Bromsberrow North Sandpit: Hydrogeological Risk Assessment

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Prepared for Bromsberrow Sand and Gravel Company
(a subsidiary of Allstone Sands Gravels Aggregates Trading Co. Ltd.)

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Bromsberrow North Sandpit: Hydrogeological Risk Assessment

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1 Introduction

1.1 Background

Bromsberrow Sand and Gravel Company Ltd (BSGC), a wholly owned subsidiary of Allstone Sands Gravels Aggregates Trading Company Limited (Allstone) submitted an application to Gloucestershire County Council (GCC) for an Initial Review of planning conditions relating to the extraction of sand from Bromsberrow North Sandpit at Bell Lane, Bromsberrow Heath, near Ledbury, Gloucestershire, HR8 1NX (the Site)[1]. The application Site extends to approximately 5 ha.

GCC is the determining Minerals Planning Authority (MPA) and it has a statutory duty to review what are commonly referred to as 'old' planning permissions for mineral working. The process of review is referred to by the acronym 'ROMP' – Review of Old Mineral (planning) Permissions.

Further development of the quarry has been divided into eight phases according to the development plans provided by Allstone and this will provide a total of 341,000 tonnes of mineral (red sand) to be extracted during the period up until February 2032.

In addition to the phased extraction of the remaining mineral reserve, Allstone proposes a joint programme of phased restoration to either agriculture or amenity use, using imported inert material to re-establish original ground levels. A rolling programme of continued sand extraction and phased restoration will be established, and it is estimated that a total of 670,000 m^3 of inert material will be imported. The restoration will comprise filling the void progressively. Allstone are applying for an Environmental Permit (EP) for this restoration of the quarry by inert landfill.

Allstone has contracted Stantec UK Ltd (Stantec) to provide hydrogeological and hydrological support on the impacts of quarrying and restoration at the Site and the risk of flooding during both operational and restoration phases. These outputs will support the ROMP determination and the EP application.

Details of the proposed development are set out in the phased mineral extraction and restoration details in Appendix A.

Operations at the Site will not involve extracting sand below the groundwater level, therefore there is no need for the Site to be dewatered, and hence there is no need to assess impacts on groundwater levels from pumping at the quarry, nor any off-site discharges with the exception of run-off water.

Based on current rates of extraction the end of the quarrying extraction is expected to be in 2032, while the subsequent completion of restoration is estimated to be in 2044.

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[1] The Site is referred to elsewhere as Bromsberrow Quarry, or Bromsberrow Sandpit. In this report we refer to it as Bromsberrow North Sandpit, to distinguish it from Bromsberrow South Sandpit nearby (see Section 2.1).

This report constitutes a Hydrogeological Risk Assessment (HRA) that has been prepared on behalf of Allstone in support of the EP application for Site restoration, and to inform the decision in regard to the ROMP application. A Hydrological Impact Assessment (HIA, in support of the ROMP application) and an updated Flood Risk Assessment (FRA, in support of both the ROMP and EP applications) have also been produced as separate documents (Stantec, 2021a, 2024a).

Figure 1.1 shows the Site boundaries and the surrounding area.

1.2 Adopted approach

In this report Stantec has employed the widely accepted source-pathway-receptor methodology that is set out by DEFRA (2011). The methodology provides a tiered framework for environmental risk assessment, so that appropriate levels of effort and expense are invested, according to the complexity and environmental sensitivity of the Site, and the potential consequences of the hazards. For an inert landfill site, an initial risk screening and prioritization will be important to identify hazards at the beginning of the assessment. A simple quantitative risk assessment will follow if the site is in a sensitive setting. Since the Site's environmental setting is deemed sensitive, a quantitative risk assessment has been undertaken and is presented in this report.

The Environmental Permitting Regulations require that all disposal sites are appropriately monitored, to ensure that they do not cause any pollution of the environment. This includes defining and installing suitable monitoring points and setting appropriate trigger and control levels for indicators of potential contamination. Stantec have provided a suite of reports to support the EP application and we have made recommendations regarding a suitable monitoring scheme in Stantec (2024b). Appropriate control and trigger levels are presented in Section 6.1 of this report.

1.3 Scope of work

Allstone instructed Stantec in June 2021 to undertake an HRA in support of the ROMP application and then to update the HRA in October 2023 in the support of the EP application for the restoration of the Site by inert landfill. This report focusses on the hydrogeological impacts of the rolling programme of phased mineral extraction and restoration at the Site by inert landfill.

The scope of work undertaken for this HRA includes the following:

- Review of the baseline hydrogeology for the Site and surrounding area;
- Identification of receptors and assessment of potential impacts;
- Recommendations for appropriate monitoring and mitigation measures; and
- Preparation of a HRA report for the proposed development.

1.4 Data sources

The information and assessments in this report are predominantly based on secondary data analysis associated with both the Site itself and the surrounding land area. The main sources of data are summarised below:

- Phased mineral extraction and restoration details provided by Allstone (Appendix A);

- Previous reports for Bromsberrow South Sandpit (Stantec, 2019);
- British Geological Survey (BGS) mapping;
- Ordnance Survey mapping;
- Freely available data published by UK Government;
- Details of unlicensed private water abstractions from Forest of Dean District Council, Gloucestershire County Council; and
- Data from the Environment Agency (EA) including groundwater levels, water quality, rainfall, historic landfill data, LiDAR data, abstraction licences and discharge consents;
- Data from Severn Trent Water Limited (STWL) including groundwater levels, groundwater quality and abstraction rates from the Bromsberrow Public Water Supply boreholes.

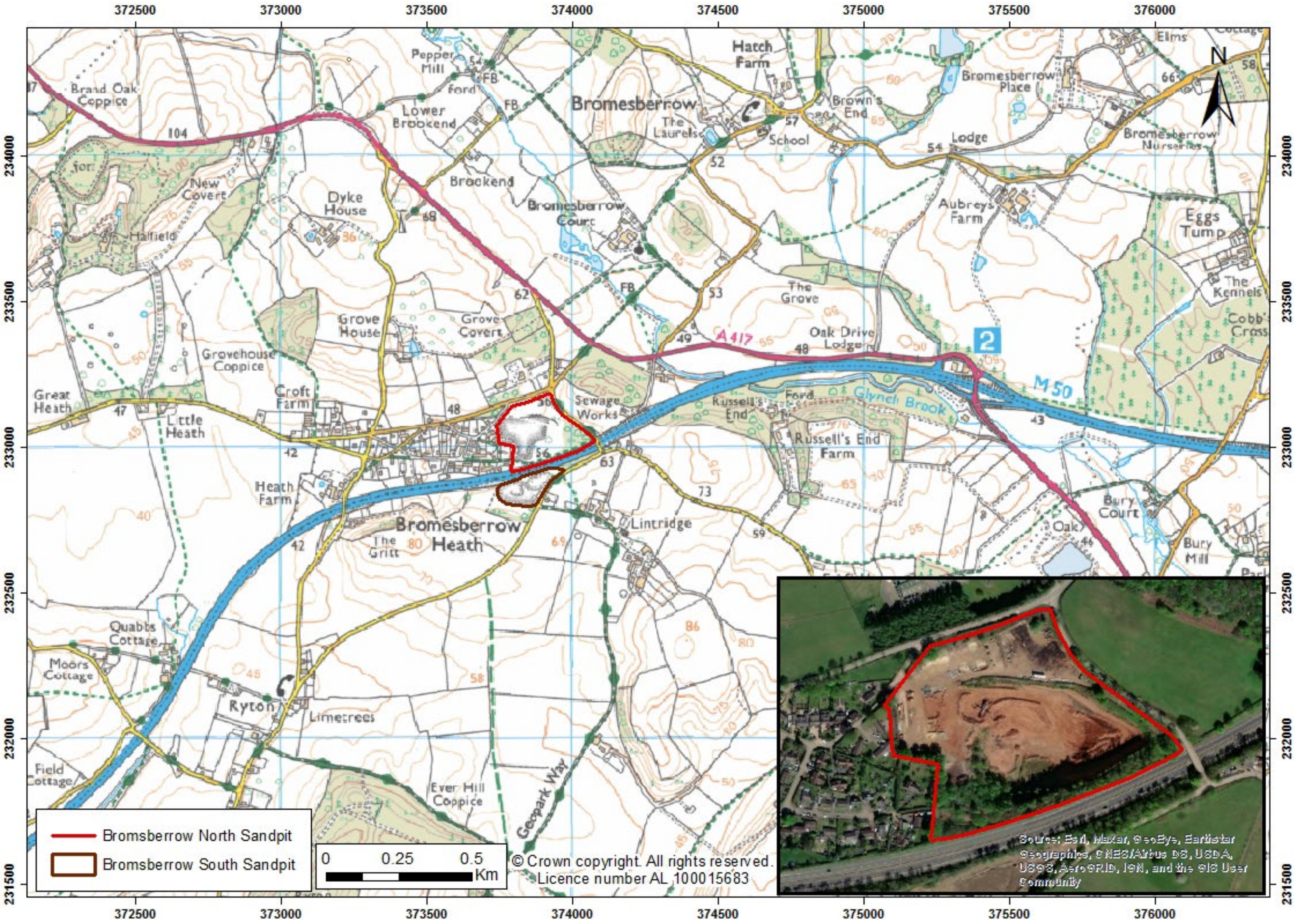
1.5 Report outline

This report constitutes the HRA for the proposed rolling programme of mineral extraction and linked restoration and includes the following:

- A review of the relevant baseline conditions (Section 2);
- An outline of the proposed quarry development (Section 3);
- A Conceptual Site Model (CSM) (Section 4);
- The hydrogeological risk assessment (Section 5); and
- Requisite surveillance and groundwater compliance limits (Section 6).

The technical approach of this HRA is in accordance with groundwater protection requirements set out by the EA (DEFRA, 2018).

Figure 1.1 Site location showing topography and surrounding area



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Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

2 Baseline Conditions

2.1 Site setting

The Site is located in Bromsberrow Heath, Gloucestershire, approximately 4.5 km southwest of Ledbury and 7 km north of Newent, close to the village of Bromsberrow in Gloucestershire (approximate NGR SO 73896 33065). The nearest postcode is HR8 1NY. The southern boundary of the Site is adjacent to the M50 which runs in a southwest-to-northeast direction, beyond which Bromsberrow South Sandpit is situated (Figure 1.1). Note that Bromsberrow South Sandpit was operated as an inert landfill from around 2010 and was restored by 2023. Bromsberrow Heath residential area extends to the western Site boundary. Beyond the northern boundary there is a groundwater borehole pumping station (BPS) public water supply (PWS) operated by STWL. To the east lies agricultural land and sewage works.

Figure 2.1 presents the topography of the Site and its surroundings.

The surrounding land is predominantly agricultural, with polytunnel fields identified on aerial photographs, to the south of the Site, beyond Bromsberrow Lane at approximately 250 m, and to the north of the Site beyond the pumping station, at approximately 240 m.

The elevation of the perimeter of the Site ranges between 55 and 60 mAOD, while the proposed extraction void will be deepened to a minimum of 36 m AOD. The Site topography is generally consistent with the western surroundings; however, the land rises eastwards to form Bevanhill Coppice, to more than 75 mAOD. To the south the land also rises from the Site, ranging between 70 to 75 mAOD around Russellsend Coppice to the southeast. East and north of the coppices, the land falls to 50 mAOD in the Glynch Brook valley.

2.2 Geology

2.2.1 Regional geology

Bedrock

The bedrock geology is shown in Figure 2.2, taken from the 1:50,000 scale geological map of the area (BGS, 2021). Underlying the Site is the Permian Bridgnorth Sandstone Formation (sandstone), which is described as presenting cross-bedded aeolian sandstones, mainly brick-red, soft, medium-grained, with buff mottling common. The Permian strata dip gently to the south.

To the immediate south of the Site boundary, beyond the M50, the Bridgnorth Sandstone Formation is overlain by the stratigraphically younger Triassic Helsby Sandstone Formation (sandstone). This formation is described as fine- to medium-grained, locally micaceous, cross-bedded and flat-bedded sandstones, weathering to sand near surface. Sandstones are of fluvial (sub-angular to sub-rounded grains) and aeolian (well-rounded grains) facies. Pebbles may be common, particularly near the base of the formation, and thin units of hard intraformational conglomerate occur in the south-west. Thin lenticular beds of reddish-brown siltstone and mudstone occur and may be common in fining-upward sequences; calcretes and rhizocretions occur at some horizons in the south-west (BGS, 2021).

Figure 2.1 LiDAR topography around the Site

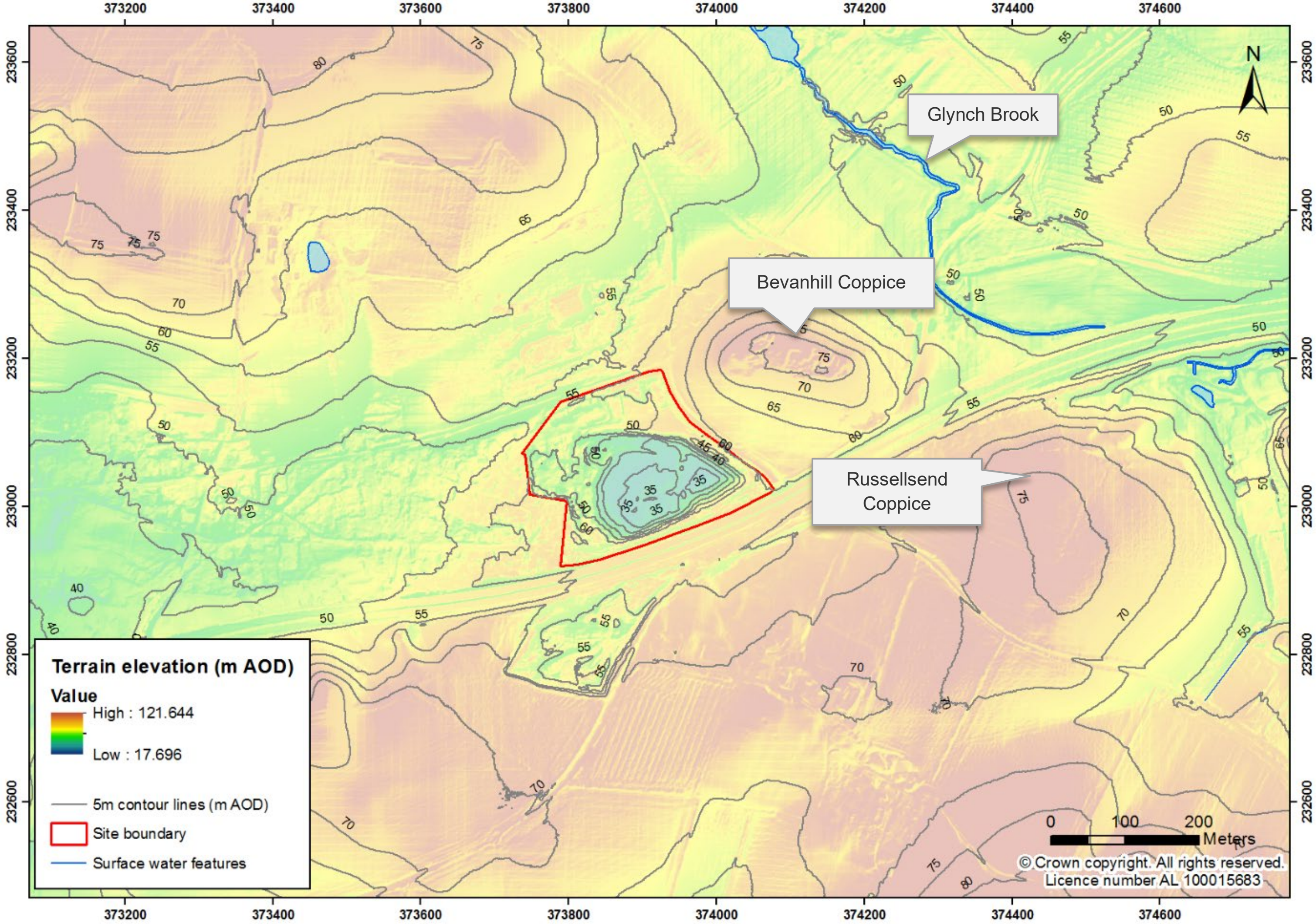
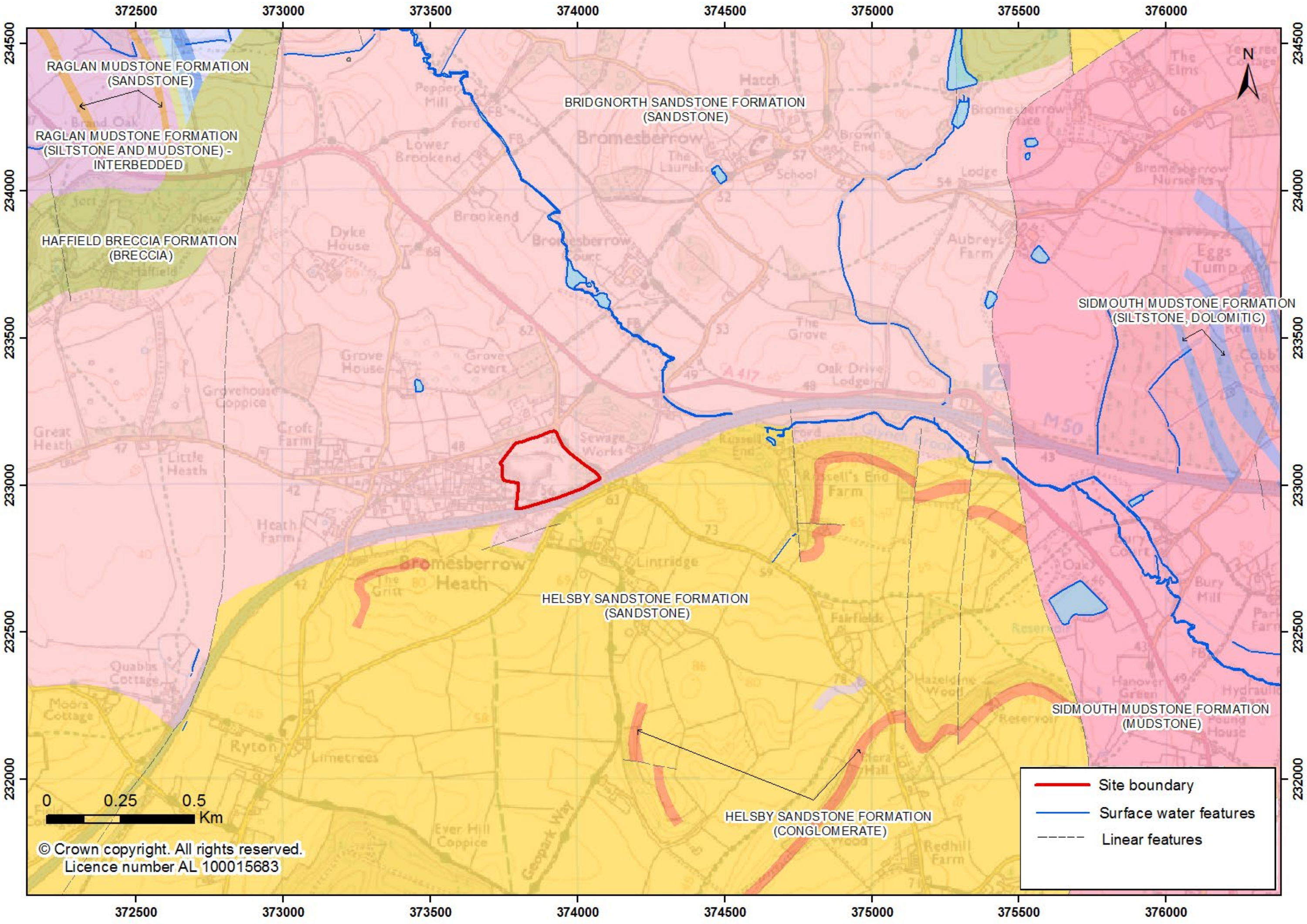


Figure 2.2 Bedrock geology



Interbedded within the sandstone of the Helsby Sandstone Formation there are isolated beds of conglomerate, as shown in orange on Figure 2.2. Approximately 1.6 km east from the Site, beyond a faulted north-south boundary, lies the Sidmouth Mudstone Formation. To the northwest of the Site, approximately 1.3 km away, the Haffield Breccia Formation extends westwards. This formation comprises Lower Palaeozoic breccia-conglomerate.

