# Wivenhoe Quarry

## Hydrogeological Risk Assessment

### Tarmac Trading Limited

**Report No. K6008-ENV-R004**
July 2022
Revision 00

TARMAC
A CRH COMPANY

BYRNELOOBY

IRELAND | UK | UAE | BAHRAIN | KSA

BYRNELOOBY

# Document Control

Document: Hydrogeological Risk Assessment

Project: Wivenhoe Quarry

Client: Tarmac Trading Limited

Report Number: K6008-ENV-R004

Document Checking:

| Revision | Revision/ Review Date | Details of Issue | Authorised | | |
|---|---|---|---|---|---|
| | | | Prepared By | Checked By | Approved By |
| 00 | July 2022 | Final | Craig Fannin | John Baxter | Craig Fannin |
| | | | | | |
| | | | | | |
| **Disclaimer:** Please note that this report is based on specific information, instructions and information from our Client and should not be relied upon by third parties. | | | | | |

BYRNELOOBY

**www.ByrneLooby.com**

# Contents

Drawings

| | |
|---|---|
| W328-00062-01-D | Site Location |
| W328-00062-03-D | Proposed Working Plan |
| W328-00062-12-D | Outline Restoration |
| W328-00062-13-D | Cross Sections |

# 1 Introduction

## 1.1 Report Objectives

Byrne Looby Partners (UK) Ltd (ByrneLooby) have been commissioned by Tarmac Trading Limited (Tarmac) to produce an Environmental Permit Application for the restoration of the Wivenhoe East Quarry under a recovery permit. A separate waste recovery plan has been produced (ByrneLooby Report K6009-ENV-R001). This report presents a Hydrogeological Risk Assessment for the quarry restoration, the details of which are presented in a parallel Environmental Setting and Site Design (ESSD) report (ByrneLooby Report K6009-ENV-R002).

There is an obligation to restore the land to the south of Colchester Main Road (known as Sunnymead, Elmstead and Heath Farms), Arlesford, Essex, CO7 8DB (the Site) as required by Planning Permission ESS/17/18TEN. The approved restoration scheme comprises a combination of return to agricultural land and the creation of low-level water-based nature conservation habitats, lowland meadow, woodland planting and hedgerow enhancement.

A Recovery Permit is required as, to recreate the landscape, a proportion of the removed mineral will be replaced by imported soils and other inert materials. This hydrological risk assessment (HRA) has been prepared to describe the changes in the hydrogeological regime at the site including consideration of any potential effects on downgradient receptors.

## 1.2 Site Location and Surrounding Land Uses

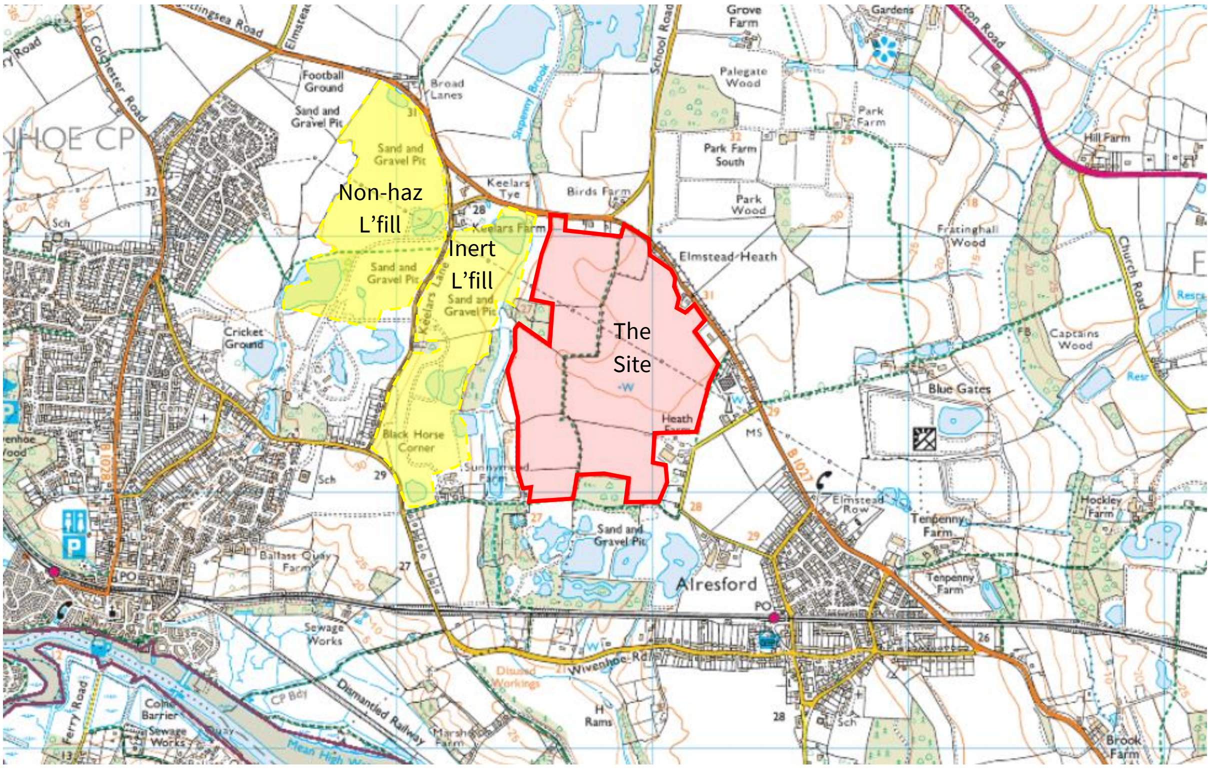
The Site is located between Wivenhoe and Alresford at Elmstead Heath, some 3.5km to the south-east of Colchester, Essex and is centred at National Grid Reference (NGR) TM 05855 22582 (Figure 1.1 and Drawing W328-00062-01-D). The Site is an area of agricultural land, with an active quarry to the west and a former quarry to the south. The land to the north and east is predominantly by agricultural land, isolated dwellings, woodland and water bodies, with the village of Arlesford to the southeast.

Full details of the site setting are provided in the parallel Environmental Setting and Site Design[1] document which should be read in conjunction with this assessment. However, for clarity the site is best described as being a ~60ha area bounded by the B10207 to the north, minor roads to the east, the Sixpenny Brook to the west and an early phase of quarrying, now restored to ponds to the south.

Key water features include the Sixpenny Brook which flows north to south adjacent to the western boundary of the Site and then flows in an easterly direction to the south of the Cockaynes Wood nature reserve. The Sixpenny Brook flows into the Alresford Creek approximately 3km southeast of the site. Arlesford Creek is a tidal arm of the River Colne formed by the Sixpenny Brook and the Tenpenny Brook a north to south flowing stream, which at its closest is 1.6km to the east of the Site. The Colne Estuary is characterised as a Ramsar site, Site of Special Scientific Interest (SSSI), Special Area of Conservation (SAC) and Special Protection Area (SPA).

[1] ByrneLooby (2022) Wivenhoe Quarry East. Environmental Setting and Site Design. Rep. K6008-ENV-002

**Figure 1.1 – Site Location and Surrounding Features**




Inert L'fill = Mapped Inert Landfill EPR/FP3194LV in operational quarry (Note landfill's are smaller than permitted /licensed areas) Non-haz L'fill = Mapped Biodegradable Landfill EPR/PP3199NN

## 1.3 Site Details

The Site covers an area of ~60.9ha and currently exists as agricultural field parcels delineated by hedgerows. The Site is bisected by a Public Right of Way (footpath) and a series of overhead power lines. The topography of the site is almost entirely level and only varies by 3m, rises from ~27mAOD along the western edge of the site to ~30mAOD within the central part of the site. Towards the north-east the ground elevation remains relatively flat. There is a fall in topography towards the south-east of the Site near Cockaynes Wood with elevations at Willow Lodge at ~27.5mAOD . The site topography is illustrated on Drawing W328-00062-02-D.

The extraction area covers some 43.4ha. Details of the proposed working scheme including the application boundary and proposed extraction area are illustrated on Drawing W328-00062-03-D.

The footprint of the site has remained undeveloped since at least 1874 and comprises agricultural land and crossing footpaths and bridleways.

# 2 Proposed Development

## 2.1 Scheme Overview

The Site is being developed for the extraction of approximately 3.8 million tonnes of sand and gravel. The Site is to be progressively restored to a mixture of agriculture and low-level water-based nature conservation habitats, lowland meadow, woodland planting and hedgerow enhancement. The approved restoration scheme for the site including final ground contours is illustrated on Drawing W328-00062-12-D and presented as a Drawing Extract as Figure 2.1.

**Figure 2.1 – Permitted Restoration Profile**


See Drawing W328-00062-12-D for full details of Restoration Scheme and Drawing Key

The proposed mineral extraction zone covers an area of ~43.4ha, within an overall planning permission area of 60.9ha. The additional area includes the stand-offs from properties, the bridleway and other buffer zones .

The restoration profile and phased planning conditions requires that the final restoration scheme comprises an arc formed by the western and southern flanks of the development which are returned to their original ground level for either agriculture (in the west) and lowland meadow in the south, which then surround an open water lake feature. The bridleway is to be retained and will separate the western area from the lake.

The slopes towards the lake are of a shallow (1 in 30) gradient, which will then steepen to 1 in 10 at the Lake margins, with a slope of 1 in 3 beneath the water line below 26mAOD. The lake is located across the area with the greatest thickness of extractable mineral (**Error! Reference source not found.**), and therefore its inclusion within the scheme minimises the amount of material that is required to be imported. However, some “below post-dewatering water level” fill will be required to ensure stable slope angles.

In order to complete this restoration scheme there is a requirement to import and place approximately 1.2 million cubic metres of suitable restoration materials. As the importation volume is to supplement the on-site excavated materials *i.e.* interburden and overburden, then the precise quantity of material requiring importation is not known.

Quarry restoration is to be undertaken under a Recovery Plan[2], which has been agreed by the Environment Agency[3].

The Environment Agency’s letter included the following advisory statements

- the quality of the proposed waste to be deposited below the water table and the engineering mitigation measures needed to ensure the deposit of waste below the water table achieves the requirement of the Guidance - Waste recovery plans and deposit for recovery permits including the need to satisfy Schedule 22 of the Environmental Permitting (England and Wales) Regulations 2016 particularly Schedule 22 Section 6.

- the application will need to address how the waste achieves the geotechnical and chemical standard for a geological barrier for an inert site

- which component of the proposed waste deposit will specifically be classed as the ‘attenuation layer’ or ‘geological barrier’. For example, there needs to be a drawing which shows the applicants explanation and delineates the difference components of engineering and waste.

- Specific detail of the leachable fractions of the proposed waste codes will be needed to support the application Guidance - Engineering construction proposals for deposit for recovery

- The information provided shows the site is located on Secondary A Aquifer containing groundwater. This means the site falls within a category of being in a sensitive groundwater location irrespective of the additional sensitivities bought about by the Source Protection Zone (SPZ) 3 of the groundwater contained in the chalk geology located beneath the London Clay. This is not just

[2] ByrneLooby (2021) Wivenhoe Quarry East, Waste Recovery Plan. Report J6008-ENV-R001
[3] Environment Agency (2022) Recovery or Disposal Operation. Wivenhoe East Quarry. Letter Reference EPR/KB3009FM/A001, dated 04/03/2022

constrained to SPZ locations or principal aquifers. Please refer to the guidance on what is consider a sensitive groundwater location Sensitive locations

The advisory information as outlined above is taken into consideration when preparing this document.

## 2.2 Operational Programme

The site is to be progressively developed in seven phases. Each phase will be excavated to approximately the base of the sand and gravel deposit (*i.e.* to the top of the London Clay). Processing plant, a site office, freshwater lagoon and processed mineral stockpiles will be located within the northern part of Phase 1 once this area has been excavated. Two silt lagoons are to be developed within the southern part of Phase 1. The northern and southern areas will be separated by a retained hedgerow *i.e.* unexcavated ground.

The quarry will be developed in a phased manner in accordance with the requirements of the Planning Permission. Once the first three phases have been quarried, the restoration of each excavated phase will be completed prior to excavation of the next phase. As Phase 1 will form the mineral processing area, then it will be the first phase to be operated and last to be restored. However, as there is a requirement for only three phases to be active at one time, then in order for Phase 4 to be operational Phase 2 must have been restored, with Phase 5 operations commencing following the restoration of Phase 3.

Overburden, interburden, topsoil and subsoil will initially be used to form amenity screening bunds and then in the restoration of the preceding extraction phases. These materials will be supplemented with imported inert materials where necessary to complete the restoration of a phase. It is anticipated that Phases 2, 3, 4 and 5 will be partially restored with imported inert materials. Phases 1, 6 and 7 are expected to be restored using only site derived materials. However, the source of material used for restoration will be dependent on how much site derived non-commercially viable material is present. Consequently, some imported materials may be required for Phases 1, 6 and 7.

"Footpath 24" which runs from north to south through the central part of the site and separates Phases 1-3 from Phases 4-7 will remain unexcavated. A tunnel will be constructed beneath the footpath to allow excavated material from Phases 4 to 7 to be conveyed to Phase 1 for processing.

Each phase will be worked dry and therefore de-watering will be required. An assessment of the de-watering requirements was completed as part of the planning application for the site and these are detailed in the supporting Hydrogeological Risk Assessment (HRA) produced for the site by Stantec[4]. The de-watering works will be carried out under a separate Transfer Licence. The expected radius of influence from the de-watering activity is 447m.

---

[4] Stantec (2018) Wivenhoe Quarry Extension. Hydrogeological Risk Assessment. Ref 61272/R1

The site layout is illustrated on Figure 2.2, with illustrative cross sections of the infilled profile with higher exaggerated vertical scales are presented as Figure 2.3 –Schematic Cross-Section (North-South)Figure 2.3 and Figure 2.4.

**Figure 2.2 – Phase Layout and Monitoring Locations**

**Figure 2.3 –Schematic Cross-Section (North- South)**

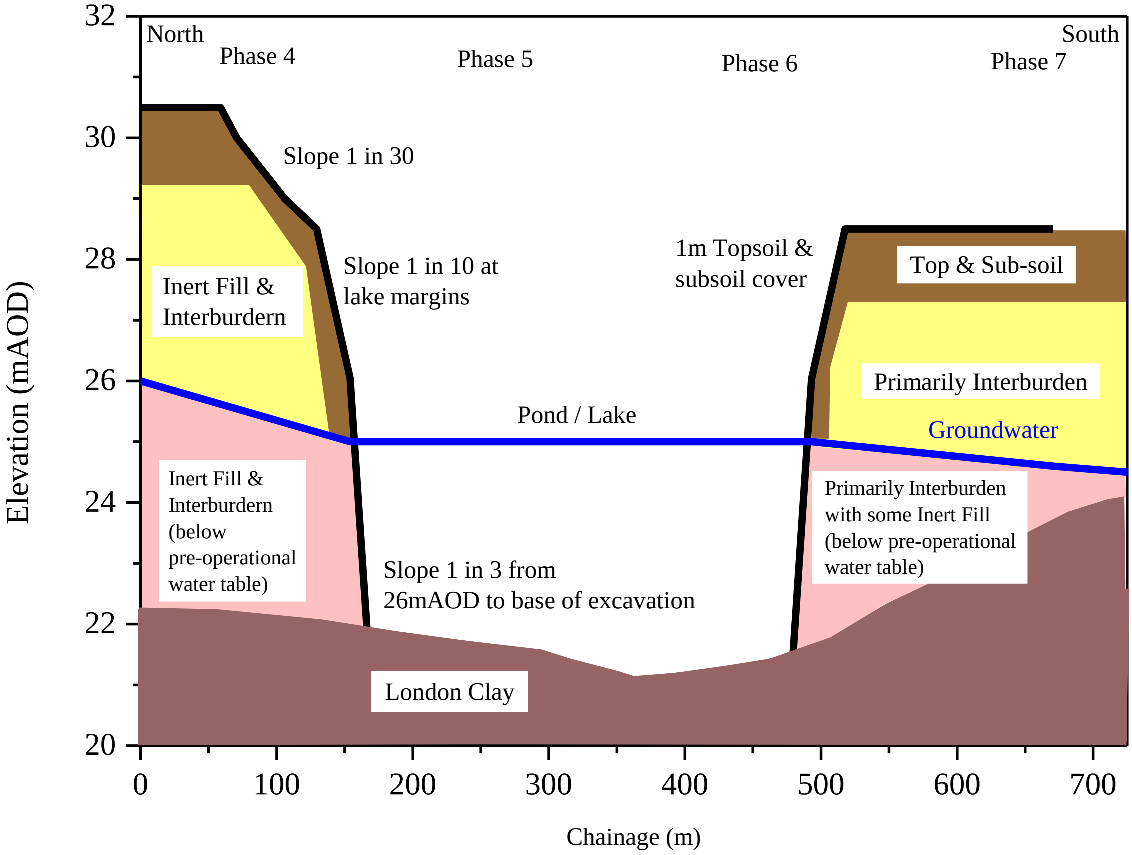
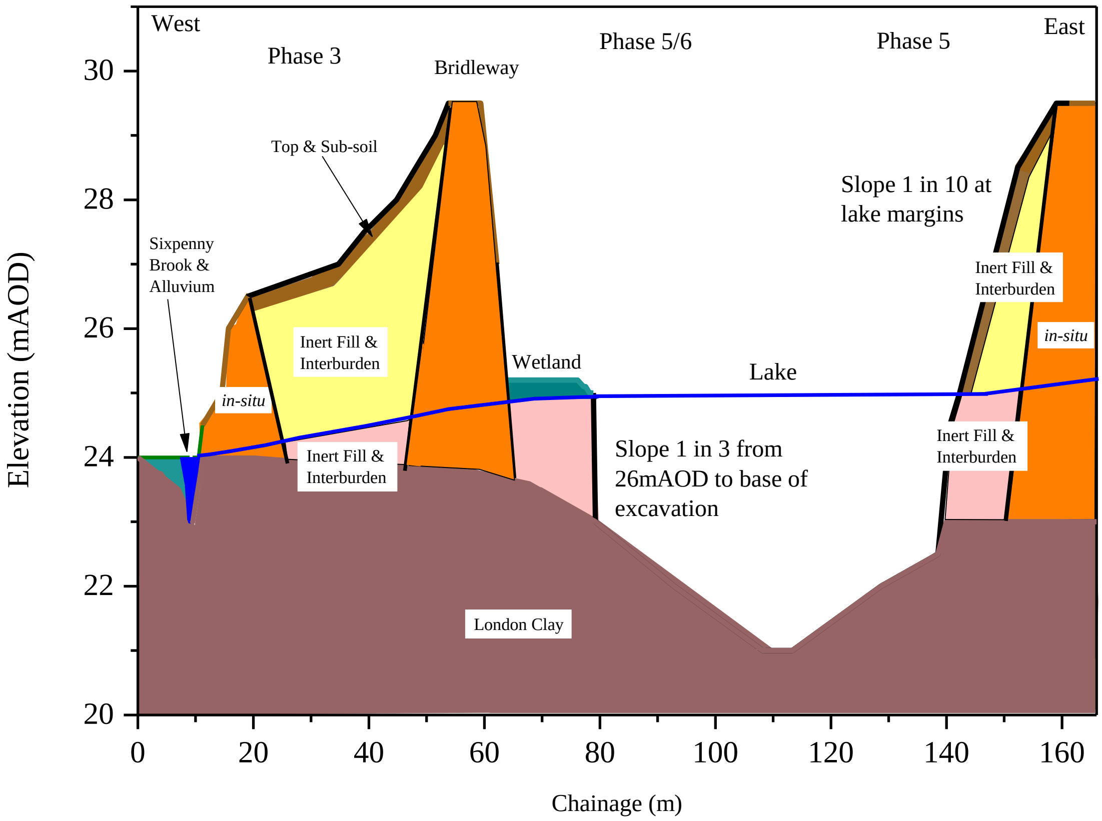



**Figure 2.4 –Schematic Cross-Section (West - East)**



## 2.3 Quantity of Material to be Imported

The imported material quantity is expected to be approximately a third of the intended extractable mineral, which will be used to supplement on-site excavated materials *i.e.* quarry overburden and interburden. Therefore, the quantity of imported material required will be dependent on the proportion of recovered mineral. Materials will be imported throughout the operational period of the quarry at a rate proportional to the mineral output. However, as noted above Phases 1, 6 and 7 are expected to be restored using solely site derived materials. These will be the last phases to be restored and therefore will host the stockpiled interburden and surrounding perimeter bund material.

