the underlying Northampton Sand Formation (Secondary A Aquifer). An artificial geological barrier is to be installed on top of the Grantham Formation across the base of the site which will provide further attenuation and retardation to any leachable contaminants generated.

4.3.3 Extraction works commenced at the site in c. 2019 and are expected to finish in c. 2028. Prior to starting extraction and stripping of sub-soils, the Glacial Till deposits would have limited rainfall recharge to the underlying Lincolnshire Limestone. The limestone aquifer is recharged where the limestone outcrops at or close to the surface in areas where the Glacial Till is thin or absent such as to the north-west and west of the site. The limestone aquifer would also receive recharge from surface water run-off from the overlying Glacial Till.

4.3.4 Three faults have been identified to transect through the site which trend east, north-east to west and south-west through Phases A and B. The faults are understood to have downthrown the underlying geology by as much as 5m within the south-eastern area of the site. Faulting at the site combined with the former ironstone workings within the Northampton Sand Formation to the north-west are significant controls on groundwater flows / levels as outlined in Section 2.8.13 and 2.8.14.

4.3.5 A hydrogeological conceptual model is discussed in the following sections and is depicted in Figure 5 (a & b) and Figure 6 (a & b), for the site in its current condition and proposed restoration phases, respectively.

Groundwater Levels

4.3.6 Groundwater monitoring boreholes have been installed into both the Lincolnshire Limestone and Northampton Sand aquifers in 5No. boreholes locations (W01, W02, W03, W04 and W05) as outlined in Section 2.10 and 2.11. Groundwater levels have been recorded between May 2016 and August 2020 for W01-04 while W05D only has groundwater levels from August 2020. The results are summarised in Table 4.2 for the shallow Lincolnshire Limestone and Table 4.3 for the deeper Northampton Sands. Groundwater hydrographs for the groundwater levels recorded over the monitoring period are presented in Insert 1 and Insert 2.

Table 4.2 – Lincolnshire Limestone Formation Groundwater Levels

BH ID		Groundwater Level (m AOD)				
		W01S	W02S	W03S	W04S	W05S
2016	May-16	Dry	91.65	86.84	81.36	No Data
	Jun-16	Dry	91.23	86.56	81.26	No Data
	Jul-16	Dry	91.11	86.61	81.23	No Data
	Aug-16	Dry	90.89	86.33	81.22	No Data
	Sep-16	Dry	90.7	86.07	80.71	No Data
	Oct-16	Dry	90.54	85.71	80.21	No Data
	Nov-16	Dry	90.71	86.11	80.15	No Data
	Dec-16	Dry	90.59	86.00	80.13	No Data
2017	Jan-17	Dry	90.59	85.77	80.03	No Data
	Feb-17	Dry	90.74	86.65	80.21	No Data
	Mar-17	Dry	91.24	86.50	80.34	No Data
	Apr-17	Dry	90.98	86.30	80.24	No Data
	Jul-17	Dry	90.59	85.98	79.90	No Data
	Oct-17	Dry	90.37	85.52	79.65	No Data
2018	Jan-18	Dry	90.72	86.23	No Data	No Data
	Aug-18	Dry	90.70	86.06	80.39	No Data
	Oct-18	93.95	90.52	85.55	79.95	No Data
	Nov-18	Dry	90.44	86.95	Dry	No Data
2019	Jan-19	Dry	91.14	87.30	79.72	No Data
	Feb-19	Dry	91.54	85.80	79.72	No Data
	May-19	Dry	90.54	84.50	Dry	No Data
	Jul-19	Dry	90.74	83.70	Dry	No Data
2020	Feb-20	Dry	93.72	Dry	80.77	No Data

BH ID		Groundwater Level (m AOD)				
		W01S	W02S	W03S	W04S	W05S
	May-20	Dry	92.51	87.03	81.61	No Data
	Aug -20	Dry	90.78	86.29	80.49	84.45
	Nov-20	Dry	90.66	86.20	No Data	84.62

Note: W01S reported to be dry for majority of monitoring period. No data collection at W04S on 2No. occasions as hole is reported to be blocked. No data collection from W05S until August 2020 as borehole was not installed until August 2020.

Table 4.3 – Northampton Sand Formation Groundwater Levels

BH ID		Groundwater Level (m AOD)				
		W01D	W02D	W03D	W04D	W05D
2016	May-16	84.83	90.01	75.62	81.32	No Data
	Jun-16	84.69	89.83	76.42	81.22	No Data
	Jul-16	84.80	89.66	76.59	81.21	No Data
	Aug-16	84.48	89.48	76.56	81.21	No Data
	Sep-16	84.77	89.54	76.47	80.67	No Data
	Oct-16	84.77	86.27	76.18	80.17	No Data
	Nov-16	84.59	83.77	76.6	80.1	No Data
	Dec-16	84.76	83.60	76.30	80.08	No Data
2017	Jan-17	No Data	83.11	77.62	79.99	No Data
	Feb-17	84.52	87.12	78.32	80.11	No Data
	Mar-17	85.31	82.94	78.42	79.92	No Data
	Apr-17	84.78	82.87	77.12	79.84	No Data
	Jul-17	84.79	82.84	77.08	79.52	No Data
	Oct-17	84.42	82.69	76.82	79.60	No Data
2018	Jan-18	84.75	82.59	77.09	No Data	No Data
	Aug-18	84.79	82.68	77.52	80.02	No Data
	Oct-18	84.78	82.61	76.99	79.61	No Data
	Nov-18	Dry	82.61	77.32	79.35	No Data
2019	Jan-19	84.79	83.24	78.72	79.42	No Data
	Feb-19	85.09	86.14	78.32	81.22	No Data
	May-19	Dry	83.74	77.82	No Data	No Data
	Jul-19	Dry	82.24	76.92	No Data	No Data
2020	Feb-20	84.78	82.84	77.74	Dry	No Data
	May-20	Dry	82.84	78.71	No Data	No Data
	Aug -20	Dry	82.73	79.42	80.13	84.46
	Nov-20	84.77	82.67	80.91	No Data	84.64

Note: No data collection possible at W01D on 1No. occasion and W04D on 5No. occasions as hole is reported to be blocked. No data collection from W05D until August 2020 as borehole was not installed until August 2020.

4.3.7 Since the advancement of the borehole and installations, the base of some boreholes has become heavily silted. Therefore, Table 4.4 below summarises the depths to which boreholes were advanced, their respective screened sections and the measured based of the borehole, taken during field measurements in November 2020.

Table 4.4 – Northampton Sand Formation Groundwater Levels

Borehole ID	Drill Depth (m / mAOD)	Screen Depth (mbgl)	Base Depth* (m / mAOD)
W01S	16m / 85.83mAOD	2 – 8	7.9m / 93.93mAOD
W02S	14.5m / 89.74mAOD	8.5 – 14.5	14.45m / 89.79mAOD
W03S	22m / 81.30mAOD	9 – 21	20.46m / 82.84mAOD
W04S	22m / 79.22mAOD	8 – 22	21.6m / 79.62mAOD
W05S	17m / 83.41mAOD	7.7 – 17	17.36m / 83.05mAOD
W01D	19m / 82.89mAOD	13 – 18	17.36m / 84.53mAOD
W02D	25m / 79.24mAOD	14 – 24.50	24.2m / 80.04mAOD
W03D	32m / 71.32mAOD	24 – 32	28.58m / 74.74mAOD
W04D	31m / 70.22mAOD	25 – 31	29.5m2 / 71.70mAOD
W05D	27m / 73.66mAOD	18.5 – 23	23.74m / 76.92mAOD

** Base depth determined via field measurements in November 2020.*

4.3.8 Subsequent discussions on saturated thicknesses, base of borehole and other relevant associated information is based off this data presented in Table 4.4.

4.3.9 A commentary on the recorded groundwater levels for each of the 5No. groundwater monitoring borehole locations is discussed below in the following sub-headings.

Monitoring Borehole W01

4.3.10 Groundwater has been regularly recorded in all monitoring boreholes installed into the Lincolnshire Limestone at the site with the exception of borehole 'W01S' which is located in the north-western corner of the site. Of the twenty six monitoring rounds, groundwater was only encountered during one visit and during this visit, there is only a recorded 0.02m of groundwater within the borehole. The 2016 Hafren Water report states that this borehole is separated from the other monitoring boreholes to the east and south-east by a series of recorded faults. Three faults are shown to extend across Phase A and Phase B and are trending north-east to south-west through the site. These faults are all shown to be downthrown to the south-east by approximately 1.50 to 2.50m.

4.3.11 The Hafren report states that *"It is unclear whether this borehole is dry because of its location on* *the north side of a series of geological faults or because it may be affected by former nearby working of Ironstone, which may have caused drainage of water from the Lincolnshire Limestone."* A review of the borehole log for W01D reveals a void was encountered between 15.40m bgl (85.98m AOD) and 18.00m bgl (83.38m AOD) within the Northampton Sand Formation. This void could be the result of previous mining of the ironstone which has potentially artificially drained groundwater present in the overlying Limestone aquifer in this area of the site. However, this void could also indicate presence of a fracture in the sandstone. There is no clear evidence to suggest that ironstone workings extended beneath the site.

4.3.12 The installation of borehole W01S (Lincolnshire Limestone) includes a screened section from 2mbgl to 8mbgl (99.83mAOD to 93.83mAOD); however, the base of the Limestone Unit is not proven until 89.10mAOD based on Table 2.2. It is considered that during initial site investigations and borehole design, the base of the Lincolnshire Limestone has been mistaken for the Grantham Formation as the transitional boundary can be very sandy. Due to the lack of organic or shell debris within the log, it is considered that the Grantham Formation is not encountered until 12.20mbgl (89.63mAOD). Review of the relevant log indicates the borehole was backfilled from 16 to 10mbgl and then infilled with bentonite from 10 to 8mbgl (93.83mAOD). Based on the most recent plumbed depth of the borehole, the borehole is 7.9m deep, i.e. extends from 101.83mAOD to 93.93mAOD.

4.3.13 Therefore, there is a 4.73m section of Limestone which is not screened at this location with a potential maximum and minimum saturated thickness of 4.5m within the Lincolnshire Limestone; however, this is considered improbable as the monitoring location has been dry for the vast majority of the monitoring period and based on the install discrepancy described above.

4.3.14 Groundwater levels recorded in monitoring borehole W01D (Northampton Sand) are shown to be generally consistent over the monitoring period with an average of 84.76m AOD. This average groundwater level is below the base of the Grantham Formation and therefore, confining conditions do not exist within the Northampton Sand aquifer in this area.

4.3.15 Based on the recorded groundwater levels in W01D (84.42 – 85.31mAOD), the Northampton Sand aquifer has an unsaturated zone of 3.47 – 4.36m thickness below the base of the overly Grantham Formation and groundwater levels recorded are indicative of the water table within the sand aquifer. A maximum and minimum saturated thickness of 1.93m and 1.04m respectively is anticipated at this location.

Monitoring Borehole W02

4.3.16 Groundwater monitoring borehole W02 is located within the south-western area of the site and is located between 2No. recorded faults. Groundwater levels recorded in W02S, which is installed within the Lincolnshire Limestone, are shown to be generally consistent (see Insert 1) over the monitoring period with an average of 90.96m AOD which equates to an un-saturated portion of approximately 13.87m within the limestone aquifer. Conversely there is a potential saturated thickness of 4.13m based on the maximum groundwater levels and a minimum of 0.78m based on the minimum groundwater levels within the Lincolnshire Limestone.

4.3.17 Groundwater levels recorded in monitoring boreholes W02D, which is installed within the deeper Northampton Sand aquifer, are not shown to be consistent in comparison to the overlying limestone; with a fluctuation of more than 7.7m recorded over the monitoring period as shown in Note: *W01S reported to be dry for majority of monitoring period. No data collection at W04S on 2No. occasions as hole is reported to be blocked. No data collection from W05S until August 2020 as borehole was not installed until August 2020.*

4.3.18 Table 4.3 – Northampton Sand Formation Groundwater Levels and Insert 2 below. Therefore, the Northampton Sand aquifer is shown to exhibit both confining and unconfining conditions over this period and therefore is likely to receive groundwater recharge; either from flooded ironstone workings (see below) or from nearby faults which are providing a preferential flow path from other recharge sources.

Monitoring Borehole W03

4.3.19 Groundwater monitoring borehole W03 is installed along the southern boundary of the site. Groundwater levels recorded in W03S within the Lincolnshire Limestone are generally consistent (see Insert 1), with an average of 86.1m AOD which equates to an un-saturated zone of approximately 19m within the limestone aquifer. Conversely, there is a potential saturated thickness of 5.53m based on the maximum groundwater levels and a minimum of 1.93m based on the minimum groundwater levels within the Lincolnshire Limestone.