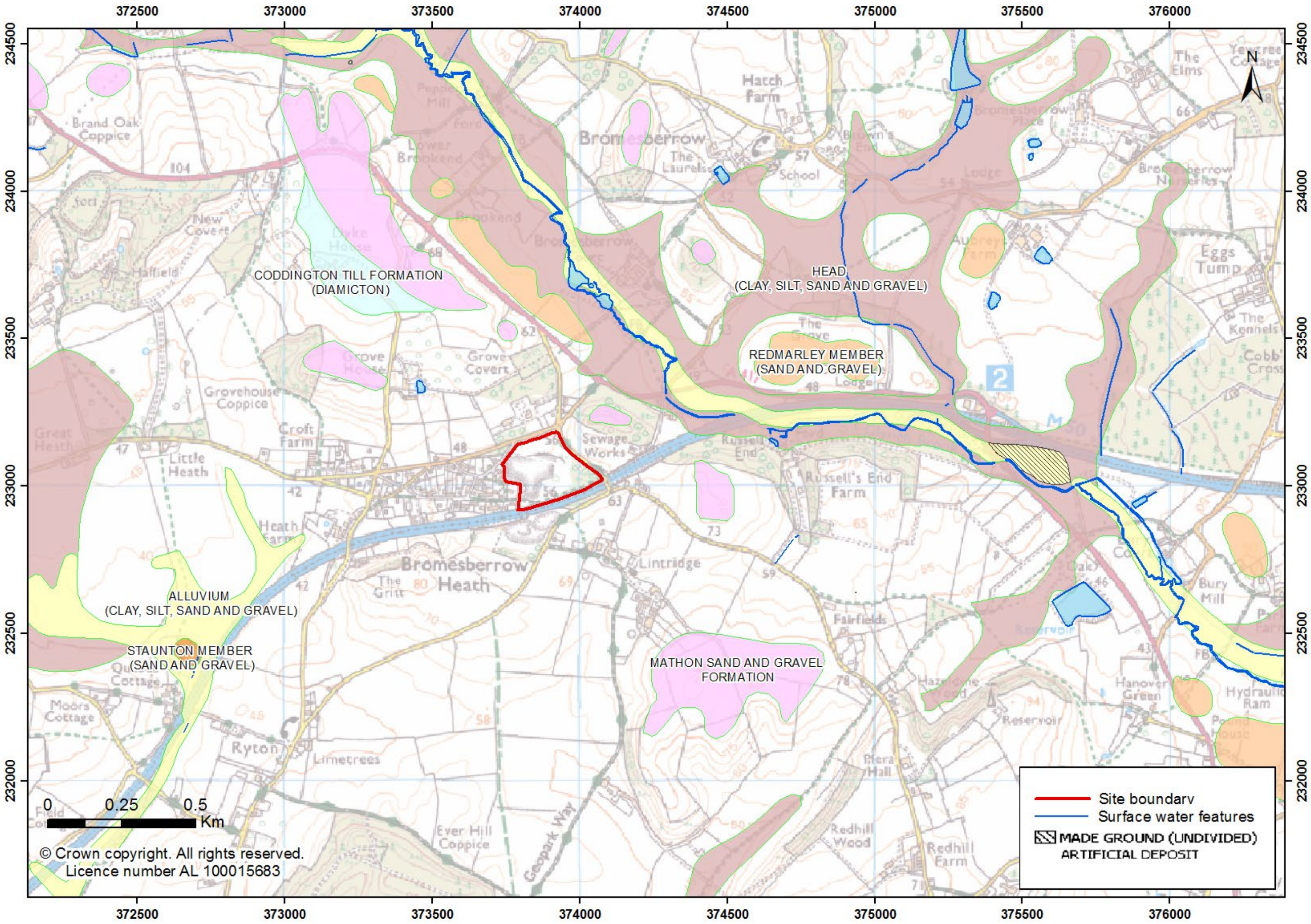
There are two main faults at rockhead identified near the Site. To the east, one of these faults forms the boundary between the Bridgnorth Sandstone and Sidmouth Mudstone Formations. At 1 km west, a parallel fault crosses the Bridgnorth Sandstone Formation north to south. However, the closest mapped fault to Site is an inferred one approximately 150 m south, beyond the M50, extending west to east for approximately 280 m. Three additional minor faults, parallel to each other, are identified crossing the Helsby Sandstone Formation in a north-south direction, the closest one being approximately 720 m east from the Site.

Superficial deposits

According to available mapping (BGS, 2021), there are no superficial deposits underlying the Site (Figure 2.3). The closest superficial deposits, defined as Mathon Sand and Gravel Formation, are found as isolated pockets, with the closest being approximately 200 and 400 m east of the Site. These date from the Anglian Stage and are described as basal gravels overlain by red cross-bedded sands with coal debris on foresets; locally overlain by an upper gravel. Sand and gravel, locally with lenses of silt, clay or peat. Beyond this, Head deposits (clay, silt, sand and gravel) extends northwest to southeast, which is crossed by Alluvium (also clay, silt, sand and gravel) alongside the Glynch Brook. Other superficial deposits in the vicinity of the Site are the Redmarley Member and the Staunton Member, both comprised by sand and gravels, and the Coddington Till Formation (diamicton) at approximately 0.6 km northwest.

Artificial deposits (Made Ground) are identified approximately 1.5 km east to the Site, between the M50 junction and Glynch Brook. These are described as an area where the pre-existing (natural or artificial) land surface has been raised by artificial deposits. The purpose of the Made Ground is unspecified (variable composition).

Figure 2.3 Superficial geology



2.2.2 Local geology

There are several records of historical BGS borehole logs near the Site (BGS, 2021); however, the closest ones adjacent to the north boundary are confidential and therefore no information can be retrieved. Near Bromsberrow Court, at approximately 0.60 km northeast of the Site boundary, there is an available record (ref. SO73SW31 on Figure 2.4) from 2013 which shows the geological strata detailed in Table 2.1.

Table 2.1 BGS borehole log (ref SO73SW31)

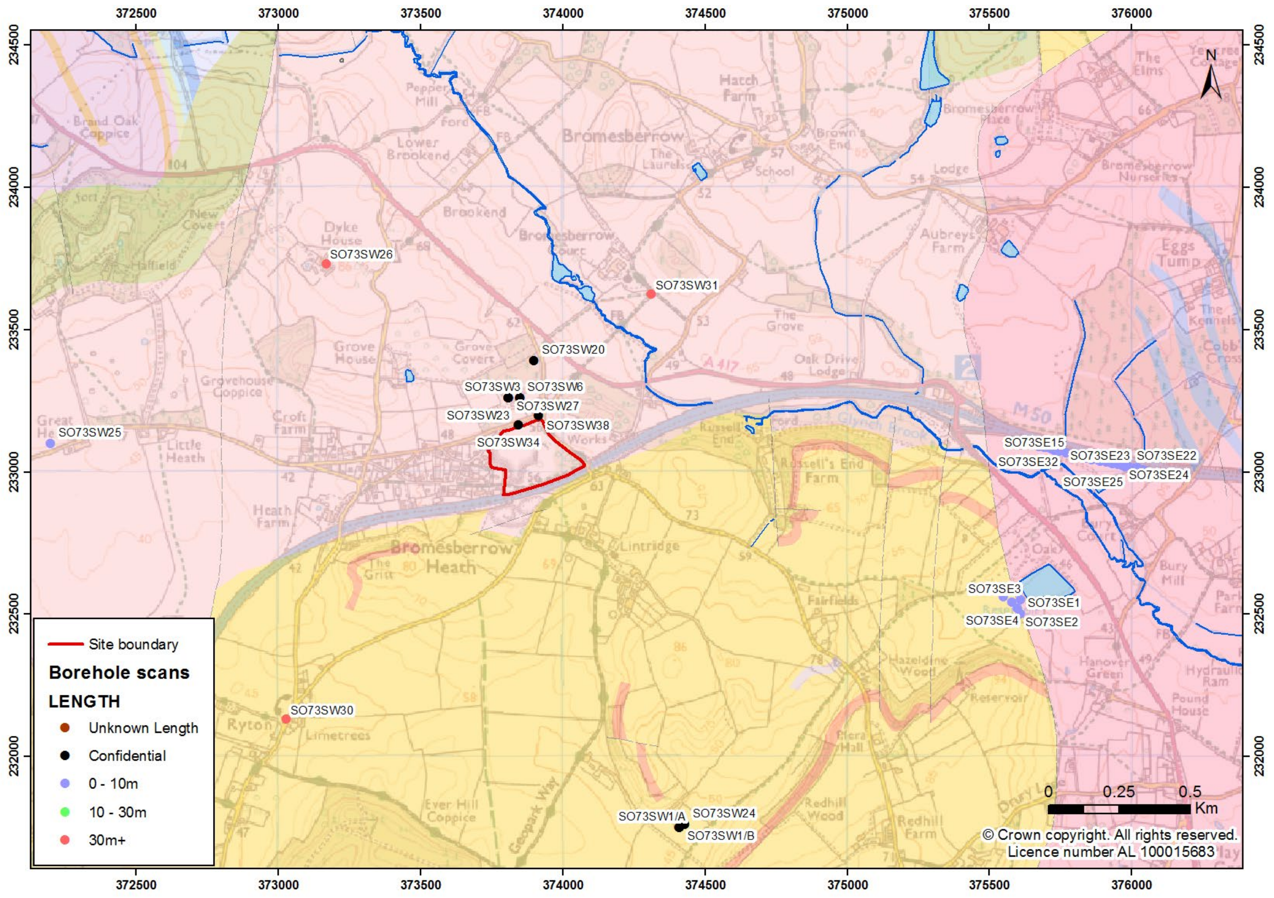
From (m bgl)	To (m bgl)	Description
0	0.3	Topsoil: Soft brown sandy silt with humus.
0.3	1.2	Brown slightly silty SAND with occasional medium sub angular gravels of sandstone.
1.2	6.0	Brick red SAND with occasional lithorelicts of sandstone. (Weathered Bridgnorth Sandstone).
6.0	50.0	Extremely weak, brick-red, fine- to medium-grained, thinly cross-bedded SANDSTONE (Bridgnorth Sandstone).

Note: m bgl (metres below ground level)

Groundwater was recorded as first struck at 21 m below ground and rose to 18.6 m bgl.

A series of seven monitoring boreholes were installed at Bromsberrow North in 2021 to depths between 20 and 35 mbgl: these encountered red sand overlain by 1.2m of Made Ground in some locations (Stantec, 2024c). Three additional boreholes were drilled in 2022 in the base of the quarry; these encountered red brown sandstone. The drilling logs and installation records (provided in Stantec (2024b)) and the depths and locations are summarised in Table 2.5.

Figure 2.4 Historical borehole locations



2.2.3 Infilled ground/landfilling

There is only one record for an authorised landfill (landfill sites that are currently authorised by the EA under Environmental Permitting Regulations) within 3 km of the Site.[2] This landfill, related to the (now restored) Bromsberrow South Sandpit, is located around 35m from the southern Site boundary, beyond the M50, and is categorised as inert (EP no. EPR/JP3698VP).

The landfill is shown in Figure 2.5 and further details are provided in Table 2.2. Figure 2.5 also shows neighbouring properties to the Site as well as main roads.

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[2] Environment Agency data indicate a historical landfill at the same location.

Figure 2.5 Historical & operational landfills within a 3 km radius of the Site

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Table 2.2 Historical and operational landfills within 3 km radius of the Site

Landfill	Operator	Status	Distance from Site	Waste Accepted	Area (ha)
Bromsberrow South (**EP no. EPR/JP3698VP)**	Terra Firma (Gloucestershire) LLP	Restored	c. 35 m south	Inert	c. 2.39

2.3 Hydrology

2.3.1 Rainfall

The Site is located in the east of MORECS square 147; the monthly long-term average (LTA) rainfall and actual evapotranspiration data calculated for crop type grass with medium AWC over the period 2000-2023 is presented in Table 2.3.

Table 2.3 MORECS data for square 147 (crop type: grass with medium AWC ; period 2000-2023)

Month	Monthly LTA rainfall (mm)	Monthly LTA actual evapotranspiration (mm)
Jan	74.4	15.5
Feb	63.6	20.3
Mar	60.1	39.6
Apr	52.7	62.3
May	66.1	84.7
Jun	60.7	84.8
Jul	69.0	73.3
Aug	69.6	65.0
Sep	57.3	49.6
Oct	97.2	32.9
Nov	88.2	19.5
Dec	89.3	13.4
Annual average	**848.4**	**560.4**

2.3.2 Surface water features

Watercourses

Figure 2.6 shows the surface watercourses within 2 km radius of the Site. Each watercourse is described in more detail in Table 2.4.

The vast majority of the Site lies within the Glynch Brook catchment area (ID GB109054039620) which occupies an area of 45.69 km^2 (UK Centre for Ecology and Hydrology, 2021). However, a small area of the western boundary lies within River Leadon catchment area (ID GB109054032511), which occupies an area of 66.26 km^2.

The Site lies within the River Leadon operational catchment area and Severn Vale management catchment area. The Glynch Brook is the closest watercourse to the extraction area, which runs in a north-to-southeast direction approximately 400 m east of the eastern boundary of the Site. Glynch Brook headwaters rise at Eastnor Lake, Ledbury and it flows in a southerly direction until it joins downstream with Wynd Brook, near Lowbands, to finally confluence with the River Leadon approximately 6 km southeast of the Site. The Glynch Brook has a total length of 18.87 km.

According to the EA (2021), in 2019 this watercourse was classified as having a "Moderate" status with regard to its condition, meaning that a greater level of protection and management is needed if it is to improve to a good level of health. High levels of phosphate were identified within the watercourse, likely to be derived from continuous sewage discharge.

The River Leadon, categorised as a main river, runs near the Site. It is a tributary of the River Severn. It rises near the village of Evesbatch, Worcester and flows south and east past Dymock, Upleadon and Highleadon to join the Severn at Over, just west of Gloucester. The closest section of the river to Site is located c. 2.3 km southwest of the Site. The river is approximately 29 km long.

Table 2.4. Watercourses within 2 km of the Site

Name	Type	Distance from extraction area	Description
A	Drain / Ditch	c. 780 m southeast	Constructed along a path off Bromsberrow Road, located at the bottom of Wyevale Transplants. A tree line is identified along the length of the ditch.
B	Spring/ stream	c. 1.2 km southwest	Associated with Quabbs Cottage fields on the upper part and followed by trees. It is intersected by the M50, and presumably joins the motorway drainage.
C	Spring/ stream	c. 1.7 km west	Isolated stream between fields, c.50 m long, presumably runs into field drains.
D	Stream tributary of the River Leadon	c. 1.9 km northwest	It rises near Smallends Farm and flows westwards for approximately 2.1 km to its confluence with the River Leadon.
E	Spring / Stream tributary of the Glynch Brook	c. 1.7 km northwest	Likely to be a seasonal stream, as the majority of it appears dry on aerial photographs and it is levelled with the surrounding terrain. It splits in three overground sections with a spring between the further two sections. It flows approximately eastwards for 1.3 km to its confluence with the Glynch Brook.
F	Stream tributary of the Glynch Brook	c. 1.3 km north	It rises at Toney's Coppice where the terrain is more elevated and flows for approximately 1.7 km to confluence with the Glynch Brook.
G	Stream tributary of the Glynch Brook	c. 1.10 km northeast	This stream rises at Pendock's Grove woodland, where the terrain is more elevated, and flows in a southward direction forming a series of ponds in course until its confluence with the Glynch Brook. It also collects a few minor streams on its way. Its total length is approximately 3.4 km.
H	Ditch / stream tributary of the Glynch Brook	c. 1.7 km east	It borders Cobb's Cross woodland along the western side for approximately 600m downstream. It is crossed over by the M5,

Name	Type	Distance from extraction area	Description
			however there are no signs of this being culverted.

Other water bodies

The extraction area is located almost entirely within the catchment area of the Glynch Brook and therefore the majority of the water bodies are associated with this stream or its affluents. The closest water body however appears to be man-made.

Figure 2.7 shows other surface waterbodies within a 2 km radius of the Site, which are described in more detail in Table 2.5.

Table 2.5 Waterbodies within 2 km of the Site

Name	Type	Size (area)	Distance from extraction area
I	Likely to be an artificial pond	c.1027 m^2	400 m northwest
J	Pond raised by a tributary of the Glynch brook	c.900 m^2	660 m east
K	Reservoir	c.12,800 m^2	1.6 km southeast
L	Spring	c.437 m^2	1.8 km south
M	A series of isolated ponds	Ranging from c.600 m^2 to 1300 m^2	1.4 to 1.8 km northeast
N	Likely to be an artificial pond. Bordered by mature vegetation	c.800 m^2	1.0 km northeast
O	Reservoir	c 6900 m^2	1.6 km northeast
P	Ponds raised by a tributary of the Glynch brook (watercourse G)	c.14,370 m^2	1.8 km northeast

Figure 2.6 Surface watercourses within 2 km of the Site

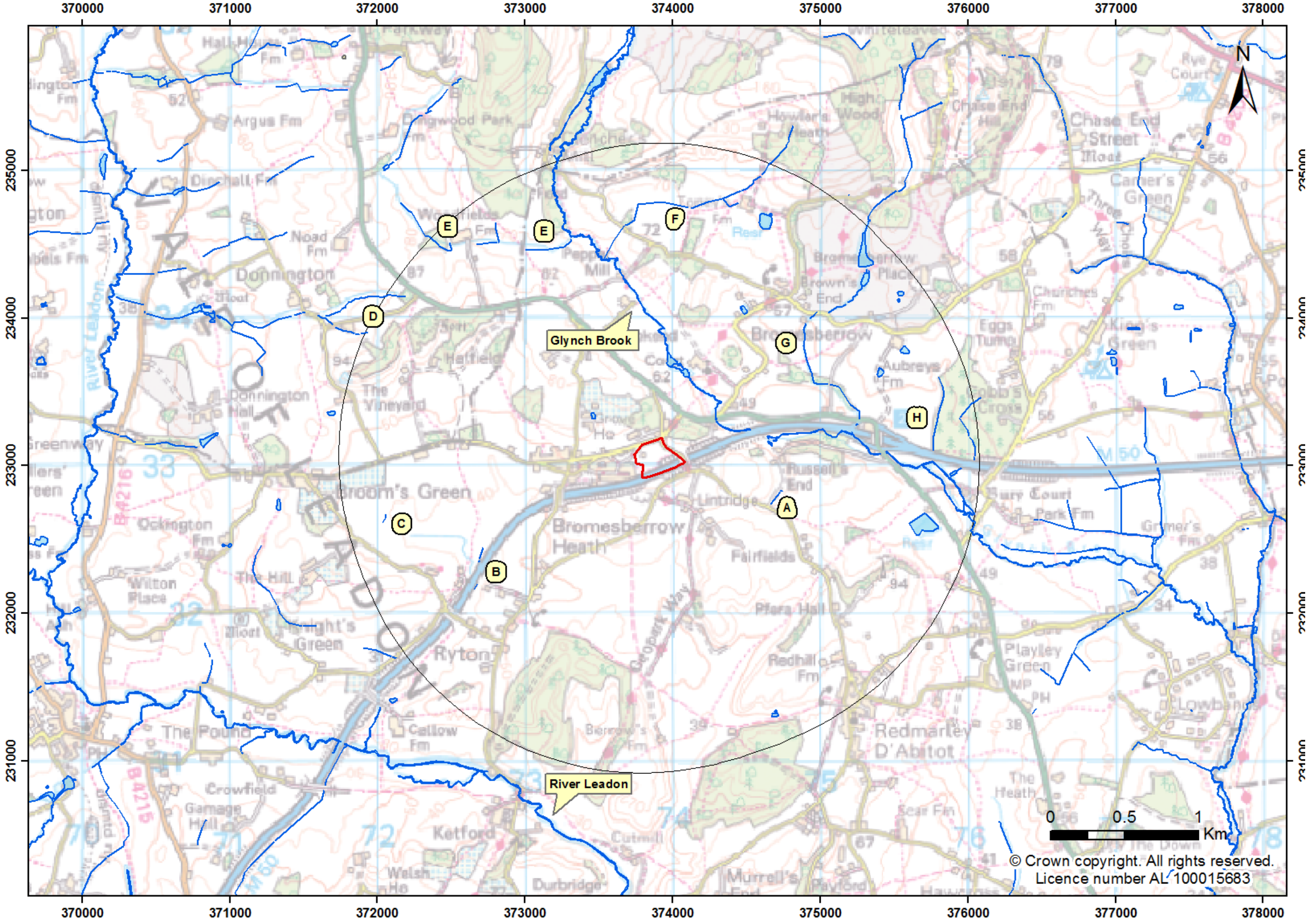
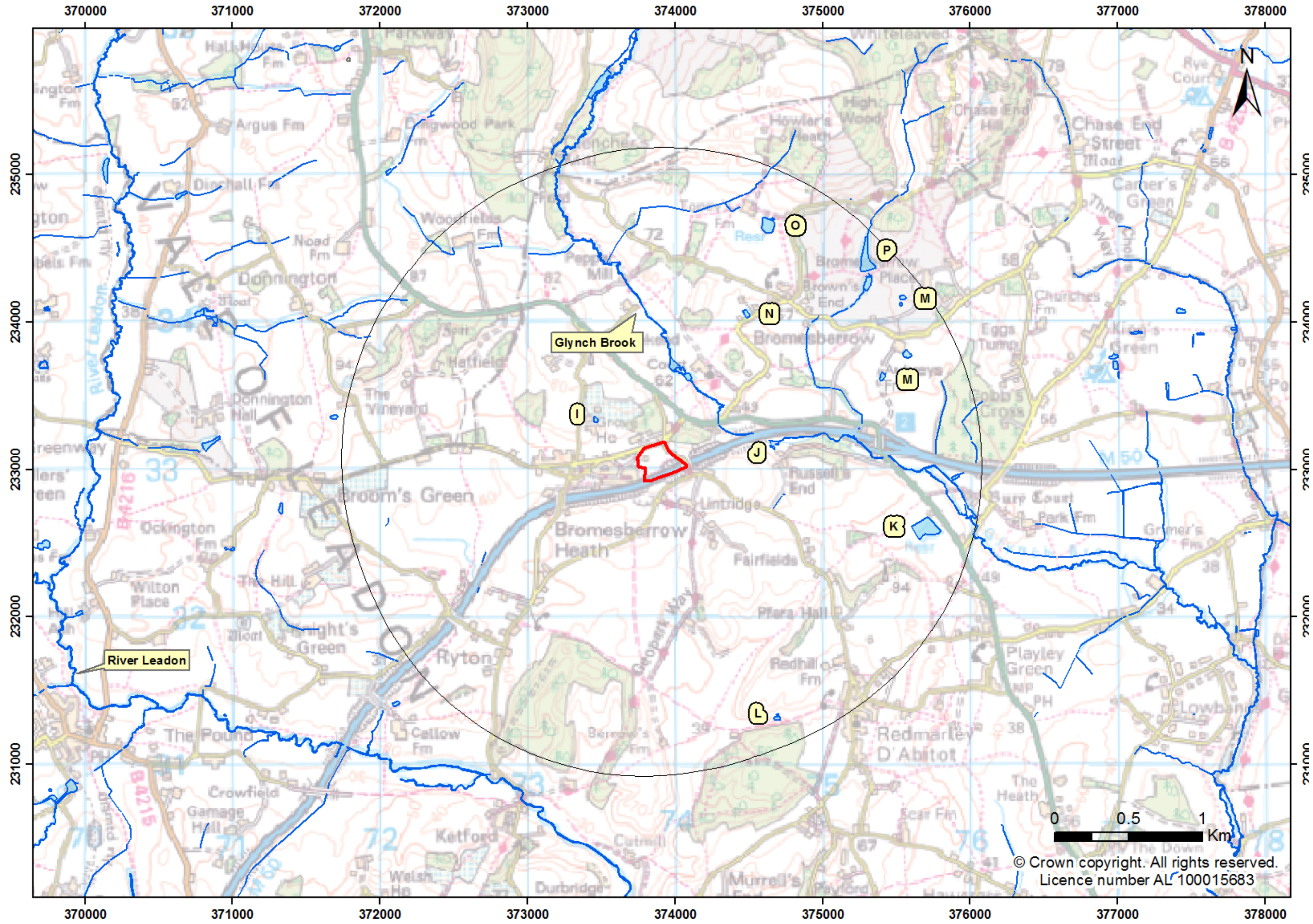


Figure 2.7 Other water bodies within 2 km of the Site



2.4 Hydrogeology

2.4.1 Groundwater classifications and systems

The bedrock underlying the Site is the Bridgnorth Sandstone Formation (sandstone), which is classed as a Principal Aquifer by the EA. A Principal Aquifer means layers of bedrock or drift deposits that have high intergranular and/or fracture permeability, meaning they usually provide a high level of water storage. They may support water supply and/or river baseflow on a strategic scale. This geological stratum has a thickness of 183 m and is underlain by Coal Measures.