General infill thicknesses are intended to be as shown in Table 1. These depths are for the perimeters of the lake area, as the infill thickness from the bottom of the stable side slope will be zero.

**Table 1 – Proposed Phasing Development Summary**

| Phase | Position | Base of Excavation, (to Thames Group) | Restoration Level (resultant topographical slope) | Comments |
|---|---|---|---|---|
| | | mAOD | mAOD | |
| 1 | Northwest | 21.3 to 26.0 | 26 to 30.0 | |
| 2 | Southwest | 20.5 to 23.9 | 26 to 29.5 | |
| 3 | West | 19.0 to 22.5 | 26 to 29.5 | |
| 4 | Northeast | 20.8 to 24.5 | 21 to 30.5 | Restored to open water |
| 5 | East | 20.0 to 23.5 | 21 to 28.5 | Restored to open water |
| 6 | East | 20.7 to 23.5 | 21 to 28.5 | Restored to open water |
| 7 | Southeast | 21.8 to 25.0 | 28 to 29.5 | |

Blue highlighted – restoration intended to be with site derived material (if possible)
Green highlighted – restoration with site derived and imported material
Nominal depth of fill assumed in lake area

Above lake water levels will be shallow and to the contours approved in the Planning Permission illustrated on Drawing W328-00062-12-D and shown on Figure 2.1. Slope angles will grade from 1in 30 to 1 in 10 towards the lake. All external slope angles will be to the natural topographical contours.

It has been estimated that approximately 1.2million $m^3$ of infill materials will be required to restore the Site back to the approved Planning Permission levels. This equates to 1.9 – 2.3 million tonnes of material at a density of 1.6 – 1.9T/$m^3$. It is proposed that inert restoration materials will be imported at a maximum rate of 60,000$m^3$ per annum, and therefore importation will take place over an approximate 20year period.

The minimum amount of waste is being used to achieve the benefit as it is restoring the mineral working back to a combination of water habitat and low level landform in accordance with the Site's Planning Permission. There is no increase in contour heights over the existing contours and therefore no additional void has been created by for example, constructing a domed profile above predevelopment contours. The placement of the lake is deliberate in order to minimise material imports as this area contains the greatest thickness of mineral product.

## 2.4 Source and types of Waste Materials

The Planning Permission for the site restricts the types of infilling materials to inert materials only. This is further caveated to only those materials approved under the Waste Recovery Plan[2], which will primarily comprise largely of soils characterised as

- 17 04 05 "*Soils and stone other than 17 05 03*" and
- 20 02 02 "*Soil and stones*".

The full list of waste to be accepted has been taken from Standard Rules Permit SR2015 No. 39 and these are represented below as Table 2.

**Table 2 –Waste Types Approved under Site Recovery Plan**

| EWC | Description | |
|---|---|---|
| **01** | **Wastes resulting from exploration, mining, quarrying, and physical and chemical treatment of minerals** | |
| **01 01** | **wastes from mineral excavation** | |
| 01 01 02 | Wastes from mineral nonmetalliferous excavation.<br>Limitation: - Restricted to waste overburden and interburden only. | AN |
| **01 04** | **wastes from physical and chemical processing of non-metalliferous mineral** | |
| 01 04 08 | Waste gravel and crushed rock. | MN |
| 01 04 09 | Waste sands and clays. | AN |
| **10** | **Waste from thermal processes** | |
| **10 12** | **Wastes from manufacture of ceramic goods, bricks, tiles and construction products** | |
| 10 12 08 | Waste ceramics, bricks, tiles and construction products (after thermal processing) | AN |
| **17** | **Construction and Demolition Waste** | |
| **17 01** | **Concrete, bricks, tiles and ceramics** | |
| 17 01 01 | Concrete | MN |
| 17 01 02 | Bricks | MN |
| 17 01 03 | Tiles and ceramics | MN |
| 17 01 07 | Mixtures of concrete, bricks, tiles and ceramics other than those mentioned in 17 01 06.<br>Limitation : - Metal from reinforced concrete must have been removed. | MN |
| **17 05** | **soil (including excavated soil from contaminated sites), stones and dredging spoil** | |
| 17 05 04 | Soils and stone other than 17 05 03.<br>Limitation: - Restricted to topsoil, peat, subsoil and stones only. | MN |
| **19** | **Waste from mechanical treatment of waste (sorting, crushing, compacting palletising not otherwise specified)** | |
| **19 12** | **wastes from the mechanical treatment of waste (for example sorting, crushing, compacting, pelletising) not otherwise specified** | |
| 19 12 09 | Minerals (for example sand, stones) only.<br>Limitation:- Restricted to wastes from treatment of waste aggregates that are otherwise naturally occurring minerals.<br>Does not include fines from treatment of any non-hazardous waste or gypsum from recovered plasterboard. | MN |
| 19 12 12 | Other wastes (including mixtures of materials) from mechanical treatment of wastes other than those mentioned in 19 12 11.<br>Limitations: - Restricted to crushed bricks, tiles, concrete and ceramics only.<br>Metal from reinforced concrete must be removed.<br>Does not include fines from treatment of any non-hazardous waste or gypsum from recovered plasterboard. | MN |
| **20** | **Municipal wastes (household waste and similar commercial, industrial and institutional wastes) including separately collected fractions** | |
| **20 02** | Garden and park wastes (including cemetery waste) | |
| 20 02 02 | Soil and stones.<br>Limitations: - Restricted to topsoil, peat, subsoil and stones only. | AN |

AN – Absolute Non-hazardous entry MH – Mirror non-hazardous entry

The green shaded cells within Table 2 are identified under Paragraph 2.1.1 of European Council Decision 2003/33/EC[5] as being acceptable to be received at inert landfills without testing, provided source characterisation demonstrates that the materials are suitable.

# 3 Pathways and Receptors

## 3.1 Geology

The geological sequence at the site comprises permeable sand based superficial deposits overlying the London Clay (reclassified as part of the Thames Group) which forms a hydraulic barrier between the surface and the underlying sequence to the chalk (Table 3).

It is the Cover Sand and Kesgrave Formation within the footprint of the site which will be exploited by the quarry.

**Table 3 – Regional Geology Succession**

| Age | Formation/ Lithology | Description |
|---|---|---|
| Pleistocene and recent | Loam | Absent across much of the site. Described by BGS as a variable pebbly sandy clay, locally silty and sandy upper part. |
| | Cover Sand | Clay, Silt and Sand - Wind Blown Deposits formed up to 3 million years ago in the Quaternary Period. Deposits are aeolian in origin. They are detrital forming lenses, beds and dunes |
| | Kesgrave Formation | Sand and gravel. Superficial Deposits formed up to 3 million years ago in the Quaternary Period. Local environment previously dominated by rivers. Absent at the western boundary of the Site where the London Clay is exposed in the banks of the Sixpenny Brook |
| Eocene | London Clay (Thames Gp) | Bluish grey silty clay containing occasional thin cementstone lenses. Estimated depth of 20 – 30m at the site based on BGS records. |
| | Woolwich and Reading Beds (Thames Gp) | Silts, loams and sands in variable proportions. Estimated depth of 22 – 26m.<br>Mottled sands and clays with beds of pebbles. Present beneath the London Clay. Where the London Clay pinches out (approximately 1km to the west of the site) the Reading Beds directly underlie the superficial deposits. Comprises a thickness of some 30m beneath the London Clay to the east. Pinches out approximately 6km to the west of the site. (26m depth) |
| Cretaceous | Upper Chalk | Soft white limestone with flint bands and nodule. The top of the Upper Chalk at the site is at a level of approximately 30m below Ordnance Datum. |

The extent of quarrying is identified on geological mapping (Figure 3.1 and Figure 3.2) where the superficial sediments are absent, with alluvium tracing the surface water courses.

[5] Paragraph 2.1.1 of European Council Decision 2003/33/EC of 19th December 2002 as establishing criteria and procedures for the acceptance of waste at landfills pursuant to Article 16 and Annex II of Directive 1999/31/EC (of 26 April 1999 on the landfill of waste)

**Figure 3.1 – Superfical Geology (Extract taken from Stantec 2018[4])**

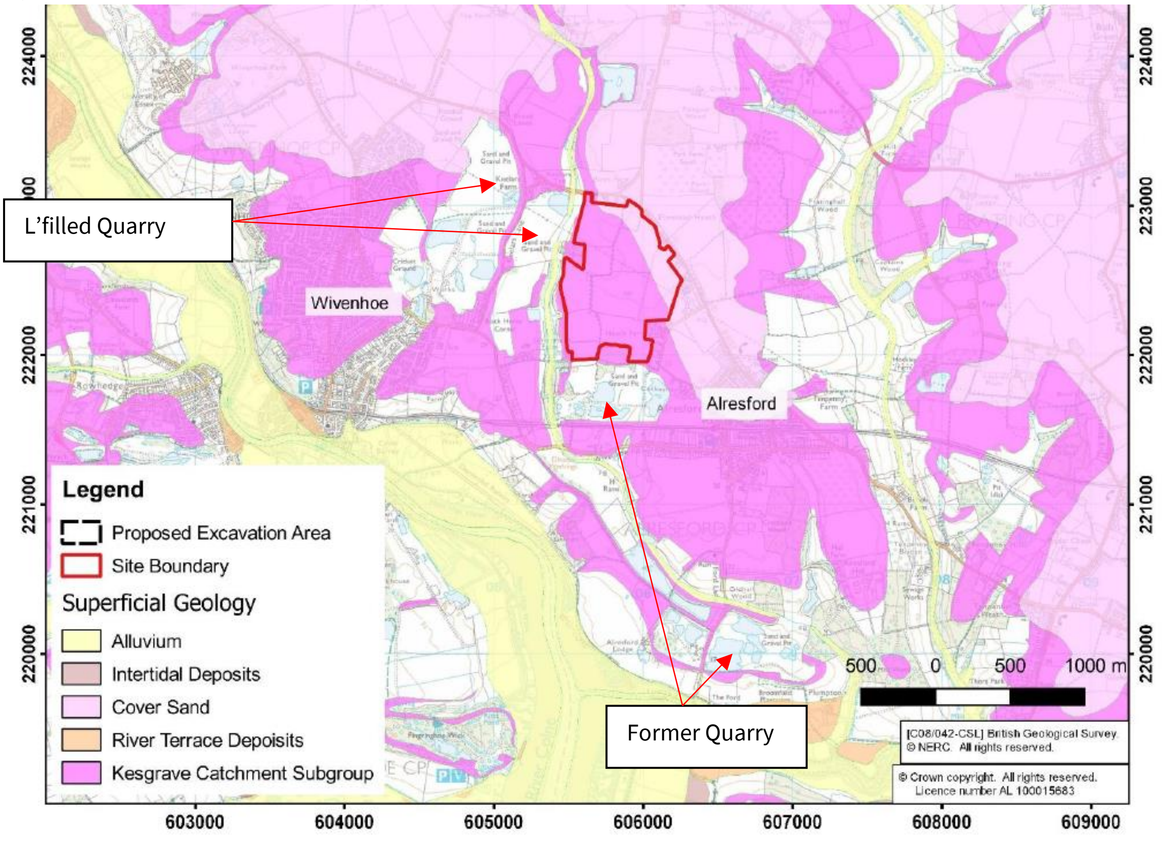
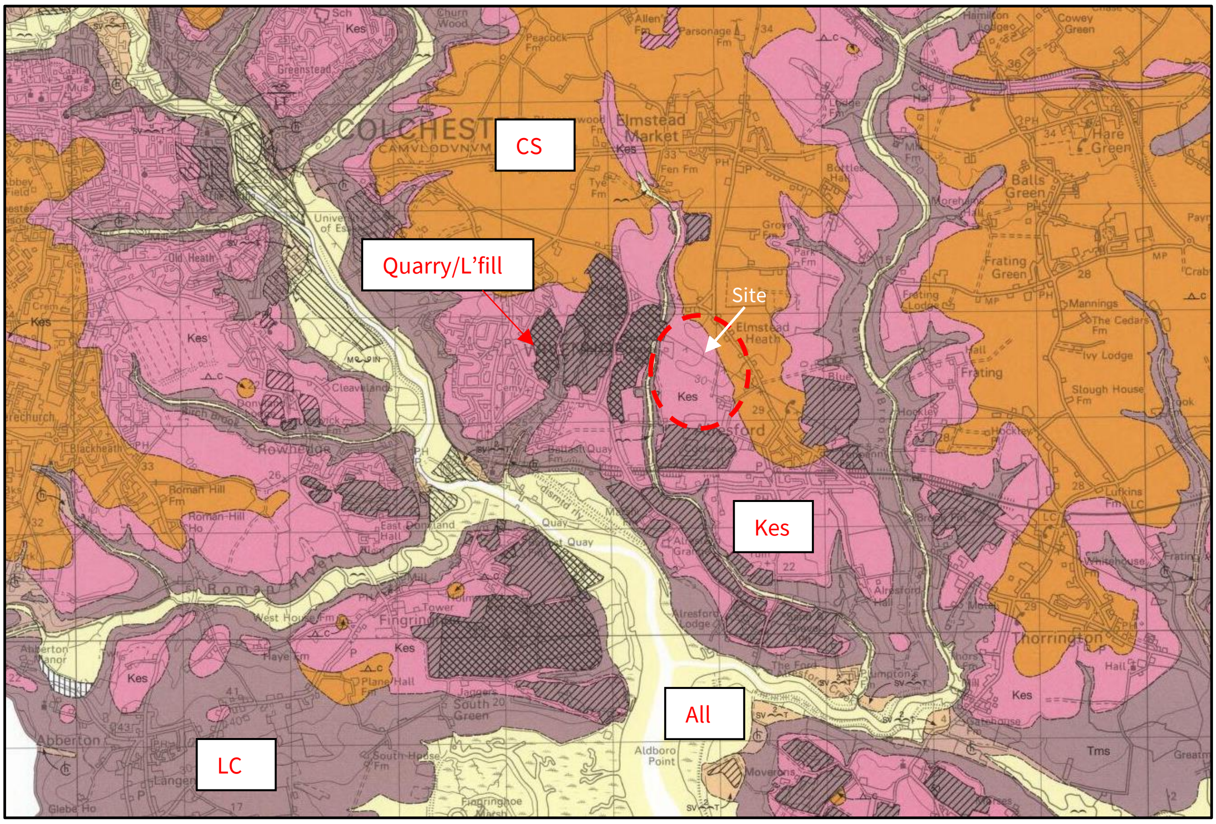



**Figure 3.2 – Geology (Extract taken from BGS Map 224 and 242)**




LC – London Clay Kes – Kesgrave Fm CS – Cover Sands All – Alluvium

Site investigation has identified between 5m and 7.5m of exploitable mineral within a superficial sequence comprising:

- Overburden (silty and/or sandy clay/silt with some gravel);
- Upper mineral (fine to medium sand and gravels);
- Interburden (silt or silty clay); and
- Lower mineral (fine to medium sand and gravels).

The superficial deposits have been placed on an erosion surface at the top of the London Clay, which varies between 19.0 and 26.0mAOD as detailed in Table 1. It is this erosion surface that has informed the location of the lake towards the lowest point of the clay surface in order to minimise the importation of wastes. The clay surface rises towards the south and west, the locations which are to be returned to agriculture and grassland.

## 3.2 Aquifer Status

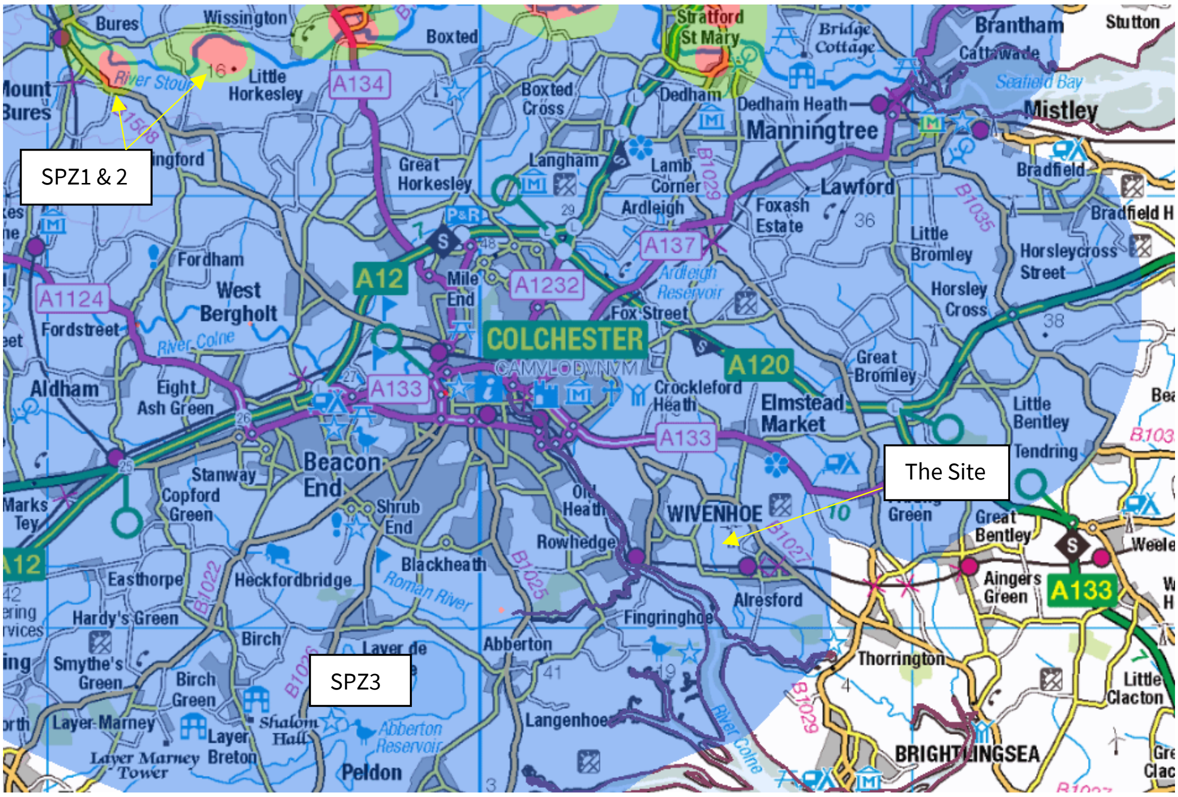
There are two hydrogeological water systems at the site, separated by the London Clay and the wider Thames Group. The Thames Group is classified as unproductive strata (non-aquifer), with the overlying and underlying strata classified as aquifer bodies.