4.3.20 Groundwater levels recorded in monitoring borehole W03D, which is installed within the deeper Northampton Sand aquifer, is not shown to be consistent in comparison to the overlying limestone; however, less fluctuation of levels is recorded when compared to W02 with a range of 3.10m over the monitoring period. An average groundwater level of 77.45m AOD has been recorded in W03D over the monitoring period which is below the base of the overlying Grantham Formation and therefore, unconfined conditions exist in this part of the site. Based on the maximum and minimum groundwater levels recorded, the Northampton sands are expected to range from full saturated with a potentiometric surface in the Limestone, to a saturated thickness of 2.44m.

Monitoring Borehole W04

4.3.21 As shown in the above groundwater summary tables and in Inserts 1 and 2 below, groundwater levels recorded in both W04S and W04D are broadly similar. The groundwater levels recorded in W04D, which is installed within the deeper Northampton Sand Formation is above the top of the Grantham Formation (encountered at 79.30m AOD), with an average level of 80.24mAOD over the monitoring period. As the groundwater levels are above that of Grantham Formation which separates the two aquifers, groundwater is confined and under pressure within the Northampton Sand Formation in this area of the site. The piezometric level recorded in W04D has risen to that of the water table in the Lincolnshire Limestone (average 80.36mAOD) which indicates that two aquifers are in hydraulic connection.

4.3.22 Based on the recorded groundwater levels within W04S, an unsaturated zone of approximately 21.57m exists within the Lincolnshire Limestone in this area of the site beneath the Glacial Till. A saturated thickness of up to 2.25m is possible based on the maximum groundwater levels within the Lincolnshire Limestone at this location. A minimum thickness of 0.29m is anticipated based on minimum groundwater levels recorded.

Monitoring Borehole W05

4.3.23 Groundwater monitoring borehole W05 is installed along the northern boundary of the site. As only one data point has been reported to date, it is not possible to determine the trend of groundwater levels within the Lincolnshire Limestone, nor has it been added to Insert 1 or 2. Groundwater levels recorded in monitoring borehole W05S (installed within the shallower Lincolnshire Limestone) and W05D (installed within the deeper Northampton Sand aquifer), are shown to be consistent; a difference of 0.01m between the monitoring points. The Northampton Sands are under slight confined conditions in this part of the site.

4.3.24 Based on the single recorded groundwater level available, it equates to an un-saturated zone of approximately 13m within the limestone aquifer. A saturated depth of approximately 2.0m will exist at W05D due to the marginally confined conditions

Groundwater Flow Direction

4.3.25 Groundwater levels recorded within the Lincolnshire Limestone, with the exception of W01S, indicate that groundwater flow is largely to the north east down geological dip of the aquifer. The 2016 Hafren report did not determine whether the faults present at the site are acting as hydrogeological barriers or preferential pathways for groundwater flow beneath the site. The site itself is situated on a topographic high, approximately between 105 to 100m AOD, with the topography shown to fall to the north, east and south of the site. It is acknowledged that a catchment divide for surface water flows is present across the site (trending approximately west to east, across the southern half of the site. This catchment divide is a result of the topography. It is considered that groundwater beneath the site is not subject to the same divide and does not mimic the site topography.

4.3.26 Based on available groundwater level monitoring data, groundwater flow beneath the site (Phases A and B) within the shallower Lincolnshire Limestone is shown to be towards the east / northeast. This flow direction is consistent on drawn groundwater contour plots during both periods of high groundwater levels (Figures 7a [January 2019] and 7b [November 2020]) and low groundwater levels (Figures 7c [May 2020] and 7d [August 2020]). The groundwater levels monitored in August 2020 are anticipated to be a seasonal low. This remained consistent during the one monitoring period when water was detected in monitoring borehole W01S.

4.3.27 Faults recorded to be present at the site have likely brought the Lincolnshire Limestone aquifer on the eastern side of the fault into hydraulic connection with potentially water bearing ironstone workings / Northampton Sands aquifer on the western side of the faults and therefore, these faults could be providing pathways for groundwater flow / recharge between aquifers.

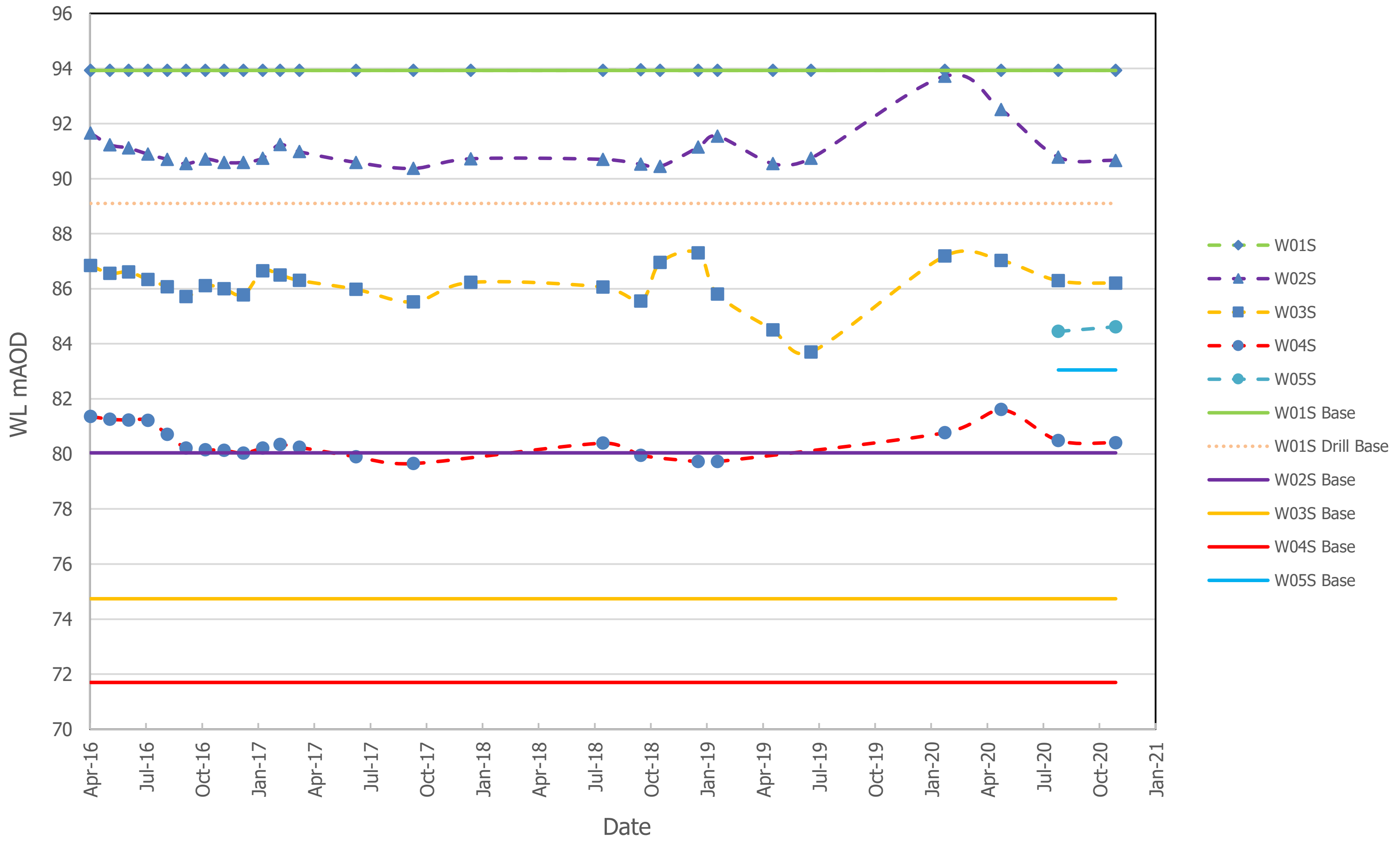
4.3.28 Groundwater flow is inferred to be cross gradient of springs annotated to the north of the site. There are also the aforementioned faults trending through the site which has the potential to reduce or provide flow to that direction. Based on available data and groundwater contours, flow is not towards the springs.

4.3.29 Based on available groundwater level monitoring data, groundwater flow beneath the site within the deeper Northampton Sands is shown to be towards the southeast. This flow direction is consistent on drawn groundwater contour plots during both periods of high groundwater levels (Figures 7e [January 2019] and 7f [November 2020] and low groundwater levels (Figure 7g [August 2020]). Groundwater levels are generally higher in monitoring borehole W01D and W02D, with borehole W03D consistently recording the lowest groundwater levels across the monitoring period. Please note, as shown on Insert 2 below, groundwater levels recorded in W02D were initially above the groundwater levels recorded in W01D for the first 5 No. monitoring visits with an average level of 89.5m AOD; which indicates the potential for groundwater flow north eastwards within the Northampton Sand Formation in this area of the site. This alteration to expected direction is not considered a common occurrence as the groundwater level at W02D has only been recorded as higher than W01D on one occasion in a period of 44No. months of monitoring.

4.3.30 As discussed previously, groundwater levels recorded in both W04S and W04D are similar in level which indicates that the two aquifers are in hydraulic connection, certainly at this location, and that the Grantham Formation is acting as a leaky aquitard in this part of the site. Groundwater levels recorded in the Lincolnshire Limestone within W02S and W03S are consistently above the levels recorded in the Northampton Sand which indicates that a vertical hydraulic head gradient exists; allowing potential vertical migration across the Grantham Formation. However, based on the average pressure head differences recorded (between 5 and 10m), this is anticipated to be limited and that the clays layers of the Grantham Formation will provide retardation and attenuation to any generated 'leachate' contaminants within the waste mass.

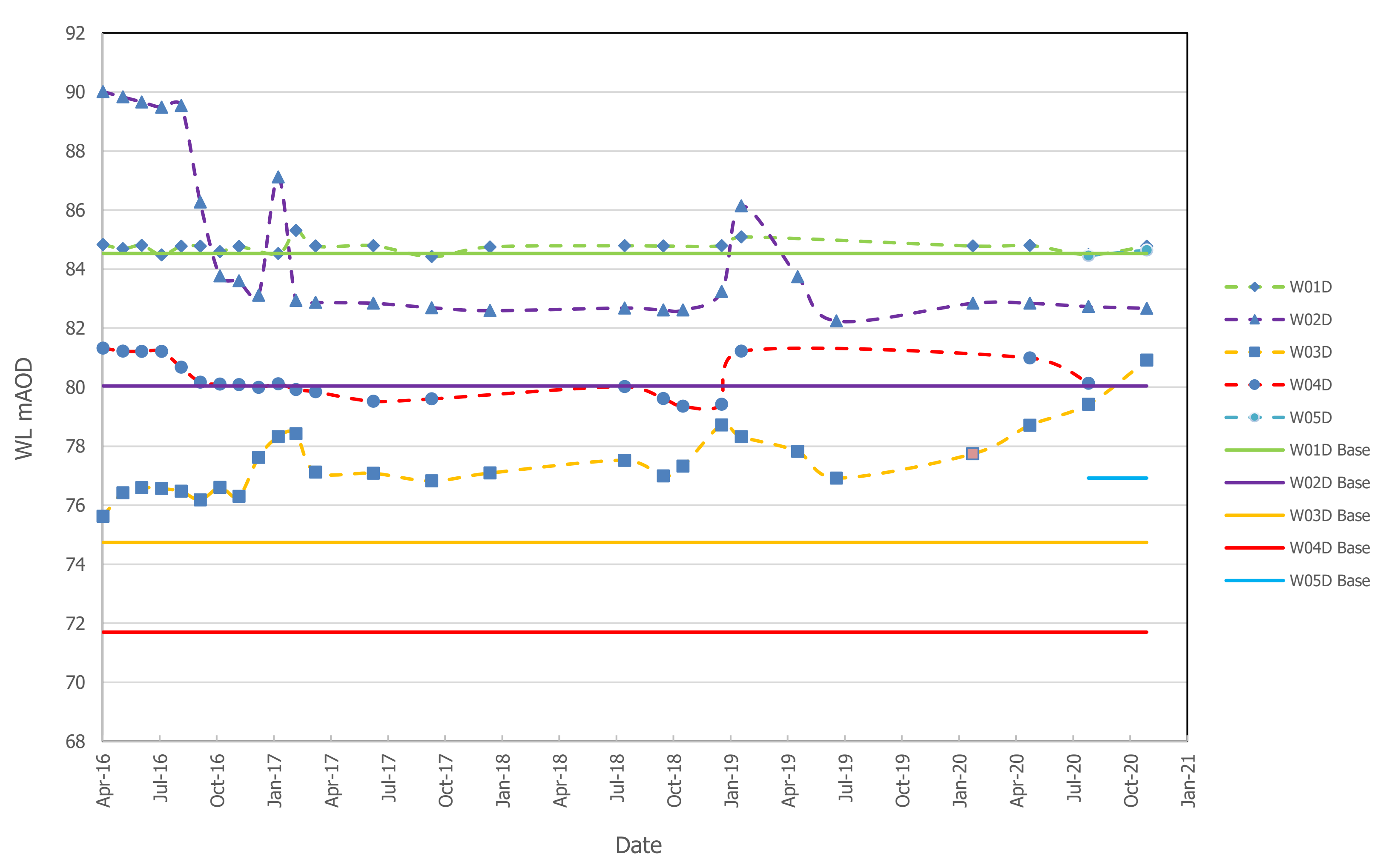
4.3.31 Groundwater within the Lincolnshire Limestone are not anticipated to be in hydraulic connection with the surface water features identified to the east of the site (between 100 and 95mAOD) due to the predominate thickness of Glacial Till (greater than 12m thickness) and potential presence of the Rutland Formation in this area. Therefore, these surface water features are not considered receptors to groundwater flow within the CSM.