The entire extraction area of the Site lies within Zone II of the Source Protection Zone (SPZ) for Bromsberrow Public Water Supply (PWS) which lies to the north of the site with the northern boundary lying immediately next to SPZ Zone I.

The aquifer is a highly productive sandstone, with some conglomerates, yielding up to 25 L/s further north in the Eden and Clwyd valleys (Allen, et al., 1997). Geological dip is generally southerly (measured at 8 degrees in Bromsberrow South Sandpit (BGS, 1988) and natural groundwater flow is expected to follow the dip and the regional topography, south and east towards the River Severn valley. However, more locally groundwater flow is expected to run northwards due to abstraction from the PWS to the north of the Site.

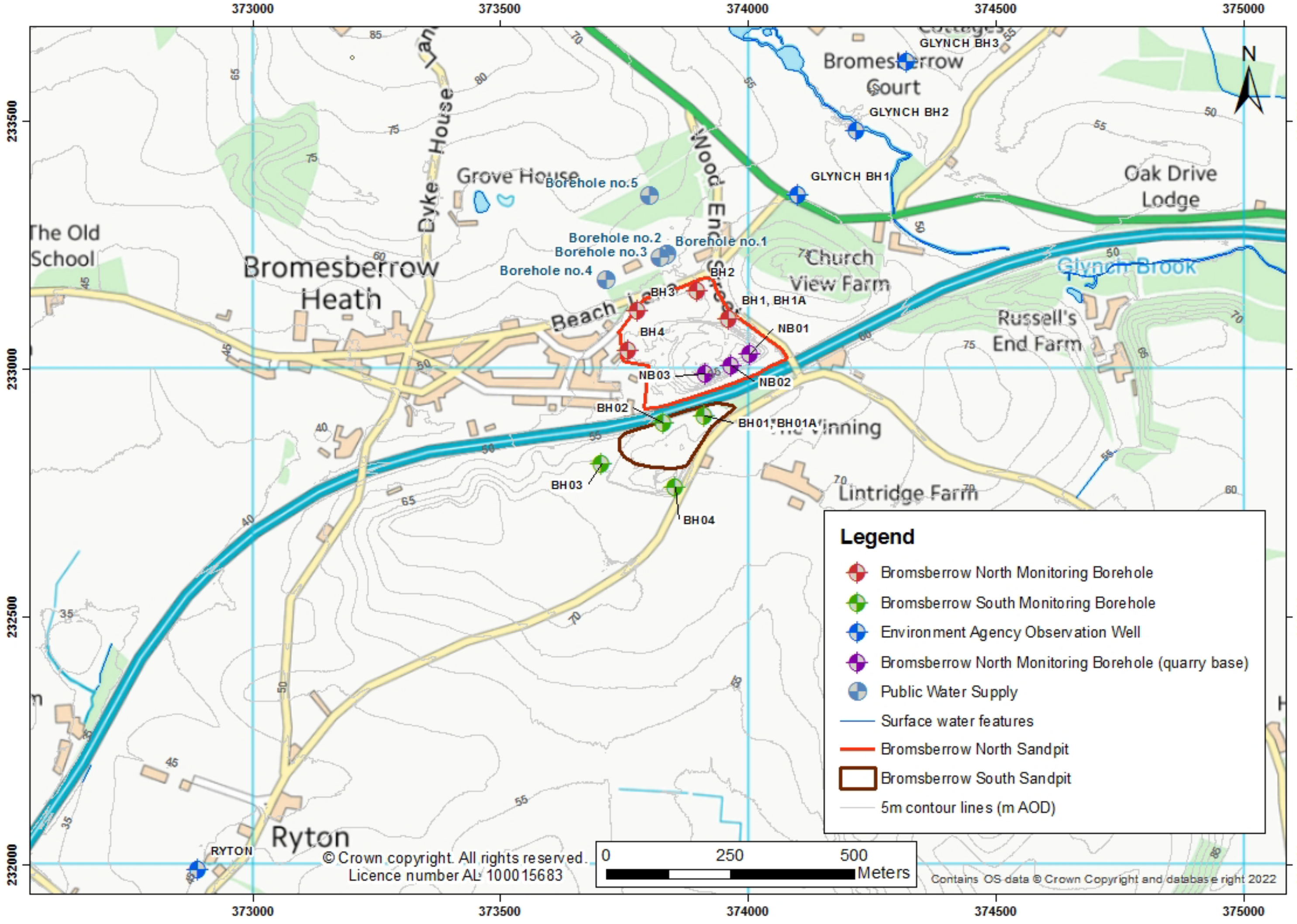
Dewatering is not anticipated to occur at the Site as the extraction of sands will remain above the water level below the base of the sandpit.

2.4.2 Groundwater levels and flow

Available data

Four combined groundwater and gas monitoring points (BH01 - BH04) were installed around Bromsberrow South quarry, approximately 100 to 250 m south of the Site, in 2008 (Figure 2.8). These boreholes monitor the sandstone water table.

Figure 2.8 Groundwater monitoring points at Bromsberrow



Groundwater levels recorded from these locations, with associated reports, have been provided by Allstone.

Four new monitoring boreholes (BH01, BH02, BH03 and BH04) were installed in August and September 2021 at the Site; these are also shown on Figure 2.8 and detailed in Table 2.5. These boreholes were installed to 35 m depth and the drillers noted standing water levels between 24 and 30 mAOD. In addition, three shallower boreholes BH01A, BH02A and BH04A were installed adjacent to BH01, BH02 and BH04 respectively for gas monitoring purposes and are not considered further for the purpose of this HRA.

In December 2023 three additional boreholes (NB01, NB02 and NB03) were installed at the Site in the quarry base adjacent to the southern boundary; these are also on Figure 2.8 and detailed in Table 2.6.

Table 2.6 Summary of groundwater level data within the Site after drilling

Borehole	East (m)	North (m)	Depth (m)	Datum Elevation (mAOD)	GW Dips after drilling (mbgl)	Calculated GW Level (mAOD)
BH01	373960.4	233100.0	35	57.58	27.32	30.26
BH02	373898.2	233157.9	35	54.61	25.84	28.77
BH03	373778.0	233118.0	35	50.71	26.89	23.82
BH04	373757.9	233036.5	35	48.83	20.00*	28.83
NB01	374004	233030	10	36.37	5.3*[1]	31.07
NB02	373966	233007	10	35.83		30.53
NB03	373914	232989	10	36.53		31.23

*Strike to water.

[1]One strike recorded on driller log for all 3 boreholes.

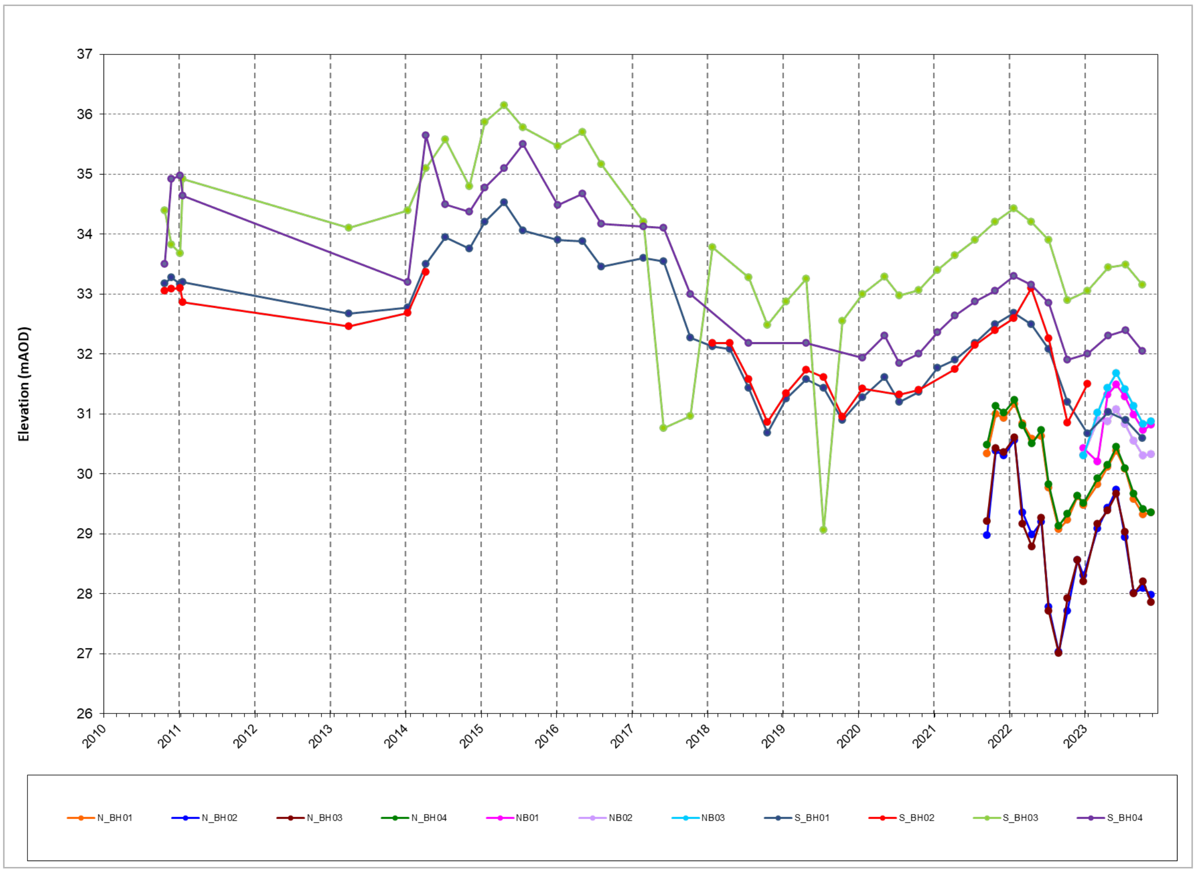
Figure 2.9 shows the available data from Bromsberrow South and Bromsberrow North. Groundwater levels at Bromsberrow South have a typical annual range of about 1 m, with larger interannual variations, which, based on Stantec's experience, is not untypical of the Permian sandstone. The temporal trends appear similar at the four boreholes, with the highest levels recorded in 2015 and the lowest in 2018-19 and 2022 when similar lows were recorded. The interannual variations are presumably influenced by rainfall patterns and the pumping regime at the nearby abstraction boreholes. It is likely that the measurements for BH03 at Bromsberrow South in June and October 2017 and July 2019 have been recorded incorrectly given that a similar trend is not observed at the remaining boreholes at Bromsberrow South.

Groundwater level data have been monitored at the Site in BH01 to BH04 since September 2021; the recent data shown in Figure 2.9 indicates that the average groundwater level at the

Site is approximately 4 m below the average groundwater level at Bromsberrow South. The lowest levels were recorded in 2022 in line with those in Bromsberrow South.

Groundwater level data have been monitored at the Site in NB01 to NB03 since January 2023; the recent data shown in Figure 2.9 indicates that the average groundwater level along the southern boundary of the Site is between levels in the north of the Site and levels at Bromsberrow South by approximately 1-2 m. It is noted that the groundwater levels at Bromsberrow South BH01 have been approximately an additional 1 m below the groundwater levels at Bromsberrow South BH03 since 2023 and are also below the groundwater levels at NB01 and NB03.

Figure 2.9 Groundwater levels from Bromsberrow South and Bromsberrow North between 2010 and 2023



Bromsberrow South, like the Site, lies within Zone II of the Source Protection Zone for Bromsberrow PWS, located at the north of both extraction areas; therefore, it is considered likely that the PWS abstraction will influence groundwater levels and flow directions in the vicinity of both Bromsberrow South and the Site.

Figure 2.10 shows that the water level at the PWS varies between about 20 and 32 mAOD between 2010 and 2020, while the average for the PWS boreholes is 27 mAOD for the same period of time. Figure 2.11 shows the hydrographs for the EA observation boreholes between 1996 and 2023 (locations shown in Figure 2.8).

Figure 2.10 Groundwater levels in PWS

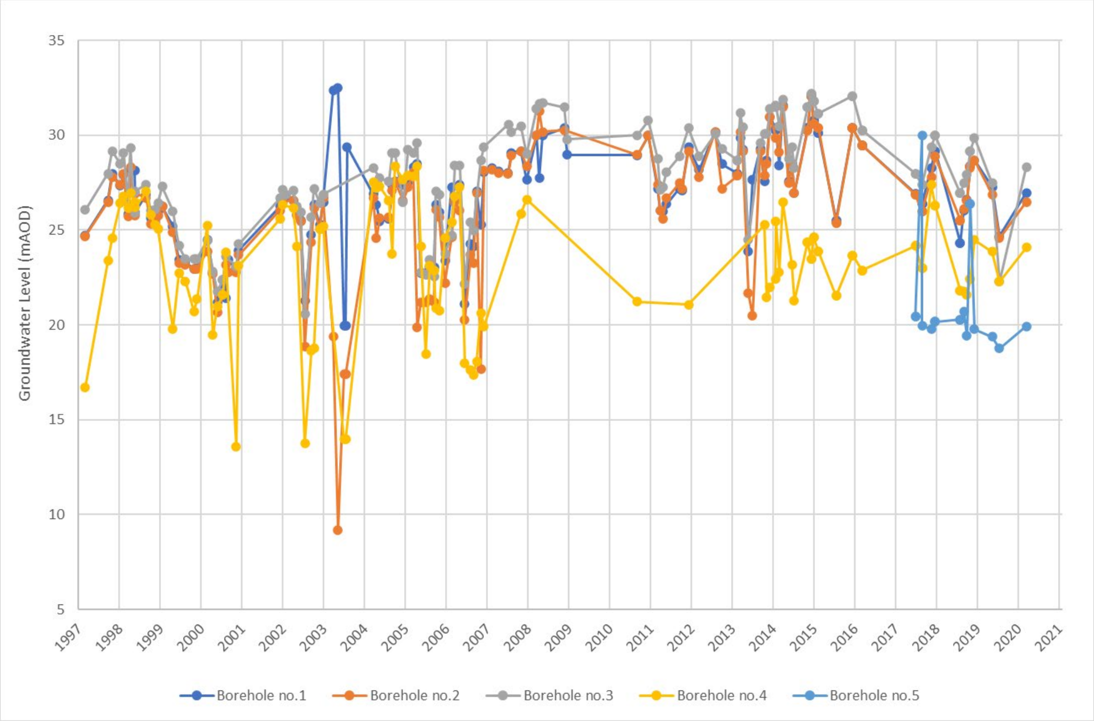
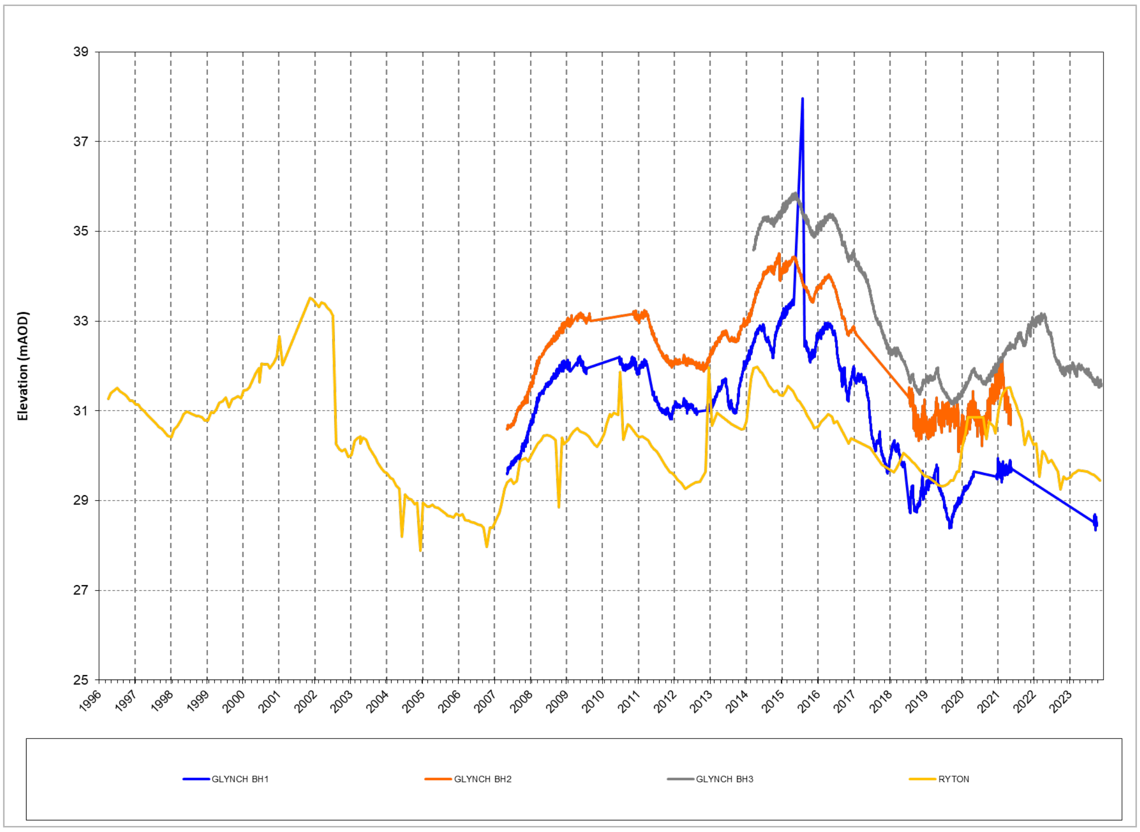


Figure 2.11 Groundwater levels in Environment Agency Observation boreholes



Groundwater flow

Considering the local groundwater levels and topography, the natural groundwater regime is likely to involve recharge over large parts of the sandstone (which has no significant superficial cover over the outcrop) with flow towards the lowest part of the unit outcrop and discharge in the valley of the River Leadon, which runs at an elevation below 25 mAOD approximately 2.5 km south of the Site. The Glynch Brook valley to the north-east lies at around 45 to 50 mAOD and is likely to be above the natural water table.

However, the effect of abstraction at Bromsberrow PWS is to draw water from around the Site area and beyond (as indicated by the SPZ shape) and in the context of this pumping it is believed that groundwater beneath the Site moves towards the northwest. This is indicated by the comparative groundwater levels at Bromsberrow North and South, at the EA Observation Wells, and at Bromsberrow PWS (shown on Figure 2.12 for low groundwater levels and Figure 2.13 for high groundwater levels). Note that as there is no data for the boreholes at Bromsberrow North until 2021 the levels at these boreholes were estimated by using data from October 2023 for the low levels as groundwater levels for this month are similar to levels in October 2019. The groundwater levels for Bromsberrow North during April 2015 were estimated based on differences between groundwater levels at Bromsberrow South and Bromsberrow North boreholes.

Inspection of the contours presented on Figure 2.12 and Figure 2.13 also indicates the presence of a groundwater divide located between the Bromsberrow South site and the Ryton observation borehole.

A summary of the groundwater levels, unsaturated zone thickness and difference in groundwater levels between Bromsberrow South, the northern site boundary of Bromsberrow North and the PWS for the 2015 (high groundwater levels) and 2019 (low groundwater levels) is presented in Table 2.7. These data show the groundwater levels and hence the unsaturated zone thickness can vary by approximately 4 m between maximum and minimum observed groundwater levels.