The Kesgrave Catchment Subgroup is classified by the Environment Agency as a Secondary A Aquifer (minor aquifer). A Secondary A aquifer is defined by the Environment Agency as "*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*". The Cover Sands at the northwest of the site is classified as a Secondary B aquifer which is defined by the Environment Agency as "*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.*"

The site is located within the Total Catchment or Source Protection Zone (SPZ) 3 for a series of abstraction points in the chalk located in an arc of abstractions at Bures, Little Horkesly and Strafford St Mary some 11km to the northwest (Figure 3.3).

There is no hydraulic connection between the quarry area above the London Clay and the Source Protection Zone for these abstractions. The site is actually at the outer fringes of the catchment, which is limited by the proximity to the coast and the associated marine saline intrusion.

**Figure 3.3 – Source Protection Zones**




## 3.3 Hydrology

The closest water course is the Sixpenny Brook, a tributary of the River Colne which flows north to south along the western edge of the site (Figure 3.4). As the watercourse passes the site it splits into two separate channels, converging a short distance further downstream. It is understood that flow may be limited within the western channel during parts of the year[4]. A lined reservoir used for agricultural purposes is present to the southwest of the site. The water level within this lined reservoir is above that within the Sixpenny Brook.

The Sixpenny Brook flows into the Alresford Creek, a tributary of the River Colne, approximately 3km south-east of the site. The lowest reach of the Alresford Creek is tidal. The Alresford Creek is formed by the Tenpenny Brook entering the River Colne flood plain and lies ~2km to the south of the site at its nearest point. Tenpenny Brook flows from north to south ~1km to the east of the site with contributions from both the Elmstead Brook and Frating Brook. The water shed between Sixpenny Brook and Tenpenny Brook is to the east of the quarry.

The River Colne is also tidal as far as Colchester. However, a flood barrier is in place at Wivenhoe to minimise the risk of flooding. At it's nearest point to the site, the River Colne is 68m wide at low tide and 310m wide at high tide. The River Colne discharges to the North Sea at Brightlingsea Reach.

**Figure 3.4 – Nearby watercourses**


There are a number of nearby lakes which have formed as relic features following the historical quarrying activities at Cockaynes Wood immediately to the south of the site (Figure 3.5). The closest of these lakes are:

- Cox Lake (120m south-east);
- Worcester Lake (165m south of the Site); and
- Bramley Lake (325m south).

The base of Cox Lake and Worcester Lake are naturally lined with clay and are fed by spring flows as well as direct rainfall and surface water runoff[4]. The springs enter the lakes above the *in-situ* clay surface and flow mainly into the Cox and Worcester lakes. The Bramley Lake is mainly fed by overflow from the other two lakes and groundwater inflows. One spring has been identified in the north-western part of the Worcester Lake. It is understood that the lakes outfall to a drain that flows north to south towards a small pond positioned some 600m to the south of the site. This drain appears to originate from Heath Farm and will discharge to the Sixpenny Brook.

A series of smaller ponds and a former silt lagoon are located ~80m from the site boundary form part of the Cockaynes Nature Reserve. An outlet from the lake system is understood to transmit flow to the Sixpenny Brook[4].

**Figure 3.5 – Nearby water features**


The site is located within Flood Risk Zone 1 which means it is land assessed as having a less than 1 in 1,000 annual probability of river or sea flooding. The site is therefore considered to be at low risk from flooding.

## 3.4 Groundwater and Surface Water Flow

Groundwater flow within the Chalk strata and the lower Thames Group Members (Woolwich and Reading Beds) are physically separate from the quarry and not at risk of influence from the quarrying and restoration works.

Recharge to the superficial strata is via direct precipitation and infiltration to ground both within and to the north of the site. The infiltrating waters are then diverted laterally by the surface of the London Clay to form the baseflow to the Sixpenny Brook and the Tenpenny Brook. Hydrogeological recharge to the site area is therefore direct infiltration and groundwater flow from a recharge area to the north.

This superficial aquifer unit is terminated to the west of the site by the Sixpenny Brook and to the south of the site by the Cockaynes Wood Quarry. Mineral extraction will then push the limits of the superficial aquifer back towards the north and east to the boundary of the quarry.

The water system in the superficial strata overlying the London Clay will therefore be affected by the scheme. Firstly from dewatering during the quarry works, and in the longer term by any diversion to the flow patterns caused by the replacement of the sands by a lower permeability fill than is currently present.

Although the quarry footprint will no longer have an aquifer status, baseflow to Sixpenny Brook will be protected firstly as the brook will be the receiving waters from the dewatering programme and secondly in the longer term, diverted waters around the placed materials will also discharge into the brook hence long term baseflow patterns will not be interrupted.

Following completion of the works groundwater will follow three pathways, groundwater flow that is impeded by the placed materials will be diverted towards the west and east. Baseflow loss along the east of Sixpenny Brook will likely be replaced by an increased contribution from the north of the site compared to current patterns, whilst a similar effect is expected around the eastern perimeter of the site where the water will continue to provide an uninterrupted baseflow to Cox Lake and Worcester Lake

However, *in-situ* material will remain beneath the footprint of the bridleway which separates quarry Phases 1 – 3 from Phases 4 – 7. This will act as a conduit from north to south and discharge into the Cockaynes quarry above Bramley Lake.

The lake that is to be created within the site will be primarily recharged from direct infiltration and run-off from the surrounding sloped ground into the lake. It is expected that this could form a closed and isolated hydraulic system independent of the wider groundwater system and therefore water levels unless connected through a higher permeability conduit will be dependent on the ingress and evaporative losses.

## 3.5 Water Level and Volume Monitoring

There are two superficial water systems at the site, which can be correlated to waters in the Cover Sands above a layer of interburden which separates it from the main sands (the Kesgrave Fm) which are the primary target to be exploited by the quarry operations.

The Cover sands are limited to the western section of the site. When plotted as a continuous water surface this is expressed as a "ridge of groundwater" which along the central axis of the site, which then declines to the west, south and southeast in the direction of Sixpenny Brook (Figure 3.6). However, this "ridge structure" is an interpolation artefact and the continuous groundwater surface within the quarry fluctuates between 25mAOD and 26mAOD (Figure 3.7) with waters in the Cover Sands unit primarily "decanting" into the lower Kesgrave Sands unit.

**Figure 3.6 – Groundwater Piezometric Surface (March 2021)**

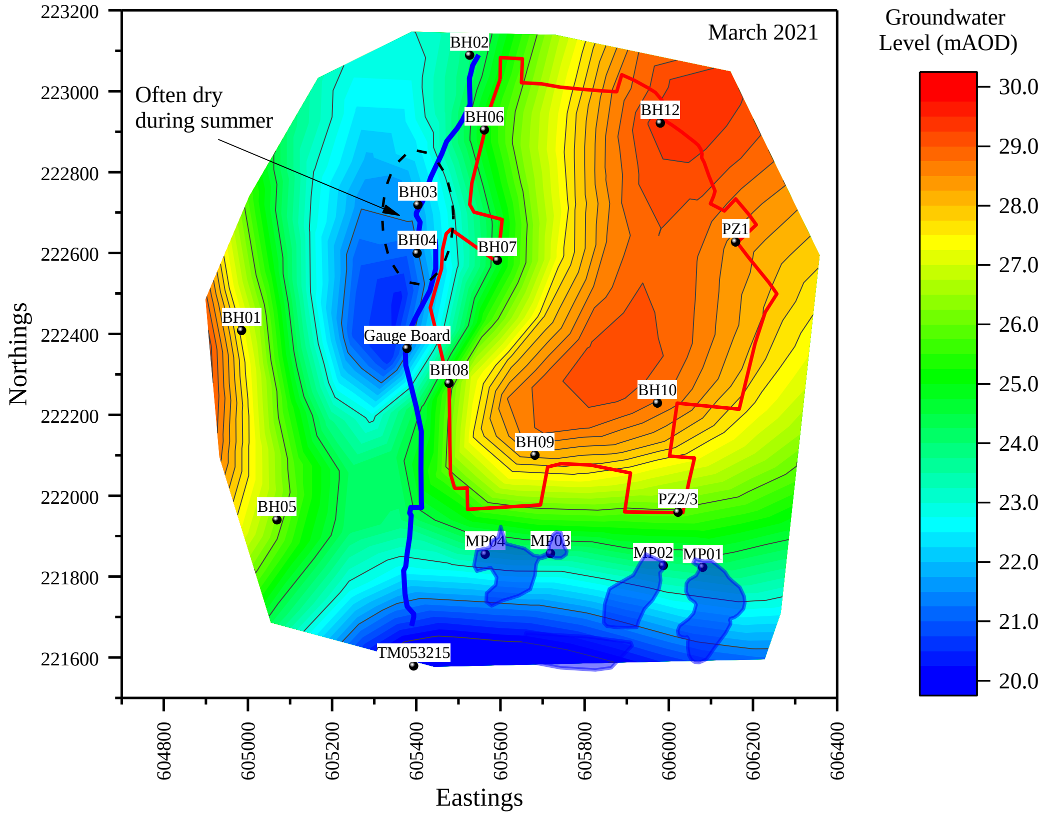
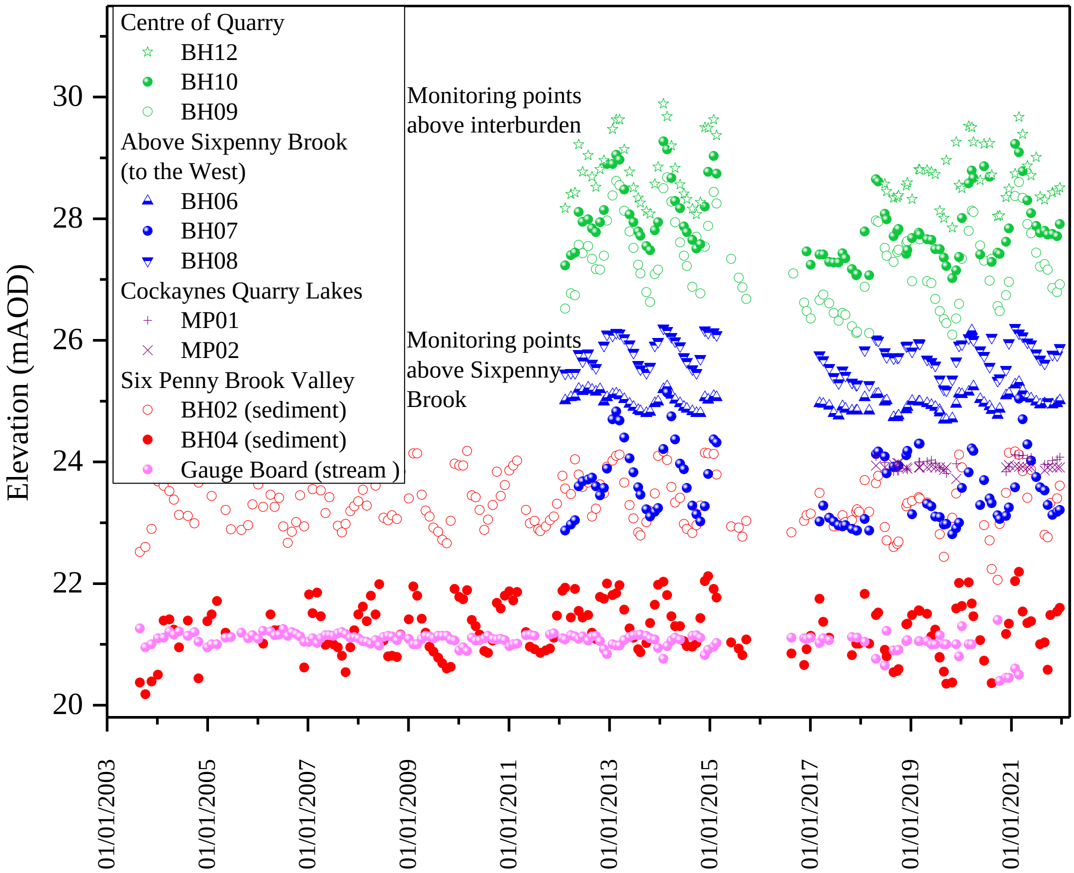



**Figure 3.7 – Groundwater and Surface Water Elevation**



If taken as a model of the future hydraulics of the site, the entirety of the imported material will act in a similar manner as this interburden layer with regards to vertical seepage /infiltration, hence a larger proportion of the incidental rainfall is expected to be diverted via surface run-off than at present.

Groundwater elevations and saturated water heights within the Kesagrave Fm is in turn influenced by the topography of the London Clay, the stream-cut valley topography to the west and the quarry topography to the south. Consequently, groundwater recharge from within the site area must decant over the raised topography of the London Clay at or about 23 - 25mAOD beneath Phases 1 – 3 and Phase 7 before discharging downslope into the Sixpenny Brook.

Water levels are illustrated on Figure 3.7 in which BH06 and BH08 indicate the “decant” elevation, with BH07 and the Cockaynes Quarry Lakes water levels controlled by recharge from this decanting / groundwater divide zone and the fall in topography to (and of) the brook.

The Cockaynes Quarry Lakes are themselves artificial constructs and held at a single water level (23.5 – 24.1mAOD) recharged by spring lines in the former quarry walls around the remaining Cockaynes Wood with overflow outlets which form tributary streams to Sixpenny Brook.

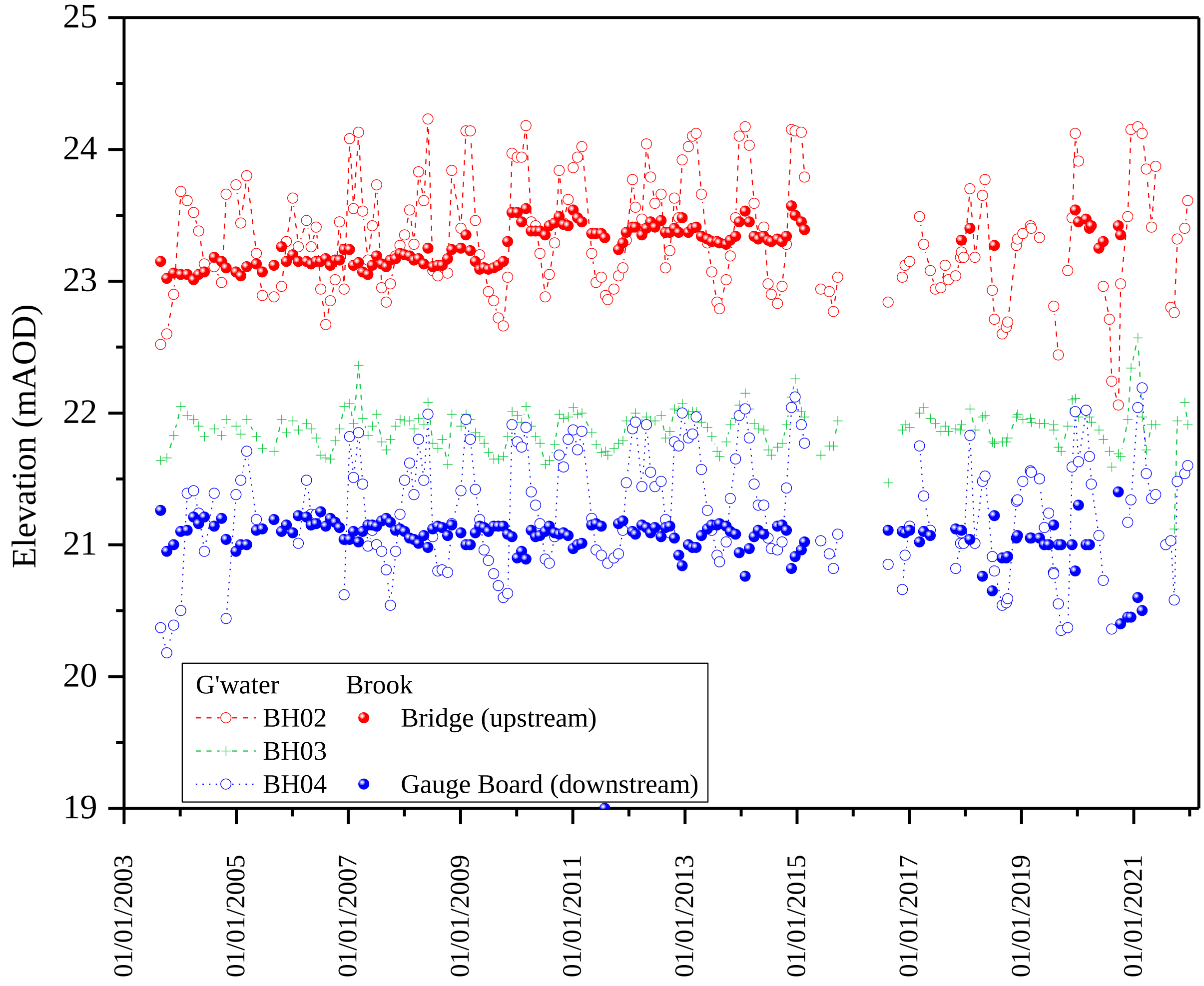
The relatively lower water level at BH07 is not an anomaly compared to the nearby BH06 and BH08 as it is located in a depression in the surface of the London Clay which forms a sub-cropping “valley feature” from the main quarry area to Sixpenny Brook near the Phase 3 – Phase 1 interface.

BH02, BH03 and BH04 are located in the Sixpenny Brook flood plain, and are in part installed through the disturbed ground caused by the adjacent quarrying works. Water levels within these monitoring points are consistent with that of the Sixpenny Brook monitored at the bridge by BH02 and a Gauge Board a short distance downstream of BH04 and upstream of BH08 (Figure 3.8). There is a fall in water level from north to south, with water levels at BH03, located between BH02 and BH04 showing less seasonal variation than BH02 and BH04.

Given that all three monitoring points BH02, BH03 and BH04 are in areas of land disturbed by previous quarrying and restoration works, then there is little inference that can be drawn from the apparent loss of water from the Brook to groundwater as this could be an artefact of recharge via the closed inert landfill and the base of a monitoring point terminating in the London Clay, and is in any case reversed at BH06 and BH08 so any influence is limited in extent. There is also a weir a short distance downstream of the gauging board and therefore to some extent the water level in the brook is artificially stepped.