Insert 1: Groundwater Level Hydrograph in Lincolnshire Limestone (W01S – W04S)



Note: Symbols represent spot physical measurements. The connecting dashed lines represent the inferred fluctuation of the groundwater table

Insert 2: Groundwater Level Hydrograph in Northampton Sands (W01D – W04D)



Note: Symbols represent spot physical measurements. The connecting dashed lines represent the inferred fluctuation of the groundwater table

Baseline Groundwater Quality

4.3.32 The previous Hafren Water Boreholes (W01S/D to W04S/D) were monitored for water levels and water quality from May 2016 onwards. The data has been screened against the UK Drinking Water Standards (UKDWS) initially due to the presence of a private water supply (groundwater) approximately 700m south of the site. In the absence of a UKDWS, available Environmental Quality Standards (EQSs) are used instead. These screening values are highlighted in bold in the below tables (Table 4.4 and 4.6). It should be noted that potential outliers have not been removed at this stage, but statistical analysis has been performed on the data set for the calculation of Environmental Assessment Levels (EALs) in Section 4.4. The full results from the groundwater quality monitoring rounds are available at Appendix F.

4.3.33 Exceedances of metals (manganese, cadmium, iron, mercury and zinc) and ammoniacal nitrogen are recorded within samples collected from the Lincolnshire Limestone. Manganese concentrations exceed the UKDWS within W02S in May and September 2016, but exceedances are not observed in the other boreholes around the site. Similarly, cadmium exceeds the UKDWS in W02S in May 2016 and mercury UKDWS is exceeded in W03S in July of 2017 and 2019. However, iron and zinc concentrations consistently exceed the UKDWS and EQS screening levels. Iron concentrations are variable across the period and exceed the UKDWS on all occasions except August 2016. Zinc concentrations are highly variable, exceeding the DWS by varying amounts across different borehole locations.

4.3.34 Exceedances of some metals (iron, nickel and zinc) and ammoniacal nitrogen also occur within the groundwater within the Northampton Sands aquifer. The exceedance for nickel in the groundwater only occurs on one occasion in W03D, with levels consistently below the DWS. Similarly, to the concentrations within the overlying Lincolnshire Limestone, concentrations of iron in the groundwater within the sands are highly variable as shown by the calculated standard deviation, and concentrations consistently exceed the UKDWS with the exception of a monitoring round conducted in August 2016. Similarly, concentrations of zinc are highly variable but commonly exceed the EQS by orders of magnitude.

4.3.35 Elevated concentrations or iron and manganese within samples collected from the Northampton Sand aquifer is expected as these determinants are synonymous with aquifers with thick sandstone horizons. However, samples obtained from the limestone aquifer from monitoring boreholes W02S-W03S have recorded similarly elevated concentrations with higher manganese concentrations recorded in the Lincolnshire limestone. This provides evidence that the two aquifers are likely to be in hydraulic connection as a result of the faulting present at the site.

Table 4.5 - Baseline Groundwater Quality within the Lincolnshire Limestone

Determinand	Units	DWS	EQS	Minimum	Average	Maximum	Median	95th percentile	Standard deviation
pH		6.5 - 9.5	6.5 - 9.5	7	7.75	8.3	7.85	8.2	0.37
Conductivity	uS/cm	2500	1000	210	769.80	1100	790	980	172.69
Alkalinity	mg/l	n/a	n/a	50	266.49	490	250	452	104.73
Ammoniacal N	mg/l	0.5	0.3	0.019	0.54	3.2	0.185	1.8	0.75
Copper	ug/l	2000	1.0	1	2.30	7.9	1.6	6.1	1.83
Manganese	ug/l	50	123	1.6	18.42	180	5.9	90.6	36.53
Ammonia	ug/l	n/a	n/a	0.01	0.05	0.14	0.05	0.14	0.04
Sodium	mg/l	200	n/a	7	19.12	44	16	38	9.33
Cadmium	ug/l	5	0.25	0.097	8.22	30	1.4	25.71	14.53
Chloride	mg/l	250	n/a	13	38.34	96	30	71.1	19.07
Sulphate	mg/l	250	n/a	12	89.67	240	77	182	50.61
BOD	n/a	n/a	n/a	4	4.88	9	4	7.825	2.02
COD	n/a	n/a	n/a	10	19.74	83	13	44.3	16.89
Calcium	mg/l	n/a	n/a	26	146.37	320	150	196	44.84
Chromium	ug/l	50	n/a	1.1	4.22	10	3.4	7.76	2.02
Iron	ug/l	200	1000	34	382.12	920	350	688	176.05
Lead	ug/l	10	1.2	1	1.27	1.5	1.3	1.48	0.25
Magnesium	mg/l	n/a	n/a	1.8	8.88	26	8	19.2	5.05
Mercury	ug/l	1	0.07	0.88	4.42	13	1.9	11.41	5.75
Nickel	ug/l	20	4	1.1	2.66	9.9	2.1	5.22	1.96
Potassium	mg/l	n/a	n/a	0.52	2.20	9.4	1.6	5.135	1.86
Selenium	ug/l	n/a	10	1	2.06	7.4	1.65	5.265	1.51
Zinc	ug/l	n/a	12.9	1.7	74.80	1400	17	292	218.25

Note: Cells coloured in grey exceed the relevant EQS value, while cells coloured in orange exceed the relevant DWS value

Table 4.6 - Baseline Groundwater Quality within the Northampton Sands

Determinand	Units	DWS	EQS	Minimum	Average	Maximum	Median	95th percentile	Standard deviation
pH		6.5 - 9.5	6.5 - 9.5	6.90	7.72	8.40	7.80	8.30	0.42
Conductivity	uS/cm	2500	1000	200	739	960	770	890	150.16
Alkalinity	mg/l	n/a	n/a	42	280	510	300	439	102.56
Ammoniacal N	mg/l	0.5	0.3	0.02	0.53	3.30	0.29	1.50	0.64
Copper	ug/l	2000	1	1.00	1.66	12.00	1.00	5.10	1.88
Manganese	ug/l	50	123	0.50	12.27	160.00	7.35	30.90	21.26
Ammonia	ug/l	n/a	n/a	0.01	0.03	0.14	0.02	0.08	0.03
Sodium	mg/l	200	n/a	7.50	15.60	42.00	14.00	36.85	7.95
Cadmium	ug/l	5	0.25	0.01	0.10	1.00	0.08	0.08	0.12
Chloride	mg/l	250	n/a	1.00	29.3	77.0	25.5	72.3	16.83
Sulphate	mg/l	250	n/a	12.00	78.4	190.0	79.0	139.5	34.54
BOD	n/a	n/a	n/a	4.00	4.55	22.00	4.00	5.88	2.54
COD	n/a	n/a	n/a	10.00	14.93	58.00	10.00	36.15	9.34
Calcium	mg/l	n/a	n/a	24.00	144.24	240.00	140.00	189.50	38.00
Chromium	ug/l	50	n/a	1.00	2.66	11.00	1.80	7.65	2.32
Iron	ug/l	200	1000	31.00	446	1800	355	977	292.03
Lead	ug/l	10	1.2	1.00	1.03	3.00	1.00	1.00	-
Magnesium	mg/l	n/a	n/a	1.20	6.82	22.00	6.60	13.90	3.75
Mercury	ug/l	1	0.07	0.01	0.55	7.00	0.50	0.76	1.02
Nickel	ug/l	20	4	1.00	2.29	22.00	1.60	4.38	2.78
Potassium	mg/l	n/a	n/a	0.50	2.04	9.80	1.30	6.05	2.10
Selenium	ug/l	n/a	10	1.00	1.66	7.40	1.20	3.79	1.40
Zinc	ug/l	n/a	12.9	1.00	217.96	2700.00	24.50	800.00	554.85

Note: Cells coloured in grey exceed the relevant EQS value, while cells coloured in orange exceed the relevant DWS value

Transport Mechanisms

4.3.36 The following transport mechanisms are considered within the quantitative assessment (Section 4):

- **Advection** - The principal mechanism by which contaminations move through the aquifer is advection, which means that the contaminants move with the average velocity of the groundwater. The average velocity of the groundwater flow is the average velocity of the mobile water molecules;
- **Dispersion** - The spreading of the advancing solute front as a result of tortuous flow paths within porous media. This is assumed to occur in the direction of groundwater flow (longitudinal dispersion), and also perpendicular to the flow path (lateral / transverse dispersion) whereby contaminants moved around the grains of the rock;
- **Dilution** – Leachate generated from the inert waste materials which migrate vertically through the base of the landfill will be subject to dilution beneath the site area within the Northampton Sand Formation (after retardation within the overlying Grantham Formation). Although unlikely, owing to the construction of a sidewall barrier and preferential vertical flow pathway, leachate migration horizontally into the adjacent Lincolnshire Limestone will be subject to dilution within the aquifer. Dilution calculations for the Lincolnshire Limestone have been performed in Section 5.
- **Adsorption and Desorption** - The process of adsorption of contaminant molecules to soil particles, retarding the movement of the advecting solute front. Retardation processes are likely to occur primarily within the geological barrier and underlying Grantham Formation (Vertical Pathway) in the LandSim Model (Section 5) Retardation is also expected to occur as contaminants migrate through the saturated pathway i.e. Northampton Sand & Lincolnshire Limestone aquifers. Contaminants will be subject to sorption processes such as adsorption, chemisorption, absorption and cation exchange;
- **Biodegradation** - The breakdown of organic contaminant molecules, principally as a result of microbially mediated processes (biodegradation) within the unsaturated zone and saturated aquifer pathway. These processes can occur aerobically or anaerobically and vary between contaminants and groundwater conditions. Biodegradation of phenol has been considered in the Northampton Sand aquifer only. No degradation (denitrification) of ammonium (NH_4) is considered in the quantitative assessment.

4.4 Receptors

4.4.1 The following are considered to represent potential receptors for any contamination from the proposed infilling of Phase A and Phase B at Wakerley Quarry:

- Groundwater present in the adjacent Lincolnshire Limestone following extraction of the mineral (Principal Aquifer);
- Groundwater present within the underlying Northampton Sand Formation (Secondary A Aquifer) beneath the Grantham Formation;
- An unnamed surface water feature (stream) located approximately 700m to the south of the site within the woodland known as 'Wood Hollow' which is potentially receiving baseflow from the Lincolnshire Limestone (if a hydraulic connection exists);

4.4.2 The Lincolnshire Limestone Formation which is present adjacent to the site boundary is considered a receptor to horizontal 'leachate' migration from the site during post operation phase. The risks to this aquifer have been assessed quantitatively in Section 5.

4.4.3 The Northampton Sand Formation which is present adjacent to the site and below the proposed works is considered a receptor to vertical 'leachate' migration from the site during post operation phase. The risks to this aquifer have been assessed quantitatively in Section 5.

4.4.4 The private water supply (borehole) located approximately 750m to the south of the site at Town Wood Farm which is installed into the Northampton Sand aquifer is not considered a receptor. This is due to the calculated groundwater flow direction which takes into account of W02, W03, W04 and W05 (see Figure 7g). W01 has not been included as the borehole was considered dry throughout the monitoring period. Groundwater flow within the Northampton Sand aquifer is calculated to flow to the southeast, away from the private water supply.

4.4.5 An unnamed surface water feature (stream) located approximately 700m to the south of the site within the woodland known as 'Wood Hollow' is potentially receiving baseflow through the groundwater within the Lincolnshire Limestone Formation. Calculated groundwater flow direction which takes into account W01-05 indicates a southeast distribution of flow which will radially extend to the south.

4.4.6 Surface water and groundwater features located to the north of the site are not considered receptors to any potential contamination. Calculated groundwater flow direction within the shallower Lincolnshire Limestone Formation indicates a southeast distribution of flow. Groundwater flow within the deeper Northampton Sand aquifer is calculated to flow to the east-northeast. Therefore, identified springs to the north of the site are not potential receptors and are not considered further in this assessment.