The distance between boreholes BH03 and BH04 at Bromsberrow South and the PWS is in the order of 340 m, giving an average hydraulic gradient of 0.026 during low groundwater levels and 0.020 during high groundwater levels; however, it is expected that the hydraulic gradient steepens towards the PWS because of the abstraction.

Table 2.7 Summary of groundwater levels and unsaturated zone thickness

	High groundwater levels (2015)	Low groundwater levels (2019)
Average groundwater levels (maOD)		
Bromsberrow PWS (BH01-BH04)	28.87	23.45
Bromsberrow South (BH01 and BH02)	34.28	30.93
Bromsberrow South (BH03 and BH04)	35.63	32.25
Bromsberrow North (NB01 - NB03)	34.39	30.62
Bromsberrow North (BH01 and BH04)	33.45	29.37
Bromsberrow North (BH02 and BH03)	32.55	28.15

	High groundwater levels (2015)	**Low groundwater levels (2019)**
Unsaturated zone thickness (m)		
Bromsberrow North (NB01 - NB03)	1.61	5.38
Bromsberrow North (BH01 and BH04)	2.55	6.64
Bromsberrow North (BH02 and BH03)	3.45	7.85
Difference in groundwater levels (m)		
Bromsberrow South BH03 and BH04 to Bromsberrow North BH03 and BH02	3.08	4.16
Bromsberrow South BH03 and BH04 to Bromsberrow PWS (BH01-BH04)	6.75	8.80

Figure 2.12 Interpreted groundwater level contours representing low levels (from October 2019)

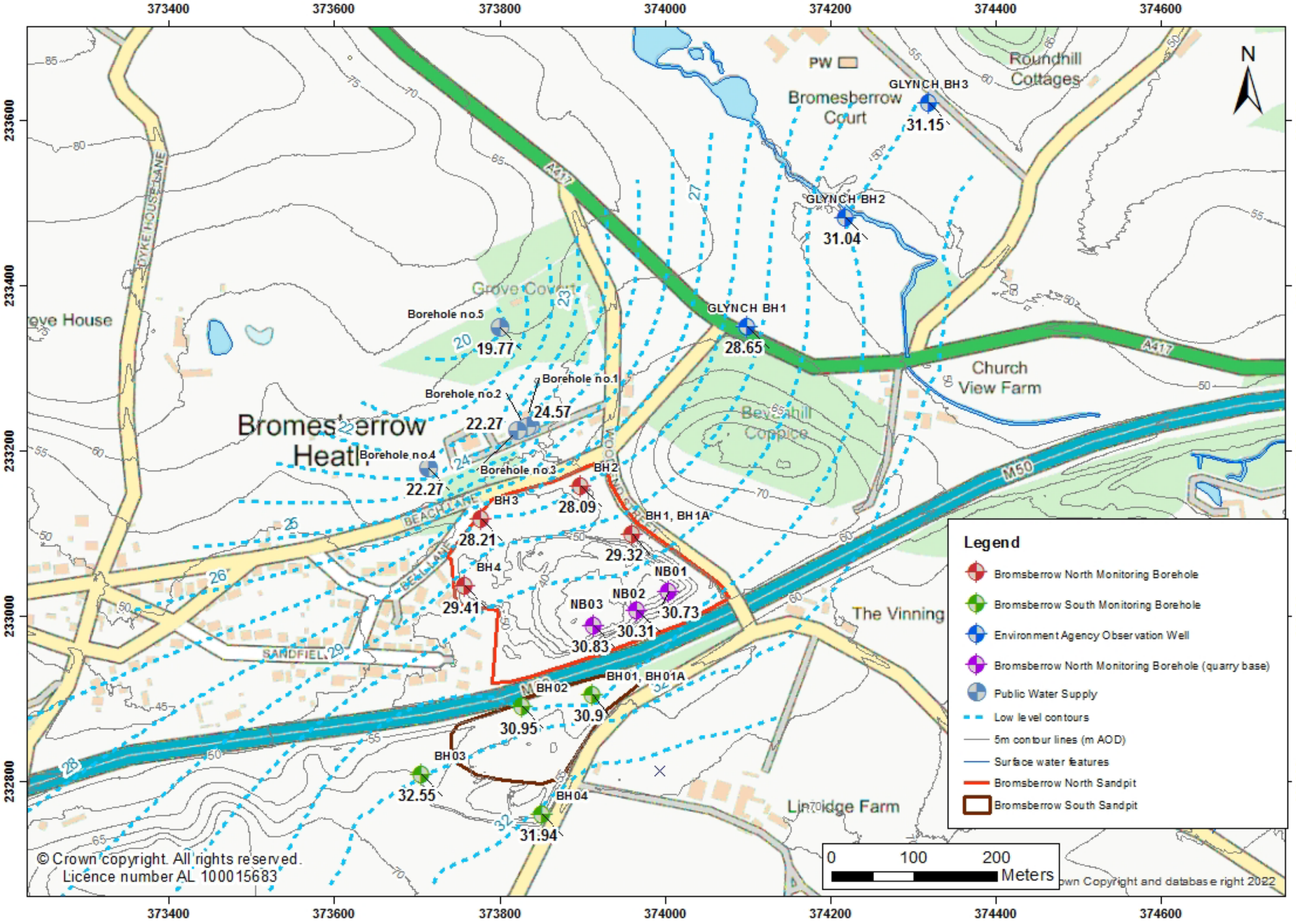
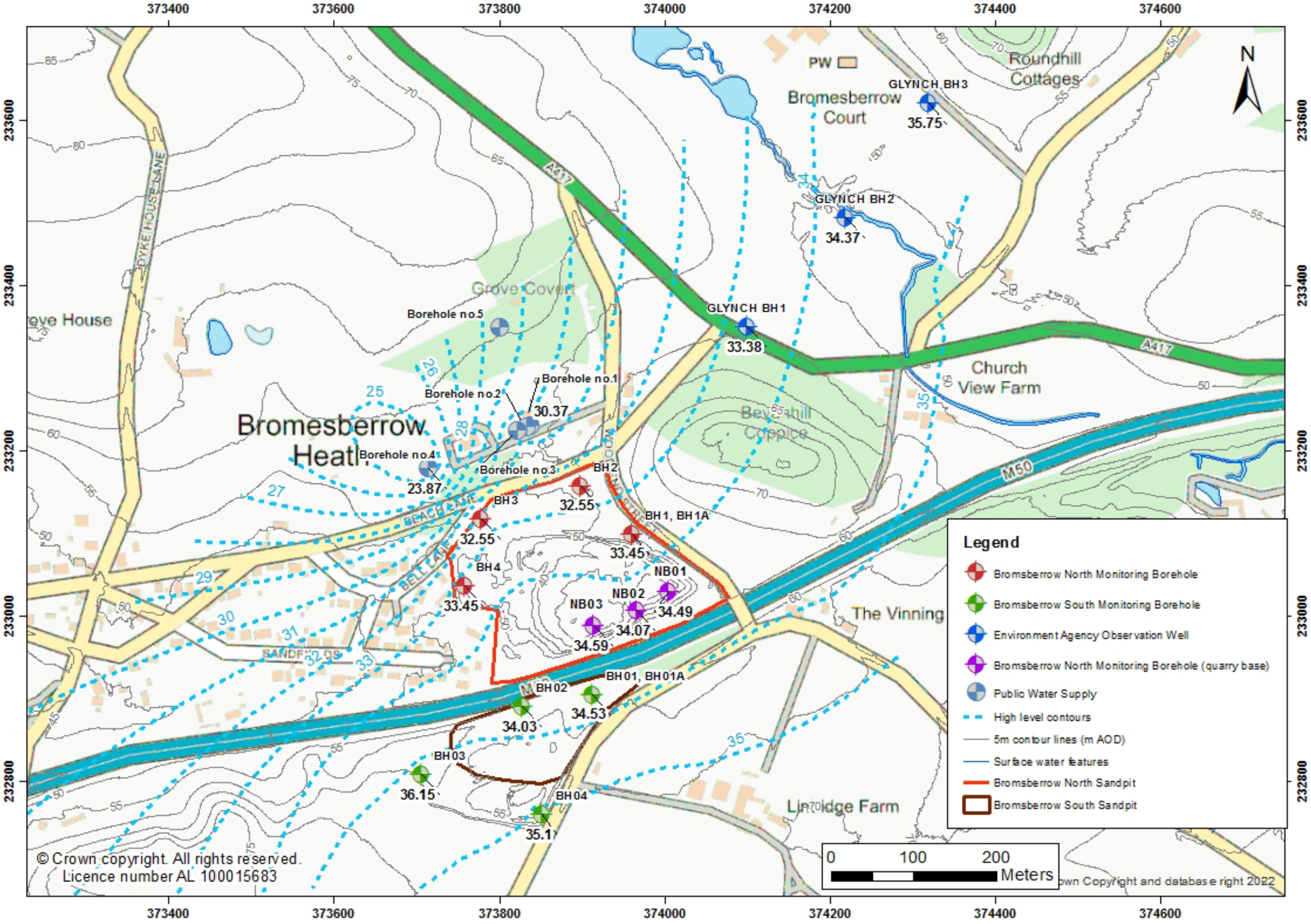


Figure 2.13 Interpreted groundwater level contours representing high levels (from April 2015)



2.4.3 Aquifer properties

The Bridgnorth Sandstone is a Principal Aquifer, with correspondingly high values for porosity and hydraulic conductivity. Groundwater flow occurs mainly via intergranular movement. The major aquifer property manual (Allen, et al., 1997) gives ranges of hydraulic conductivity and total porosity as presented in Table 2.8 and Table 2.9.

Table 2.8 Hydraulic conductivity of the Bridgnorth Sandstone

Orientation	Range (m/d)	Interquartile range (m/d)	Median (m/d)	Geometric mean (m/d)
Unspecified	2.5*10^{-4} to 9.4	1.1 to 4.01	1.95	0.95
Horizontal flow	-	1.4 to 5.07	2.6	1.43
Vertical flow	-	0.81 to 2.22	1.4	0.36

Table 2.9 Total porosity of the Bridgnorth Sandstone

Range	Interquartile range (%)	Median (%)	Arithmetic mean (%)
16.6 to 33.6	27.5 to 31.8	29.5	28.4

The aquifer is expected to be relatively homogeneous in the area local to the Site, with significant vertical as well as horizontal conductivity. No geological faulting is mapped close to the Site, with the exception of a minor east-west trending fault that crosses Bromsberrow South Sandpit.

2.4.4 Licensed water abstractions and discharges

The area classed as SPZ Zone I, adjacent to the northern boundary of the extraction area, is associated with PWS boreholes operated by STWL. that are located within the premises to the north of the Site, beyond Beach Lane. The borehole licences are all for abstractions up to a total of 2,821,000 m^3/a. A detailed description of these PWS abstractions is presented in Table 2.10.

Table 2.10 Licensed abstractions at Bromsberrow PWS

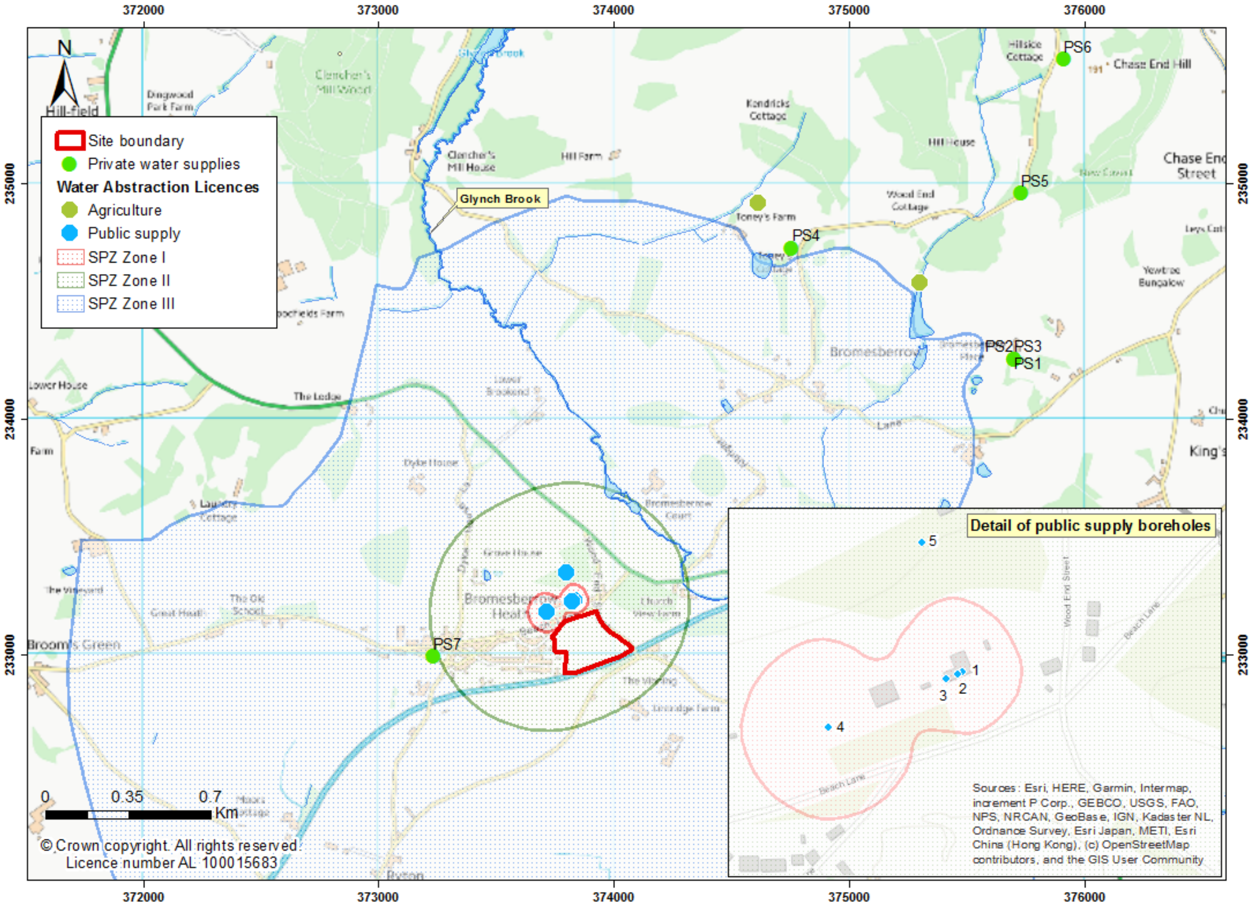
ID (figure)	1	2	3	4	5
Location name	BH1 - C	BH2 - D	BH3 - E	BH4 - F	BH5 - G
Distance from extraction area	71 m north	71 m northwest	70 m north	82 m north	196 m north
Licence No.	18/54/21/0116				
Description	Public Water Supply				
Use description	Potable Water Supply - Direct				
Source type	Groundwater				
Maximum Annual Quantity (m^3)	2,821,000				
Maximum Daily Quantity (m^3)	11,592				

The EA has defined SPZs for groundwater sources such as wells, boreholes and springs used for public drinking water supply. These zones show the risk of contamination from any activities that might cause pollution in the area. The closer the activity, the greater the risk. The maps show three main zones (Zone I or inner, Zone II or outer and Zone III or total catchment).

Zone I is defined as the 50-day travel time from any point below the water table to the source (this zone has a minimum radius of 50 metres), whereas Zone II is defined by a 400-day travel time from a point below the water table.

Figure 2.14 shows the defined SPZ associated with the public water abstraction boreholes situated in the vicinity of the Site.

Figure 2.14. Source protection zones and neighbouring water supplies



2.5 Groundwater quality

Groundwater quality is monitored at Bromsberrow South (upgradient to the Site) and at the Site boreholes. The available data (from 2010 to 2023) are summarised in Table 2.10 for Bromsberrow South and Table 2.11 for Bromsberrow North. Data for key determinands are presented graphically in Figure 2.15 to Figure 2.22. and time-series charts for determinands that are regularly above the limit of detected are presented in in Appendix B. The UK Drinking Water Standard[3] (UK DWS) concentrations as included on the charts where applicable.

Inspection of the data presented in Table 2.11 and Table 2.12 indicate that groundwater quality at Bromsberrow South is of a lower quality that at Bromsberrow North. The data presented on Figure 2.15 to Figure 2.22 and in Appendix B indicates that the highest concentrations are generally observed at Bromsberrow South BH02 for magnesium, calcium and sulphate and at Bromsberrow South BH01 for chloride, sodium, manganese and nickel. It was noted in the Stantec (2019) that the source of the high chloride and sodium concentrations at BH01 are likely due to the proximity of the borehole to the M50 motorway and it should be noted that the concentrations for each of these determinands was above the UKDWS before a significant volume of waste was accepted at Bromsberrow South.

Manganese concentrations are frequently below the UK DWS at Bromsberrow South and North with the exclusion of BH01 at Bromsberrow South. BH04 at Bromsberrow South has occasional spikes, notably in 2011 and more recently in 2021 and 2022, whilst BH04 at Bromsberrow North has been consistently above the UK DWS since monitoring began in 2020. Concentrations of iron regular exceeded the UK DWS at Bromsberrow South between 2012 and 2021 although concentrations have decreased significantly since the start of 2021. The average iron concentrations at Bromsberrow North is an order of magnitude lower than the UK DWS although there was one exceedance at NB01 in March 2023. It should be noted that both iron and manganese are naturally presented in sandstone and their aqueous concentrations are impacted by the geochemical conditions in the groundwater.

The concentrations of ammoniacal nitrogen are occasionally above the UKDWS at Bromsberrow South whilst concentrations at Bromsberrow North are regularly below the limit of detection.

STWL has provided groundwater quality data for the PWS boreholes and a summary of this data is presented in Table 2.13; time-series charts for determinands regularly above the limit of detection are presented in Appendix B. These data show that groundwater quality at the Bromsberrow PWS boreholes is good with nitrate being the only determinand with concentrations regularly above the UK DWS.

It is noted that agricultural activities adjacent to the Site could have an impact on groundwater quality. The nitrate concentrations at the PWS are known to have been impacted by such activities.

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[3] *Water Supply (Water Quality) Regulations 2016

Table 2.11 Upgradient groundwater quality summary from Bromsberrow South (2010-2023).