Notwithstanding the above and irrespective of the cause, the volume change is not significant and demonstrates that the primary constraint is the valley topography and fall in stream level from north to south which is consistent with flow across the surface of the London Clay at approximately 20 - 21mAOD, which then falls in turn to the River Colne some 20m lower at or about sea level.

**Figure 3.8 – Sixpenny Brook and adjacent Groundwater Monitoring Point Water Level**




## 3.6 Sixpenny Brook Flow Rates

There is a gauging station, part of the National River Flow Archive (NRFA) at Ship House Bridge[6], where the brook is crossed by Arlesford Road to the south of Cockaynes Wood some 550m south of the site. Gauged flows are small at a median rate of 14L/s or 1,210m$^3$/day for the period 1960 – 1971 when the station was operational (Table 4).

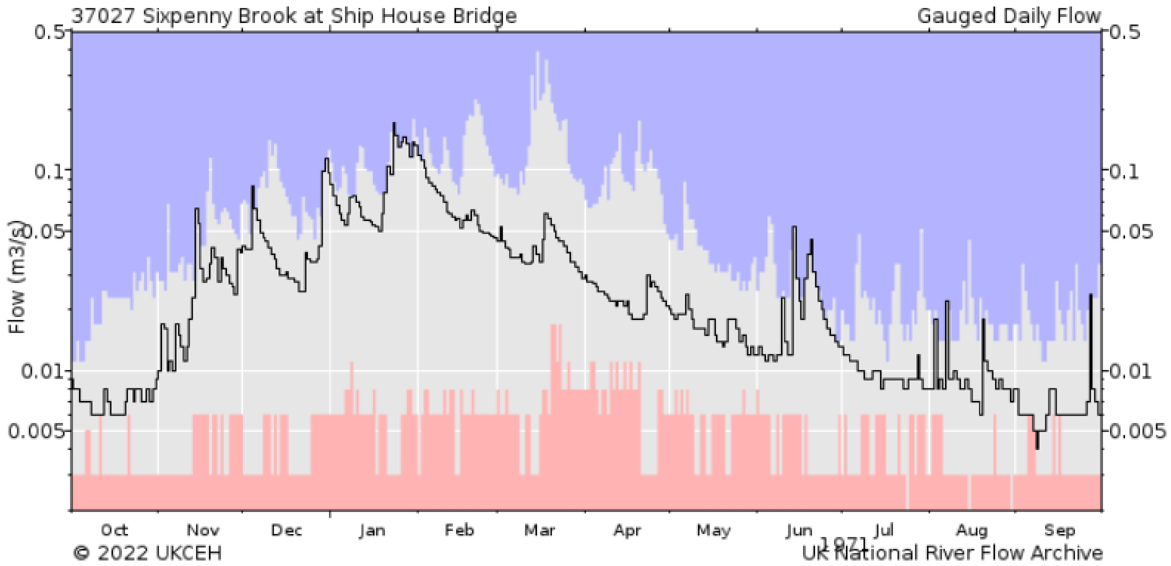
The flow rate is seasonally biased with low to negligible flow occurring in summer, with flow rates increasing from November to January, when flow peaked at or about 0.1m$^3$/s (8,640m$^3$/day) and then depleted progressively through the spring (Figure 3.9) to a low rate of 0.003m$^3$/s at the end of the summer. The data is therefore indicative that there is little if any real groundwater discharge from the site area into Sixpenny Brook during a large part of the year.

[6] https://nrfa.ceh.ac.uk/data/station/info/37027

**Table 4 –Sixpenny Brook Flow at Ship House Bridge**

| | $m^3/s$ | $m^3/day$ |
|---|---|---|
| Average | 0.025 | 2,160 |
| Median | 0.014 | 1,210 |
| 70th %ile | 0.008 | 691 |
| 95th %ile | 0.003 | 259 |
| 10th %ile | 0.059 | 5,098 |

**Figure 3.9 – Sixpenny Brook Guaged Flow Rates at Ship House Bridge[6]**




**Key:** Red and blue envelopes represent lowest and highest flows on each day over the period of record. Underlying data supplied by the Environment Agency

## 3.7 Water Quality

Baseline groundwater and surface water quality data has been collected for the site and surrounding area over the period October 2021 to January 2022. The groundwater data collected is summarised below in Tables 5 and Table 6. Surface water data is summarised in Tables 7 to 10.

Monitoring data presented was for the seasonally lowest water levels and then the autumn recharge period when concentrations could be expected to be at their seasonal highest.

The groundwater is a slightly acidic water containing agricultural influences. The agricultural influences are expressed by the nitrate and potassium content, particularly at BH10, and BH09 in the centre of the site, PZ01 to the northeast as well as BH07 and BH03 to the west of BH10 immediately above and adjacent to Sixpenny Brook. The potassium influence is missing from BH09, BH03 and periodically at PZ01 although nitrate is present. This influence is localised and is not apparent at BH4, also adjacent to Sixpenny Brook, to the south of BH03 and west of BH07.

BH02 also contains a potassium influence, but not the nitrate influence. There is however, a sodium chloride influence at BH02, which is located to the northwest of the site adjacent to both Sixpenny Brook and the B1027 Colchester Road. There is a similar sodium chloride and potassium influence at BH05 which is located to the west of Sixpenny Brook. BH05 is also located near to an access road (Alresford Road to the south of the various quarries near Sunnymead Farm).

**Table 5 – Groundwater Quality Matrix Summary (Oct 2021 – Jan 2022)**

| Location | Date | TOC | $NH_4$-N | TON | pH | EC | Ca | Mg | Na | K | Cl | $SO_4$ | Alk |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mg/l | mg/l | mg/l | | µS/cm | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| **North-East** | | | | | | | | | | | | | |
| PZ01 | 27/10/21 | 22.0 | 9.10 | 3.2 | 6.7 | 713 | 87 | 19 | 24 | 19 | 58 | 55 | 313 |
| | 30/11/21 | 2.8 | <0.01 | 24.0 | 6.4 | 644 | 81 | 16 | 25 | 1 | 56 | 83 | 56 |
| | 20/12/21 | 2.6 | <0.01 | 25.2 | 6.5 | 617 | 77 | 15 | 26 | 2 | 56 | 78 | 51 |
| | 24/01/22 | 2.6 | <0.01 | 27.9 | 6.2 | 510 | 72 | 14 | 23 | 1 | 54 | 67 | 63 |
| **Centre of Quarry** | | | | | | | | | | | | | |
| BH10 | 27/10/21 | 4.2 | 0.30 | 50.0 | 5.7 | 835 | 105 | 18 | 23 | 26 | 91 | 79 | 26 |
| | 30/11/21 | 3.9 | 0.02 | 47.8 | 5.7 | 909 | 107 | 19 | 25 | 25 | 79 | 96 | 14 |
| | 20/12/21 | 3.4 | <0.01 | 48.4 | 5.6 | 835 | 102 | 17 | 25 | 25 | 72 | 86 | 13 |
| | 24/01/22 | 3.3 | <0.01 | 48.9 | 5.5 | 643 | 85 | 15 | 20 | 22 | 58 | 75 | 13 |
| BH09 | 27/10/21 | 15.0 | 3.00 | 0.7 | 6.3 | 281 | 33 | 4 | 18 | 2 | 23 | 47 | 62 |
| | 30/11/21 | 5.1 | 0.60 | 17.0 | 6.4 | 456 | 54 | 10 | 17 | 2 | 24 | 93 | 24 |
| | 20/12/21 | 2.9 | <0.01 | 18.2 | 5.7 | 476 | 65 | 11 | 19 | 2 | 28 | 114 | 16 |
| | 24/01/22 | 3.1 | <0.01 | 23.0 | 5.5 | 421 | 62 | 10 | 18 | 2 | 30 | 117 | 16 |
| **Above Sixpenny Brook (West of Quarry)** | | | | | | | | | | | | | |
| BH06 | 27/10/21 | 10.0 | 0.02 | 4.5 | 6.6 | 330 | 60 | 5 | 9 | 2 | 20 | 39 | 95 |
| | 30/11/21 | 5.5 | <0.01 | 3.9 | 7.0 | 376 | 63 | 6 | 10 | 2 | 20 | 43 | 103 |
| | 20/12/21 | 4.8 | <0.01 | 4.1 | 7.0 | 369 | 70 | 6 | 11 | 2 | 17 | 45 | 107 |
| | 24/01/22 | 5.8 | <0.01 | 4.8 | 6.5 | 317 | 66 | 6 | 11 | 2 | 20 | 52 | 97 |
| BH07 | 27/10/21 | 2.6 | 0.02 | 24.0 | 6.4 | 517 | 86 | 11 | 17 | 1 | 32 | 81 | 64 |
| | 30/11/21 | 2.5 | <0.01 | 23.5 | 6.7 | 576 | 82 | 12 | 18 | 1 | 30 | 91 | 65 |
| | 20/12/21 | 2.1 | <0.01 | 23.9 | 6.6 | 557 | 87 | 12 | 19 | 2 | 29 | 87 | 63 |
| | 24/01/22 | 2.7 | 0.08 | 21.8 | 6.3 | 454 | 83 | 12 | 20 | 2 | 29 | 88 | 63 |
| BH08 | 27/10/21 | 7.2 | 0.02 | 8.1 | 6.7 | 395 | 78 | 6 | 10 | 3 | 21 | 35 | 124 |
| | 30/11/21 | 5.4 | 0.02 | 8.7 | 7.0 | 464 | 82 | 7 | 11 | 3 | 22 | 46 | 123 |
| | 20/12/21 | 5.6 | 0.30 | 7.8 | 6.9 | 465 | 92 | 7 | 12 | 3 | 23 | 48 | 125 |
| | 24/01/22 | 5.2 | 0.04 | 8.5 | 6.7 | 422 | 86 | 7 | 11 | 3 | 28 | 52 | 124 |
| **Adjacent to Sixpenny Brook** | | | | | | | | | | | | | |
| BH02 | 27/10/21 | 16.0 | 0.05 | <0.2 | 6.5 | 2,960 | 293 | 51 | 277 | 34 | 855 | 165 | 302 |
| | 30/11/21 | 14.0 | 0.06 | <0.2 | 6.9 | 3,010 | 290 | 49 | 287 | 33 | 687 | 155 | 323 |
| | 20/12/21 | 14.0 | 0.09 | 0.5 | 6.8 | 2,430 | 235 | 38 | 237 | 30 | 522 | 161 | 231 |
| | 24/01/22 | 14.0 | 0.04 | <0.2 | 6.7 | 1,120 | 111 | 17 | 143 | 19 | 220 | 96 | 225 |
| BH03 | 27/10/21 | 12.0 | 0.20 | 24.2 | 6.6 | 548 | 86 | 12 | 20 | 2 | 49 | 49 | 86 |
| | 30/11/21 | 4.7 | <0.01 | 23.9 | 6.9 | 660 | 97 | 14 | 21 | 1 | 46 | 60 | 116 |
| | 20/12/21 | 3.8 | <0.01 | 29.5 | 6.9 | 707 | 105 | 15 | 24 | 1 | 51 | 57 | 115 |
| | 24/01/22 | 4.2 | <0.01 | 28.9 | 6.5 | 571 | 98 | 13 | 21 | 1 | 46 | 53 | 105 |
| BH04 | 27/10/21 | 13.0 | 0.03 | 0.3 | 6.4 | 606 | 101 | 13 | 22 | 2 | 86 | 86 | 114 |
| | 30/11/21 | 10.0 | 0.02 | <0.2 | 6.7 | 822 | 119 | 17 | 29 | 2 | 118 | 109 | 133 |
| | 20/12/21 | 11.0 | <0.01 | 0.3 | 6.6 | 776 | 117 | 17 | 29 | 2 | 114 | 99 | 126 |
| | 24/01/22 | 12.0 | 0.02 | <0.2 | 6.4 | 563 | 101 | 13 | 22 | 1 | 75 | 72 | 152 |
| **West near Keelers Lane (outside of Site's sphere of influence, but potentially influencing Six pent Brook)** | | | | | | | | | | | | | |
| BH01 | 27/10/21 | 11.0 | 0.13 | <0.2 | 6.2 | 608 | 64 | 9 | 50 | 12 | 110 | 19 | 141 |
| | 30/11/21 | 12.0 | 0.08 | <0.2 | 6.2 | 593 | 57 | 8 | 41 | 10 | 113 | 14 | 94 |
| | 20/12/21 | 10.0 | 0.16 | <0.2 | 6.2 | 582 | 54 | 8 | 47 | 11 | 95 | 10 | 126 |
| | 24/01/22 | 9.3 | 0.15 | <0.2 | 6.2 | 514 | 52 | 10 | 38 | 10 | 90 | 30 | 140 |
| BH05 | 30/11/21 | 11.0 | 0.08 | <0.2 | 5.7 | 1,880 | 140 | 15 | 203 | 18 | 456 | 152 | 27 |
| | 20/12/21 | 6.5 | <0.01 | 3.8 | 5.7 | 1,530 | 118 | 13 | 181 | 18 | 363 | 120 | 27 |
| | 24/01/22 | 5.0 | <0.01 | 3.6 | 5.5 | 1,310 | 98 | 12 | 170 | 19 | 359 | 110 | 24 |

Green Shaded cells are in excess of the DWS, Yellow Shaded cells are discussed in text

There is a secondary possibility, that instead of a potassium nitrate phosphate fertiliser influence, this could also be derived from manure spreading and is also consistent with a local domestic sewage treatment plant. However, neither particularly describes what is most probably a regional agricultural artefact influencing groundwater both directly at and upgradient of the site.

An agricultural influence also explains the ammonium and dissolved organic matter (as indicated by the Total Organic Carbon – TOC measurement) reported for PZ01 and BH09. Ammonium is elevated to 9mg/l and 3mg/l at PZ01 and BH09 in October 2021, and both ammonium observations are accompanied by a step change increase in TOC and depletion of the nitrate. In other locations there is a general correlation between low nitrate (*i.e.* <10mg/l TON) and high TOC (*i.e.* >10mg/l TOC).

The salt influence could be either a result of historical quarrying and restoration works to the west of Sixpenny Brook or a simple accumulated road salting influence.

The groundwater is otherwise a calcium bicarbonate and / or a calcium sulphate influence groundwater. Both minerals are natural inclusions within the superficial sand deposits as calcite or gypsum minerals and are expected in this type of water and are apparent in the lakes to the south of the site.

This background potassium nitrate influence is also accompanied by a nickel and zinc influence. The strongest correlation is for BH10 and BH09, which contain up to 56µg/l nickel and 50µg/l zinc. However, there are some discrepancies to the various correlations as BH04 contains elevated copper, nickel and zinc, but not at the upstream BH03. These water types demonstrate localised influences which can exceed Drinking Water Standards (DWS) and/or Environmental Quality Standards (EQS).

BH10, BH09 and occasionally at PZ01 are also under manganese reducing conditions. These are only slightly reducing conditions and likely sustained from entering iron reducing conditions by, the nitrate content of the water. It is also probable that this is a near-surface artefact caused by biological activity in the agricultural soils and influencing only the perched water horizons in the cover sands unit, rather than the deeper water body below the interburden layer. Iron is invariably below detection levels, although it can be occasionally identified. This could be for one of two reasons, firstly particulate iron oxide suspended solids being incorporated into the sample or a periodic saturation of the ground leading to the exclusion of oxygen from a particular horizon. Both cases are common in background water systems.

Cadmium, chromium and lead are of no significance in the groundwater.

**Table 6 – Groundwater Quality Priority Metals Summary (Oct 2021 – Jan 2022)**

| Location | Date | Fe | Mn | Cd | Cr | Cu | Ni | Zn | Pb |
|---|---|---|---|---|---|---|---|---|---|
| | | mg/l | mg/l | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l |
| **North-East** | | | | | | | | | |
| PZ01 | 27/10/21 | 1.56 | 2.02 | <0.02 | <1 | <1 | 4 | 28 | <1 |
| | 30/11/21 | <0.01 | 0.02 | 0.12 | <1 | <1 | 13 | 20 | <1 |
| | 20/12/21 | <0.01 | 0.01 | 0.10 | <1 | <1 | 11 | 38 | <1 |
| | 24/01/22 | <0.01 | <0.01 | 0.05 | <1 | <1 | 11 | 9 | <1 |
| **Centre of Quarry** | | | | | | | | | |
| BH10 | 27/10/21 | <0.01 | 0.61 | 0.77 | <1 | <1 | 52 | 41 | <1 |
| | 30/11/21 | <0.01 | 0.58 | 0.80 | <1 | 2 | 56 | 32 | <1 |
| | 20/12/21 | <0.01 | 0.54 | 0.70 | <1 | <1 | 51 | 44 | <1 |
| | 24/01/22 | <0.01 | 0.55 | 0.65 | <1 | <1 | 49 | 26 | <1 |
| BH09 | 27/10/21 | 0.06 | 0.08 | 0.11 | <1 | 2 | 7 | 32 | <1 |
| | 30/11/21 | <0.01 | 0.10 | 0.32 | <1 | 3 | 20 | 29 | <1 |
| | 20/12/21 | <0.01 | 0.14 | 0.47 | <1 | 2 | 26 | 50 | <1 |
| | 24/01/22 | <0.01 | 0.18 | 0.57 | <1 | 3 | 32 | 35 | <1 |
| **Above Sixpenny Brook (West of Quarry)** | | | | | | | | | |
| BH06 | 27/10/21 | <0.01 | <0.002 | <0.02 | <1 | 2 | 3 | 9 | <1 |
| | 30/11/21 | <0.01 | 0.003 | 0.07 | <1 | 2 | 2 | 3 | <1 |
| | 20/12/21 | <0.01 | <0.002 | <0.02 | <1 | 2 | 3 | 22 | <1 |
| | 24/01/22 | <0.01 | <0.002 | <0.02 | <1 | 2 | 2 | 2 | <1 |
| BH07 | 27/10/21 | <0.01 | <0.002 | 0.12 | <1 | <1 | 8 | 31 | <1 |
| | 30/11/21 | <0.01 | 0.014 | 0.16 | <1 | <1 | 9 | 9 | <1 |
| | 20/12/21 | <0.01 | 0.003 | 0.08 | <1 | <1 | 8 | 22 | <1 |
| | 24/01/22 | 0.02 | <0.002 | 0.08 | <1 | <1 | 9 | 3 | <1 |
| BH08 | 27/10/21 | <0.01 | <0.002 | 0.05 | <1 | 3 | 2 | 13 | <1 |
| | 30/11/21 | 0.52 | 0.005 | 0.06 | <1 | 3 | 2 | 4 | <1 |
| | 20/12/21 | <0.01 | 0.028 | 0.04 | <1 | 2 | 3 | 18 | <1 |
| | 24/01/22 | <0.01 | 0.028 | 0.02 | <1 | 2 | 2 | 2 | <1 |
| **Adjacent to Sixpenny Brook** | | | | | | | | | |
| BH02 | 27/10/21 | <0.01 | 0.90 | 0.10 | <1 | 4 | 8 | 52 | <1 |
| | 30/11/21 | 0.05 | 0.70 | 0.08 | <1 | 2 | 7 | 16 | <1 |
| | 20/12/21 | 1.40 | 0.55 | <0.02 | <1 | <1 | 7 | 40 | <1 |
| | 24/01/22 | 0.04 | 0.22 | <0.02 | <1 | 2 | 6 | 7 | <1 |
| BH03 | 27/10/21 | <0.01 | 0.03 | 0.04 | <1 | 3 | 3 | 11 | <1 |
| | 30/11/21 | 0.11 | 0.006 | 0.08 | <1 | 2 | 2 | 2 | <1 |
| | 20/12/21 | <0.01 | 0.007 | 0.04 | <1 | <1 | 2 | 25 | <1 |
| | 24/01/22 | <0.01 | <0.002 | 0.04 | <1 | <1 | 2 | 2 | <1 |
| BH04 | 27/10/21 | <0.01 | 0.037 | 0.17 | <1 | 11 | 24 | 30 | <1 |
| | 30/11/21 | <0.01 | 0.008 | 0.15 | <1 | 8 | 24 | 12 | <1 |
| | 20/12/21 | <0.01 | 0.008 | 0.10 | <1 | 7 | 21 | 26 | <1 |
| | 24/01/22 | <0.01 | 0.022 | 0.09 | <1 | 9 | 22 | 7 | <1 |
| **West near Keelers Lane (outside of Site's sphere of influence, but potentially influencing Sixpenny Brook)** | | | | | | | | | |
| BH01 | 27/10/21 | 2.69 | 1.88 | <0.02 | <1 | <1 | 4 | 26 | <1 |
| | 30/11/21 | 0.51 | 2.35 | 0.04 | <1 | <1 | 7 | 5 | <1 |
| | 20/12/21 | 3.51 | 1.85 | <0.02 | <1 | <1 | 4 | 5 | <1 |
| | 24/01/22 | 6.30 | 2.21 | <0.02 | <1 | <1 | 2 | 2 | <1 |
| BH05 | 30/11/21 | 3.47 | 1.50 | 0.17 | <1 | <1 | 13 | 37 | <1 |
| | 20/12/21 | 0.03 | 0.92 | 0.28 | <1 | <1 | 11 | 38 | <1 |
| | 24/01/22 | 0.02 | 0.38 | 0.33 | <1 | <1 | 15 | 9 | <1 |

yellow shaded cells discussed in the text

There are two types of surface water at the site all of which are recharged, at least in part from the site, namely the former quarry lakes to the south of Phases 3 and 7, as well as the Sixpenny Brook to the west of Phases 1, 2 and 3. Surface water data collected for the southern lakes over the period October 2021 to January 2022 is summarised in Table 7 and 9. Data collected for the Sixpenny Brook has been collected over a longer period (2011 to 2021) and is summarised in Table 8 and 10.