4.4.7 The spring mapped c. 900 m north of the site along the southern valley wall of the Welland River emerges over the Whitby Mudstone formation (a 'non-aquifer'). Therefore, groundwater is likely discharging from the overlying Northampton Sand Formation at this location. Groundwater contour plots for the site indicate that groundwater beneath the western portion of the site moves towards the south and southwest during periods high groundwater levels (Figure 7 e and f), however the dominant groundwater flow direction is towards the southeast. A review of the BGS borehole records north of the site indicated the presence of multiple faults along the valley wall, down throwing the strata to the north of the fault lines. Most of the boreholes in this area have penetrated through to the Whitby Mudstone but did not encounter water during drilling (marked as 'dry hole'). Groundwater flow through the Lincolnshire Limestone and Northampton Sandstone Formations in the area is expected to be limited by the presence of these faults therefore groundwater emerging from this spring is not likely to be hydraulically connected to groundwater beneath the site and is more likely to be shallow water from the superficial deposits collecting in a low point in the topography.

Environmental Assessment Levels (EALs)

4.4.8 Compliance with the Groundwater Regulations (2009) requires that the proposed development will not result in discernible discharges of hazardous substances entering the groundwater and will not cause pollution of groundwater by non-hazardous pollutants. The setting of EALs is therefore required to assess whether the EPR (2016) Regulations and Groundwater Regulations (2009) are likely to be achieved.

4.4.9 Inert WAC substances have been used as the key indicator substances both in the risk assessment (Section 5) and also in deriving the below EALs.

4.4.10 For hazardous substances, the EALs will be set at the Minimum Reporting Values (MRVs) as defined in EA guidance – 'Hazardous substances to groundwater: minimum reporting values'[11] and UK Technical Advisory Group (UKTAG) – 'Technical report on Groundwater Hazardous Substances'[12]; or where background quality exceeds the specified standard.

[11] Hazardous substances to groundwater: minimum reporting values. Environment Agency. Last updated 13 January 2017 - https://www.gov.uk/government/publications/values-for-groundwater-risk-assessments/hazardous-substances-to-groundwater-minimum-reporting-values

[12] UK Technical Advisory Group on the Water Framework Directive. Technical report on Groundwater Hazardous Substances. Version 11b (iii) v 12. September 2016.

4.4.11 For non-hazardous substances, the EALs shall be set at the UKDWS or the EQS for freshwater in the absence of a UKDWS, except where background quality exceeds the specified standard. The UKDWS are given preference over the EQS owing to the sites sensitive setting on a Principal Aquifer and to afford protection to future groundwater supplies in close proximity to the site given the resource value of the Northampton Sand and Lincolnshire Limestone aquifers.

4.4.12 Background quality has been obtained from W02 in the absence of groundwater quality data from the up-gradient borehole W01 for both the Lincolnshire Limestone and Northampton Sand aquifer.

4.4.13 Where background quality exceeds the specified standards the EAL's will be set at the maximum recorded concentration after outliers have been removed. Statistical analysis has been performed using Pro UCL software (Version 5.1) to identify and remove potential outliers prior to using the data as part of calculating the EALs and Compliance Limits (Section 6). The data set had less than 25 No. concentrations for each of the contaminants modelled and as such, the Dixon Outlier Test (Dixon, 1950) has been used. The tests identify potential outliers within the dataset to multiple degrees of confidence (99%, 95% and 90%). As per the CIEH/CL:AIRE (2008), a confidence level of 95% has been selected for the exclusion of outliers.

4.4.14 The statistical analysis outputs for the groundwater quality analysis for both the Northampton Sand and Lincolnshire Limestone aquifers are attached in Appendix G.

4.4.15 EAL's have been calculated for both the Lincolnshire Limestone and Northampton Sand aquifers and presented below in Table 4.7 and Table 4.8, respectively.

Table 4.7 – Lincolnshire Limestone (EALs)

Contaminant	EQS (μg/l)	UKDWS (μg/l)	MRV (μg/l)	Selected EAL (μg/l)	Max. Conc. (μg/l) (W02S)[a]
Hazardous Substances					
Arsenic	20	10	5	**5**	NM
Lead	20	10	0.2	**0.2**	<1
Mercury	1	1	0.02	**0.01**	<0.01
Non-Hazardous Substances					
Antimony	-	5	-	**5**	NM
Barium	-	1,300	-	**1,300**	NM
Cadmium	5	5	-	**2.54**	<0.08
Chloride	250,000	250,000	-	**140,000**	30,000
Chromium	20	50	-	**28.80**	7.6

Contaminant	EQS (µg/l)	UKDWS (µg/l)	MRV (µg/l)	Selected EAL (µg/l)	Max. Conc. (µg/l) (W02S)[a]
Copper	1	2,000	-	**1,001**	2.1
Fluoride	-	1,500	-	**1,500**	NM
Molybdenum	-	70	-	**70**	NM
Nickel	4	20	-	**11.70**	3.4
Selenium	-	10	-	**6.5**	3
Sulphate	-	250,000	-	**168,500**	87,000
Zinc	12.3		-	**37**	37
NH44 (Ammoniacal Nitrogen)	-	500	-	**470**	440
Phenol	7.7	-	-	**7.7**	NM

Table Notes:

[a] *Maximum concentrations after removal of outliers.*

'NM' indicates parameter not monitored as part of groundwater quality monitoring. Arsenic, Antimony, Barium, Fluoride, Molybdenum & Phenol not included in groundwater analysis data set.

Cells coloured grey indicated no water quality screening or minimum reporting value available.

Table 4.8 – Northampton Sand Formation (EALs)

Contaminant	EQS (µg/l)	UKDWS (µg/l)	MRV (µg/l)	Selected EAL (µg/l)	Max. Conc. (µg/l) (W02D)[a]
Hazardous Substances					
Arsenic	20	10	5	**5**	NM
Lead	20	10	0.2	**0.2**	<1
Mercury	1	1	0.02	**0.01**	<0.01
Non-Hazardous Substances					
Antimony	-	5	-	**5**	NM
Barium	-	1,300	-	**1,300**	NM
Cadmium	5	5	-	**2.54**	<0.08
Chloride	250,000	250,000	-	**162,000**	74,000
Chromium	20	50	-	**29**	8
Copper	1	2,000	-	**1,004**	7.7
Fluoride	-	1,500	-	**1,500**	NM

Contaminant	EQS (µg/l)	UKDWS (µg/l)	MRV (µg/l)	Selected EAL (µg/l)	Max. Conc. (µg/l) (W02D)[a]
Molybdenum	-	70	-	**70**	NM
Nickel	4	20	-	**12**	4
Selenium	-	10	-	**6.90**	3.8
Sulphate	-	250,000	-	**174,000**	98,000
Zinc	12.3		-	**48**	48
NH4$_4$ (Ammoniacal Nitrogen)	-	500	-	**1,200**	1,200
Phenol	7.7	-	-	**7.7**	NM

Table Notes:

[a] Maximum concentrations after removal of outliers.

'NM' indicates parameter not monitored as part of groundwater quality monitoring. Arsenic, Antimony, Barium, Fluoride, Molybdenum & Phenol not included in groundwater analysis data set.

Cells coloured grey indicated no water quality screening or minimum reporting value available

4.4.16 The limit of detection (LOD) for the lead and mercury is greater than the UKTAG limit of quantifications (MRV's). Lead and mercury concentrations for groundwater samples obtained from W02 in both the Northampton Sand and Lincolnshire Limestone aquifers have not recorded above the LOD and therefore, the basline LOD's have been used as the EALs in the assessment.

4.4.17 It should be noted that there is no UKDWS for molybdenum or barium so the World Health Organisation (WHO) drinking water standard has been used instead.

Compliance Points

4.4.18 The compliance points used in the risk assessment (Section 5) are set at the base of the vertical pathway (i.e. top of the water table) for hazardous substances and at the edge of the site in the direction of groundwater flow for both the hazardous and non-hazardous substances

5 Hydrogeological Risk Assessment

5.1 Nature of the Hydrogeological Risk Assessment

5.1.1 Quantitative assessments are not typically requested for inert restoration sites as they fall outside the scope of the Groundwater Directive unless the proposed site is located within a setting which presents a risk to a sensitive receptor (i.e. Principal Aquifer or Secondary A Aquifer), in which case further consideration of risk due to the accidental acceptance of contaminated material is required. Regardless of whether the Groundwater Directive applies or not, the activity must still comply with the requirements of the Landfill Directive and compliance levels must be set along with environmental monitoring.

5.1.2 The site is located on the Lincolnshire Limestone which is designated a Principal Aquifer by the EA. The limestone and overlying Glacial Till soils are to be excavated to the top of the Grantham Formation which separates the limestone from the underlying Northampton Sand Formation which is designated a Secondary A Aquifer by the EA. The site is not situated within a groundwater source protection zone however, a potable groundwater supply abstracting groundwater from the Northampton Sand Formation is situated approximately 700m south of the site.

5.1.3 Following extraction of the limestone, a geological barrier is to be constructed along the base and sides of the void. The void is then to be restored using inert waste which will be partially above and partially below the groundwater table within the Lincolnshire Limestone adjacent to the landfill. The saturated aquifer thickness of the Lincolnshire Limestone down-hydraulic gradient of the landfill, i.e. at W04 is between 0.29m and 2.25m, and in the cross gradient borehole W03 is 1.93m to 5.53m. Leachate generation is anticipated to be minimal owing to the restoration of the site using low permeability clay soils. Based on landSim modelling completed, leachate head is likely to vary within the waste and is anticipated to range from 0.23m to 2.8m, with an average (50^{th} percentile) predicted value of 0.98m above the top of the geological barrier.

5.1.4 Comparing the range of predicted maximum heads to the recorded saturated thickness of groundwater within the Lincolnshire Limestone, the predicted range for the maximum head (0.23m to 2.8m) is lower than or equal to the saturated thickness of the limestone (0.29m to 5.53m). As a result, the primary migration of leachate out of the landfill is expected to be vertically, through the geological barrier and the Grantham Formation into the underlying Northampton Sand Formation. To support this assumption, a water balance for the site has been carried out using LandSim to calculate the water flux through the cap and the base of the landfill, and hydraulic containment flux worksheets to estimate the flow through the sidewall liner (Section 5.4.9).

5.1.5 Given the potential for leachate migration from the site into groundwater within the Northampton Sand Formation and the location of a nearby potable supply (c. 700m south of the site), a detailed Quantitative Risk Assessment (dQRA) using LandSim (v.2.5) software has been undertaken in line with EA guidance which states that that a dQRA is required when:

- The site setting is sensitive – for example on permeable strata such as Principal or Secondary A Aquifers, within an SPZ or close to sensitive surface water bodies; or,
- The uncertainty in aspects of the source, pathway and receptor terms cannot be overcome using conservative assumptions, because those assumptions lead to an unsatisfactory outcome in terms of risks to groundwater.

5.1.6 Groundwater levels within the Lincolnshire Limestone down-hydraulic gradient of the landfill are likely to limit horizontal migration of leachate out of the landfill. However, the EA have stated in their Schedule 5 Notice response (dated 08 July 2020) that hydraulic contaminant is unlikely long term and have requested a conservative assessment for the Lincolnshire Limestone be undertaken to support the risk assessment. It should be noted that a part of the landfill is below the groundwater levels in the adjacent Lincolnshire Limestone and such as the use of LandSim is not suitable. Instead, the risk to groundwater within the adjacent Lincolnshire Limestone has been undertaken using dilution & attenuation factor calculations, as outlined in Section 5.8.

5.1.7 The quantitative assessment has been adopted to ensure the risks, particularly to the limestone aquifer, are comprehensively evaluated. This approach recognises the sensitivity of the aquifer associated with the source, pathway and receptor terms and considers the high level of confidence needed to ensure compliance with Groundwater Regulations.

5.2 The Proposed Assessment Scenarios

Lifecycle Phases

5.2.1 The restoration of the site will be achieved by using inert waste materials which will be subject to a robust Waste Acceptance procedure during the entire operation.

5.2.2 A geological barrier will be formed at the base of the current void along with a sidewall liner along all sidewalls. Both the geological barrier and sidewall liner will be will 1m in thickness with a minimum hydraulic conductivity of less than 1.0 x 10m^{-7}m/s or 0.5m thick with a hydraulic conductivity of 5.0 x 10^{-8}m/s.

5.2.3 There will be no difference in the water balance or contaminant transport mechanisms and processed between the operational and post close phases. Therefore, a single lifecycle has been considered in the quantitative assessments. The models conservatively assume that the site is instantaneously filled and therefore the operational phase is not simulated. The model considers the post-completion phase.