												UKDWS		
Determinand	No. of Results	Unit	Min	Max	Mean	Median	Standard Deviation	5th Percentile	95th Percentile	# > LOD	% > LOD	No. Exceeding	% Exceeding	Action Level
Field / lab parameters														
Conductivity- Electrical 20deg	140	µS/cm	95	3400	1251	795	1019	130	3100	140	100	24	17.14	2500
pH	140	pH Units	5.4	8.8	7.2	7.1	0.764	5.9	8.51	140	100	20	14.29	9.5
Major ions														
Alkalinity as CaCO3	140	mg/l	<3	570	104	76	96.3	n.d.	331	129	92.1	0	0	-
Calcium	140	mg/l	<5	430	95.4	67	89.3	12	301	139	99.3	0	0	-
Chloride	140	mg/l	5.9	1200	284	60	360	12	1000	140	100	40	28.57	250
Magnesium	140	mg/l	1.2	81	25.4	18	19.1	3.8	61.1	140	100	16	11.43	50
Potassium	140	mg/l	1.2	26	10.3	8.9	5.1	4	18.1	140	100	0	0	-
Sodium	140	mg/l	<0.5	3200	139	39	297	5.09	400	139	99.3	38	27.14	200
Sulphate as SO4	140	mg/l	4.5	810	102	35	178	7.6	562	140	100	18	12.86	250
Minor ions														
Cadmium	140	µg/l	0.02	2	0.216	0.08	0.323	n.d.	0.876	81	57.9	0	0	5
Chromium	140	µg/l	<0.2	43	6.83	3.9	8.86	n.d.	31	114	81.4	0	0	50
Copper	140	µg/l	0.6	19	2.76	1.75	3.07	n.d.	7.45	112	80	0	0	2000
Iron	139	µg/l	<5	9600	299	110	862	n.d.	1000	118	84.9	52	37.41	200
Lead	140	µg/l	<0.2	13	n.d.	n.d.	n.d.	n.d.	1.11	11	7.86	1	0.71	10
Manganese	140	µg/l	<1	1600	66.9	15	158	n.d.	180	129	92.1	49	35	50
Nickel	140	µg/l	<1	50	13.1	6.45	14	n.d.	42.1	126	90	40	28.57	20
Zinc	140	µg/l	<1	190	27.8	17.5	32.7	n.d.	91	132	94.3	0	0	-
Nitrogen species														

												UKDWS		
Determinand	**No. of Results**	**Unit**	**Min**	**Max**	**Mean**	**Median**	**Standard Deviation**	**5th Percentile**	**95th Percentile**	**# > LOD**	**% > LOD**	**No. Exceeding**	**% Exceeding**	**Action Level**
Ammoniacal Nitrogen as N	140	mg/l	<0.01	2.5	0.189	0.0505	0.365	n.d.	0.736	94	67.1	22	15.71	0.39
Nitrate as N	**9**	**mg/l**	**1.6**	**22.2**	**14.5**	**20**	**9.52**	**1.67**	**21.9**	**9**	**100**	**6**	**66.7**	**11.3**
Nitrate as NO3	140	mg/l	0.86	200	46.6	24.5	46.7	4.49	161	140	100	52	37.14	50
Nitrite as N	9	µg/l	<1	5.9	1.61	1.3	1.67	n.d.	4.18	6	66.7	0	0	30
Nitrite as NO2	140	µg/l	<5	1400	42.9	n.d.	150	n.d.	140	43	30.7	10	7.14	100
Landfill parameters														
TOC (filtered)	140	mg/l	0.89	79	8.69	5.95	10.3	n.d.	23.2	128	91.4	0	0	-
Hydrocarbons														
Aliphatics >C10-12	9	µg/l	<10	<10	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aliphatics >C12-16	9	µg/l	<10	<10	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aliphatics >C16-21	9	µg/l	<10	<10	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aliphatics >C21-35	9	µg/l	<10	<10	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aliphatics >C5-6	9	µg/l	<1	<1	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aliphatics >C8-10	9	µg/l	<1	<1	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aromatics >C10-12	9	µg/l	<10	<10	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aromatics >C12-16	9	µg/l	<10	<10	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aromatics >C16-21	9	µg/l	<10	<10	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aromatics >C21-35	9	µg/l	<10	<10	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aromatics >C5-7	9	µg/l	<1	<1	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aromatics >C7-8	9	µg/l	<1	<1	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aromatics >C8-10	9	µg/l	<1	<1	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
PAHs														
Acenaphthene	9	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Acenaphthylene	3	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Anthracene	9	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-

												UKDWS		
Determinand	**No. of Results**	**Unit**	**Min**	**Max**	**Mean**	**Median**	**Standard Deviation**	**5th Percentile**	**95th Percentile**	**# > LOD**	**% > LOD**	**No. Exceeding**	**% Exceeding**	**Action Level**
Benzo (g,h,i) perylene	9	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0		0	0	-
Benzo(a)anthracene	9	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Benzo(a)pyrene	9	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	0.01
Benzo(b)fluoranthene	9	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Benzo(k)fluoranthene	9	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Chrysene	9	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Dibenz-a-h-anthracene	9	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Fluoranthene	9	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Fluorene	9	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Indeno(1,2,3-cd)pyrene	9	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Naphthalene	9	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Phenanthrene	9	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Pyrene	9	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
BTEX														
Benzene	9	µg/l	<3	<3	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	9	100	1
Ethylbenzene	9	µg/l	<3	<3	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
m,p xylenes	9	µg/l	<3	<3	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
O-Xylene	9	µg/l	<3	<3	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Toluene	9	µg/l	<3	<3	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Other parameters														
Aliphatics & Aromatics >C5-35	9	µg/l	<10	<10	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aliphatics >C5-35	9	µg/l	<10	<10	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aliphatics >C6-8	9	µg/l	<1	<1	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Methyl tert-butyl ether (MTBE)	9	µg/l	<3	<3	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-

												UKDWS		
Determinand	No. of Results	Unit	Min	Max	Mean	Median	Standard Deviation	5th Percentile	95th Percentile	# > LOD	% > LOD	No. Exceeding	% Exceeding	Action Level
PAH, Total Detected USEPA 16	9	µg/l	<0.16	<0.16	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-

Note: if significant number of results that are detected exceed action limit row is coloured as follows: 10 - 25% pale red, 25 - 50% darker red, >50% dark red. n.d. statistic not determinable. Mean statistics for non-detects are calculated at half the limit of detection.
If significant number of results exceed action limit where some are non-detects the '% Exceeding' column is coloured as follows: 10 - 25% pale blue, 25 - 50% darker blue, >50% dark blue. n.d. statistic not determinable

Table 2.12 Groundwater quality summary from Bromsberrow North (2021 to 2023)

												UKDWS		
Determinand	**No. of Results**	**Unit**	**Min**	**Max**	**Mean**	**Median**	**Standard Deviation**	**5th Percentile**	**95th Percentile**	**# > LOD**	**% > LOD**	**No. Exceeding**	**% Exceeding**	**Action Level**
Field / lab parameters														
Conductivity- Electrical 20deg	100	µS/cm	240	890	526	540	135	270	711	100	100	0	0	2500
pH	100	pH	5.6	7.7	6.5	6.5	0.483	5.7	7.31	100	100	43	43	6.5-9.5
Major ions														
Alkalinity as CaCO3	100	mg/l	<3	120	42.5	37.5	30.1	n.d.	91.1	94	94	0	0	-
Calcium	100	mg/l	24	120	62.7	60.5	20	31	96.1	100	100	0	0	-
Chloride	100	mg/l	15	300	105	100	47.7	25.9	171	100	100	1	1	250
Magnesium	100	mg/l	4.7	18	8.96	8.85	2.42	5.3	13	100	100	0	0	50
Potassium	100	mg/l	3.7	13	7.6	7.6	1.82	4.6	10	100	100	0	0	-
Sodium	100	mg/l	10	91	39.7	40	18.4	14	71.1	100	100	0	0	200
Sulphate as SO4	100	mg/l	16.9	191	42.3	38.1	19.9	24.5	65.4	100	100	0	0	250
Minor ions														
Cadmium	100	µg/l	<0.02	0.14	0.0373	0.03	0.0285	n.d.	0.11	74	74	0	0	5
Chromium	100	µg/l	<0.2	7.8	0.744	0.5	0.928	0.2	1.72	96	96	0	0	50
Copper	100	µg/l	<0.5	7.3	2.43	2.15	1.18	1	4.41	99	99	0	0	2000
Iron	100	µg/l	<4	250	18.6	8	35.9	n.d.	49.1	76	76	1	1	200
Lead	100	µg/l	<0.2	1.1	n.d.	n.d.	n.d.	n.d.	0.105	5	5	0	0	10
Manganese	100	µg/l	1.3	520	42.6	12	82.4	1.8	201	100	100	19	19	50
Nickel	100	µg/l	2.8	21	8.52	7.45	4.22	3.5	16	100	100	1	1	20
Zinc	100	µg/l	2.9	63	15.4	12.5	11	4.69	34.1	100	100	0	0	-
Nitrogen species														

												UKDWS		
Determinand	No. of Results	Unit	Min	Max	Mean	Median	Standard Deviation	5th Percentile	95th Percentile	# > LOD	% > LOD	No. Exceeding	% Exceeding	Action Level
Ammoniacal Nitrogen as N	100	mg/l	<0.015	0.074	0.0118	n.d.	0.00918	n.d.	0.0271	28	28	0	0	0.39
Nitrate as N	100	mg/l	1.63	15.5	9.2	9.85	4.09	2.49	14.8	100	100	39	39	11.3
Nitrate as NO3	100	mg/l	7.23	68.8	40.7	43.6	18.1	11	65.5	100	100	40	40	50
Nitrite as N	100	µg/l	<1	19	3	1.25	3.94	n.d.	12.1	54	54	0	0	30
Nitrite as NO2	100	µg/l	<5	61	10.1	n.d.	12.6	n.d.	39.2	47	47	0	0	100
Landfill parameters														
TOC (filtered)	100	mg/l	0.79	6.26	2.23	1.92	1.1	1.1	4.5	100	100	0	0	-
Hydrocarbons														
Aliphatics >C10-12	56	µg/l	<10	<10	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aliphatics >C12-16	56	µg/l	<10	<10	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aliphatics >C16-21	56	µg/l	<10	<10	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aliphatics >C21-35	56	µg/l	<10	<10	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aliphatics >C5-6	56	µg/l	<1	<1	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aliphatics >C8-10	56	µg/l	<1	<1	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aromatics >C10-12	56	µg/l	<10	<10	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aromatics >C12-16	56	µg/l	<10	<10	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aromatics >C16-21	56	µg/l	<10	<10	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aromatics >C21-35	56	µg/l	<10	<10	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aromatics >C5-7	56	µg/l	<1	<1	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aromatics >C7-8	56	µg/l	<1	<1	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aromatics >C8-10	56	µg/l	<1	<1	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
PAHs														
Acenaphthene	56	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Acenaphthylene	21	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Anthracene	56	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-

												UKDWS		
Determinand	No. of Results	Unit	Min	Max	Mean	Median	Standard Deviation	5th Percentile	95th Percentile	# > LOD	% > LOD	No. Exceeding	% Exceeding	Action Level
Benzo (g,h,i) perylene	56	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Benzo(a)anthracene	56	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Benzo(a)pyrene	56	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	0.01
Benzo(b)fluoranthene	56	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Benzo(k)fluoranthene	56	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Chrysene	56	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Dibenz-a-h-anthracene	56	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Fluoranthene	56	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Fluorene	56	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Indeno(1,2,3-cd)pyrene	56	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Naphthalene	56	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Phenanthrene	56	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Pyrene	56	µg/l	<0.01	<0.01	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
BTEX														
Benzene	56	µg/l	<1	<3	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	49	87.5	1
Ethylbenzene	56	µg/l	<1	<3	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
m,p xylenes	56	µg/l	<1	<3	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
O-Xylene	56	µg/l	<1	<3	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Toluene	56	µg/l	<1	<3	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
PCBs														
Other parameters														
Aliphatics & Aromatics >C5-35	56	µg/l	<10	<10	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aliphatics >C5-35	56	µg/l	<10	<10	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Aliphatics >C6-8	56	µg/l	<1	<1	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Methyl tert-butyl ether (MTBE)	56	µg/l	<1	<3	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-

												UKDWS		
Determinand	**No. of Results**	**Unit**	**Min**	**Max**	**Mean**	**Median**	**Standard Deviation**	**5th Percentile**	**95th Percentile**	**# > LOD**	**% > LOD**	**No. Exceeding**	**% Exceeding**	**Action Level**
PAH, Total Detected USEPA 16	56	µg/l	<0.16	<0.16	n.d.	n.d.	n.d.	n.d.	n.d.	0	0	0	0	-
Cadmium	100	µg/l	<0.02	0.14	0.0373	0.03	0.0285	n.d.	0.11	74	74	0	0	5
Chromium	100	µg/l	<0.2	7.8	0.744	0.5	0.928	0.2	1.72	96	96	0	0	50
Copper	100	µg/l	<0.5	7.3	2.43	2.15	1.18	1	4.41	99	99	0	0	2000
Iron	100	µg/l	<4	250	18.6	8	35.9	n.d.	49.1	76	76	1	1	200
Lead	100	µg/l	<0.2	1.1	n.d.	n.d.	n.d.	n.d.	0.105	5	5	0	0	10

Note: if significant number of results that are detected exceed action limit row is coloured as follows: 10 - 25% pale red, 25 - 50% darker red, >50% dark red. n.d. statistic not determinable. Mean statistics for non-detects are calculated at half the limit of detection.

If significant number of results exceed action limit where some are non-detects the '% Exceeding' column is coloured as follows: 10 - 25% pale blue, 25 - 50% darker blue, >50% dark blue. n.d. statistic not determinable.

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Figure 2.15 Ammoniacal nitrogen concentrations for Bromsberrow South and North