The data collected to date demonstrates that the surface water at the site is of a similar quality and type to the groundwater, albeit it is at a higher neutral to slightly alkaline pH. The lakes are a calcium sulphate-bicarbonate based water. Calcium sulphate is higher within the groundwater fed Cox Lake to the east, which then reduces towards the west. Potassium, magnesium, chloride and ammoniacal-N are consistently low within the southern lakes. The nitrate influence can be observed in Worcester Lake, and to a lesser extent in the lakes on either side. The organic content of the western lakes (Cockaynes Wildlife Ponds and Bramley Lake) are noticeably higher in TOC, which is consistent with the vegetation accumulation and this is also associated with a small amount of ammonium. This influence in the western ponds is expected to continue within ponds which are gradually becoming overgrown with a limited throughput of waters, hence "self-induced" anaerobic/anoxic conditions are expected to increasingly predominant in the future.

**Table 7 – Southern Lakes Matrix Summary (Oct 2021 – Jan 2022)**

| Location | Date | TOC | $NH_4$-N | TON | pH | EC | Ca | Mg | Na | K | Cl | $SO_4$ | Alk |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mg/l | mg/l | mg/l | | µS/cm | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| MP01 (Cox Lake) | 27/10/2021 | 7.6 | 0.04 | 0.2 | 7.5 | 739 | 100 | 29 | 29 | 9 | 52 | 237 | 112 |
| | 30/11/2021 | 7.5 | 0.01 | 0.3 | 7.5 | 834 | 103 | 30 | 30 | 9 | 52 | 267 | 121 |
| | 20/12/2021 | 7.3 | 0.01 | 0.2 | 8.2 | 795 | 101 | 28 | 31 | 9 | 51 | 232 | 113 |
| | 24/01/2022 | 7.4 | 0.04 | 5.4 | 7.7 | 651 | 97 | 27 | 30 | 9 | 52 | 226 | 119 |
| MP02 (Worcester Lake) | 27/10/2021 | 4.3 | 0.03 | 4.0 | 7.5 | 475 | 66 | 18 | 18 | 3 | 41 | 97 | 98 |
| | 30/11/2021 | 3.8 | 0.02 | 4.7 | 7.5 | 548 | 67 | 18 | 18 | 3 | 41 | 106 | 101 |
| | 20/12/2021 | 3.7 | 0.01 | 5.5 | 7.9 | 523 | 66 | 17 | 19 | 3 | 40 | 98 | 95 |
| | 24/01/2022 | 4.1 | 0.01 | 18.3 | 7.6 | 437 | 63 | 17 | 18 | 3 | 39 | 94 | 88 |
| MP03 (Near Bramley Lake) | 27/10/2021 | 8.4 | 0.04 | <0.2 | 6.8 | 466 | 61 | 14 | 24 | 3 | 50 | 82 | 102 |
| | 30/11/2021 | 7.6 | 0.01 | 1.3 | 7.0 | 585 | 70 | 16 | 27 | 5 | 52 | 104 | 111 |
| | 20/12/2021 | 8.3 | 0.01 | 3.0 | 7.3 | 576 | 73 | 16 | 28 | 5 | 52 | 115 | 96 |
| | 24/01/2022 | 10.0 | 0.13 | 4.9 | 6.9 | 550 | 81 | 17 | 26 | 5 | 48 | 148 | 90 |
| MP04 (Cockaynes Wildlife Ponds) | 27/10/2021 | 13.0 | 0.11 | <0.2 | 7.2 | 396 | 54 | 11 | 19 | 4 | 42 | 31 | 126 |
| | 30/11/2021 | 12.0 | 0.09 | 0.2 | 7.5 | 462 | 58 | 12 | 21 | 4 | 42 | 44 | 126 |
| | 20/12/2021 | 12.0 | 0.01 | 0.2 | 7.9 | 400 | 51 | 11 | 21 | 5 | 40 | 41 | 110 |
| | 24/01/2022 | 14.0 | 0.13 | 0.2 | 7.1 | 344 | 51 | 11 | 18 | 5 | 34 | 51 | 107 |

yellow shaded cells discussed in the text

**Table 8 – Sixpenny Brook Matrix Summary (Jul 2011 – Nov 2021)**

| | TOC | $NH_4$-N | TON | pH | EC | Ca | Mg | Na | K | Cl | $SO_4$ | Alk |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/l | mg/l | mg/l | | µS/cm | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| **SW01 (Upstream)** | | | | | | | | | | | | |
| Min | 5 | 0.01 | 0.1 | 6.9 | 531 | 33 | 10 | 17 | 2 | 56 | 53 | 41 |
| Med | 6 | 0.24 | 10.0 | 7.7 | 662 | 74 | 18 | 29 | 4 | 73 | 94 | 99 |
| 85th %ile | 11 | 0.27 | 12.8 | 8.2 | 733 | 89 | 21 | 35 | 7 | 88 | 120 | 108 |
| Max | 250 | 10.30 | 14.3 | 8.9 | 938 | 110 | 32 | 66 | 35 | 155 | 208 | 286 |
| **SW02 (Downstream)** | | | | | | | | | | | | |
| Min | 1 | 0.01 | 0.3 | 7.1 | 340 | 33 | 7 | 20 | 2 | 39 | 40 | 58 |
| Med | 7 | 0.19 | 10.4 | 7.8 | 650 | 75 | 16 | 29 | 4 | 72 | 86 | 96 |
| 85th ile | 10 | 0.27 | 12.8 | 8.1 | 701 | 88 | 18 | 34 | 5 | 82 | 97 | 103 |
| Max | 21 | 0.41 | 15.6 | 8.4 | 760 | 104 | 21 | 45 | 7 | 113 | 137 | 136 |

yellow shaded cells discussed in the text

Sixpenny Brook is also a calcium – bicarbonate-sulphate water with chloride typically only marginally below that of sulphate. In recent years, sulphate has however begun to dominant the upstream surface water, whilst on one occasion chloride was reported at 155mg/l, some two - three time that of the typical concentration range (Figure 3.10).

It is this upstream water quality which will inform the future monitoring strategy, hence the other organic process indicators ammoniacal-N, nitrate and TOC (Figure 3.11) are also key reference levels. Of these ammoniacal-N (Figure 3.12Figure 3.12 – Sixpenny Brook Ammoniacal-N) is usually considered as a "primary landfill indicator" substance. However, at this site, the agricultural influence predominates as evidenced by the 10mg/l observed at the upstream monitoring point SW1 in 2015, and the similar concentrations reported in the groundwater at PZ01, BH09 and BH06.

Given the groundwater influence is remote from any historical quarry and disposal activities, then similar ammoniacal-N concentrations should periodically be expected in the future due to the background off-site water influences.

**Figure 3.10 – Sixpenny Brook Upstream Moniotring SW1 Point Matrix Chemistry**

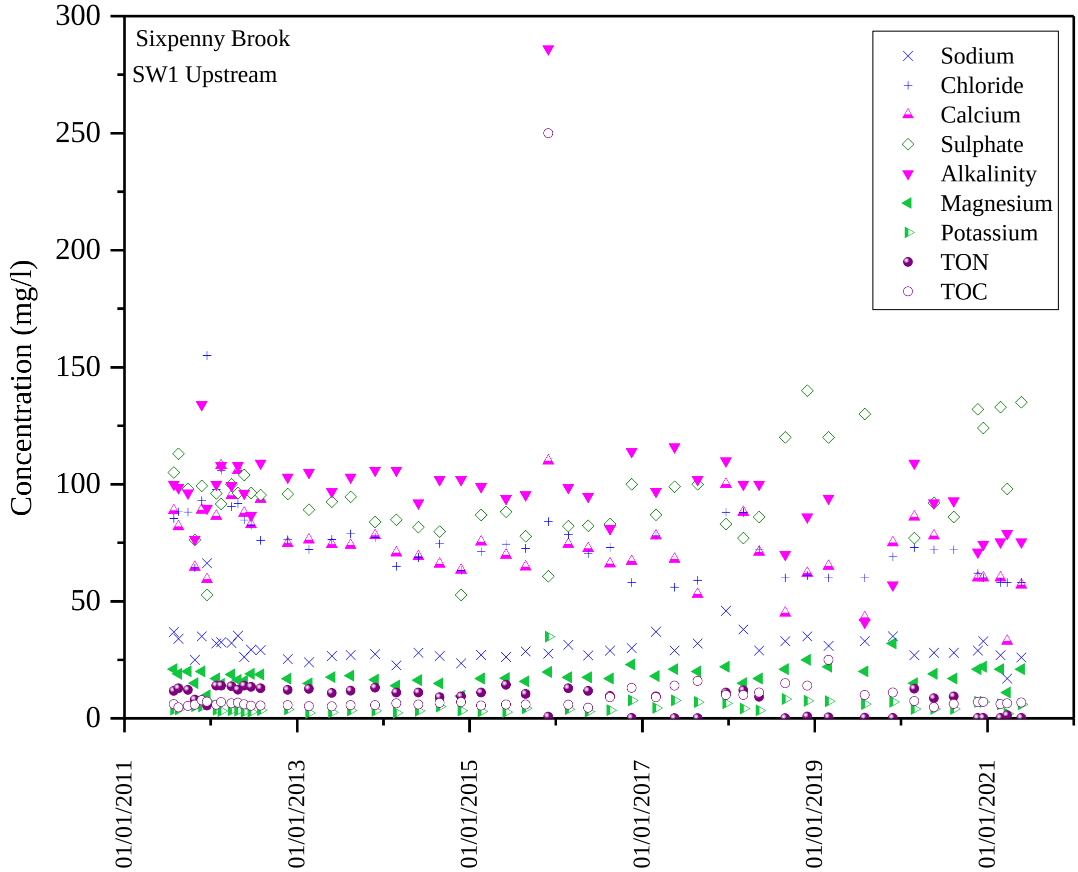


**Figure 3.11 – Sixpenny Brook Upstream Monitoring Point SW1 Organic Indicators**

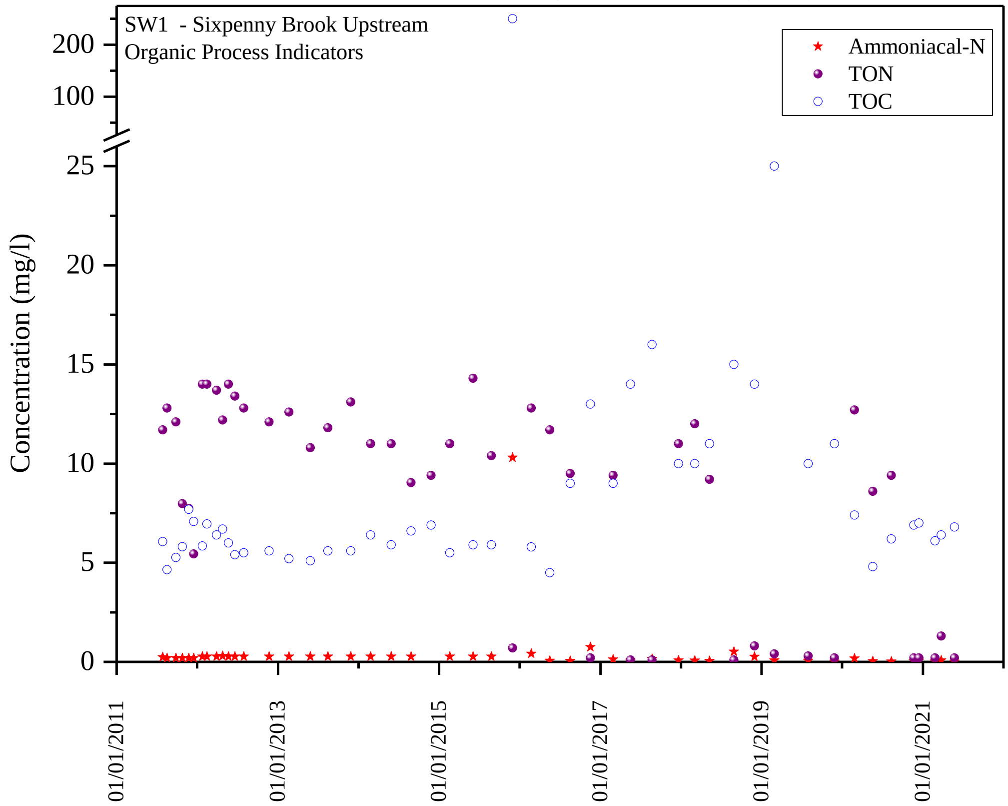
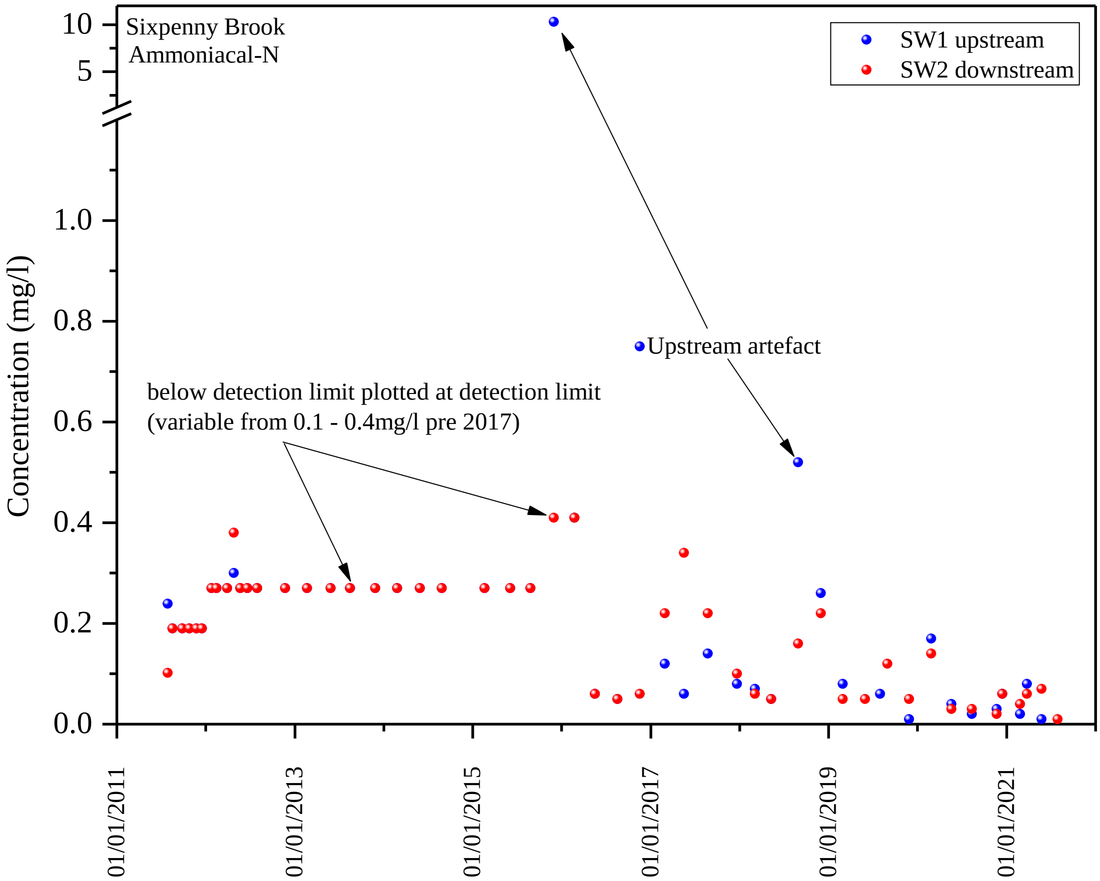



**Figure 3.12 – Sixpenny Brook Ammoniacal-N**



The priority metals also follow a similar distribution to the groundwater with negligible lead and chromium. Copper and cadmium are low, whilst the most significant metals are nickel and zinc in both the lakes to the south of the site (Table 9) and Sixpenny Brook (Table 10 and Figure 3.13).

The 4µg/l nickel EQS, 8.9µg/l zinc and 1µg/l copper dissolved EQS should be expected to be exceeded in Sixpenny Brook, with nickel and zinc exceeded in the lakes. Notwithstanding this, EQS levels for dissolved concentrations are only indirectly applicable to this situation as the effects of calcium, pH and organic carbon in solution reduce the significance of these metals and the observed concentrations are not in themselves harmful to the water system, whilst the data collected represents the basis for assessing the site's affects within an ongoing monitoring programme.