5.2.4 As there is no cap or artificial sealing liner considered, there is no consideration of deterioration of these components by the risk model.

5.2.5 In addition to the above, a 'Rogue Load' Assessment has also been carried out, which simulates higher leachate concentrations resulting from a 'rouge' non-inert waste types being present in the waste mass.

5.2.6 Horizontal migration of leachate into the Lincolnshire Limestone has been considered separately using deterministic spreadsheet models in the event of 'leachate' head migration horizontally into the limestone aquifer and the potential dilution within the saturated portion of the aquifer.

5.3 'Leachate' Priority Contaminants to be Modelled

5.3.1 As reported in the Environment Agency Guidance – 'Environmental Permitting Regulation: Inert Waste Guidance', suitable contaminants for modelling have been selected based on specified parameter categories, the type of waste at the site (i.e. inert) and the potential nature of the 'leachate' generated.

5.3.2 WAC (waste acceptance criteria) parameters for inert waste have been used as the key indicator substances to be modelled. Equivalent leachability concentrations for the Inert WAC values have been calculated using the methodology presented in Appendix H.

5.3.3 The equivalent 'leachate' concentrations have been screened against the EALs which are outlined in Section 4. Concentrations which exceed the EALs (highlighted in orange) have been taken forward to the dQRA and are detailed below in Table 5.1.

Table 5.1 – Inert WAC and Equivalent 'Leachate' Quality

Species	Leaching Limit (mg/kg) L/S = 10 l/kg	Leachate Concentration (mg/l)	EALs (Lincolnshire Limestone) (mg/l)	EALs (Northampton Sand) (mg/l)
Hazardous Substances				
Arsenic	0.5	0.05	0.005	0.005
Chromium VI[b]	0.5	0.05	0.0076	0.008
Lead	0.5	0.05	0.0002	0.0002
Mercury	0.01	0.001	0.00001	0.00001

Species	Leaching Limit (mg/kg) L/S = 10 l/kg	Leachate Concentration (mg/l)	EALs (Lincolnshire Limestone) (mg/l)	EALs (Northampton Sand) (mg/l)
Non-Hazardous Substances				
Antimony	0.06	0.006	0.005	0.005
Barium	20	2	1.3	1.3
Cadmium	0.04	0.004	0.0025	0.0026
Chloride	800	80	140	162
Copper	2	0.2	1.001	1.004
Fluoride	10	1	1.5	1.5
Molybdenum	0.5	0.05	0.07	0.07
Nickel	0.4	0.04	0.011	0.012
Selenium	0.1	0.01	0.0065	0.0069
Sulphate	1000	100	168.5	174
Zinc	4	0.4	0.037	0.048
Phenol Index [a]	1	0.1	0.0077	0.0077

Table Notes:

Concentration exceeds the EAL

[a] Phenol Index is not a contaminant, so instead, the chemical 'Phenol' has been modelled.

[b] We note that chromium VI is a hazardous substance. However, the source term concentration taken from European Union Council Decision 2003/33/EC is for total chromium. It is conservatively assumed here that all chromium is present as chromium VI and is therefore hazardous. Maximum baseline concentrations recorded for Chromium (Total) are below the laboratory limit of detection of 8µg/l which is above the UKATG quantification limit of 5µg/l for chromium VI. Therefore, the EAL has been set at 8µg/l.

5.3.4 In addition to Inert WAC limits, the Landfill Directive recommends using parameters for early indication of a change in quality. Ammoniacal Nitrogen will also be used within the model to determine the potential nature of the 'leachate' generated. The source term for Ammoniacal Nitrogen has been assumed in the absence of a WAC limit. A value of 0.5mg/l has been applied in the model as the 'leachate' source which is the UKDWS for ammonium and therefore is considered to be a highly conservative assessment of 'leachate' quality for inert waste.

5.3.5 Benzene, Toluene, Ethylbenzene & Xylenes (BTEX compounds) and Poly Aromatic Hydrocarbons (PAHs) are not taken forward to the assessment. This is because Total Petroleum Hydrocarbons (TPH) have recorded below the laboratory limit of detection in all monitoring rounds across the monitoring programme. In addition, these contaminants are unlikely to be present in significant concentrations owing to the inert nature of the waste. Phenol has been included in the assessment to model an organic contaminant.

5.3.6 The priority contaminants to be taken forward to the quantitative assessments include: arsenic, chromium VI, lead, mercury, antimony, barium, cadmium, nickel, selenium, zinc and phenol.

5.3.7 It should be noted that the inert WAC limit values represent the maximum values (worst case scenario) and the majority of imported waste is expected to be significantly below these levels.

5.4 Numerical Modelling

Justification for Modelling Approach and Software

5.4.1 The Environment Agency approved computer software model LandSim (Version 2.5.17) has been used to quantitatively model the risk from Wakerley Quarry to groundwater in the Northampton Sand Formation. The software uses a probabilistic approach (using the Monte Carlo simulation technique) to quantitatively assess the risks to groundwater posed by the restoration works.

5.4.2 The probabilistic software was developed to allow for computer simulations of leakage through the base of the landfill phase to be modelled on the basis of key landfill design parameters and its physical settings. This assessment recognises that all models are simplified representations of reality and should be viewed as aids to the decision-making process. Decisions as to whether the site complies with the Landfill Directive and groundwater regulations must combine professional judgement, the model results and an understanding of the assumptions within each model.

5.4.3 Few of the input parameters are known with great certainty. However, LandSim allows for each parameter to be characterised by a range of possible/probable values, incorporating the available information. During each simulation the parameters are assigned a value from within defined ranges. After a number of iterations, a range of possible predicted leakage or outcome values are obtained, and it becomes possible to quantify the likelihood of a certain outcome. LandSim makes the characterization and input of each parameter possible through statistical distributions or probability density functions (DPFs).

5.4.4 The risk screening of the Lincolnshire Limestone aquifer has been supported by dilution and attenuation calculations using deterministic spreadsheets. The risk screening exercise for the Lincolnshire Limestone is outlined in Section 5.8.

Model Parameterisation - LandSim

5.4.5 In order to undertake the assessment, the scenario described must be characterised using a number of parameters. Site specific data has been used where available. Where site specific data is not available, conservative estimates based on literature sources, mapping data and geological / hydrogeological data for the local area have been used instead. All input parameters used in the model are included in Appendix I and summarised in the following Tables.

Infiltration

Table 5.2 – Infiltration

Parameter	Value	Distribution	Justification
Infiltration to Waste (mm/year)	(80, 119)	UNIFORM	Estimated vertical leakage through the base of the inert waste materials based upon an estimated effective rainfall range through restoration soils.
Restoration Design Infiltration (mm/year)	(80, 119)	UNIFORM	
End of filling (years)	0	SINGLE	Model assumes instantaneous filling of the void.

Cell Geometry

5.4.6 Only one 'phase/cell' has been modelled in the assessment which is representative of Phases A and B. The table below outlines the cell geometry used as part of the modelling and are based on the engineering design for the restoration of Phases A and B.

Table 5.3 – Cell Geometry

Cell	Value	Justification
Cell Width (m)	547.5	Average void width & length taken from drawing MGL/A099077/PER/02. For the purposes of the LandSim model the shape has been simplified.
Cell Length (m)	800	
No of cells	1	One 'cell' to represent Phases A and B
Cell top area (Ha)	44	Area based on drawing MGL/A099077/PER/02. For the purposes of the LandSim model the shape has been simplified.
Cell base area (Ha)	43.80	
Final Waste Thickness (m)	11.1, 21.7	Based on geological cross-sectional drawings and Borehole (W01-W05) Logs and drawing Ref. W4/18/02 – using a restoration ground level of 102m AOD which includes 1m thick geological barrier.
Waste Porosity (fraction)	0.25, 0.45	Estimated for inert waste materials

Cell	Value	Justification
Field Capacity (fraction)	0.2, 0.25, 0.30	Estimated for inert waste materials
Waste Density (kg/l)	1, 1.8	Estimated for inert waste materials

5.4.7 'Leachate' concentrations calculated from the Waste Acceptance Criteria have been used to define the model input and have been used to simulate the realistic impact at the compliance point. The maximum concentration of Ammoniacal Nitrogen for inert waste quoted by the Landfill directive has been used in the absence of a WAC limit. These concentrations were multiplied by a factor of 1.5 to assess the impact of a rogue loads being mistakenly accepted at the site.

Table 5.4 – Leachate Concentration Inputs

Modelled Contaminants	Leachate Quality (mg/l)	Justification
Ammoniacal Nitrogen (NH_4)	SINGLE (0.5)	No WAC limit for Ammonium. Concentration range has been assumed based on inert waste stream and applied at the UKDWS for ammonium
Arsenic	SINGLE (0.05)	Table 5.1
Chromium IV	SINGLE (0.05)	Table 5.1
Lead	SINGLE (0.05)	Table 5.1
Mercury	SINGLE (0.001)	Table 5.1
Antimony	SINGLE (0.006)	Table 5.1
Barium	SINGLE (2)	Table 5.1
Cadmium	SINGLE (0.004)	Table 5.1
Nickel	SINGLE (0.04)	Table 5.1
Selenium	SINGLE (0.01)	Table 5.1
Zinc	SINGLE (0.4)	Table 5.1
Phenol	SINGLE (0.1)	Table 5.1

Table 5.5 – Leachate Source Term Kappa Values

Modelled Contaminants	Distribution	Justification
Ammoniacal Nitrogen (NH_4)	m = 0 c = 0.59	Kappa values based on suggested LandSim v2.5 values.
Arsenic	m =0.0415 c = -0.0862	
Chromium	m = 0.0514 c = 0.045	
Lead	m = 0.0443 c = 0.0171	
Mercury	m = 0.0767	

Modelled Contaminants	Distribution	Justification
	c = 0.1643	Kappa values based on suggested LandSim v2.5 values.
Antimony	m = 0.1303 c = 0.0763	
Barium	m = 0.0806 c = -0.2754	
Cadmium	m = 0.0823 c = 0.1589	
Nickel	m = 0.0987 c = -0.1479	
Selenium	m = 0.1063 c = -0.062	
Zinc	m = 0.0403 c = 0.0561	

Table 5-6 – Restoration Material Properties

Parameter	Units	Distribution	Justification
Porosity	fraction	UNIFORM (0.25,0.45)	Range based on the measurements of MSW porosity from Staub *et al*. (2009).
Density	kg/l	UNIFORM (1, 1.8)	Estimate based on the estimated bulk density.
Field Capacity	fraction	UNIFORM (0.1, 0.2)	Estimate based on the lower estimate of field capacity of sandy soils http://nrcca.cals.cornell.edu/soil/CA2/CA0212.1-3.php
Final Thickness	m	UNIFORM (10, 20)	Waste thickness based on CSM figures (Figure 5).
Head of Leachate when surface water breakout occurs	m	SINGLE (11.1)	Minimum level at which leachate generated in waste would breakout at surface. 11.1m is assumed as the minimum level that this would occur.

Drainage System

5.4.8 No internal drainage will be installed within the void.

Water Balance

Calculated Leachate Head

5.4.9 The leachate head is likely to vary according to the balance of infiltration to the waste soils and leachate leakage through the geological barrier. Leachate leakage is anticipated to be greater during the operation period, with a higher flux of rainfall allowed to percolate through the waste soils. The site will be restored with low permeability, clay rich soils, reducing the infiltration through the soils and therefore the leakage. To model a conservative assessment, the EA have requested that a long term (20,000 years) management control of leachate is applied and a fixed leachate head is modelled.

5.4.10 The leachate head above the geological barrier has been calculated in LandSim for use within the contaminant models, based upon the parameters indicated in Table 5.7. In LandSim, the calculation of the leachate head is derived from inflow through infiltration is balanced by outflow through the base of the site, and any leachate pumping or surface breakout that arises from management control pumping of leachate, or a rise in leachate levels to the breakout point respectively (not expected to occur at the site). Flow through the sidewall liner is considered in Section 5.4.13.

Table 5-7 - Drainage System

Parameter	Units	Distribution	Justification
Waste Hydraulic conductivity	m/s	LOGTRIANGULAR ($1x10^{-6}$, $1x10^{-5}$, $1x10^{-3}$)	Assuming mixed inert waste, clay to sand.
Primary Drainage System	-	None	Estimate based on the estimated bulk density.
Sump diameter	m	745	No sump. Value input to represent whole phase base.
Landfill Base Slope	ratio	1 in 50	Based on fall across site; equates to 1.15°.

5.4.11 The calculated fixed leachate head for the site has been input into LandSim as a triangular distribution for the contaminant modelling runs. The percentiles for the maximum leachate head calculated for the site are as follows:

- 5^{th} percentile: 0.23m;
- 50^{th} percentile: 0.98m;
- 95^{th} percentile: 2.80m.