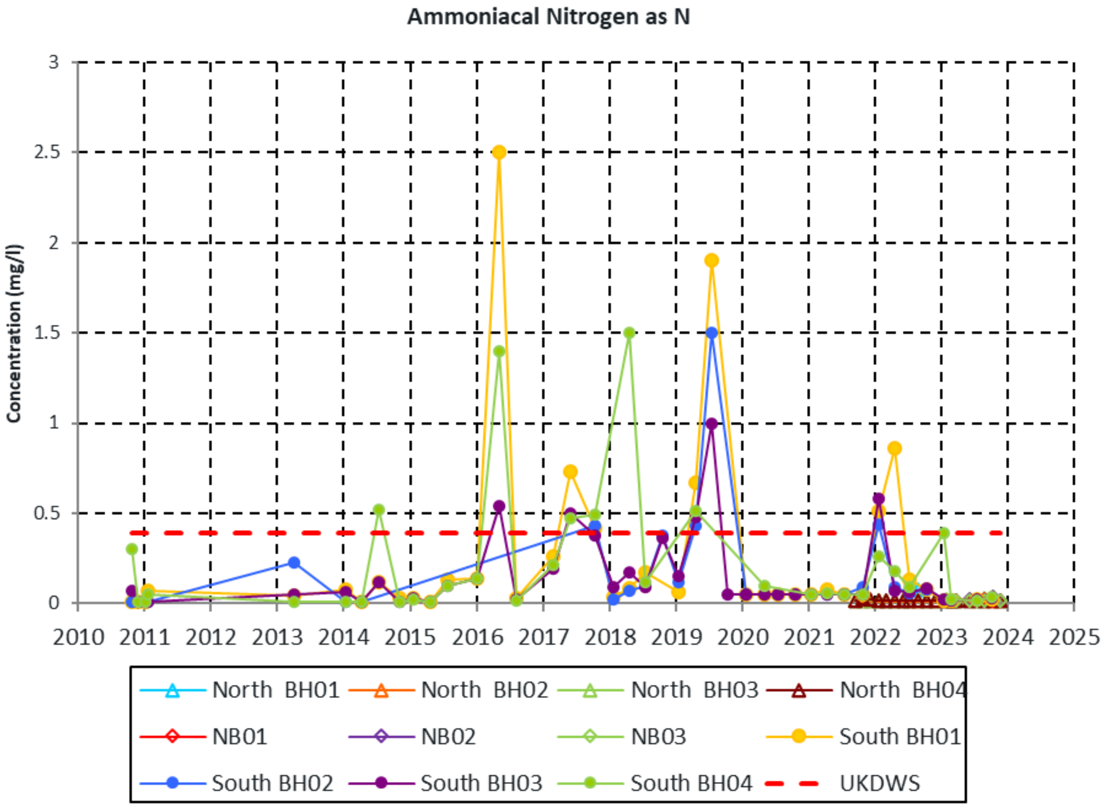


Figure 2.16 Chloride concentrations for Bromsberrow South and North

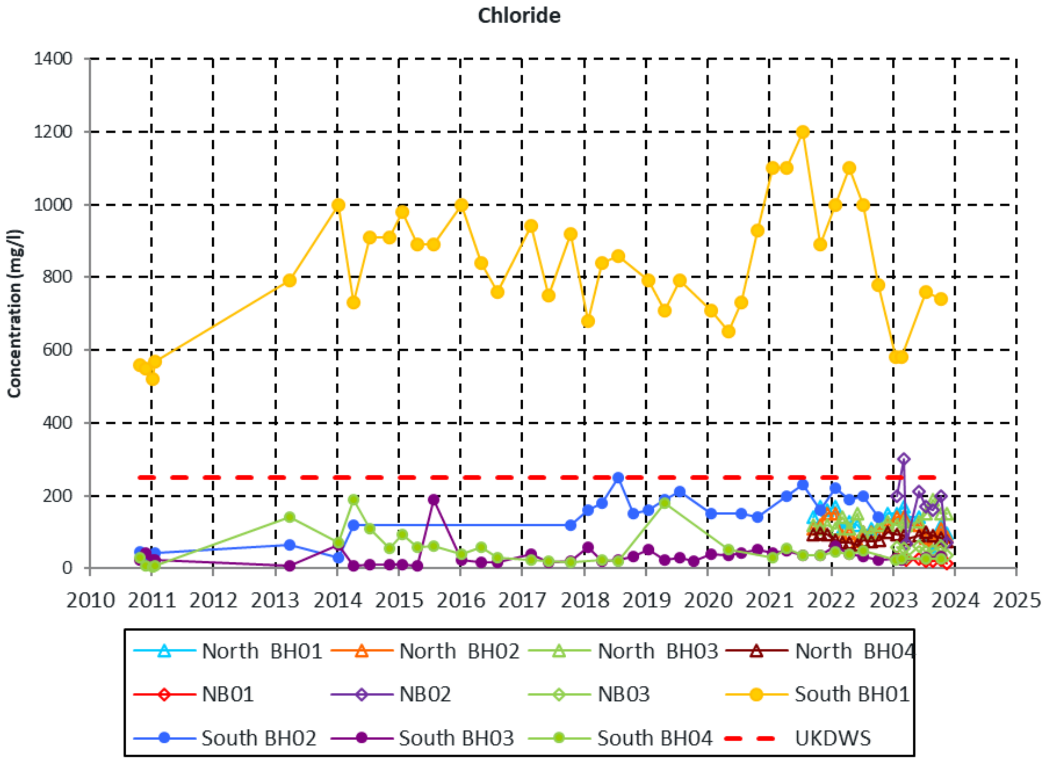


Figure 2.17 Sodium concentrations for Bromsberrow South and North

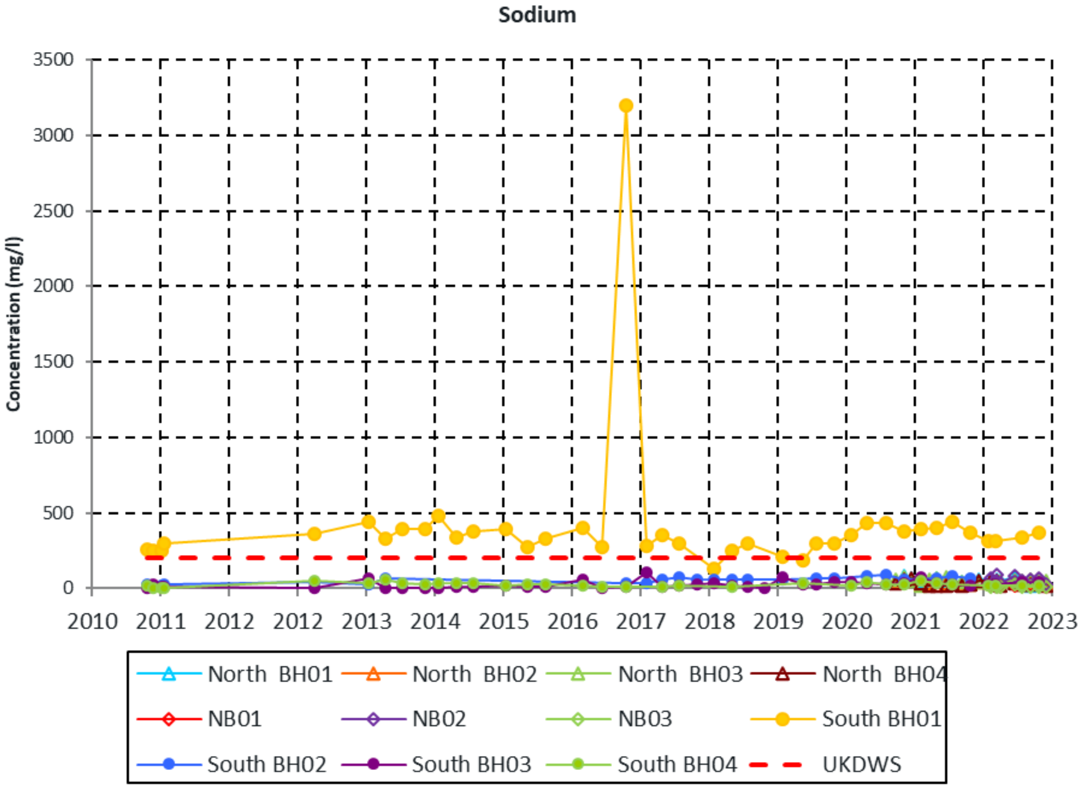


Figure 2.18 Sulphate concentrations for Bromsberrow South and North

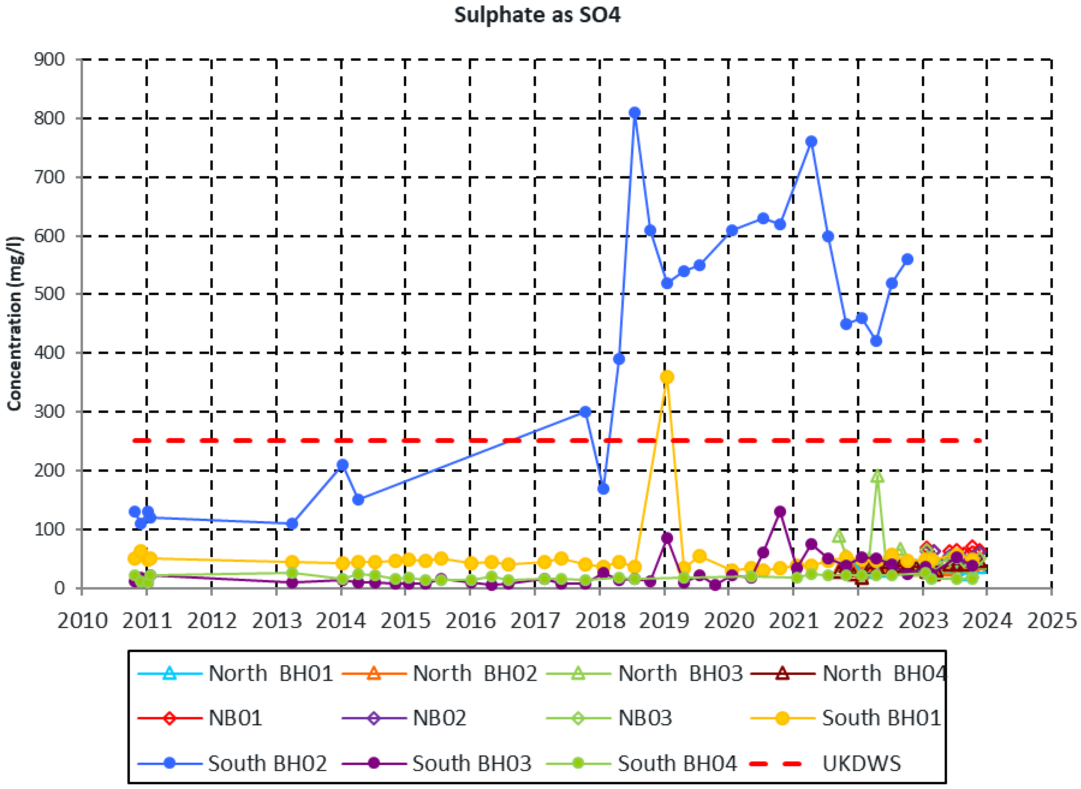


Figure 2.19 Calcium concentrations for Bromsberrow South and North

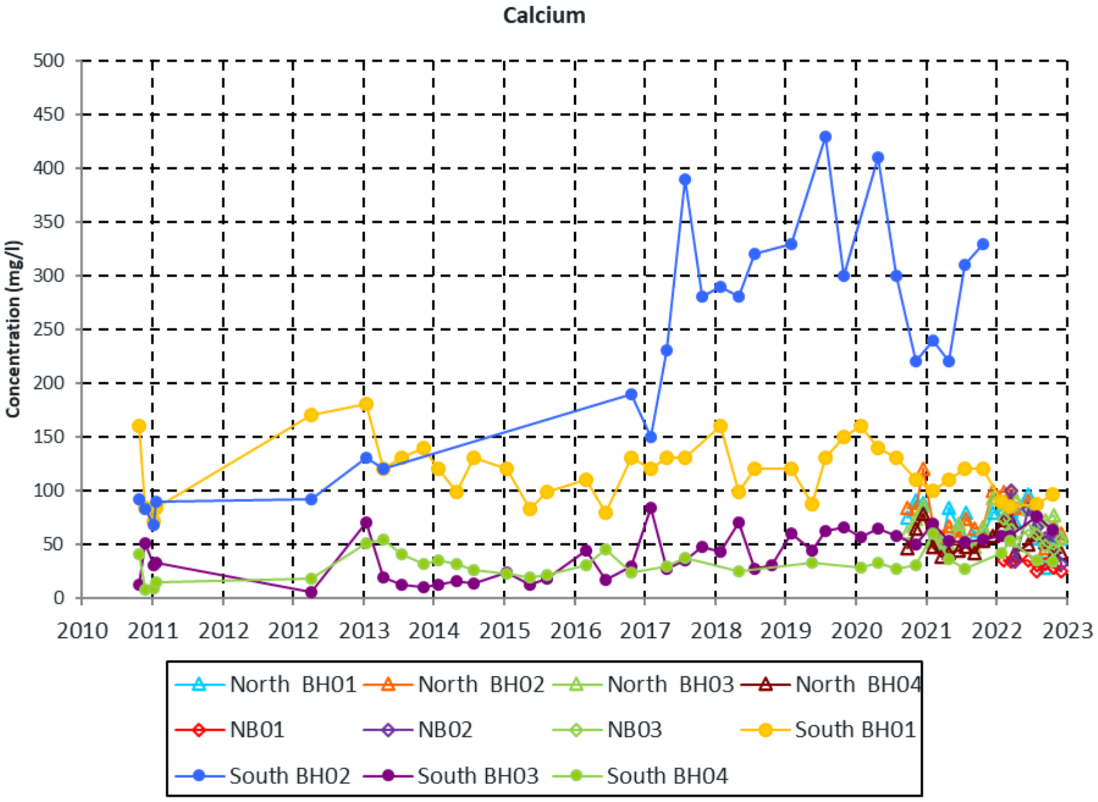


Figure 2.20 Iron concentrations for Bromsberrow South and North

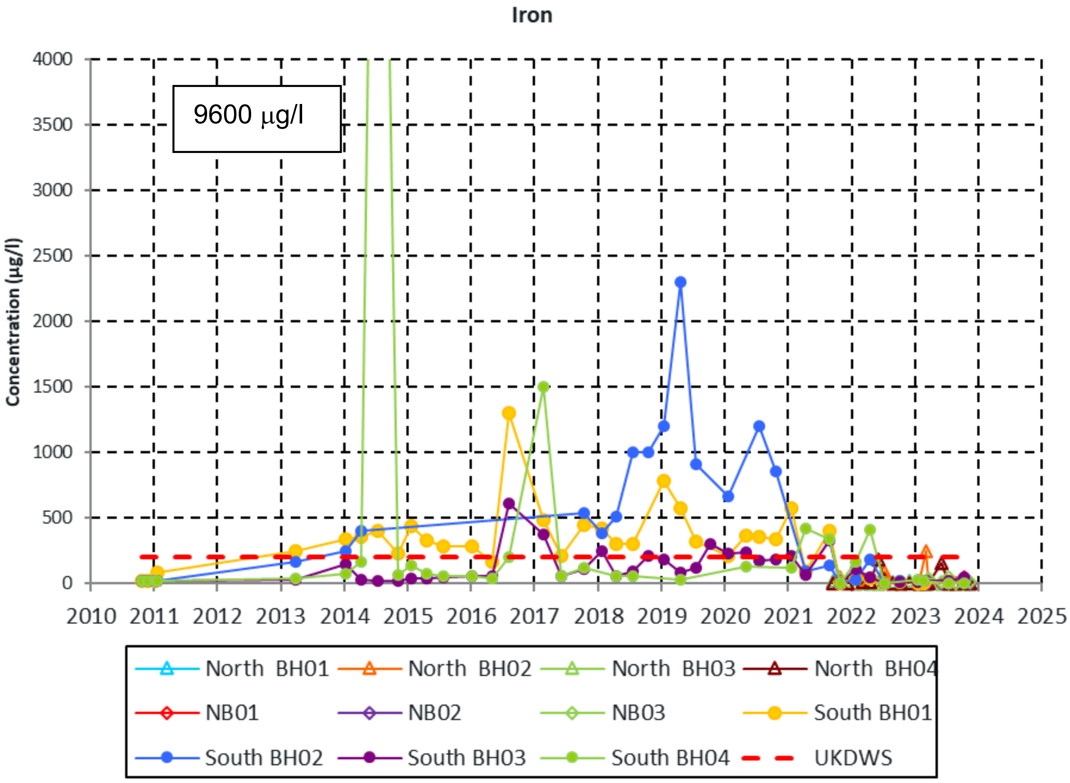


Figure 2.21 Cadmium concentrations for Bromsberrow South and North

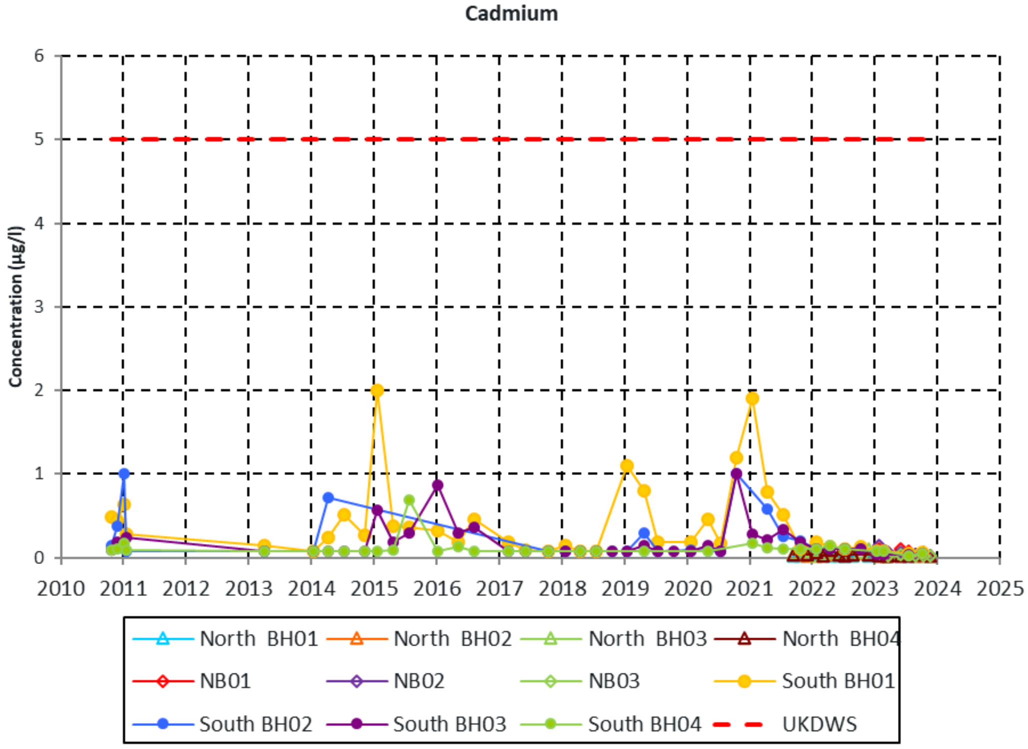


Figure 2.22 Nickel concentrations for Bromsberrow South and North

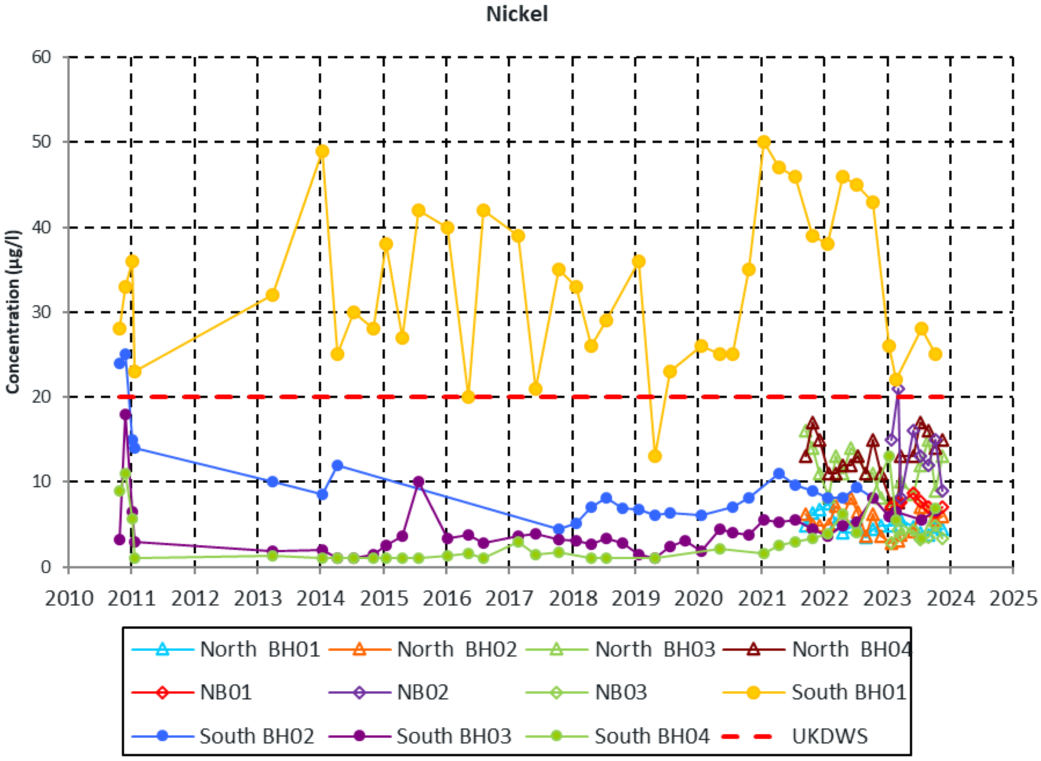


Table 2.13 Groundwater quality summary from Bromsberrow PWS BH1-BH5 (Feb 1986 – Nov 2022)

												UKDWS		
Determinand	**No. of Results**	**Unit**	**Min**	**Max**	**Mean**	**Median**	**Standard Deviation**	**5th Percentile**	**95th Percentile**	**# > LOD**	**% > LOD**	**No. Exceeding**	**% Exceeding**	**Action Level**
Major ions														
Calcium	230	mg/l	65	91	76.7	78	5.84	67.4	85.8	230	100	0	0	-
Chloride	313	mg/l	3	64.2	35.3	35.9	7.73	25.4	52.6	313	100	0	0	250
Sulphate as SO4	282	mg/l	5	63.9	25.3	25.6	4.73	18.8	31	282	100	0	0	250
Minor ions														
Arsenic	207	µg/l	0.47	2.8	1.17	1	0.459	0.58	1.84	207	100	0	0	10
Cadmium	163	µg/l	0.006	1	0.0751	0.04	0.109	0.0103	0.23	163	100	0	0	5
Chromium	163	µg/l	0.11	5	0.731	0.7	0.739	0.2	2	163	100	0	0	50
Iron	335	µg/l	3	560	26.1	10	65.4	7	56	335	100	8	2.39	200
Lead	130	µg/l	0.1	1.99	0.49	0.4	0.298	0.1	1	130	100	0	0	10
Mercury	100	µg/l	0.005	0.097	0.0223	0.022	0.0115	0.005	0.034	100	100	0	0	1
Nickel	171	µg/l	0.5	21	1.83	1.1	2.54	0.7	6.25	171	100	1	0.58	20
Nitrogen species														
Ammoniacal Nitrogen as N	315	mg/l	0.009	0.064	0.0306	0.021	0.0183	0.009	0.064	315	100	0	0	0.39
Nitrate as NO3	**739**	**mg/l**	**20.5**	**90.6**	**53.5**	**51.9**	**11.7**	**37.5**	**72.6**	**739**	**100**	**403**	**54.5**	**50**
PAHs														
Benzo (g,h,i) perylene	55	µg/l	0.001	1	0.0565	0.002	0.229	0.00114	0.308	55	100	0	0	-
Benzo(a)pyrene	55	µg/l	0.00074	0.018	0.00159	0.001	0.00322	0.00074	0.001	55	100	2	3.64	0.01
Benzo(b)fluoranthene	55	µg/l	0.00097	1	0.0565	0.002	0.229	0.00097	0.312	55	100	0	0	-
Benzo(k)fluoranthene	55	µg/l	0.00074	1	0.0565	0.002	0.229	0.00074	0.307	55	100	0	0	-
Fluoranthene	3	µg/l	0.002	0.002	0.002	0.002	0	0.002	0.002	3	100	0	0	-
Indeno(1,2,3-cd)pyrene	53	µg/l	0.001	0.012	0.00292	0.003	0.0014	0.0016	0.003	53	100	0	0	-

												UKDWS		
Determinand	No. of Results	Unit	Min	Max	Mean	Median	Standard Deviation	5th Percentile	95th Percentile	# > LOD	% > LOD	No. Exceeding	% Exceeding	Action Level
BTEX														
Benzene	112	µg/l	0.04	0.12	0.059	0.05	0.0251	0.04	0.12	112	100	0	0	1
Ethylbenzene	112	µg/l	0.05	0.19	0.0828	0.06	0.047	0.05	0.19	112	100	0	0	-
m,p xylenes	101	µg/l	0.09	0.36	0.181	0.11	0.118	0.09	0.36	101	100	0	0	-
O-Xylene	112	µg/l	0.06	0.34	0.159	0.11	0.119	0.06	0.34	112	100	0	0	-
Toluene	112	µg/l	0.03	0.17	0.076	0.05	0.0551	0.03	0.17	112	100	0	0	-
Other parameters														
1,1,1-Trichloroethane	51	µg/l	0.06	1.06	0.258	0.06	0.334	0.06	0.97	51	100	0	0	-
1,2-Dibromoethane	40	µg/l	0.09	0.98	0.286	0.09	0.287	0.09	0.98	40	100	0	0	-
1,2-Dichloroethane	112	µg/l	0.08	0.88	0.152	0.1	0.107	0.08	0.3	112	100	0	0	3
Methyl tert-butyl ether (MTBE)	112	µg/l	0.07	0.25	0.113	0.08	0.0623	0.07	0.25	112	100	0	0	-
Methyl tert-pentyl ether	101	µg/l	0.07	0.4	0.175	0.12	0.124	0.07	0.4	101	100	0	0	-
PAH, Total Detected USEPA 16	2	µg/l	0.016	0.051	0.0335	0.0335	0.0247	0.0178	0.0493	2	100	0	0	-
Tetrachloroethene	51	µg/l	0.05	0.27	0.138	0.14	0.0664	0.05	0.27	51	100	0	0	10
Tetrachloromethane (Carbon Tetra Chloride)	51	µg/l	0.018	0.2	0.087	0.08	0.0558	0.018	0.2	51	100	0	0	3
Trichloroethene	51	µg/l	0.05	0.38	0.151	0.14	0.096	0.05	0.38	51	100	0	0	10

Note: if significant number of results that are detected exceed action limit row is coloured as follows: 10 - 25% pale red, 25 - 50% darker red, >50% dark red. n.d. statistic not determinable. Mean statistics for non-detects are calculated at half the limit of detection.

If significant number of results exceed action limit where some are non-detects the '% Exceeding' column is coloured as follows: 10 - 25% pale blue, 25 - 50% darker blue, >50% dark blue. n.d. statistic not determinable.

Table 2.14 Background groundwater quality summary (from all locations excluding BH02 at Bromsberrow South)

												UKDWS		
Determinand	**No. of Results**	**Unit**	**Min**	**Max**	**Mean**	**Median**	**Standard Deviation**	**5th Percentile**	**95th Percentile**	**# > LOD**	**% > LOD**	**No. Exceeding**	**% Exceeding**	**Action Level**
Major ions														
Alkalinity as CaCO3	215	mg/l	<3	570	61.5	46	63	n.d.	153	198	92.1	0	0	-
Calcium	445	mg/l	<5	180	70.5	73	25.5	25.2	120	444	99.8	0	0	-
Chloride	528	mg/l	3	1200	109	37.1	214	22.4	747	528	100	41	7.77	250
Magnesium	215	mg/l	1.2	81	15.4	10	13.3	4.84	43.6	215	100	5	2.33	50
Potassium	215	mg/l	1.2	26	8.91	7.8	4.35	4.1	18	215	100	0	0	-
Sodium	215	mg/l	<0.5	3200	102	37	244	7.16	390	214	99.5	38	17.7	200
Sulphate as SO4	497	mg/l	4.5	360	30.5	26.7	21	13.8	55	497	100	1	0.2	250
Minor ions														
Arsenic	207	µg/l	0.47	2.8	1.17	1	0.459	0.58	1.84	207	100	0	0	10
Cadmium	378	µg/l	0.006	2	0.108	0.04	0.209	n.d.	0.443	308	81.5	0	0	5
Chromium	378	µg/l	0.11	43	2.56	0.7	5.68	n.d.	13	354	93.7	0	0	50
Copper	215	µg/l	<0.5	19	2.65	2	2.51	n.d.	6.2	191	88.8	0	0	2000
Iron	549	µg/l	3	9600	73.4	11	429	n.d.	340	508	92.5	48	8.74	200
Lead	345	µg/l	0.1	6.4	0.395	n.d.	0.439	n.d.	1	144	41.7	0	0	10
Manganese	215	µg/l	<1	1600	59.4	11	139	n.d.	186	204	94.9	64	29.8	50
Mercury	100	µg/l	0.005	0.097	0.0223	0.022	0.0115	0.005	0.034	100	100	0	0	1
Nickel	386	µg/l	0.5	50	7.13	3.15	10.1	0.625	32.8	372	96.4	40	10.4	20
Zinc	215	µg/l	<1	190	21.7	14	26.2	1.78	63.6	208	96.7	0	0	-
Nitrogen species														
Ammoniacal Nitrogen as N	530	mg/l	0.009	2.5	0.0625	0.021	0.189	n.d.	0.175	422	79.6	18	3.4	0.39

Nitrate as N	109	mg/l	1.6	22.2	9.63	9.9	4.92	2.11	17.9	109	100	45	41.3	11.3
Nitrate as NO3	954	mg/l	0.86	102	49.8	50.1	17.1	14	72.9	954	100	477	50	50
Nitrite as N	109	µg/l	<1	19	2.88	1.3	3.82	n.d.	11.6	60	55	0	0	30

Note: if significant number of results that are detected exceed action limit row is coloured as follows: 10 - 25% pale red, 25 - 50% darker red, >50% dark red. n.d. statistic not determinable. Mean statistics for non-detects are calculated at half the limit of detection.

If significant number of results exceed action limit where some are non-detects the '% Exceeding' column is coloured as follows: 10 - 25% pale blue, 25 - 50% darker blue, >50% dark blue. n.d. statistic not determinable.

3 Proposed Development

3.1 Operational stage

The operational development is shown in a series of drawings presented in Appendix A. The drawings show six progressive phases of expanding the existing approved quarry over the following 8 years, which are summarised in Table 3.1.

During development water management will continue as at present; surface water entering the quarry will be allowed to soak into the ground and no off-Site discharge will be required.

Table 3.1 Phased development details

Phase	Description	Approximate quantity (m^3)	Date of completion
Phase 1	Remove original access ramp to 36m AOD	17,000	07/07/2024
Phase 2	Western area extracted down to 36m AOD	52,000	17/05/2027
Phase 3	Westen area extracted down to 36m AOD and Northern extension to 39M AOD	18,000	12/05/2028
Phase 4	Completion of western extension to 36m AOD and Northern extension to 39m AOD. Form new access ramp to quarry floor.	24,000	06/09/2029
Phase 5	Northern extension extracted to 36m AOD	17,000	13/08/2030
Phase 6	Remove phase 4 access ramp to 36m AOD	27,000	06/02/2032

3.2 Restoration stage

Restoration at the Site will be worked in conjunction with mineral extraction; worked out areas will be restored in lockstep with extraction over a period of 21 years to the original ground level and the Site will be returned to agricultural or amenity use. Eight phases of restoration are described by the drawings in Appendix A and summarised in Table 3.2.