Iron and manganese should also be considered in such a scheme, however, these also fluctuate in line with the background groundwater system and upstream influences.

**Table 9 – Southern Lakes Priority Metals Summary (Oct 2021 – Jan 2022)**

| Location | Date | Fe | Mn | Cd | Cr | Cu | Ni | Zn | Pb |
|---|---|---|---|---|---|---|---|---|---|
| | | mg/l | mg/l | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l |
| MP01 (Cox Lake) | 27/10/21 | <0.01 | <0.002 | <0.02 | <1 | <1 | 6 | 44 | <1 |
| | 30/11/21 | <0.01 | <0.002 | 0.06 | <1 | <1 | 6 | 2 | <1 |
| | 20/12/21 | <0.01 | 0.005 | <0.02 | <1 | <1 | 6 | 20 | <1 |
| | 24/01/22 | <0.01 | <0.002 | <0.02 | <1 | <1 | 7 | 2 | <1 |
| MP02 (Worcester Lake) | 27/10/21 | <0.01 | <0.002 | 0.03 | <1 | <1 | 5 | 8 | <1 |
| | 30/11/21 | <0.01 | <0.002 | 0.07 | <1 | <1 | 6 | 2 | <1 |
| | 20/12/21 | <0.01 | <0.002 | <0.02 | <1 | <1 | 7 | 12 | <1 |
| | 24/01/22 | <0.01 | <0.002 | <0.02 | <1 | <1 | 7 | 2 | <1 |
| MP03 (Near Bramley Lake) | 27/10/21 | 0.02 | 0.003 | 0.03 | <1 | <1 | 2 | 36 | <1 |
| | 30/11/21 | <0.01 | 0.031 | 0.04 | <1 | <1 | <1 | 3 | <1 |
| | 20/12/21 | <0.01 | 0.048 | <0.02 | <1 | <1 | 2 | 26 | <1 |
| | 24/01/22 | <0.01 | 0.084 | <0.02 | <1 | <1 | 2 | 2 | <1 |
| MP04 (Cockaynes Wildlife Ponds) | 27/10/21 | 0.03 | 0.009 | <0.02 | <1 | <1 | <1 | 49 | <1 |
| | 30/11/21 | 0.03 | 0.021 | 0.04 | <1 | <1 | <1 | 2 | <1 |
| | 20/12/21 | 0.09 | 0.091 | <0.02 | <1 | <1 | <1 | 20 | <1 |
| | 24/01/22 | 0.22 | 0.337 | <0.02 | <1 | <1 | <1 | 2 | <1 |

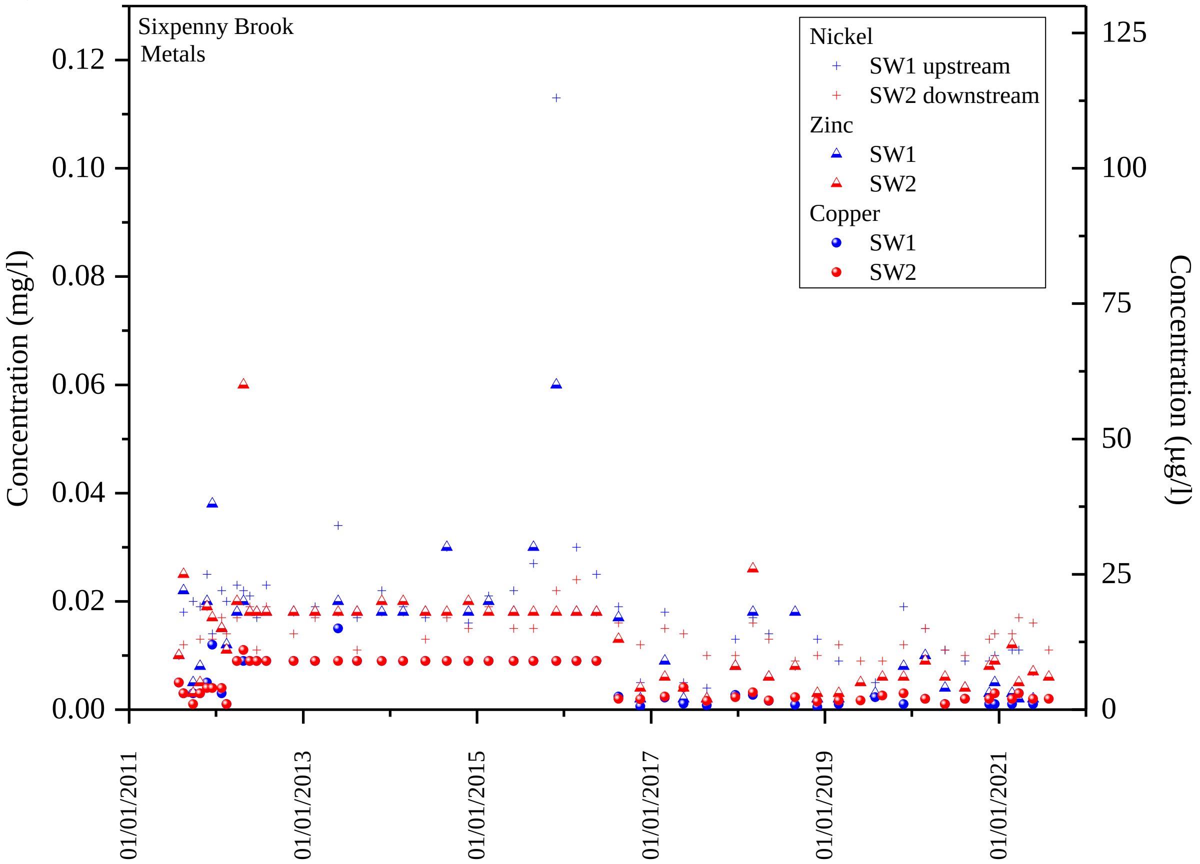
Highlighted cells discussed in text

**Table 10 – Sixpenny Brook Priority Metals Summary (Jul 2011 – Nov 2021)**

| Location | Date | Fe | Mn | Cd | Cr | Cu | Ni | Zn | Pb |
|---|---|---|---|---|---|---|---|---|---|
| | | mg/l | mg/l | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l |
| SW01 | Min | <0.01 | <0.001 | <0.02 | <1 | <1 | 4 | 2 | <1 |
| | Med | 0.19 | 0.03 | 0.60 | <1 | 3 | 18 | 18 | <1 |
| | 85$^{th}$ %ile | 0.33 | 0.05 | 0.60 | 2 | 9 | 23 | 20 | <1 |
| | Max | 11.20 | 1.03 | 3.50 | 14 | 15 | 113 | 60 | <1 |
| SW02 | Min | <0.01 | <0.001 | <0.02 | <1 | <1 | 5 | 2 | <1 |
| | Med | 0.21 | 0.02 | 0.60 | <1 | 3 | 14 | 13 | <1 |
| | 85$^{th}$ %ile | 0.34 | 0.05 | 0.60 | 2 | 9 | 18 | 18 | <1 |
| | Max | 3.44 | 0.24 | 3.60 | 10 | 11 | 24 | 60 | <1 |

Highlighted cells discussed in text

**Figure 3.13 – Sixpenny Brook Priority Metals Copper, Nickel and Zinc**




## 3.8 Abstractions

There are a number of known abstraction licences in the vicinity of the site, used variously for mineral washings, crop irrigation and domestic supply, of which there are:

- 7 private water supplies within 500m of the site boundary; and a further
- 6 private water supplies between 500m and 1km of the site
- 2 licensed groundwater abstractions with 500m and
- 1 surface water abstraction within 500m of the site.

as illustrated on Figure 3.14 and Figure 3.15.

The abstractions of relevance are those recharged by baseflow from or towards the soil fill recovery activity in the superficial deposits and therefore may be influenced by dewatering in the short term and a change in hydraulic patterns or water quality in the long term after the quarry has been restored.

There are however two boundary conditions, namely The Sixpenny Brook which is recharged from the north and west as well as through the site, and the London Clay basement to the site which forms a hydraulic barrier between the quarry and the underlying Chalk aquifer unit.

**Figure 3.14 – Licensed Groundwater and Surface Water Abstractions**

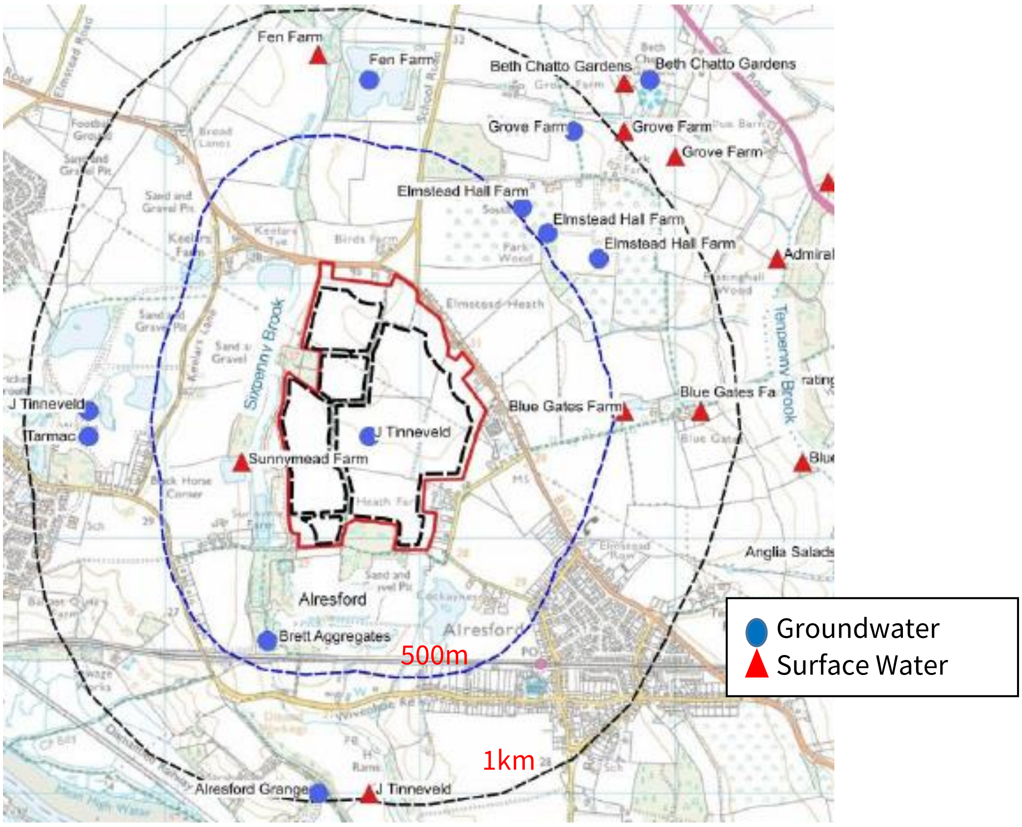



**Figure 3.15 –Private Water Abstractions**

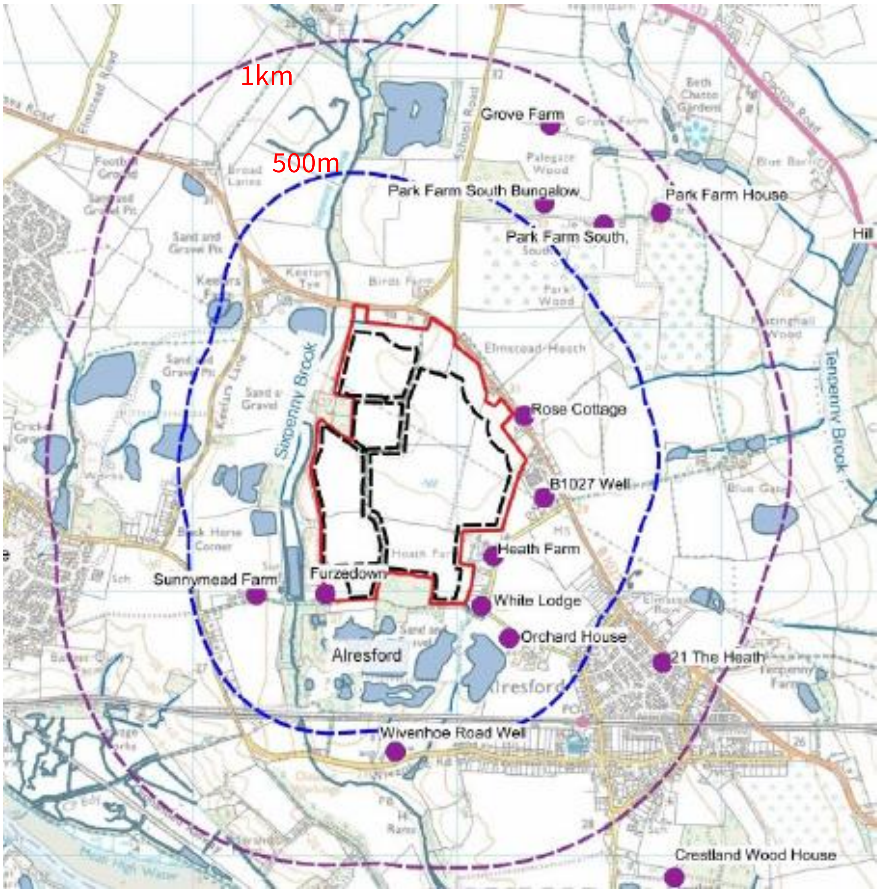


**Table 11 - Key Groundwater and Surface Water Abstractions**

| Name | Licence | Dist | Direction | Use | Vol | Comments |
|---|---|---|---|---|---|---|
| | | m | | | $m^3$/day | |
| **Private Water Supplies** | | | | | | |
| Furzedown Cottage | | 0 | SW Corner | Private WS | | Domestic Supply-Groundwater Sourced |
| Rose Cottage | | 50m | East | | | |
| White Lodge | | 60m | East | | | |
| B1027 Well | | 115m | East | | | |
| Orchard House | | 220m | Southeast | | | |
| Sunnymead Fm | | 260m | West | | | |
| Wivenhoe Rd | | 560m | South | | | |
| **Sixpenny Brook** | | | | | | |
| Sunnymead Fm | 8/37/25/*S/0222 | 170m | West | Spray irrigation | 22,700 | from lined reservoir |
| J Tinneveld | 8/37/25/*S/0041 | 975m | South | Spray irrigation | 683 | Reservoir on Sixpenny Brook |
| **Groundwater** | | | | | | |
| J Tinneveld | 8/37/25/*G/0093 | 0m 745m | Site West | Spray irrigation | 6,342 | Borehole & Gravel pits |
| Tarmac | 8/37/25/*G/0282 | 750m | West | Mineral Washing | 2,100 | Quarry voids |
| Brett Aggregates | 8/37/25/*G/0188 | 400m | South | Mineral Washing | 650 | No Longer in use (quarry restored) |

The position for Sixpenny Brook, the former quarry to the south of the site and the surrounding Private Water Supplies are more complex and will be discussed in detail as part of the supporting Hydrogeological Risk Assessment. Notwithstanding this, Stantec 2018[4] estimated a 446m sphere of influence in the superficial sand deposits during dewatering.

The Chalk itself is hydraulically isolated and therefore no abstractions from the Chalk will be affected.

The abstraction rates identified in Table 11 are not sustainable from the baseflow into Sixpenny Brook if the flow rates from the Ship House Bridge gauging station are correct (Table 4). Consequently the sustainable recharge source must be from the underlying Chalk Aquifer. This is common practice in this region, where a sustainable recharge can be derived throughput the year, with storage in surface water lagoons, such as from the Sunnymead Farm reservoir.

No specific abstractions are therefore at risk from the proposed development in the long term.

## 3.9 Habitats Sites

A search of the Magic website (http://www.magic.gov.uk/) has identified the following habitats/Natura 2000/European sites within a 2km radius of the site:

- Cockaynes Wood Nature Reserve – Priority Habitat and Local Nature Reserve (<10m South of site boundary)
- Wivenhoe Gravel Pit – Site of Special Scientific Interest (620m north-west)
- Essex Estuaries – Special Area of Conservation (770m south-west)
- Colne Estuary – Ramsar Site, Site of Special Scientific Interest and Special Protection Area (1km south)
- Upper Colne Marshes - Site of Special Scientific Interest (1.5km south-west and south of the Colne Estuary)
- Colne Local Nature Reserve - Local Nature Reserve (1.7km west and west of the town of Wivenhoe)

There are no habitats/Natura 2000/European sites within 500m of the site. It is considered unlikely that there will be any hydrogeological impact on nearby designated sites from the proposed development.

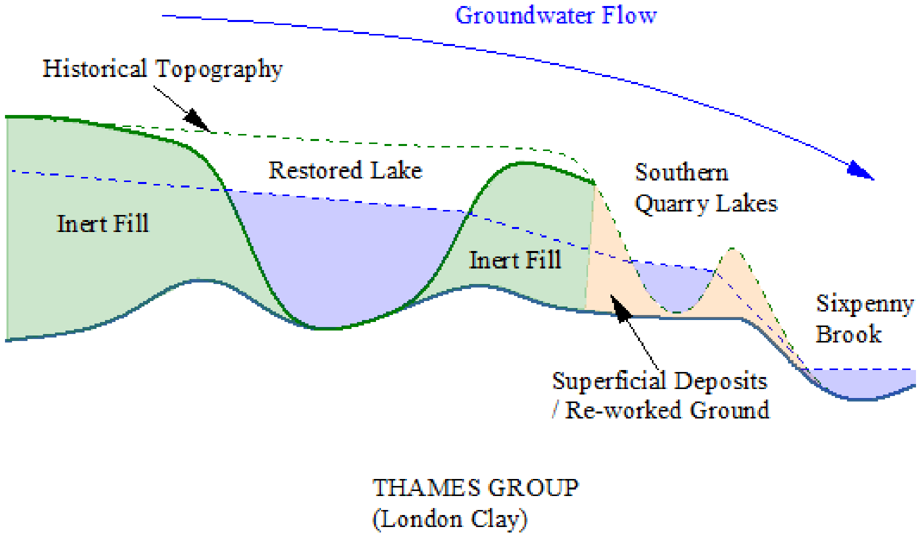
# 4 Conceptual Site Model

A simple relationship can be assessed for the proposed development where the:

- source is the inert restoration fill material
- the pathway is the cast back quarry overburden material (or any remaining *in-situ* unsaturated strata)
- the hydrogeological and hydrological receptors are
    a) the Sixpenny Brook to the east of the site;
    b) the quarry lakes and Cockaynes Nature Reserve to the south of the site

A generalised conceptualisation of the system after reworking is presented as Figure 4.1 for t how the hydrogeology, hydrology and groundwater would inter-relate assuming the same hydraulic properties for the inert fill as the existing superficial deposits.