5.4.12 'Leachate' breakout at surface is not predicted to occur, as the 95^{th} percentile leachate head of 2.80m is below the breakout level of 11.1m.

<u>Flux Through Sidewall Liner</u>

5.4.13 Flow through the sidewall liners from the Lincolnshire Limestone into the site is not accounted for in the LandSim calculation for the maximum obtained head. Some minor inflows would be expected into the restoration site through the low permeability side wall liner. To ensure that any such inflows would create a negligible impact, the inflows to the site through the side wall liner have been calculated using the Environment Agency worksheet *Contaminant Fluxes from Hydraulic Containment Landfills Worksheet* (Version 1.0, project SC310).

5.4.14 The flux through the sidewall liner is 0.0009 m^3/s, assuming a head difference of 4.0m in the Lincolnshire Limestone above the leachate within the landfill. This is equivalent to approximately 6% of the 50th percentile predicted outflow of leachate through the base of the site under the predicted head leachate head distribution (0.0140m^3/s), and therefore should have only a minor impact upon leachate levels within the landfill.

5.4.15 As a further check, the area of sidewall liner under a head difference of 4.0m through which water can enter the landfill is only 2,340m^2, compared with a total basal area of 440,000m^2. Flow through the sidewall liners only contributing to minor inflows under a conservative (high) modelled head difference of 4.0m therefore appears reasonable.

5.4.16 It is expected that inflows through the sidewall liner would lead to a slight increase in leachate heads compared to those predicted in 5.4.11 but that overall levels of leachate within the waste would remain below the levels within the Lincolnshire Limestone.

Properties of Artificial Geological Barrier System

5.4.17 An artificial geological barrier will be constructed on the base and sides to be 1m thick with a minimum permeability of 1.0 x10^{-7} m/s or equivalent. The artificial barrier will be constructed in accordance with the requirements of the Landfill Directive and EA guidance 'Landfill for inert waste guidance - The environmental permitting requirements for landfills for inert waste and how to comply with your permit' (30 January 2020)[13] which has now replaced the 'Environmental Permitting Regulation: Inert Waste Guidance, Standards and measures for the deposit of Inert waste on Land, Environment Agency 2010'.

5.4.18 To model this barrier system a "Single Clay BES" barrier has been selected with the corresponding parameters shown in **Error! Reference source not found.**.8.

Table 5.8 - BES Properties

Parameter	Units	Distribution	Justification
Moisture Content	fraction	UNIFORM (0.3,0.5)	WYG assumption.
Hydraulic conductivity	m/s	1x10^{-7}	The hydraulic permeability assumed based on 1m thickness.
Design thickness	m	SINGLE (1)	Engineered design in accordance with the requirements of the LFD.
Longitudinal dispersivity	m	SINGLE (0.1)	1/10 of pathway length

[13] Environment Agency (January 2020) - https://www.gov.uk/guidance/landfill-operators-environmental-permits/landfills-for-inert-waste [Accessed 07 May 2020]

Parameter	Units	Distribution	Justification
Retardation	Kg/l	Contaminant Specific	See Table 5.12

Unsaturated Pathway

5.4.19 The unsaturated zone within the Northampton Sand Formation, beneath the Grantham Formation, ranges across the site from less than 1m to as much as 18.96m (W03) on average. Because of the way that LandSim is set up and to model a conservative assessment, a limited un-saturated zone has been included in the model. Instead, the Grantham Formation, which is present above the Northampton Sand Formation has been modelled as the 'Vertical Pathway' (see below). As such, the model assumes that no un-saturated zone exists, and that any 'leachate' generated will migrate vertically through the base of the artificial geological barrier and the mudstone layers of the Grantham Formation. To comply with this and requirements of the model, a minimal length of 0.001m has been included in the un-saturated zone with the following parameters also included.

Table 5.9 – Unsaturated Pathway

Parameter	Units	Value	Justification
Pathway length	m	0.001	No unsaturated pathway beneath the site, set at minimum
Moisture content	Fraction	0.03, 0.05	Estimated values
Conductivity	m/s	1x10-9	Estimated value for a mudstone
Longitudinal Dispersivity	m	0.0001	0.1 x pathway length
Retardation	Kg/l	Contaminant Specific	See Table 5.12

Vertical Pathway

5.4.20 The Grantham Formation is modelled to be the Vertical Pathway in the assessment. Input parameters are outlined below.

Table 5.10 – Vertical Pathway Parameters

Parameter	Units	Value	Justification
Pathway Length	m	0, 2, 4	Borehole Logs.
Pathway Porosity	Fraction	0.05, 0.2	Estimated porosity for a mudstone
Longitudinal Dispersivity	m	0, 0.2, 0.4	0.1 x pathway length.
Retardation	Kg/l	Contaminant Specific	See Table 5.12

5.4.21 To account for the absence of the Grantham Formation in borehole logs for boreholes R4 and W05D, the thickness of the Grantham formation has been set to a triangular distribution of 0, 2, 4.

5.4.22 Additionally, the impacts of faulting at the site providing a preferential pathway between the Lincolnshire Limestone and the Northampton Sands through the Grantham Formation is accounted for in the model by setting the minimum thickness to zero meters. The absence of the Grantham Formation in a model run represents preferential flow through faults from the Lincolnshire Limestone bypassing the Grantham Formation.

Aquifer Pathway

5.4.23 The aquifer beneath the site is the Northampton Sand Formation, a Secondary A Aquifer. Input parameters for the aquifer pathway are as follows.

Table 5.11 – Aquifer Pathway Parameters

Parameter	Units	Distribution	Justification
Pathway Length	m	UNIFORM (15, 815)	LandSim Calculated Value.
Pathway Width	m	UNIFORM (550, 650)	Range of widths perpendicular to groundwater flow.
Aquifer Thickness	m	UNIFORM (3.4,6.6)	Borehole (W01-W05) Logs.
Mixing Zone Thickness	m	UNIFORM (3.4,6.6)	Mixing zone has been set at the aquifer thickness beneath the site.
Pathway density	kg/l	UNIFORM (2,2.6)	Estimated density of a sandstone.
Hydraulic conductivity	m/s	LOG TRIANGULAR (5.0x10-6, 6.0x10-5, 5.x10-4)	Min and max values based on expected permeability for a sandstone aquifer. The most likely value is based on a value from the physical properties of minor aquifers in England and Wales (Ref. WD/00/04).
Regional Gradient	-	TRIANGULAR (0.0056, 0.009, 0.0130)	Range calculated based on groundwater monitoring rounds (excluding May – October 2016) for boreholes monitoring groundwater levels in the Northampton Sand Formation.
Porosity	Fraction	UNIFORM (0.2, 0.3)	Estimated values for a sandstone aquifer.
Longitudinal Dispersivity	m	UNIFORM (1.5, 81.5)	10% of the pathway length.
Transverse Dispersivity	m	UNIFORM (0.5, 27.16)	33% of the longitudinal length.

Retardation

Table 5.12 – Retardation Values (Kd) Input Parameters

Contaminant	Units	Distribution	Source
Arsenic	Kg/l	LOG UNIFORM (39.8, 19,952)	EPA/600/R-05/074 July 2005
Barium	Kg/l	LOG UNIFORM (7.94,1585)	EPA/600/R-05/074 July 2005
Cadmium	Kg/l	LOG UNIFORM (1.6. 1,500)	LandSim/ConSim suggested range
Chromium VI	Kg/l	LOG UNIFORM (79, 794,328)	EPA/600/R-05/074 July 2005
Lead	Kg/l	LOG UNIFORM (100, 39811)	EPA/600/R-05/074 July 2005
Mercury	Kg/l	UNIFORM (450, 3,835)	LandSim/ConSim suggested range
Antimony	Kg/l	LOG UNIFORM (3.98, 63,095)	EPA/600/R-05/074 July 2005
Nickel	Kg/l	LOG UNIFORM (2, 10,000)	EPA/600/R-05/074 July 2005
Selenium	Kg/l	LOG UNIFORM (10 – 10,000)	EPA/600/R-05/074 July 2005
Zinc	Kg/l	LOG UNIFORM (31.6, 63,095)	EPA/600/R-05/074 July 2005
NH4-N (Ammoniacal Nitrogen)	Kg/l	UNIFORM (0.5 – 2.0)	LandSim/ConSim suggested range

5.4.24 Retardation parameters have been input from two sources – ConSim/LandSim suggested input parameters, or from the EPA document EPA/600/R-05/074: *Partition Coefficients for Metals in Surface Water, Soil and Waste* (2005), which presents metal partition coefficients developed for watershed, surface water, and source models used in the EPA contaminant modelling programs.

5.4.25 For the organic contaminant, phenol, the Kd has been calculated based on the KoC and fraction organic carbon (foc) as these contaminants migrate through the geological barrier and unsaturated portion of the aquifer.

Table 5.13 – Retardation Parameters (KoC)

Modelled Contaminants	Units	Partition Coefficient (KoC)	Justification
Phenol	l/kg	UNIFORM (8.32 – 83.2)	Environment Agency (2008) Compilation of data for priority organic pollutants for derivation of soil guideline values, Report No: SC050021/SR7. Minimum is based on 10% of maximum as a worse case value.

Table 5.14 – Fraction Organic Carbon

Pathway	Fraction Organic Carbon	Justification
Geological Barrier	LOG UNIFORM (0.0006 – 0.062)	Environment Agency (2004) Attenuation of mecoprop in the subsurface, Science Group Report No: NC/03/12
Grantham Formation	LOG UNIFORM (0.00003 – 0.0012)	Environment Agency (2004) Attenuation of mecoprop in the subsurface, Science Group Report No: NC/03/12 – Table 7.2 (Marl in Lincolnshire Limestone)
Northampton Sand Formation	LOG UNIFORM (0.00001 – 0.00071)	Environment Agency (2004) Attenuation of mecoprop in the subsurface, Science Group Report No: NC/03/12 – Table 7.2 (based on Sherwood Sandstone)

Biodegradation

5.4.26 Biodegradation of phenol has been modelled in the aquifer pathway only. The half-life of phenol included in the assessment is 300 days (0.82 years) based on 'The Effects of Contaminant Concentration on the Potential for Natural Attenuation R & D Technical Report P2-228/TR'.

Accidents and Their Consequences

5.4.27 Consideration must be given to accidents and their consequences within the HRA. The main potential environmental accidents that could have a bearing on the water environment would be the acceptance of material which falls outside the classification as 'inert'. The acceptance of material other than inert could result in the generation of 'leachate' which could pose a risk to groundwater quality within the Northampton Sands Formation. It is not possible to precisely assess the risks from such an event, but any acceptance of restoration material will be in accordance with procedures set out in the Environmental Permit which are designed to minimise this risk.

5.4.28 Provided only inert material is accepted at the site, the probability of an accident occurring that would result in a risk to groundwater quality is considered to be low owing to the strict procedures outlined in the WYG Operating Techniques Report, dated December 2019.

5.4.29 Additionally, the effects of acceptance of material in excess of the site's Waste Acceptance Criteria has been considered in Section 5.6 of this report. To assess the risk of 'rogue loads' being accepted at the site and as part of the sensitivity analysis, model simulations based on the maximum concentration of WAC source term inputs multiplied by a factor of 1.5 have been run and compared with the EALs. This modelling is intended to provide a worst-case scenario, assuming that all waste deposited at the site is greater than the inert WAC limits.

5.4.30 In order to demonstrate the acceptability of waste at the regulated facility, Mick George will implement waste acceptance procedures in accordance with Annex I of Council Decision 2003/33/EC which includes the following stages:

- Basic Characterisation (Level 1);
- Compliance Testing (Level 2); and
- On-site Verification (Level 3).

5.4.31 Any load identified as unacceptable will be isolated whilst the Environment Agency in contacted to agree the most appropriate course of action. Records of rejected loads will be kept and made available to the environment Agency containing the relevant details.

5.5 Emissions to Groundwater

5.5.1 The LandSim model (Model 1), Rogue Load (Model 2) and Kd Sensitivity Analysis (Model 3) for the Northampton Sand Formation were run for 1,001 iterations with results attached in Appendix J. Baseline groundwater concentrations have been included in the assessment where baseline data was reported to be above the laboratory limit of detection.

5.5.2 Predicted concentrations for both hazardous and non-hazardous contaminants are reported at the 'Phase Monitor Well' as this represents the predicted concentrations in groundwater at the edge of the site boundary following dilution. Predicted concentrations for hazardous substances are also reported at the base of the vertical pathway i.e. base of the Grantham Formation.

5.5.3 The results are presented as the '50th percentile' (most likely) concentrations as well as the '95th percentile' (worst case) concentrations. The 95th percentile is considered as an appropriate confidence criterion by which the impact of leachate leakage and migration can be assessed. The 95th percentile represents the value for which there is only a 5% probability of exceedance; this 5% probability is considered as unlikely.