Table 3.2 Phased restoration details

Phase	Description	Approximate quantity (m^3)	Date of completion
Phase 1	Extension of ramp onto quarry floor		01/08/2023
Phase 2	Stabilisation of Eastern boundary and creation of stocking area	88,000	18/05/2026
Phase 3	Southern boundary face stabilisation	76,000	16/10/2028
Phase 4	Enlargement of Sothern Face tip	43,000	27/02/2030
Phase 5	South West corner - plant area	80,000	12/09/2032
Phase 6	Old ramp infill	24,000	18/06/2033
Phase 7	Central area	174,000	28/12/2038
Phase 8	Whole site overlay to original ground level	185,000	13/11/2044

Further details of the proposed development are presented in Stantec (2024b).

During the joint operational and restoration stages, surface water will continue to be allowed to soak into the quarry floor. During Phases 7 and 8 of restoration, an alternative soakage basin will be developed on the north-western side of the Site as described by the FRA (Stantec, 2024a), and a surface water drain will be constructed to route surface runoff from the restored area, around the quarry, to the new basin. This alternative basin will remain in the longer term to take runoff from the restored Site surface so that, as before, no off-Site discharge will be required.

The restoration scheme will include the construction of an artificially enhanced geological barrier on the base and sidewalls of the excavation. The geological barrier will comprise clean imported clay (non-waste) and as such will not be contaminated with hazardous pollutants.

4 Conceptual Model

An understanding of the key physical components of a soil and groundwater system must be developed prior to undertaking any risk assessment modelling for controlled waters. To simplify the complexity of observed soil and groundwater conditions and to identify the relevant flow and transport parameters, a conceptual site model (CSM) has been prepared. The model accounts for both the physical ground conditions (including surface and subsurface conditions, and the natural geology) and the key hydrological inputs and outputs to and from the system.

The baseline conditions and data presented in the Section 2 of this report have been conceptualised into a set of potential source, pathway, receptor (S-P-R) linkages. These are described in this section, for the assessment of risk to controlled waters from the restoration materials deposited at the Site.

The hydrogeological CSM has been developed based upon the proposed site layout, construction and geo-environmental setting described in this report, the ESSD (Stantec, 2024c) and the FRA (Stantec, 2024a).

4.1 Source-pathway-receptor methodology

The source-pathway-receptor methodology has been applied for this Site (DEFRA, 2011) and is presented in Figure 4.1.

4.1.1 Water balance

The restoration scheme will include an artificially enhanced geological barrier (AEGB) on the base and sidewalls of the excavation and is considered by this risk assessment.

Water inputs to the landfill are limited to effective rainfall, calculated as the positive difference between rainfall and actual evapotranspiration after allowing for surface run-off:

$$Q_{ER} = (1 - RO)Q_{RF} - AE \qquad (1)$$

where

Q_{ER} is the effective rainfall mm/a;

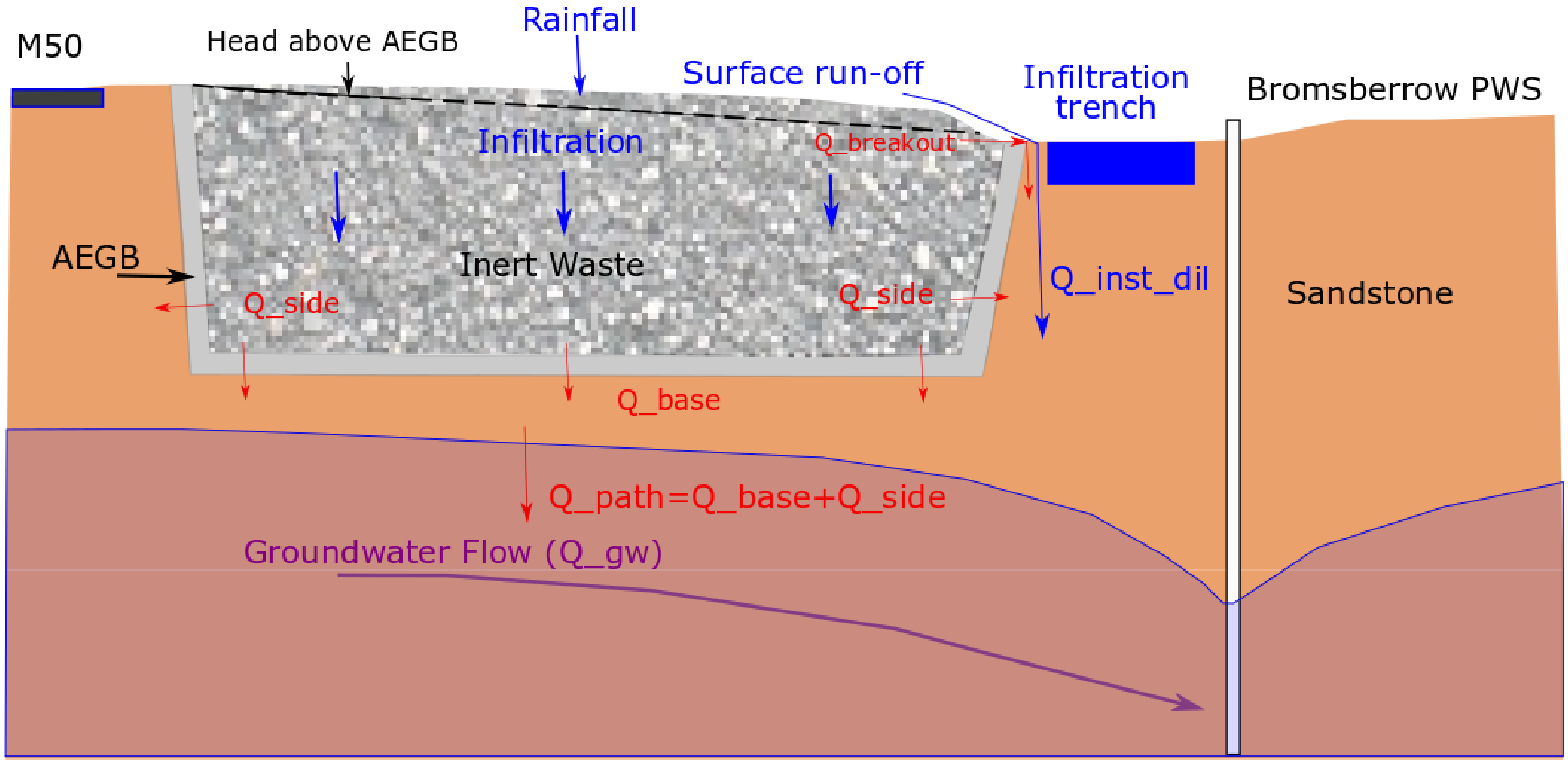
Q_{RF} is the rainfall (mm/a)

AE is the actual evapotranspiration (mm/a) and

RO is the run-off factor (-).

The AEGB will be constructed from Blue Lias clay and will have a permeability approximately 3 orders of magnitude lower than the Landfill Directive minimum of 1×10^{-7} m/s: as such there is the potential for the waste to become saturated if the maximum head is not high enough to drive the infiltration out of the base and sides of the waste.

Figure 4.1 Conceptual site model cross section



As the Site is above the water table, the flux out of the base and sides of the AEGB are given by the following equations:

$$Q_{base} = K_{AEGB} A_{base} \frac{h_l + t_{base}}{t_{base}} \tag{2}$$

$$Q_{side} = K_{AEGB} A_{side} \frac{h_l}{2t_{side}} = K_{AEGB} Perim \frac{{h_l}^2}{2t_{side}} \; as \; A_{side} = Perim \, h_l \tag{3}$$

where

Q$_{base}$ is the basal flux (m^3/s);

Q$_{side}$ is the flux through the sidewall (m^3/s);

K_{AEGB} is the hydraulic conductivity of the AEGB (m/s);

A$_{base}$ is the basal area (m^2)

Permi is perimeter of the site (m);

h_l is the calculated head in the waste(m) above the top of the basal AEGB (m).

The water balance for the Site is

$$Q_{ER} = Q_{base} + Q_{side} \tag{4}$$

Substituting equations (2) and (3) into equation (4) gives:

$$Q_{ER} = K_{AEGB} A_{base} \frac{h_l + t_{base}}{t_{base}} + K_{AEGB} Perim \frac{{h_l}^2}{2t_{side}} \tag{5}$$

which can be rearranged to give the following quadratic equation in h_l:

$$\frac{K_{AEGB} Perim}{2t_{side}} {h_l}^2 + \frac{K_{AEGB} A_{base}}{t_{base}} h_l + (K_{AEGB} A_{base} - Q_{ER}) = 0. \tag{6}$$

This can be solved for h_l using the standard quadratic equation solution $h_l = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$ where $a{h_l}^2 + bh_l + c = 0$.

The fluxes out of the landfill can be calculated using the values of h_l limited to the maximum leachate head of h_{max}; when h_l is greater than h_{max} and there is additional run-off then equation (4) becomes:

$$Q_{ER} = Q_{base} + Q_{side} + Q_{run-off} \tag{7}$$

where

$$Q_{run-off} = Q_{ER} - K_{AEGB} A_{base} \frac{h_{max} + t_{base}}{t_{base}} - K_{AEGB} Perim \frac{{h_{max}}^2}{t_{side}} \tag{8}$$

The contaminant flux along the pathway (Q_{path}) is defined as

$$Q_{path} = Q_{base} + Q_{side}. \tag{9}$$

Inert waste material is heterogeneous and consists predominately of low permeability construction and clayey materials. As such the volume of water that can flush through the upper parts of the waste and overflow the sides will be very limited. Rather, excess water in the restoration layer above the waste, that cannot infiltrate the waste, will flow laterally to the sides where it will be captured by the perimeter drains and form surface runoff. This water will have very limited contact with the waste and will not be impacted by any contaminants present within the waste.

In this circumstance $Q_{run-off}$ will not infiltrate the waste mass and this surface run-off will be collected in the infiltration trench on the perimeter of the waste.

However, due to the sensitive location of the Site, a breakout pathway from the upper layer of the waste to the infiltration basin and through the unsaturated zone to the water table will be modelled as a sensitivity run.

A key consideration for this pathway is that the volume of waste the flux will infiltrate is a fraction of the total waste volume so should such a path exist the impact would be short-lived and the dilution attributed by mixing with clean run-off in the infiltration will be significant.

A review of the surface contours in the restoration plan (Appendix A) indicates that when phase 7 is complete the waste material is not above the top of the side wall AEGB so no breakout will occur. Once Phase 8 is complete the restored elevations do not exceed the adjacent ground elevations on the boundary of the restored area. However, there is a steeper gradient to the contours adjacent to the infiltration basin on the northwest of the Site. Therefore, it is across this steeper slope where breakout could occur and any run-off from the restored surface will be directed to the infiltration basin and the infiltration trench.

If the leachate head is greater than the lowest elevation of the restored surface, then the breakout flux is estimated using the Dupuit equation:

$$Q_{breakout} = \frac{K_{waste}}{2Waste\_length} Width\_breakout\left({h_{lb}}^2 - {h_b}^2\right) \tag{10}$$

where

$Q_{breakout}$ is the breakout flux (m^3/s);

K_{waste} is the hydraulic conductivity of the waste (m/s);

Width_breakout is the distance over which breakout will occur (perpendicular to flow) (m);

Waste_length is the distance between the maximum head on the southern boundary and the edge of the waste adjacent to the infiltration basin (m).

h_{lb} is the calculated leachate head (m) above the elevation of the infiltration basin (m) and

h_b is the head at the edge of the waste above the elevation of the infiltration basin (m).

4.1.2 Source

The waste mass will consist of inert restoration material (i.e. inert clays, subsoils and soils). Note that the granular fraction of the restoration material is removed during processing due to requirement for recycling, and that no on-site treatment of this material is proposed.

4.1.3 Pathways

The modelled pathway for the imported restoration materials is through the AEGB on the base and sides of the landfill and subsequent sub-horizontal transport in groundwater within the aquifer. Transport through the unsaturated zone is not considered

On reaching the water table, non-hazardous pollutants will be diluted in groundwater (Q_{gw}) where Q_{gw} is calculated from Darcy's Law:

$$Q_{gw} = K_{aq} A\, i. \qquad (11)$$

Here

K_{aq} is the hydraulic conductivity of the aquifer (m/s);

i is the hydraulic gradient at the Site (-) and

A is the cross-sectional area and is the product of the mixing depth and mixing width (m^2).

The hazardous substances cannot be diluted in groundwater but can be diluted by instantaneous dilution (Q_{Inst_dil}- originating from run-off across the Site) within the unsaturated zone.

The dilution factor (DF) for the pathway is given by:

$$DF = \frac{Q_{path}}{Q_{path}+Q_{dil}} \qquad (12)$$

where Q_{dil} (m^3/s) is the dilution appropriate to the determinand.

4.1.4 Receptors

The groundwater receptors are at the edge of the Site (labelled Site Boundary in the model) and the nearby public water supply borehole (PWS). The receptor for the hazardous substances is the water table directly below the geological barrier (Water Table). There is no surface water in continuity with the groundwater beneath the Site.

5 Risk Assessment

5.1 The nature of the Hydrogeological Risk Assessment

5.1.1 General modelling approach

EA guidance[4] (DEFRA, 2018) states that for inert sites on a Principal aquifer, or where there is uncertainty regarding any of the source, pathway and receptor terms, a detailed, quantitative risk assessment (DQRA) should be carried out. Hence, due to the sensitivity of the location and uncertainty on the source term, a probabilistic DQRA has been developed.

5.1.2 Priority contaminants to be modelled

In order to select the determinands to be taken forward into the DQRA a screening assessment has been undertaken for each determinand given in relevant criteria and procedures for the acceptance of waste at landfills (European Union Council, 2002).

For the screening assessment, it is assumed that the waste aqueous concentration (referred to here as the source term concentration) is the C_0 (percolation test) limit as given (European Union Council, 2002).

We have back-calculated a maximum acceptable waste concentration using the following equation.

$$C_{max} = C_{trg}/DF$$

where:

C_{max} is the maximum acceptable waste concentration (mg/l),

C_{trg} is the target concentration (mg/l) and

DF is the dilution factor

As described in Section 4.1.3, the CSM considers one pathway described as vertical percolation through the unsaturated zone and sub-horizontal transport in groundwater. The screening assessment considers groundwater dilution in the aquifer for all the non-hazardous pollutants and instantaneous dilution in the unsaturated zone for hazardous substances when calculating the maximum allowable waste concentration (C_{max}).

The dilution factor (calculated using equation (12)) is 0.063 for non-hazardous pollutants and 0.24 for hazardous substances.

The target concentration is derived as follows:

- Hazardous Substances: minimum reporting values (MRV) in preference over the higher of the UKTAG (UK Technical Advisory Group) quantification limit and the UKTAG

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[4] https://www.gov.uk/guidance/groundwater-risk-assessment-for-your-environmental-permit

concentration to avoid deterioration in quality of the receiving groundwater (column 3 and 4 of Table 1 in UK TAG (2017))

- Non-hazardous Pollutants: lower of background data and UK Drinking Water Standard (DWS) concentration.

The calculations for the screening assessment have been undertaken in a spreadsheet (presented in Appendix C); as summary is presented in Table 5.1.

There are no site-specific concentrations for barium or molybdenum. Furthermore, these determinands do not have DWS concentrations. Therefore, they are not assessed.

Phenol index, dissolved organic carbon and total dissolved solids are not individual chemical determinands and cannot be assessed.

The maximum allowable waste concentration (C_{max}) is compared to the source term concentration (C_0). If C_{max} is higher than the source term concentration, this shows that there will be no impact on the identified receptors and the determinand is considered to pass the screening assessment. If C_{max} is lower than the source term concentration, this implies that there may be a risk from this determinand and these determinands are taken forward for further analysis in the DQRA.

Hazardous substances

We note that chromium VI is a hazardous substance. However, the source term concentration taken from European Union Council, 2002 is for total chromium. It is conservatively assumed here that all chromium is present as chromium VI and is therefore hazardous.

Arsenic, total chromium, and lead fail the initial screening assessment in the base case model. and have been selected for the source term in the risk assessment model.

Non-hazardous pollutants

Sulphate, antimony, cadmium, copper and zinc fail the initial screening assessment in the base case model.

Sulphate does not degrade and is not retarded and has been selected for the source term in the model.

Antimony, cadmium. copper, and zinc also do not degrade but are retarded to varying degrees so exhibit similar behaviour. The C_{max} concentrations for antimony and zinc only just exceed the C_0 (the target value) and as there is no baseline data for antimony nor a UK DWS for zinc, cadmium and copper are selected as indicative non-hazardous metals.

Ammoniacal nitrogen and nickel have also been selected for inclusion in the DQRA. Ammoniacal nitrogen was not on the list for initial screening but is included in case small quantities of degradable materials (such as wood or topsoil) are accidently placed with the inert waste. Nickel has been included as it is commonly found in inert waste.

Table 5.1 Waste screening summary

Chemical Name	Pass / Fail	Ratio of C_0/C_{max}	C_0: Waste leachate concentration (mg/l)	C_{max}: Max acceptable waste eluate concentration (mg/l)	C_{targ}: Target Concentration to assess against (mg/l)	Limit to avoid deterioration in groundwater quality[1] (annual mean mg/l)	UK DWS (mg/l)	Site background data[2] (mg/l)
Non-hazardous pollutants								
Barium	-	-	4	-	-	-	-	-
Molybdenum	-	-	0.2	-	-	-	-	-
Antimony	*FAIL*	1.26	0.1	0.079	0.005	-	0.005	-
Cadmium	*FAIL*	3.14	0.02	0.0064	0.0004	-	0.005	0.0004
Copper	*FAIL*	6.29	0.6	0.095	0.006	-	2	0.006
Sulphate	*FAIL*	1.71	1,500	875.0	55	-	250	55
Zinc	*FAIL*	1.18	1.2	1.02	0.064	-	-	0.064
Chloride	Pass	0.12	460	3977.0	250	-	250	747
Fluoride	Pass	0.10	2.5	23.9	1.5	-	1.5	-
Nickel	Pass	0.38	0.12	0.32	0.02	-	0.02	0.033
Selenium	Pass	0.25	0.04	0.16	0.01	-	0.01	-
Hazardous substances								
Total Chromium	*FAIL*	4.83	0.1	0.021	0.005	0.005	-	-
Arsenic	*FAIL*	2.90	0.06	0.021	0.005	0.005	-	-
Lead	*FAIL*	7.24	0.15	0.021	0.005	0.005	-	-
Mercury	*Pass*	0.97	0.002	0.0021	0.0005	0.0005	-	-

[1] Column 4 from Table 1 UK TAG (2016)

[2] 95th percentile concentration from Bromsberrow South, Bromsberrow North and Bromsberrow PWS groundwater quality data excluding South BH02 due to high concentrations.

5.2 Assessment scenarios

5.2.1 Lifecycle phases

The restoration scheme will have an operational and post-operational phase. Management through all phases is expected to comprise groundwater monitoring only. We anticipate no groundwater or leachate management, due to the nature of the Site.

5.3 Mathematical modelling

5.3.1 Justification for modelling software

The risk assessment has been undertaken in a site-specific spreadsheet model based on Stantec's commercial software package RAM (ESI, 2000)[5]. An electronic copy of the model is given in Appendix C.

When ESI initially developed RAM, it was benchmarked against a number of groundwater risk assessment tools (ESI, 2001). Additionally, they verified the equations used in RAM by comparison between direct evaluation of an analytical solution and the semi-analytic transform approach applied for more complex pathways, and by comparison with published solutions used for verification as part of the nuclear waste industry code comparison exercise INTRACOIN (Robinson & Hodgkinson, 1986).

5.3.2 General assumptions

There are a number of general assumptions made which simplify the model:

- No retardation or decay is considered within the restoration materials. This will lead to an overestimation of the strength of leachate generated by the restoration scheme.
- With the exception of ammoniacal nitrogen, no retardation or decay is considered within the Bridgnorth Sandstone.
- For the sake of simplicity and clarity the thickness of the restoration material is averaged across the Site.
- It is assumed that the entirety of the restoration material is present at the start of the simulation. Since restoration of the Site will take time, some of the contaminants in the fill will have been depleted by the time the Site is completely restored, and the source term will be smaller than that represented in the model, which thus represents a conservative approximation of the system.
- Contaminants are flushed out of the source (and therefore the source term declines) at a rate proportional to the infiltrating flux.
- The groundwater flow direction is assumed to be from the Site towards Bromsberrow PWS.

5.3.3 Spreadsheet modelling

The modelling approach has been chosen to provide a robust and transparent assessment of risk using the widely accepted source-pathway-receptor methodology.

In this approach, possible water migration pathways are identified from the conceptual model. The corresponding risk of groundwater contamination is evaluated by considering the three components in sequence, with the contaminant release from the source providing the input

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[5] ESI Ltd became part of Stantec UK Ltd in 2018.

flux to the pathway and the contaminant flux from the pathway providing the contaminant load to the receptor.

The source from the restoration scheme is modelled based on contaminant concentrations considered likely for the given material type. For this Site the material is represented by a single source term with the average dimensions of the void to be filled.

Groundwater dilution is only applied in the saturated zone whilst instantaneous dilution (from surface water run-off infiltrating through the unsaturated zone via the infiltration trench and basin) is applied to the unsaturated zone pathway.

Conservatively, retardation and degradation are only considered in the AEGB.

As a conservative approach, dilution at Bromsberrow PWS has not been accounted for in the model.

Given the sensitive location of the Site the model has been run probabilistically.