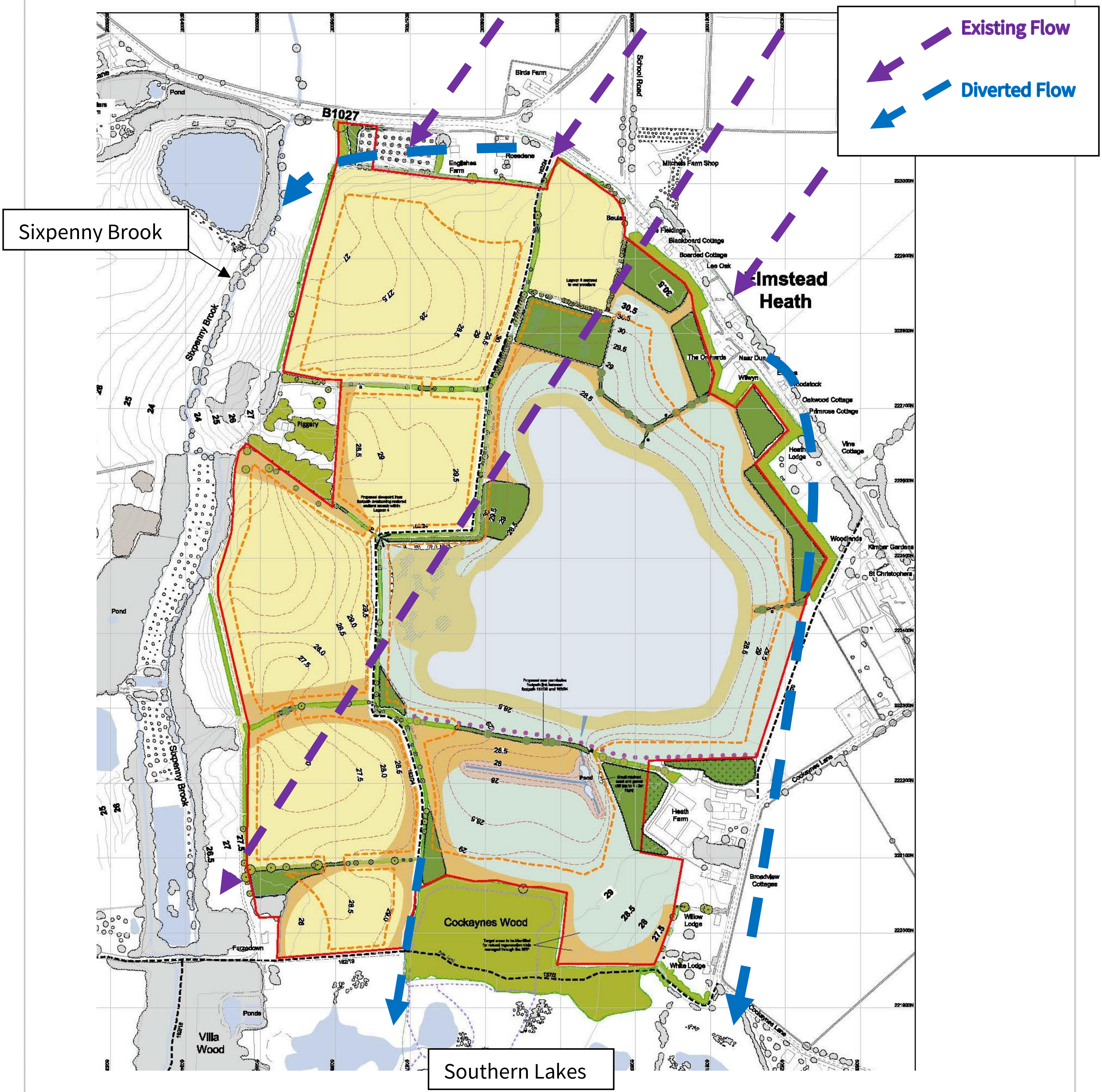
**Figure 4.1 – Conceptual Site Model (North - South Section)**




Under this scenario, there would be a continuation of the groundwater flux after the quarry has been restored, through the inert fill, forming a baseflow to the lake in addition to direct incidental rainfall, before egressing through the reworked site derived material to the south or additional fill to the east before forming the baseflow to Sixpenny Brook.

However, this is an overly simplistic representation as the fill material will by definition be of a lower hydraulic conductivity than the quarried material and therefore form a hydraulic barrier, which will divert flow around the west and east of the site as illustrated in Figure 4.2.

**Figure 4.2 –Hydraulic Flow Direction Before and After Restoration**




In addition to the placement of the infilled material, suitable selected material will also be required to act as a geological barrier between the edge of the quarry and the infilled material. This material will therefore line:

1) the northern and eastern flanks of the quarry;

2) the east and western flanks of the bridleway pathway;

3) the western flanks of the quarry; and

4) the southern flanks of Phase 3.

Phase 7 in the southwest of the site is expected to be infilled using site derived material, at least the depth below the water level.

No throughflow or substantive groundwater recharge into the central lake area is expected. If the groundwater flux was capable of being returned to the natural flow conditions, then a water level in the order of 25mAOD and seasonally varying between 24.5 and 25.5mAOD could form. However, it is expected that the lake will be largely, if not entirely recharged via direct infiltration and run-off from the surrounding slopes. It is unclear at this stage whether there will be sufficient rain derived water to sustain the lake level, as this will be determined by the seepage rate through the placed soils.

The diverted flow will enable the lakes to the south and Sixpenny Brook to be recharged as normal. There is a further advantage in diverting flow around the site, namely that the potential for a contaminant flux is significantly reduced as the majority part of the groundwater flux will not come into contact with the imported fill.

# 5 Risk Profile

## 5.1 Hydraulic Properties

There are three mechanisms for estimating the hydraulic flux through the inert fill. The first is that there is a general requirement for a geological barrier with properties equivalent to 1m thick and hydraulic conductivity of $\leq 1x10^{-7}$m/s. The second mechanism is to calculate a hydraulic conductivity of the expected materials using particle size type distributions and the third is from site based measurements accepting a similar fill.

The imported fill is intended as a replacement of sand and gravel, with soil forming materials. Any hardcore, gravel or sand type materials that can be recovered are unlikely to be imported, as this material has a commercial value and therefore it is the material that cannot be readily repurposed that will be diverted to the site. Consequently, it is expected that the site will be restored primarily with clay and silt dominated soil forming materials.

Hydraulic calculations demonstrate that as long as 10% of the infill material contains a medium silt or smaller grain size, a $1x10^{-7}$m/s hydraulic conductivity criteria would be met (Table 12). This conclusion is also supported from permeability measurements of placed soils (Table 13).

**Table 12 Hazen Formula Particle Size – Hydraulic Conductivity Relationship**

| Grain Size (Lower Size) | Particle Size 10% Passing | | Hydraulic Conductivity |
|---|---|---|---|
| | d10 | | K |
| | micron | mm | m/s |
| Medium Gravel | | 8 | 0.100 |
| Fine Gravel | | 4 | 0.025 |
| V. Fine Gravel | | 2 | 0.006 |
| V. Coarse Sand | | 1 | 0.002 |
| Coarse Sand | 500 | 0.5 | $3.9x10^{-4}$ |

| | | | |
|---|---|---|---|
| Medium Sand | 250 | 0.25 | $9.8x10^{-5}$ |
| Fine Sand | 125 | 0.125 | $2.5x10^{-5}$ |
| V. Fine Sand | 63 | 0.063 | $6.2x10^{-6}$ |
| Coarse Silt | 20 | 0.02 | $6.3x10^{-7}$ |
| Medium Silt | 6.3 | 0.0063 | $6.2x10^{-8}$ |
| Fine Silt | 2 | 0.002 | $6.3x10^{-9}$ |
| Clay | <2-0.06 | <0.002 0.00006 | $5.7x10^{-12}$ |

Hazens Formula

$$K = C_H . d_{10}^2$$

Where

K = Hydraulic Conductivity

$d_{10}$ = Particle Size 10% Passing

$C_H$ = Hazen Constant (0.00157)

Two examples from different operators illustrate this point (Table 13**Error! Reference source not found.**). For Site A, the non-hazardous landfill was designed to be capped and restored with 2m of a soil cover. The Site B data was taken from the upper 2m of the (inert) soil waste infill to the site. In both cases, the hydraulic conductivity far exceeded the requirements for a geological barrier for both non-hazardous and hazardous sites. Tarmac have then repeated this exercise at three of their soil infill sites during March and April 2022 and returned confirmatory test data that a soil infill can expect to achieve a hydraulic conductivity in the order of $5x10^{-11}$ to $5x10^{-10}$m/s

**Table 13 Placed Soil Hydraulic Conductivity Testing**

**Site A Placed Soil Restored Surface**

| Dry Density | | Hydraulic Conductivity |
|---|---|---|
| **Mg/m³** | | **m/s** |
| 1.715 | | $2.5x10^{-10}$ |
| 1.623 | | $1.1x10^{-10}$ |
| 1.672 | | $7.8x10^{-11}$ |
| 1.750 | | $6.9x10^{-11}$ |
| 1.480 | | $2.6x10^{-10}$ |
| 1.735 | | $8.1x10^{-11}$ |
| 1.653 | | $1.1x10^{-10}$ |
| 1.711 | | $1.5x10^{-10}$ |
| 1.690 | | $4.3x10^{-11}$ |
| 1.693 | | $7.3x10^{-11}$ |
| 1.559 | | $3.9x10^{-10}$ |
| 1.628 | | $1.4x10^{-10}$ |
| 1.695 | | $4.9x10^{-10}$ |
| 1.930 | | $4.5x10^{-10}$ |
| 1.744 | | $8.5x10^{-11}$ |
| 1.673 | | $1.1x10^{-10}$ |

**Site A and Site B Summarised in a Disposal Context**

| | Site A | Site B (near Surface) | Site B (Depth) |
|---|---|---|---|
| | **m/s** | **m/s** | **m/s** |
| Maximum | $5x10^{-10}$ | $7.2x10^{-10}$ | $5.1x10^{-10}$ |
| Most Likely | $1x10^{-10}$ | $4.4x10^{-10}$ | $1.5x10^{-10}$ |
| Minimum | $5x10^{-11}$ | $1.6x10^{-10}$ | $1.6x10^{-10}$ |

**Site B Soil Infill Material Properties**

| *In-situ* | Laboratory Recompacted |
|---|---|
| **m/s** | **m/s** |
| $7.2x10^{-10}$ | to $5.1x10^{-10}$ |
| $1.6x10^{-10}$ | to $1.0x10^{-10}$ |
| $4.4x10^{-10}$ | to $1.5x10^{-10}$ |

**Tarmac Soil Infill Permeability Testing Summary (April 2022)**

| Alrewas | Swarkeston | Brooksby |
|---|---|---|
| **m/s** | **m/s** | **m/s** |
| $1.2x10^{10}$ | $1.1x10^{-10}$ | $6.3x10^{-11}$ |
| $1.9x10^{-10}$ | $1.2x10^{-10}$ | $4.9x10^{-11}$ |
| $1.2x10^{-10}$ | $2.9x10^{-10}$ | $9.5x10^{-11}$ |

The data demonstrates that the placement of the clay soils with an informal compaction, *i.e.* deposited, spread and machine compacted without the benefit of third-party supervision or to a

CQA plan that an impermeable layer is produced. The re-compaction testing carried out for Site B demonstrates that the compaction achieved using this methodology is consistent with that which could reasonably be expected from formal on-site compaction. This re-compaction data does demonstrate is that the likelihood that lower hydraulic conductivities will be achieved with depth throughout the vertical profile of the deposited mass.

These conclusions of an inherently low permeability fill material are also confirmed from test data from two of Tarmac's inert landfill site, whereby the artificial geological barrier created with a target hydraulic conductivity of $\leq 1 \times 10^{-7}$m/s achieved a hydraulic conductivity of:

- $1.1 \times 10^{-10}$m/s to $4.4 \times 10^{-10}$m/s at the Spixworth Quarry site; and
- $3.8 \times 10^{-11}$m/s to $8.0 \times 10^{-11}$m/s at the Brooksby Quarry site

using a selection criteria of:

- no stones greater than 125mm;
- not oozing excess water; and
- is on visual assessment cohesive (*i.e.* "can be rolled into a sausage 3mm thick")

Consequently for a predominantly soil fill cell, the hydraulic properties are best described as a continuous geological barrier throughout the entire thickness of the imported fill. Even where larger materials are co-disposed with soils, the hydraulic characteristics are based on the lower permeability surround. For example gravely clay and Boulder Clays, contain large particle sized materials within the clay matrix, and retain low overall bulk permeability properties. A similar effect is expected for components of construction/demolition material (*e.g.* brick and concrete) entrained within the imported fill

The bulk hydraulic properties of this material are, by cross-referencing with Table 12 and Table 13**Error! Reference source not found.**, equivalent to an infiltration rate in the order of 3 – 30mm/yr, with a potential this is even lower at 0.3mm/yr (Table 14).

**Table 14 – Infiltration Rate under Hydraulic Gradient i = 1 Compared to Hydraulic Conductivity**

| Hydraulic Conductivity | Infiltration Rate under Hydraulic Gradient i= 1 |
|---|---|
| **m/s** | **mm/yr** |
| $1 \times 10^{-7}$ | 3,154 |
| $5 \times 10^{-8}$ | 1,577 |
| $1 \times 10^{-8}$ | 315 |
| $5 \times 10^{-9}$ | 158 |
| $2 \times 10^{-9}$ | 63 |
| $1 \times 10^{-9}$ | 32 |
| $5 \times 10^{-10}$ | 16 |
| $2 \times 10^{-10}$ | 6 |
| $1 \times 10^{-10}$ | 3 |
| $5 \times 10^{-11}$ | 1.6 |
| $2 \times 10^{-11}$ | 0.6 |
| $1 \times 10^{-11}$ | 0.3 |

## 5.2 Seepage Rates

The hydraulic properties are such that the proposed fill will divert the groundwater flow around the site. This can be demonstrated following Darcy's Equation for the cross-sectional area which faces the primary groundwater flow, *i.e.* from north to south with a northeast to southwest slant.

Darcys Equation $Q = KiA$

where

Q = Flow Rate
i = Hydraulic Gradient
A = Cross-sectional area

The main groundwater system is at approximately 26mAOD at and upgradient of the site (Figure 3.6) and fall to the Sixpenny Brook at 21mAOD (Figure 3.7). This water level fall occurs across at least a 50m pathway length, and equates to a hydraulic gradient of up to 0.1. The diagonal cross-sectional area towards the Sixpenny Brook is 1,000m, with the maximum vertical profile at 5m, which equates to a cross-sectional area of 5,000m$^2$, although the seepage face could be as small as 3m in height for large sections of the perimeter given the nature of the London Clay surface.

Seepage rates through this material are therefore dependent on the hydraulic conductivity of the placed material, which in all likelihood will achieve the criteria for an inert landfill geological barrier (*i.e.* 1x10$^{-7}$m/s). Consequently an upper estimate of the throughflow is likely to be in the order of 4m$^3$/day, with the potential to be as low as 20 – 40litres per day as illustrated by the sensitivity calculations shown in Table 15.

**Table 15 – Illustrative Groundwater Seepage Rates through the Soil Fill**

| | | | High Rate | | | Low Rate |
|---|---|---|---|---|---|---|
| Pathway Length | | m | 1000 | 1000 | 1000 | 1000 |
| Water Level | | mAOD | 26 | 26 | 26 | 26 |
| Base Water Column | | mAOD | 21 | 21 | 21 | 21 |
| Height | | m | 5 | 5 | 5 | 5 |
| Distance | | m | 50 | 50 | 50 | 50 |
| Hydraulic Gradient | i | m/m | 0.1 | 0.1 | 0.1 | 0.1 |
| Hydraulic Conductivity | K | m/s | 1x10$^{-7}$ | 1x10$^{-8}$ | 1x10$^{--9}$ | 5x10$^{-10}$ |
| Seepage Face | A | m$^2$ | 5,000 | 5,000 | 5,000 | 5,000 |
| | | | | | | |
| Groundwater Flow Rate | Q | m$^3$/s | 5x10$^{-5}$ | 5x10$^{-6}$ | 5x10$^{-7}$ | 2.5x10$^{-7}$ |
| | | m$^3$/d | 4.32 | 0.43 | 0.04 | 0.02 |
| | | m$^3$/yr | 1,577 | 158 | 16 | 8 |

Seepage rates of this magnitude are negligible in comparison with the Sixpenny Brook flow where median flow rates 1,250m$^3$/day and Q95 of 259m$^3$/day. It should also be noted that as the recharge to Sixpenny Brook is seasonal and that groundwater levels fall in summer, therefore the potential hydraulic gradient acting on the site will also be reduced in line with the regional recharge patterns.

Initial dilution rates in the Sixpenny Brook are therefore likely to be between 289 times and 62,500 times.

Such a low throughflow however does mean that the primary recharge to the lake will be direct rainfall and run-off from the surrounding inwards sloping faces, as the baseflow will be diverted around the north and east of the site towards the brook and the lakes or through the bridleway "channel" to the nature reserve. Consequently there may be no or negligible direct recharge during summer along with evaporative losses and the initial recharge to the lake after dewatering ceases will be slow unless there is a direct (artificial) base flow contribution.

Notwithstanding the above, over time the fill below 25mAOD in the main body of the site is expected to gradually become saturated. However, this water will be in the form of a slow moving porewater with limited turnover.

## 5.3 Source Term and Risk Screening

The risk profile of the site will be determined by the quantity of throughflow of moisture through the inert fill and the leaching potential of the infilled material.

ByrneLooby has been collating leachate chemistry from similar waste types from both inert and non-hazardous landfill sites. The leachate chemistry for most non-hazardous biological waste landfills is dominated by biological process and the degradation of organic matter, hence there is a large landfill gas production rate and the co-formation of ammonium, as the solubilised form of organic nitrogen. Soil fill has a separate geochemistry, it is not a biochemically derived solution as the bulk organic content is excluded prior to receipt at the site and deposit.

The silicate minerals in soils, ceramics and glass have low to negligible solubility characteristics and as sodium, potassium and chloride salts are rapidly dissolved and lost prior to being incorporated within wastes, then there is typically only one remaining potential solubility limiting mineral phase, mainly gypsum.

Gypsum has a solubility limit which equates to approximately 1,500mg/l sulphate and 700mg/l calcium under oxidising to anoxic conditions. It is only when significant anaerobic conditions develop that sulphate is reduced to sulphide to precipitate primarily as iron sulphide, whilst calcium is precipitated as calcium carbonate. Consequently, neither calcium nor sulphate are present within biological waste methanogenic leachates, they are however present as the primary ions in soil fill low organic waste leachates.

Monitoring of soil fill wastes leachates demonstrates that they have a very consistent chemical signature.
Biodegradable waste leachate are a sodium-chloride-bicarbonate solution containing elevated ammonium, potassium and organic substances; whereas soil fill leachates are a calcium sulphate solution, containing low ammonium, potassium, sodium, chloride and organic substances.

As a geochemically derived liquor, calcium and sulphate are limited by the solubility of gypsum, whilst in organic based waste masses, neither are significantly present as the calcium is precipitated as calcium carbonate under the enriched carbonate atmosphere (produced by the landfill gas) and sulphate is chemically and biologically reduced under the biologically induced methanogenic conditions.