5.5.4 The assessment has been run with a management control for 20,000 years.

Model 1

Hazardous Substances

5.5.5 The 50th and 95th percentile maximum concentration of hazardous substances simulated at the base of the Vertical Pathway and 'Phase Monitor Well' (edge of site boundary) over 20,000 years are presented below in Table 5.15. The time to peak for the 95th percentile concentrations for each of the modelled contaminants is also presented.

Table 5.15 – Predicted Concentrations (Hazardous Contaminants)

Contaminants	Base of Vertical Pathway (mg/l)		'Phase Monitor Well' (mg/l)		EAL (mg/l)
	50th %ile	95th %ile	50th %ile	95th %ile	
Arsenic	No breakthrough	0.018 (1,000 yrs)	0	0.00053 (7,500 yrs)	0.005
Chromium IV	No breakthrough	No breakthrough	0	No breakthrough	0.008
Lead	No breakthrough	0.0039 (1,700 yrs)	0	0.00011 (7,500 yrs)	0.00020
Mercury	$1.5x10^{-6}$	$4.5x10^{-6}$ (6,000 yrs)	$6.0x10^{-7}$	$2.7x10^{-6}$ (15,000 yrs)	$1.0x10^{-5}$

5.5.6 Predicted concentrations for arsenic and lead at the base of the vertical pathway are above their respective EALs. It should be noted that the concentrations reported at the base of the Vertical Pathway do not take account of dilution in the Northampton Sand aquifer. The 95th percentile predicted concentrations for both contaminants at the edge of the site boundary after dilution are below the EALs and therefore, considered to be indiscernible.

5.5.7 For the he 50th percentile concentrations, only mercury is predicted to break through the base of the vertical pathway during the lifecycle of the landfill. The 50th and 95th percentile concentrations and chromium VI are not predicted to breakthrough at the edge of the site in 20,000 years.

Non-Hazardous Substances

5.5.8 The 50th and 95th percentile maximum concentration of non-hazardous substances simulated at the 'Phase Monitor Well' over 20,000 years are reported below in Table 5.16. The time to peak for the 95th percentile concentrations for each of the modelled contaminants is also reported.

Table 5.16–Predicted Concentrations (Non-Hazardous Contaminants)

Contaminants	50th%ile (mg/l)	95th%ile (mg/l)	EAL (mg/l)
Antimony	0	7.3 x 10^{-5} (2,000 yrs)	0.005
Ammoniacal Nitrogen	0.44	0.96 (100 yrs)	1.2
Barium	0.0018	0.11 (1,000 yrs)	1.3
Cadmium	0	0.00064 (575 yrs)	0.00254
Nickel	0.0022	0.0045 (1,250 yrs)	0.012
Selenium	0.0020	0.0033 (2,000 yrs)	0.0069
Zinc	0.012	0.032 (2,000 years)	0.048
Phenol	0.00027	0.0028 (12 yrs)	0.0077

5.5.9 No exceedances above the EAL for Non-Hazardous contaminants are predicted in the model.

5.6 Sensitivity Analysis

5.6.1 Sensitivity analysis is the evaluation of model input parameters to see how much they affect model outputs. The relative effect of the parameters helps to provide fundamental understanding of the simulated system. Sensitivity analysis also is inherently part of model calibration.

5.6.2 Sensitivity analysis has been conducted manually by running multiple model simulations in which a single parameter has been adjusted by an arbitrary amount.

5.6.3 EA guidance requires that assessors present a comprehensive sensitivity analysis of any deterministic models used to provide greater confidence in the outcome of a risk assessment.

5.6.4 This section includes details relating to the following:

- The completion of a sufficient sensitivity analysis, which includes the use of multiple model runs to simulate different justifiable ranges of input parameter values;
- The consideration of assessment limitations, the assessment of uncertainties and the need for safety factors;

Model 2 - Rogue Load Assessment

5.6.5 The nature of the material proposed for the restoration of Wakerley Quarry is inert. The material is therefore unlikely to exceed the inert test criteria (Inert WAC Assessment) limits. It is expected that 'leachate' concentrations generated will be lower that the upper limits of the WAC threshold. However, to assess the risk of 'rogue loads' being accepted at the site and as part of the sensitivity analysis model simulations based on the maximum concentration of WAC source term inputs multiplied by a factor of 1.5 have been run. These upper limits have been used to define the source term inputs into the model 'leachate' inventory and are intended to provide a worst-case scenario as the model assumes that all waste deposited at the site is greater than the inert WAC.

5.6.6 The LandSim Model 2 results are presented in Appendix J.

5.6.7 The maximum simulated contaminant concentration of hazardous and non-hazardous contaminants are reported in Table 5.17, respectively at the 'Phase Monitor Well' when the initial concentration of contaminants is increased to account for the acceptance of a rogue load at the site.

Table 5.17 – Rogue Load Predicted Concentrations (Hazardous Contaminants)

Contaminants	Maximum Background Concentration (mg/l)	EAL (mg/l)	50th Percentile (mg/l)	95th Percentile (mg/l)
Arsenic	-	0.005	0	0.00058 (7,000 yrs)
Chromium VI	<0.008	0.008	0	0
Lead	<0.001	0.00020	0	0.00014
Mercury	<0.00001	0.00001	3.36×10^{-7}	3.36×10^{-6} (15,000 yrs)

Table 5.18 – Rogue Load Predicted Concentrations (Non-Hazardous Contaminants)

Contaminants	Maximum Background Concentration (mg/l)	EAL (mg/)	50th Percentile (mg/l)	95th Percentile (mg/l)
Antimony	-	0.005	0	0.00010 (2,000 yrs)
Ammoniacal Nitrogen	1.20	1.20	0.51	1.05 (90 yrs)
Barium	-	1.30	0	0.15 (1,100 yrs)
Cadmium	<0.08	0.00254	0	0.0009 (520 yrs)
Nickel	0.004	0.012	0.0022	0.0051 (1,200 yrs)
Selenium	0.0038	0.0069	0.0021	0.0034 (2,100 yrs)
Zinc	0.048	0.048	0.012	0.033 (2,100 yrs)
Phenol	-	0.0077	0.00043	0.0042 (13 yrs)

5.6.8 All of the simulated maximum concentrations at the edge, using rogue load 'leachate' concentration estimates as the source term, fall below their respective EAL.

5.6.9 Maximum (95th%ile) concentrations increase when rogue load leachate concentration estimates were used as the source term. For example, Lead increased 0.00011 to 0.00014 mg/l, and ammoniacal nitrogen from 0.96 to 1.05 mg/l. The model appears only moderately sensitive to contaminant concentrations at the source, as an increase of 50% in the source term concentrations appears to lead to an increase in predicted concentrations at the edge of the site in the order of 10% to 20%.

5.6.10 However, these elevated concentrations (which are above the inert WAC limits) have been applied across the entire source term. This indicates that the whole waste stream is no longer inert and therefore is highly conservative. Stringent precautions to ensure WAC are maintained will be in place at the site to limit any risk of exceedances.

Model 3 - Reduced Maximum Partition Coefficients

5.6.11 It is acknowledged that a large range of partition coefficients has been input into previously calculated model runs. Predicted contaminant concentrations are typically sensitive to Kd values. However, it is also not normally possible to source site specific, or even geology specific partition coefficients for use in contaminant modelling.

5.6.12 Published in 2005, the EPA document EPA/600/R-05/074, Partition Coefficients for Metals in Surface Water, Soil, and Waste presents partition coefficients obtained from a literature reviews of studies of Kd in environmental mediums including soil water.

5.6.13 Where high maximum retardation values have been sourced from the EPA document, an additional sensitivity analysis has been performed on those contaminants with the maximum Kd set to the mean from the same document, with the modified partition coefficients presented in Table 5.19. The mean contaminant partition coefficients presented by the EPA document are much lower than the maximum quoted in the document.

Table 5.19 – Kd Sensitivity analysis – Selected partition coefficients

Contaminant	Units	Previously Used Distribution	Sensitivity Analysis Distribution
Arsenic	Kg/l	LOG UNIFORM (39.8, 19,952)	LOG UNIFORM (39.8, 1584)
Barium	Kg/l	LOG UNIFORM (7.94,1585)	UNIFORM (7.94, 100)
Chromium VI	Kg/l	LOG UNIFORM (79, 794,328)	UNIFORM (10, 125)
Lead	Kg/l	LOG UNIFORM (100, 39811)	LOG UNIFORM (100, 5012)

Contaminant	Units	Previously Used Distribution	Sensitivity Analysis Distribution
Antimony	Kg/l	LOG UNIFORM (3.98, 63,095)	LOG UNIFORM (3.98, 199)
Nickel	Kg/l	LOG UNIFORM (2, 10,000)	LOG UNIFORM (10, 794)
Selenium	Kg/l	LOG UNIFORM (10, 10,000)	UNIFORM (2.2, 18)
Zinc	Kg/l	LOG UNIFORM (31.6, 63,095)	UNIFORM (31, 501)

5.6.14 The LanSim model has been rerun with the partition coefficients changed to those shown in Table 5.19. For substances, whose partition coefficients have been changed, the results are presented in table 5.20 for hazardous contaminants, and table 5.21 for non-hazardous contaminants.

Table 5.20 – Predicted Concentrations (Hazardous Contaminants), Kd Sensitivity analysis

Contaminants	Base of Vertical Pathway (mg/l)		'Phase Monitor Well' (mg/l)		EAL (mg/l)
	50th %ile	95th %ile	50th %ile	95th %ile	
Arsenic	No breakthrough	0.022 (830 yrs)	0	0.0023 (2,000 yrs)	0.005
Chromium IV	No breakthrough	No breakthrough	0	No breakthrough	0.008
Lead	No breakthrough	0.0060 (1,700 yrs)	0	0.00019 (5,000 yrs)	0.00020

Table 5.21–Predicted Concentrations (Non-Hazardous Contaminants), Kd Sensitivity analysis

Contaminants	50th%ile (mg/l)	95th%ile (mg/l)	EAL (mg/l)
Antimony	0	0.0007 (700 yrs)	0.005
Barium	0.0095	0.17 (2,000 yrs)	1.3
Nickel	0.0024	0.0046 (1,250 yrs)	0.012
Selenium	0.0025	0.0054 (450 yrs)	0.0069
Zinc	0.012	0.033 (2,000 years)	0.048

5.6.15 No exceedances above the EAL for Hazardous and Non-Hazardous contaminants are predicted in the model with reduced maximum partition coefficient values. It is demonstrated that the model is moderately sensitive to the maximum in the partition coefficient probability distribution; for example, decreasing the maximum Kd of Arsenic by more than a factor of ten from 19,952 to 1,584, leads to an increase in predicted concentration at the phase monitor well from 0.00053 mg/l to

0.0023, approximating an increase by a factor of four.

5.7 Assumptions / Uncertainty

5.7.1 Table 5.22 outlines what assumptions have been made as part of the model development.

Table 5.22 – Model Assumptions

Assumptions	Basis of Assumption	Reasonable / Unreasonable
Infiltration	Effective infiltration through the restoration soils is anticipated to be similar to the effective infiltration prior to extraction. This is because low permeability Glacial Till soils which currently overly the site will be used to restore the landfill upon completion of filling. A range has been applied in the model which is the effective infiltration accounting for evapotranspiration.	Reasonable
Porosity	The proposed fill for the restoration will be clayey soils. As a result, an estimate of the porosity of clay has been used.	Reasonable
Density	The proposed fill for the restoration will be clayey soils. As a result, an estimate of the dry density of clay has been used.	Reasonable
Field Capacity	The proposed fill for the restoration will be clayey soils. As a result, an estimate of the field capacity of clay has been used.	Reasonable
Hydraulic Conductivity	Hydraulic conductivity values have been assumed for the sandstone aquifer in the absence of site-specific data. A range spanning three orders of magnitude based upon literature derived values, has been included in the assessment, to model the uncertainty.	Reasonable

5.8 Hydrogeological Risk Assessment – Lincolnshire Limestone

5.8.1 The Lincolnshire Limestone Aquifer is classified by the EA as a Principal Aquifer. The Lincolnshire Limestone is currently being extracted at the site to the top of the Grantham Formation. The aquifer is considered a potential risk in the CSM however, the risk screening assessment has demonstrated that the construction of a 1m thick sidewall barrier or equivalent, along the quarry sidewall coupled with hydraulic containment of leachate within the waste mass ultimately removes the pathway to the Lincolnshire Limestone.

5.8.2 Calculation of a water balance for the site has demonstrated that it is likely that the water level within the Lincolnshire Limestone will remain above the leachate head within the site. If the groundwater level remains above the leachate head within the waste, the site is effectively operating with hydraulic containment in respect to the Principal Aquifer. It is highly unlikely that the dilute leachate generated by an inert landfill site will be capable of diffusing through the sidewall liner and into the aquifer.

5.9 Hydrogeological Completion Criteria

5.9.1 Completion requires a consideration of whether the site, as a result of restoration with inert material is likely or unlikely to cause pollution of the environment or harm to human health. As the hydrogeological risk assessment must be undertaken for the whole lifecycle of the restoration, it follows that the process should result in the initial production of hydrogeological completion criteria.

5.9.2 By way of definition 'Completion' relating to hydrogeological risks will have been achieved when there is no unacceptable risk of pollution from the site, i.e. when the site can comply with the requirements of the Groundwater Regulations (2009), without the need for any active management.

5.9.3 The hydrogeological risk assessment has shown that even using the upper limits of the WAC limits as the leachate source term there will be no exceedance of the calculated Environmental Assessment Levels and as such the site is expected to comply with the Groundwater Regulations (2009). It is expected to be impractical to monitor leachate in the inert fill material given the nature of the proposed restoration material will be clay. It is suggested that it will be more appropriate to carry out groundwater quality monitoring along the perimeter of the site and routinely assess those results against the specific control and compliance limits. Further groundwater monitoring boreholes are to be drilled at the site with the HRA to be revised based on results of groundwater sampling.

5.9.4 We recommend that groundwater quality is monitored during the operation of the restoration and for up to six years post closure to confirm the findings of this assessment.

6 Requisite Surveillance

6.1 Groundwater Monitoring Locations

6.1.1 Groundwater monitoring boreholes W01 - W05 (10 No. boreholes in total) are located around Phases A and B as shown on Figure 4. It is proposed to use these groundwater monitoring boreholes as part of the groundwater monitoring programme at Wakerley Quarry.

6.1.2 Further groundwater monitoring boreholes will be required to be installed to the north and north-east of the site over time as the extraction works progress in this direction (Phases C, D and E). The locations of these monitoring boreholes will need to be agreed with the EA in advance.

6.1.3 It is expected that given the duration of time it will take to complete the initial mineral extraction process, some monitoring boreholes may become damaged, destroyed or lost. The Operator should consult with the EA ahead of replacing boreholes to make sure that the replacement boreholes provide adequate coverage across the site.

6.2 Monitoring Frequency

6.2.1 Groundwater quality samples will be collected from each borehole and subsequently analysed for hazardous and non-hazardous substances. It is proposed to undertake the groundwater quality monitoring on a quarterly basis for 12 months and then review and agree the frequency with the Environment Agency thereafter.

6.2.2 The methodology for the groundwater level monitoring and groundwater sampling to be carried out is outlined in detail within the WYG Environmental Management and Monitoring Plan (December 2019) but a brief summary is provided below:

Groundwater Level Monitoring

1. Record the time, date and weather conditions before each measurement is obtained from the monitoring boreholes;

2. Check for any visible signs of damages or deterioration of the borehole inner/outer casing; and

3. Record the depth to groundwater level using an electronic water level meter and depth to base of the borehole;

Groundwater Quality Sampling

4. Groundwater samples will be collected from each borehole using best environmental practices (method to be agreed with Environment Agency) to minimise cross contamination risks and will

be placed inside laboratory supplied containers. Samples are to be kept cool with freezer packs to preserve their integrity;

5. Groundwater samples are then forwarded to an accredited laboratory on the day of collection for scheduled analysis; and,

6. Tubing is to be removed from the borehole upon the completion and to be disposed of appropriately.

6.3 Groundwater Monitoring & Analysis

6.3.1 It is proposed that the monitoring of groundwater quality includes the parameters detailed in Table 6.1 below. Should exceedances be recorded above the compliance/control limits the frequency of analysis of all determinants will be reviewed.

Table 6.1 – Groundwater Monitoring Schedule

Borehole Piezometer	Frequency	Determinands
W01S, W01D, W02S, W02D, W03S, W03D, W04S, W04D, W05S and W05D	Quarterly	Groundwater Levels, Electrical Conductivity, Chloride, Ammoniacal nitrogen, pH
	Annually	As above plus Total Alkalinity, Magnesium, Potassium, Sulphate, Calcium, Sodium, Chromium (VI), Copper, Iron, Lead, Nickel, Zinc, Manganese, Selenium, Cyanide, barium, cadmium, Total Phenols, Mineral Oils / Hydrocarbons (TPH)
	Annually for first six years of operation then every two years	As above plus - Mercury, Benzene, Toluene, Ethyl Benzene, Xylene, Benzo(a)pyrene, Poly Chlorinated Biphenyls (PCB), Polycyclic Aromatic Hydrocarbons (PAH)

6.4 Groundwater Control and Compliance Points

Control Levels

6.4.1 Control levels allow the site operator and the EA to identify at an early stage if the landfills performance is deviating from the predicted concentrations in the quantitative risk assessment. Control levels have been calculated for the Northampton Sand aquifer.

6.4.2 Control levels for the non-hazardous contaminants have been set at a point between the predicted concentration in the quantitative risk assessment and the EALs. Control levels have not been derived for hazardous contaminants as the Groundwater Daughter Directive requires that the entry of hazardous contaminants is prevented and since the compliance limits for hazardous substances are generally very low, it is not considered feasible to use a lower concentration as a control level. The control levels outlined below can be used to screen against down-hydraulic gradient monitoring boreholes W03 and W04 for both the Northampton Sand and Lincolnshire Limestone aquifers during the monitoring programme.

6.4.3 The proposed control levels for the Northampton Sand Formation are outlined in the below table. The control levels should be reviewed annually.

Table 6.2 – Proposed Control Levels (Northampton Sand Formation)

Contaminant	Maximum* Baseline Groundwater Concentration (mg/l)	Predicted Concentration (LandSim Model 1) 95th %ile (mg/l)	EAL (mg/l)	Proposed Control Level (mg/l)
Antimony	NM	0.000073	0.005	**0.0025**
Ammoniacal Nitrogen	1.20	0.96	1.20	**1.20**
Barium	NM	0.11	1.30	**0.705**
Cadmium	<0.08	0.00064	0.00254	**0.00159**
Nickel	0.004	0.0045	0.012	**0.00825**
Selenium	0.0038	0.0033	0.0069	**0.0051**
Zinc	0.048	0.032	0.048	**0.048**
Phenol	NM	0.0028	0.0077	**0.00525**

Table Notes
** Outliers have been removed from the data set for W02S*

6.4.4 The control levels have been set a midpoint between the EAL and the 95th%ile predicted concentration from the LandSim Model (Model 1) unless the predicted concentration is below the maximum baseline concentration (following removal of outliers) for borehole W02 at which point, the control level is set at the EAL.

Compliance Limits

6.4.5 Compliance limits (formerly known as Trigger Limits) represent the levels of contamination (or concentration) that constitutes pollution in controlled waters. The compliance limits are used as performance standards to screen the results from the groundwater monitoring undertaken in the adjacent groundwater monitoring boreholes.

6.4.6 In line with EA guidance, the compliance limits are set at the EALs which were calculated in Section 4.4. The proposed compliance limits for use in the environmental permit are outlined separately for boreholes installed within the Lincolnshire Limestone and Northampton Sand Formation.

Table 6.3 – Northampton Sand Formation - Groundwater Compliance Points

Contaminant	Maximum Baseline Groundwater Concentration (mg/l)	Predicted Concentration (LandSim Model 1) 95th %ile (mg/l)	Proposed Control Level (mg/l)	Proposed Compliance Limit (mg/l)
Arsenic	-	0.000073	-	**0.005**
Chromium IV	<0.008	0	-	**0.008**
Lead	<0.001	0	-	**0.001***
Mercury	<0.00001	0	-	**0.0001**
Antimony	-	0.000073	0.0025	**0.005**
Ammoniacal Nitrogen	1.20	0.96	1.20	**1.20**
Barium	NM	0.11	0.705	**1.30**
Cadmium	<0.08	0.00064	0.00159	**0.00254**
Nickel	0.004	0.0045	0.00825	**0.012**
Selenium	0.0038	0.0033	0.0051	**0.0069**
Zinc	0.048	0.032	0.048	**0.048**
Phenol	-	0.0028	0.00525	**0.0077**

***Note – compliance limit for Lead set at laboratory LOD, rather than EAL.**

Table 6.4 – Lincolnshire Limestone - Groundwater Compliance Points

Contaminant	Maximum Baseline Groundwater Concentration (mg/l)	Proposed Compliance Limit (mg/l)
Arsenic	-	**0.005**
Chromium IV	0.0076	**0.0076**
Lead	<0.001	**0.001**
Mercury	<0.005	**0.00001**
Antimony	-	**0.005**
Ammoniacal Nitrogen	0.44	**0.47**
Barium	-	**1.30**
Cadmium	<0.08	**0.0025**
Nickel	0.0034	**0.011**
Selenium	0.003	**0.0065**
Zinc	0.037	**0.037**
Phenol	-	**0.0077**

6.4.7 The compliance limits should be reviewed and updated periodically in line with the frequency recommended within the Environmental Permit.

7 Conclusions

7.1.1 WYG Environment (WYG) have been commissioned by Mick George Limited to undertake an updated Hydrogeological Risk Assessment (HRA) in response to a Schedule 5 Notice issued by the Environment Agency (EA) with regards to environment permit variation for the restoration of a mineral extraction site through the importation of inert material at Wakerley Quarry, Wakerley.

7.1.2 In response to point 2 of the Schedule 5 notice, the previous groundwater contour plots have been reviewed and amended as deemed necessary to clearly portray the anticipated groundwater flow regime at the site. Contour plots include the most recent rounds of monitoring which include a relatively new borehole installation, W05, both within the Lincolnshire Limestone Formation and Northampton Sandstone Formation. The plots show that groundwater flow within the Lincolnshire Limestone is to the northeast. Groundwater flow within the Northampton Sandstone is predominantly towards the southeast. The CSM include the springs identified to the north of the site. Due to the dominant groundwater flow direction and the presence of inferred faults to the north of the site it is not believed that these springs are in hydraulic connection with groundwater beneath the site. Regardless, the detailed quantitative risk assessment considers the input of substances immediately downgradient of site.

7.1.3 This HRA and quantitative modelling has demonstrated that the proposed geological barrier will provide adequate containment of landfill 'leachate' to meet the requirements of Landfill Directive (1999/31/EC) and will provide sufficient attenuation to prevent a risk to the underlying strata and groundwater environment.

7.1.4 The restoration area (and geological barrier) is underlain by the un-productive mudstones of the Grantham Formation. This offers a natural layer of protection to the underlying Northampton Sand Formation (Secondary A Aquifer). The 1 m thick or equivalent, basal and side wall geological barrier will be constructed so that it mitigates the risk of 'leachate' migration through faults and fissures transecting the site. Therefore, the proposed restoration of the site is considered to comply with EA positional statement E. The EA positional statement is as follows:

(i) We will object to any proposed landfill site in groundwater source protection zone 1;

(ii) For all other proposed landfill site locations, a risk assessment must be conducted based on the nature and quantity of the wastes and the natural setting and properties of the location; and,

(iii) Where this risk assessment demonstrates that active long-term site management is essential to prevent long-term groundwater pollution, we will object to sites:

- *Below the water table in any strata where the groundwater provides an important contribution to river flow or other sensitive surface waters;*

- *Within source protection zones 2 and 3;*
- *On or in a Principal Aquifer.*

7.1.5 The Hydrogeological Risk Assessment has demonstrated:

(i) The proposed site is not within a groundwater source protection zone 1;

(ii) A satisfactory risk to the natural setting from the proposed land use; and,

(iii) No active long-term site management is required to prevent long-term groundwater pollution.

7.1.6 The modelling predicts a negligible impact to groundwater in the underlying Northampton Sand Formation and or at springs (and by extension local surface water receptors) located beyond the site boundary.

7.1.7 The qualitative assessment for the Lincolnshire Limestone is supported by water balance calculations and has demonstrated that the proposed restoration of the quarry void with inert material would remain compliant with the Environmental Permitting Regulations 2010 i.e. that Hazardous Substances will not be discernible in the groundwater and non-hazardous pollutants will not be present at the compliance point above a level that will constitute pollution. The landfill will effectively behave as hydraulically contained with respect to the limestone aquifer.

7.1.8 A groundwater monitoring scheme and compliance limits have been derived to assess the future performance of the restoration scheme over its lifecycle. It is recommended that the compliance limits are reviewed and updated periodically following the collection of further groundwater monitoring data and as the site develops. This can be captured as part of any permit issued by the Environment Agency.

7.1.9 The HRA has demonstrated that the input of hazardous substances into groundwater will be prevented and the discharge of non-hazardous substances will be limited. The proposed development therefore complies with the requirements of Schedule 10 of the Environmental Permitting Regulations (2010).