Other substances are also low, albeit that occasional outliers have been observed, as well as short duration (weeks to months) releases of salts with low contents of heavy metals. Metals will themselves be removed from the source materials as a recoverable product, whilst contaminated source sites are to be avoided unless sufficient efforts have been made to demonstrate that the source material is not contaminated.

An expected pore solution chemistry is summarised as Table 16 as the primary constituents which could be present in the imported soils and materials. The background monitoring data (Table 16 and Table 17) demonstrates that there are consistencies between the type of leachate that could be generated and that already demonstrated to be present within the groundwater and surface water.

Some ammonium is inevitable in soils, particularly in agricultural areas where there is an expectation of manure spreading or the addition of ammonium nitrate fertilisers. Nevertheless, it is considered appropriate to consider these substances and their effects on the water system.

**Table 16 – Conservative Expectations for Soil Fill Leachate (based on non-hazardous and hazardous SNRHW based Soil Forming Material, Including Transfer Station Residues)**

| | Landfilled Soil, SNRHW & Trommel Fines | | | Background (Groundwater) | | | |
|---|---|---|---|---|---|---|---|
| **Determinand** | **Min** | **Most Likely** | **Maximum** | **Median** | **85th %ile** | **95th %ile** | **Max** |
| | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** |
| Ammoniacal-N | 1 | 10 | 45 | 0.02 | 0.2 | 1 | 9 |
| Chloride | 50 | 350 | 500 | 56 | 189 | 515 | 885 |
| Sulphate | 950 | 1,500 | 1,900 | 78 | 113 | 155 | 165 |
| | **µg/l** | **µg/l** | **µg/l** | **µg/l** | **µg/l** | **µg/l** | **µg/l** |
| Chromium | 1 | 3 | 6 | <1 | <1 | <1 | 1 |
| Nickel | 10 | 20 | 100 | 8 | 24 | 51 | 56 |
| Xylene/BTEX | | | <5 | | | | <5 |

**Table 17 – Sixpenny Brook Background Summary**

| Location | Date | $NH_4$-N | Cl | $SO_4$ | Cr | Ni |
|---|---|---|---|---|---|---|
| | | mg/l | mg/l | µg/l | µg/l | µg/l |
| SW01 (upstream) | Min | 0.01 | 56 | 53 | <1 | 4 |
| | Med | 0.24 | 73 | 94 | <1 | 18 |
| | 85th %ile | 0.27 | 88 | 120 | 2 | 23 |
| | Max | 10.30 | 155 | 208 | 14 | 113 |
| SW02 (downstream) | Min | 0.01 | 39 | 39 | <1 | 5 |
| | Med | 0.19 | 72 | 72 | <1 | 14 |
| | 85th %ile | 0.27 | 82 | 82 | 2 | 18 |
| | Max | 0.41 | 113 | 113 | 10 | 24 |

The leachate chemistry presented as Table 16 is considered as a conservative representation of the type of porewater which could be present within a Recovery site type once infilled. This type of inventory will include a higher content of active material and therefore is considered as conservative. This inventory, however, is locally consistent with that of the groundwater.

Of the salts that could be present, sulphate is enriched compared to that of the background groundwater and Sixpenny Brook. Chloride is locally consistent with a conservative inventory; however, it could be enriched compared to the downstream Sixpenny Brook quality. Similarly ammonium could reasonably be expected to be enriched compared to the steady-state brook water quality.

Nickel as a surrogate for metals not normally present in Anglian waters is present locally within the groundwater, but does appear elevated both locally within groundwater and in the upstream Sixpenny Brook sampling point. Median concentrations are generally similar between all three source types, albeit the imported fill could be slightly enriched overall compared to that of the site's water systems.

This consistency between the water systems is therefore demonstrative that there is a limited potential for harm to occur as water quality may be materially changed by the importation of the proposed waste streams. This potential for harm is also limited by the small quantities of water which are expected to percolate through the imported materials.

Nickel at this site could be considered as an enigma, as higher than expected concentrations are found within the site and therefore the primary question associated with nickel is whether there is the potential for a significant change in concentration.

Organic solvents, paints and fuel spillages, the primary source of hydrocarbons, and other priority substances will be excluded during initial pre-acceptance waste acceptance checks and therefore not transported to the site. Consequently, the risk of these substances is low to negligible. A greater risk pathway would be in the use and application of agricultural herbicides or insecticides in the western section of the site following completion and the return of the land to production.

## 5.4 Risk Assessment

The risk presented by the soil fill can be described as how the baseflow contributions from the recovery activity could potentially change the groundwater baseflow into the Sixpenny Brook, and hence if there is a change to the status of the brook.

The Sixpenny Brook is a low elevation (<80mAOD) water system with alkalinity between 58mg/l and 136mg/l as calcium carbonate and median alkalinity of 96mg/l at SW02. The brook is therefore primarily a "Type 3" water (*i.e.* alkalinity from 50mg/l to 100mg/l), with occasionally periods as a Type 5 water (alkalinity 100 – 200mg/l). It is therefore considered appropriate to assess the site against a Type 3 water standards.

The risk to the brook can be considered by an initial screening assessment which compares water quality in the brook to that which could reasonably be expected to be released from the site. Such a screen demonstrates that broadly there will be no change in water quality. However, there is the likelihood that the porewater in the imported fill will contain more sulphate than the background system, and a reasonable likelihood there will be a small increase in porewater ammonium than the background waters.

The general mechanism for establishing a potential impact on a surface water system is to follow the Environment Assessment (formerly H1) methodology[7]. This methodology follows a four step programme of:

1) Compare source discharge concentration with 4% of the EQS
2) Compare concentration after mixing with 10% of the EQS (the Process Contribution)
3) Calculate a Predicted Environmental Concentration when incorporating background concentrations
4) Compare the Predicted Environmental Concentration with water quality standards

For situations such as this the stepped programme is not necessary, as the key factor is the third step given that there is a known release rate, stream flow rate and a background concentration. For the purposes of this assessment, the Sixpenny Brook gauged flow rates in combination with the SW02 water quality data is considered the appropriate background conditions for assessment purposes.

The Step 1 condition of comparing imported soil pore water chemistry with 4% of an EQS, which for all substances being considered will be exceeded.

Two brook flow conditions are being considered, namely low flow conditions and median flow conditions which are representative of the typical conditions in the brook as well as the highest risk conditions, in combination with the upper rate expected for seepage from the imported fill and an expected rate from imported soil type conductivity conditions.

The calculations demonstrate that after mixing it is unlikely that there will be a discernible change in water brook water quality (Table 18).

**Table 18 – Predicted Environmental Concentration in Sixpenny Brook**

| Sixpenny Brook Flow Conditions | | | Low Flow (259m$^3$/day | | Median Flow (1,250m$^3$/day) | | EQS |
|---|---|---|---|---|---|---|---|
| Seepage Rate from Imported Fill | | | 0.043 m$^3$/day | 4.32 m$^3$/day | 0.043 m$^3$/day | 4.32 m$^3$/day | |
| **Location** | **Pore Water** | **Sixpenny Brook** | **Predicted Environmental Concentration after Mixing in Sixpenny Brook** | | | | |
| **Substance** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** |
| Sulphate | 1,500 | 72 | 72.2 | 95.4 | 72.0 | 76.9 | 400 |
| Chloride | 350 | 72 | 72.0 | 76.6 | 72.0 | 73.0 | 250 |
| Ammoniacal-N | 10 | 0.19 | 0.19 | 0.35 | 0.19 | 0.22 | 0.6 |
| Nickel | 20 | 14 | 14.0 | 14.1 | 14.0 | 14.0 | *16 |

*Predicted No Effect Concentration (PNEC) as established using the m-BAT tool under median SW02 water chemistry conditions

| Nickel m-BAT Conditions | pH | DOC mg/l | Ca mg/l | PNEC mg/l |
|---|---|---|---|---|
| | 7.8 | 7 | 75 | 16 |

Mixing calculations demonstrate that for nickel, there will not be a change in receiving water quality, and under all flow conditions there is no change in concentration. The Process Contribution (PC) is

[7] https://www.gov.uk/guidance/surface-water-pollution-risk-assessment-for-your-environmental-permit

effectively zero and remains below the m-BAT tool derived Predicted No Effect (PNEC) quality standard for nickel under median Sixpenny Brook (SW02) water chemistry conditions

The slight change in sulphate concentration is a minimal zero to 13mg/l, *i.e.* up to 3% of the 400mg/l sulphate EQS with the PEC remaining at less than 100mg/l, a quarter of the EQS.

The potential contribution from chloride is similarly low at zero to 6.7mg/l is similarly negligible at 3% of the 250mg/l chloride EQS, with the resultant PEC increasing from 29% to 30% of the EQS.

Ammonium concentrations also remain within the Good Water Quality status at 0.19 – 0.35mg/l after mixing. Process Contributions also increase by zero to 0.16mg/l, which although non-negligible, does not make a material change to water quality.

In each of these cases the potential impact from the site is within the usual fluctuation range which has already been demonstrated by the background monitoring data and therefore will not cause a discernible or material change to water quality.

This conclusion is also confirmed if the sensitivity analysis is repeated for outlier source term concentrations (*e.g.* Table 19). There is no potential impact from either chloride, sulphate or nickel, whilst the potential for such a release can only be of a short duration and limited in distribution from the imported fill.

The potential increase in nickel could only change background nickel by 1.4µg/l which is minimal compared to the established background fluctuation which on occasions has exceeded 24µg/l. Consequently background influences exceed the potential for the infilled material to affect water quality.

**Table 19 – Predicted Environmental Concentration in Sixpenny Brook assuming Constant Release of Outlier Elevated Concentrations**

| Sixpenny Brook Flow Conditions | | | Low Flow ($259m^3$/day | | Median Flow ($1,250m^3$/day) | | EQS |
|---|---|---|---|---|---|---|---|
| Seepage Rate from Imported Fill | | | 0.043 $m^3$/day | 4.32 $m^3$/day | 0.043 $m^3$/day | 4.32 $m^3$/day | |
| Location | Pore Water | Sixpenny Brook | Predicted Environmental Concentration after Mixing in Sixpenny Brook | | | | |
| **Substance** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** |
| Sulphate | 2,500 | 72 | 72.4 | 111.8 | 72.1 | 80.4 | 400 |
| Chloride | 500 | 72 | 72.1 | 79.0 | 72.0 | 73.5 | 250 |
| Ammoniacal-N | 45 | 0.19 | 0.20 | 0.93 | 0.19 | 0.34 | 0.6 |
| Nickel | 100 | 14 | 14.0 | 15.4 | 14.0 | 14.3 | *16 |

*m-BAT derived PNEC for median SW02 water chemistry conditions

The PEC is more subtle for ammonium, when short term outlier concentrations of up to 45mg/l ammoniacal-N are considered, then it is possible for ammonium concentrations to increase to 0.93mg/l under low flow brook conditions and a higher than expected soil hydraulic conductivity. Technically this rate could be considered as a Moderate water quality, in the brook. However, the ammonium EQS is based on a $90^{th}$ percentile frequency, and as the flow rate / dilution considered was for low flow conditions at the $95^{th}$ percentile flow rate, then these conditions are outlier and cannot be representative of the holistic water quality over the $90^{th}$ percentile flow rate, or the median flow conditions. The potential for a depreciation in Sixpenny Brook water quality from a

"Good Water Quality" status is therefore low to negligible, with the more likely cause for a change in water quality associated with the agricultural practices in the wider catchment area.

Under high flow conditions there will be a proportionate, if not logarithmic increase in flow rates within the brook due to surface run-of capture compared to the potential for an increase in groundwater flow and leakage from the site, which will be buffered by the minor hydraulic gradient induced by higher groundwater recharge and the permeability properties of the imported soils. These properties will preferentially induce the flow through the higher permeability residual sediments which surround the site. Consequently the risk potential from the site will be reduced from low to negligible during these periods.

# 6 Technical Precautions

The quarry void is to be recovered to agriculture in the west and south and habitat creation (meadow and lake) in the east and centre of the site using a combination of imported fill and site derived interburden to a thickness of some 6 – 9m (from ~21mAOD to 30.5mAOD). The site will be encapsulated by natural ground left *in-situ* to an elevation above groundwater heights and therefore there is an extended pathway from site to controlled waters.

The primary technical precaution is only to import clean, inactive materials suitable for an inert landfill site, as such technical precautions are to be proportional to that of an inert landfill.

The site is underlain by London Clay at a thickness capable of preventing harm to an underlying aquifer. The sides of the site are to comprise of silt and clay based materials capable of being compacted to a hydraulic conductivity of $\leq 1 \times 10^{-7}$m/s. However, it is expected that natural compaction due to the mass of overlying soil forming material will result in a lower hydraulic conductivity and the entirety of the infill will act as a geological barrier.

The site is to be dewatered during quarrying, a practice that will continue during restoration. Therefore materials placement will be undertaken "dry". Groundwater recharge will be allowed to recover following the cessation of materials placement to a natural elevation of ~25mAOD on the upgradient side of the site (to the north and east)

It is expected that the site will form a hydraulic barrier to groundwater flow, which will be diverted around the north of the site to Sixpenny Brook which drains the valley to the west of the site or be diverted along the eastern perimeter of the site, to then re-join Sixpenny Brook, via a series of artificial lakes to the south of the site. A north to south conduit will however be left through the centre of the site where *in-situ* material will be left intact beneath a bridleway which his to be retained throughout the quarrying works.

During operations the baseflow contribution will be maintained by the artificial recharge from pumping of dewatering waters. This diverted baseflow contribution will continue after the hydraulic block caused by the replacement of high permeability sands and gravels with a lower permeability silt and clay fill.

Groundwater abstractions to the north and east of the site will be unaffected by the creation of the new landscape, whilst the operator have made a commitment, secured within a planning permission to ensure that upgradient water users are unaffected during dewatering.

There is not a continuation of water bearing strata downgradient of the site, as there is not a continuation of the water bearing strata. To the south the Sands and Gravels have previously been extracted and to the west the aquifer unit is terminated by the Sixpenny Brook.

The lower 3 – 5m of the recovered fill profile (depending on the basal profile of London Clay) will be below the groundwater level to the north and east of the site. This ground will gradually become saturated; however, saturation times are likely to be extended due to the hydraulic characteristics of soil forming materials. It is these low permeability properties, in combination with the limited leachability of the imported fill which will prevent off-site pollution.

The inherent low permeability properties of the imported fill will also provide a hydraulic barrier between the lake and external waters. The lake feature in the centre and northeast quadrant of the site will therefore be hydraulically isolated from the wider groundwater system.

The majority of the imported materials will be placed to the west and southwest of the lake, with a limited quantity of imported material used to create the northern and eastern landform. The southern (downgradient) flank of the lake (Phase 7) is to be restored using site derived interburden materials and therefore the "below water line" outlet will comprise entirely by clean materials. Site derived materials are also intended to be used to form the northwestern (Phase 1) section of the site.

Lake levels are expected to fluctuate between 24maOD and 25mAOD, within a basin formed by slopes which fall from 28 – 30.5mAOD towards the lake. The lake will primarily be recharged from direct rainfall and surface run-off from the surrounding slopes, with the actual water level derived from the balance between recharge, evaporation from the lake surface during summer and seepages through the sides of the lake.

Minimising the quantity of infill on the upgradient flanks of the quarry lake is a deliberate act to minimise the potential for leachate to enter the lake waters and prevent harm occurring due to both limiting the size of the pollution source as well as the seepage rate that could enter the lake. The potential for harm to occur to the lake from the imported fill is therefore considered to be negligible.

These same measures will also prevent harm from occurring to the lakes to the south of the site. Risk assessment has also demonstrated that the potential for harm to the Sixpenny Brook is also low to negligible.

# 7 Monitoring

A groundwater and surface water monitoring programme has been implemented at the site, which has enabled background water quality and elevations to be established. The groundwater body being monitored will be removed as part of the quarrying works and be replaced by "unproductive strata". As there will be no future continuation of the aquifer, the key monitoring objectives are to demonstrate protection of the surface water features downgradient of the site, namely

1) Sixpenny Brook
2) the lakes to the south of the site

The monitoring points which are to be retained during the recovery operations comprise

1) Sixpenny Brook
    - SW01 (upstream)
    - SW02 (downstream)
2) Lakes
    - Cox Lake (MP2)
    - Bramley Lake (MP3)
    - Cockyanes Wood Pond (MP4)
3) Groundwater
    - PZ1 (Northeast – upgradient)
    - PZ3 (Southwest – Cross-gradient)
    - BH06 (West – Downgradient, above Sixpenny Brook)
    - BH07 (West – Downgradient, above Sixpenny Brook)
    - BH08 (West – Downgradient, above Sixpenny Brook)
    - BH09 (South – Downgradient, above Sixpenny Brook)
4) Dewatering Waters

The monitoring schedule is based on that for an inert landfill groundwater monitoring schedules as summarised as Table 20.

**Table 20 – Proposed Monitoring schedule**

| Location | Parameter | Frequency |
|---|---|---|
| Lakes and Groundwater | Water Level (mAOD) | Quarterly |
| Groundwater | Base of monitoring point (mAOD) | Annual |
| Lakes, Groundwater Sixpenny Brook and Dewatering fluid | pH, EC<br>Ammoniacal-N, TON<br>Chloride, Sulphate<br>TOC, TPH<br>Potassium<br>Nickel, Copper, Zinc | Quarterly |
| Dewatering Waters | Suspended Solids | Quarterly |

It should be noted that the Cockaynes Wood ponds are naturally becoming overgrown and infilled by vegetation such that there is limited water present in the ponds. This is the intention for the ponds in which free standing waters that can be monitored are unlikely to be present in future irrespective of whether the quarrying works and restorations scheme proceeds or not. Consequently by the time that the restoration scheme begins to be implemented it may not be possible to obtain water samples. Water quality is also expected to revert to a "stagnant" water quality enriched in organic matter and containing ammonium along with other anoxic products.

## 8 Summary and Conclusions

The Wivenhoe (East) quarry is to be restored a sand and gravel quarry under a recovery permit using a combination of site interburden and imported soil forming material to a combination of agricultural land and habitats creation.

The restored block will replace the southwestern corner of a superficial aquifer with a "hydraulic block" which will divert the normal groundwater flow around the site to return to the normal baseflow patterns to Sixpenny Brook. The site is underlain by London Clay which will prevent any connectivity between the superficial water system and the underlying bedrock aquifers.

The majority of the natural baseflow will therefore not come into contact with the imported material, due to the low permeability properties induced by a clay and silt based infill in combination with natural (under the mass of soil) and placed compaction. Consequently the potential for pollution is low.

Technical precautions in line with the requirements for inert landfills on the sides of the site will be implemented at the site.

A

## Appendix A – Planning Permission

BYRNELOOBY

## Appendix B – Section 106 Agreement

# Appendix C – Environment Agency Correspondence

IRELAND | UK | UAE | BAHRAIN | KSA

BYRNELOOBY

www.byrnelooby.com

Email: info@byrnelooby.com