5.3.4 Parameterisation

5.3.4.1 Site dimensions

The proposed restoration scheme at Bromsberrow North represents the contaminant source to be considered in the risk assessment. Table 5.2 presents the landfill geometry.

Table 5.2 Landfill Dimensions

Parameter	Value	Unit	Distribution	Data Source
Average width perpendicular to regional groundwater flow	183	m	-	Measured from Figure 2.12.
Average length parallel to regional groundwater flow	200	m	-	Measured from Figure 2.12.
Surface area	36,600	m^2	-	Calculated from source width and length.
Basal area	29,340	m^2	-	Calculated from estimates of final basal length and width (measured as 40 m less than surface dimensions from Figure 2.12).
Volume of restoration material	670,000	m^3	-	From Table 3.2.
Elevation of base	36	maOD	-	Elevation of base of the void.
Maximum elevation of restoration material	60	maOD	-	Estimated from site plans (Appendix A).
Minimum elevation of restoration material	55	maOD	-	Estimated from site plans (Appendix A).
Average material thickness	20.3	m	-	Calculated from the volume of waste and the average of the surface area and basal area.

Parameter	Value	Unit	Distribution	Data Source
Proportion of leachate that would freely drain from the restoration mass.	30 - 60	%	Uniform	Minimum value taken from Beavan (1996). Conservatively, a factor of 2 applied to estimate maximum value.

5.3.4.2 Model input concentrations

As described in Section 5.1.2, the modelled parameters are arsenic, total chromium, lead, nickel, copper, cadmium, sulphate and ammoniacal nitrogen.

There are no site-specific data on which to define source term concentrations for the model. The values selected are summarised in Table 5.3.

Table 5.3 Selected source concentrations (as leachate)

Concentration	Value	Units	Distribution	Justification
Arsenic	0.03 - 0.06	mg/l	Uniform	Maximum value: C_0 percolation test limits (European Union Council, 2002) used as an upper conservative end of likely range in source term concertation. Minimum value estimated as 50% of maximum in recognition that not all waste excepted will have concentrations at the maximum limit.
Total Chromium	0.5 - 0.1	mg/l		
Lead	0.075 - 0.15	mg/l		
Nickel	0.6- 0.12	mg/l		
Copper	0.3 - 0.6	mg/l		
Cadmium	0.01 - 0.02	mg/l		
Sulphate	750 – 1500	mg/l		
Ammoniacal nitrogen	1 - 2	mg/l		Degradable material not permitted in Site. Ammoniacal nitrogen selected in case small amounts of topsoil or other degradable material are accidentally accepted.

5.3.4.3 Hydrology

The monthly LTA rainfall and actual evapotranspiration data are presented in Table 2.3 and the annual LTA are presented in Table 5.4. The monthly LTA effective rainfall and run-off is calculated in the model for each using equation (1) from Section 4.1.1. The sum of the monthly effective rainfall and run-off is used in the water balance for the RAM model.

Table 5.4 LTA Hydrological parameters applied in model

Parameter	Value	Units	Distribution	Justification
Annual LTA rainfall	848.2	mm/a	Constant	MORECS data for square 147 for crop type as "grass with median AWC" and period 2000-2023.
Run-off factor	0.1- 0.2	-	Uniform	Fraction of rainfall that will run-off. (Infiltration factor = 1- run-off factor.)
Annual LTA actual evapotranspiration	588.95	mm/a	Constant	MORECS data for square 147 for crop type as "grass with median AWC" and period 2000-2023.

5.3.4.4 Pathway definition

The pathway parameters are presented in Table 5.5 to Table 5.8 . Retardation is applied in the AEGB for all determinands except sulphate whilst in groundwater ammoniacal nitrogen is the only determinand to model degradation and retardation. Degradation of ammoniacal nitrogen is not considered in the AEGB conditions are anaerobic. Sulphate is the only source term determinand that neither degrades nor is retarded.

Note that the Site is not being capped and the basal and sidewall AEGB consists of clay only (that is it is not lined with a geomembrane) the requirement to model degradation of the liner over the lifetime of the landfill is not applicable.

The parameters for the breakthrough pathway are presented in Table 5.9.

Table 5.5 Hydrogeological parameters of the Bridgnorth Sandstone

Parameter	Value	Units		Justification
Unsaturated Bridgnorth Sandstone				
Bulk density	2,325	kg/m^3		Estimate
Porosity	0.275 - 0.284 - 0.318	--	Triangular	Minimum and maximum for inter quartile range of porosity in Bridgnorth Sandstone and most-likely is arithmetic mean as presented by BGS (1997)

Parameter	Value	Units		Justification
Saturated Bridgnorth Sandstone Aquifer Unit				
Hydraulic conductivity	1.40 - 3.24 - 5.07	m/d	Triangular	Minimum and maximum for inter quartile range of horizontal hydraulic conductivity in Bridgnorth Sandstone as presented by BGS (1997). Most-likely value calculated as the average of the minimum and maximum.
Thickness	100	m		Estimate
Porosity	0.275 - 0.284 – 0.318	--	Triangular	Minimum and maximum for inter quartile range of porosity in Bridgnorth Sandstone and most-likely is arithmetic mean as presented by BGS (1997)
Mixing depth	0.1 of travel distance	m	-	Estimate for longitudinal dispersivity EA (2001)
Mixing width	183	m	-	Average width of the void perpendicular to groundwater flow (Table 5.2)
Parameters to calculate hydraulic gradient to site boundary receptor				
Hydraulic head difference between Bromsberrow South and Bromsberrow North (BH2-BH3)	6.75 – 7.78 – 8.80	--	Triangular	Minium value is difference during low water levels (2019 – excluding suspect data); maximum value is difference during high water levels (2015); most-likely is average of the minimum and maximum values (see Section 2.5.2).
Distance to from Bromsberrow South northern boundary and Bromsberrow North (BH2-BH3)	340	m	-	Measured from Figure 2.12. This value is used with the hydraulic head difference to calculate the hydraulic gradient.

Parameter	Value	Units		Justification
Parameters from calculate gradient to PWS receptor				
Hydraulic head difference between Bromsberrow South and Bromsberrow PWS (BH1-BH4)	3.08 – 3.62 – 4.16	--	Triangular	Minium value is difference during low water levels (2019 – excluding suspect data); maximum value is difference during high water levels (2015); most-likely is average of the minimum and maximum values (see Section 2.5.2).
Distance to from Bromsberrow South northern boundary and Bromsberrow PWS (BH1-BH4)	270	m	-	Measured from Figure 2.12. This value is used with the hydraulic head difference to calculate the hydraulic gradient.
Pathway parameters				
Distance to site boundary	111.5	m	-	Measured from site plans from centre of site to site boundary receptor.
Distance from down gradient edge of site to Bromsberrow PWS	161.5	m	-	Measured from site plans from centre of site to PWS receptor.
Dispersivity	0.1 of travel distance	m	-	Estimate for longitudinal dispersivity EA (2001)
Tortuosity	1 – 5 - 10	-	Triangular	Represents the range of tortuosity for sands and clays (from Marsily (1986) p.233)

Table 5.6 Hydrogeological parameters of the AEGB

Parameter	Value	Units	Distribution	Justification
Thickness	1	m	-	Thickness of the AEGB
Maximum head on the AEGB	20.5	m	-	Calculated from average of minimum and maximum surface elevation minus the elevations of the top of the AEGB
Hydraulic conductivity	$1x10^{-11}$ - $2x10^{-10}$	m/s	Uniform	Estimated from the minimum and maximum value from Blue Lias Clay data sheet (Appendix C).
Bulk density	1,670 - 1,790	kg/m^3	Uniform	From Blue Lias Clay data sheet (Appendix C)
Porosity	0.13 - 0.19	--	Uniform	From Blue Lias Clay data sheet (Appendix C)
Dispersivity	0.1 of travel distance	m	-	Estimate for longitudinal dispersivity EA (2001)
Tortuosity	1 - 5 - 10	-	Triangular	Represents the range of tortuosity for sands and clays (from Marsily (1986) p.233)

Table 5.7 Attenuation parameters in the saturated Bridgnorth Sandstone

Parameter	Values	Units	Distribution	Justification
Ammoniacal nitrogen partition coefficient (K_d)	0 – 0.2 – 0.6	L/kg	Triangular	For Permo-Triassic sandstone (Buss, 2003)
Ammoniacal nitrogen half life	1825 - 3650	days	Uniform	Aerobic decay of 5 to 10 years (Buss, 2003)

Table 5.8 Attenuation parameters in the AEGB

Parameter	Value	Unit	Distribution	Justification
Arsenic partition coefficient (K_d)	34 - 520	L/kg	Uniform	Minimum and maximum from Table 4-1 (Sheppard, Long, Sanipelli, & Sohlenius, 2009)
Total Chromium partition coefficient (K_d)	140 - 900	L/kg	Uniform	
Lead partition coefficient (K_d)	3100 - 44,000	L/kg	Uniform	
Nickel partition coefficient (K_d)	450 - 3800	L/kg	Uniform	
Copper partition coefficient (K_d)	160 - 3200	L/kg	Uniform	
Cadmium partition coefficient (K_d)	73 - 1200	L/kg	Uniform	
Ammoniacal nitrogen partition coefficient (K_d)	0.1 - 0.5 - 5	L/kg	Uniform	For clay (Buss, 2003)

Table 5.9 Breakout pathway parameters

Parameter	Value	Unit	Distribution	Data Source
Volume of phase 8 restoration material	185,000	m^3	-	From Restoration Plans (Appendix A)
Depth of clean top soil	0.5	m	-	Stantec (2024c)
Length of infiltration basin	100	m	-	Estimated from site plans (Appendix A)
Hydraulic conductivity of waste	$1x10^{-8}$ – $1x10^{-7}$	m/s	Uniform	Estimate of hydraulic conductivity for restoration materials.
Average material thickness	4.55	m	-	Calculated from the volume of material placed in phase 8 minus the volume of top soil and the surface area.

Parameter	Value	Unit	Distribution	Data Source
Proportion of leachate that would freely drain from the restoration mass.	30 - 60	%	Uniform	Minimum value taken from Beavan (1996). Conservatively, a factor of 2 applied to estimate maximum value.
Head at edge of basin	0	m	-	Conservatively set to 0 to maximise breakout flux.

A free water diffusion coefficient of $2x10^{-9}m^2/s$ has been applied to all the contaminants as a conservative estimate based on the value for chloride (Fetter, 1999).

5.3.4.5 Receptor

Environmental assessment levels (EAL) have been set as follows:

- Receptor for hazardous substances (water table): MRV over the higher of the UKTAG (UK Technical Advisory Group) quantification limit and the UKTAG concentration to avoid deterioration in quality of the receiving groundwater (column 3 and 4 of Table 1 i (UKTAG, 2016)); and
- Groundwater receptors: lower of UK drinking water standard (UK DWS) and the 95th percentile baseline concentration calculated from groundwater quality data from Bromsberrow South (excluding BH02 due to high concentrations), Bromsberrow North and Bromsberrow PWS (Appendix B).

The selected EALs are presented in Table 5.10.

Table 5.10 Environmental Assessment Levels (EAL) (mg/l)

Description	EAL	Units	Description
Arsenic	0.005	mg/l	Limit to avoid deterioration in groundwater quality (annual mean mg/l) (UK TAG, 2016)
Total Chromium	0.005	mg/l	
Lead	0.005	mg/l	
Nickel	0.02	mg/l	UK DWS
Copper	0.006	mg/l	95th percentile baseline concentration calculated from groundwater quality data.
Cadmium	0.0004	mg/l	
Sulphate	55	mg/l	
Ammoniacal nitrogen	0.17	mg/l	

The receptors represented in the model are the water table for hazardous pollutants and groundwater at the site boundary for the non-hazardous pollutants. Two additional pathways model the impact at the Bromsberrow PWS with and without dilution within the abstraction have also been include, where the annual average abstraction of 7.72 Ml/d is used for the pathway that considers dilution within the abstraction.

5.3.5 Sensitivity analysis

Sensitivity analyses were carried out to determine the impact of key scenarios as described in the sections below. The results of the analysis are presented in Section 5.4.2. The sensitivity models are presented in Appendix F.

5.3.5.1 Landfill Directive AEGB specification

In order to protect groundwater, the Site will have a basal and sidewall AEGB constructed from Blue Lias clay (non-waste) which has a hydraulic conductivity of the order $1x10^{-10}$m/s (Appendix D). The hydraulic conductivity specified in the Landfill Directive for Inert Landfills by comparison is $1x10^{-7}$m/s.

This scenario uses a constant hydraulic conductivity of $1x10^{-7}$m/s in the base case model to demonstrate the impact of the enhanced engineering (i.e. AEGB at a hydraulic conductivity of around $1x10^{-10}$ m/s).

5.3.5.2 Rogue Load

The EA provided a range of leachate quality to use under Rogue Load scenario (Environment Agency, 2023); these concentrations for the determinands considered in the HRA model are presented in Table 5.11. The base case concentrations are used where a rogue load distribution was not provided for that specific determinand.

Note that, with the exception of ammoniacal nitrogen, the rogue load concentrations are not significantly different to the base case concentrations presented in Table 5.3. The maximum rogue load ammoniacal nitrogen concentration may be representative of a load containing a significant proportion of putrescible material and will be a significant overestimate of the average concentration across the total waste mass.

A sensitivity scenario has been run using the base case model updated with this source term.

Table 5.11 Rogue load source concentrations (as leachate).

Determinand	Value	Units	Distribution	Justification
Arsenic	0.001 - 0.007 - 0.6	mg/l	Triangular	Environment Agency (2023)
Total Chromium	0.5 - 0.1	mg/l	Uniform	Table 5.3
Lead	0.002 – 0.007 – 0.15	mg/l	Triangular	Environment Agency (2023)
Nickel	0.002 – 0.02 – 0.12	mg/l	Triangular	Environment Agency (2023)
Copper	0.3 - 0.6	mg/l	Uniform	Table 5.3

Determinand	Value	Units	Distribution	Justification
Cadmium	0.1 - 0.02	mg/l	Uniform	Table 5.3
Sulphate	200 - 1200 - 1800	mg/l	Triangular	Environment Agency (2023)
Ammoniacal nitrogen	0.3 - 8 - 25	mg/l	Triangular	Environment Agency (2023)

5.3.5.3 Impact of groundwater rebound

The abstraction licence at Bromsberrow PWS is time limited to 2027 at which point the EA may stipulate a reduction in abstraction rate of approximately 1 Ml/d which equates to approximately 10%. The impact of a reduction in abstraction will be for groundwater levels to rebound with the increase in groundwater levels being more decreasing as the distance from the PWS increases.

The impact of groundwater rebound on the base case model has been considered as a sensitivity run.

The groundwater rebound was estimated using the Theis equation for predicting the drawdown profile associated with abstraction from a well.

The following approach was taken:

- The Theis well function was used to calculate the drawdown profile based on the current annual average abstraction rate at Bromsberrow PWS and the horizontal hydraulic conductivity for the Bridgnorth Sandstone (Table 5.5).
- The difference in hydraulic head between the Bromsberrow South and distances representing the location of the boreholes at Bromsberrow North and the PWS were calculated and compared to the average observed difference in hydraulic head (Table 5.5). The most likely horizontal hydraulic conductivity for the Bridgnorth Sandstone (Table 5.5) gave good agreement between the observed and calculated values.
- Based on the current the annual average abstraction rate (7.72 Ml/d) drawdown profiles were calculated assuming a reduction in abstraction of 10% and 20%. From these drawdown profiles the impact on the difference in hydraulic head between the Bromsberrow South and Bromsberrow North and the PWS were calculated.

The calculations are presented in Appendix E and the reduction in the difference in hydraulic head between Bromsberrow South and the PWS and Bromsberrow South and the BH02 and BH03 at Bromsberrow North are presented in Table 5.12 for a 20% reduction in the annual average abstraction rate. The higher reduction is considered to provide additional confidence in the predictions.

Table 5.12 Decrease in the difference in hydraulic head across the Site for 20% reduction in abstraction at Bromsberrow PWS

Between Bromsberrow South and Bromsberrow PWS (m)	Between Bromsberrow South and Bromsberrow North BH2 and BH3 (m)
1.22	0.64

The increase in the groundwater level at Bromsberrow North has been calculated to be 2.43 m for an abstraction rate reduction of 20%. Although the unsaturated zone is not considered in the contaminant transport model, the unsaturated zone thickness is also calculated in the simulation and presented in Section 5.4.

The impact of this scenario is to reduce the hydraulic gradient on the groundwater pathways and hence reduce the dilution in groundwater.

5.3.5.4 Impact of climate change

The UK Climate projections (UKCP18[6]) have been utilised in a scenario that considers the impact of climate change. The key results from the climate change models (Appendix E) provide a set of percentiles for the change in average precipitation average temperatures. These data could be used as part of a soil moisture balance model to understand the possible impact climatic changes could have on groundwater levels local to the site.

However, the impact of climate change on groundwater levels at the local scale will be consistent. This means the groundwater levels will either increase or decrease over time by the same amount across the Site and as such this will impact the thickness of the unsaturated zone and will not change the hydraulic gradient. Since the model does not consider the unsaturated zone underlying the Site, groundwater rebound due to climate-change has not been considered as part of this scenario.

The climate projects can be used to assess the possible impact infiltration and run-off. The minimum and maximum fractional change in rainfall have been calculated and a similar approach has been applied to the actual evapotranspiration using an estimated range for the increase in the LTA monthly average values. The calculations are presented in Appendix E and the ranges for rainfall and actual evapotranspiration are presented in Table 5.13.

The range for the rainfall data has been applied to the LTA monthly data (Table 2.3) to derive the minimum and maximum values for a triangular distribution, and the LTA monthly rainfall most-likely value. A similar approach has been applied to the actual evapotranspiration data but here the LTA monthly average AE is used as the minimum and the most-likely and maximum values for the triangular distribution are calculated from the estimated minimum and maximum fractional change given in Table 5.13. The ranges are calculated in the sensitivity model as presented in Appendix F.

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[6] https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/summaries/headline-findings - accessed January 2024

As with the base case, the monthly LTA effective rainfall and run-off is calculated in the model for each using equation (1) from Section 4.1.1 but here the monthly LTA rainfall and actual evapotranspiration data is generated from the triangular distribution for each realisation of the probabilistic run.

The sum of the monthly LTA effective rainfall and run-off is used in the water balance for the RAM model.

Table 5.13 Fractional change in monthly LTA rainfall and evapotranspiration based on climatic data

	Minimum	Maximum	Justification
Fractional change in rainfall	-0.28	0.24	Minimum is 5th percentile and maximum is 95th percentile of predicted change in average annual precipitation from 2020-2099 from UK Climate Projections (UKCP18[7] - Appendix E) for the South West of England.
Fractional change in actual evapotranspiration	0.05	0.1	Estimated

5.4 Model results

The results from the base case model run for 10,000 simulations and 1,000 simulations where compared and confirmed that 1,000 simulations were sufficient to give results consistent with 10,000 simulations.

In the model, the maximum concentration in the breakthrough curve and concentrations for a set of pre-defined timeslices are calculated for each pathway and determinand. The maximum 95th and 50th percentile concentrations from these data are reported in Sections 5.4.1 and 5.4.2. In order to give an indication of the time at which the maximum concentration occurred, the highest concentration and associated timeslice are also reported.

The impact of the transport processes considered in the RAM model are summarised below:

Dilution: the dilution factor will increase if the contaminant flux decreases and will decrease if the contaminant flux increases. Conversely, the dilution factor increases and decreases with an increase or decrease in groundwater flux.

Advection: decreasing the velocity along a pathway will cause the breakthrough profile to extend, allowing more time for attenuation giving a lower peak concentration at a later time.

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[7] https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/summaries/headline-findings - accessed January 2024

Path length and dispersion: increasing the path length (and the dispersion, which is set to 10% of the pathlength) has a similar impact as decreasing the velocity (advection) in that the peak concentration will be lower and occur at a later time.

Retardation: a retarded substance will breakthrough at a later time and have a lower peak concentration when compared to breakthrough of an unretarded contaminant. The breakthrough curves for heavily retarded substances can extend over thousands of years.

Degradation: the process of degradation removes contaminant mass from the pathway. The degree of degradation is controlled by the ratio of half-life of the contaminant to the travel-time on the pathway. Essentially, the half-life is the time it takes the concentration to decrease by a factor of two. If the travel time along a pathway is much less than the half-life then degradation will be negligible. Conversely, if the travel time is much greater than the half-life the concentrations will reduce significantly and cause the peak concentration to occur at a much earlier time: this is because a contaminant that decays rapidly will degrade along the pathway before the source has depleted.

Declining source: the rate at which a source declines is controlled by the infiltration rate through the source. A high infiltration rate will increase the rate of decline and can reduce the peak concentration.

5.4.1 Base case results

The model was run using the parameters defined in Section 5.3.4: the full set of results are presented in Appendix C.

The predicted dilution factors, unsaturated zone thickness and groundwater levels are presented in Table 5.14. These data indicate that based on the 5th percentile the thickness of the unsaturated zone for the base case is not predicted to fall below 3 m.

Table 5.14 Predicted pathway flows and dilution flows in the base case risk assessment model

	Det	95th	90th	75th	50th	25th	5th
Base case dilution factor							
Site Boundary	0.0606	0.1094	0.0984	0.0781	0.0549	0.0302	0.0103
Groundwater at PWS	0.0295	0.0550	0.0498	0.0384	0.0264	0.0147	0.0051
Abstraction at PWS	0.0011	0.0018	0.0017	0.0015	0.0010	0.0006	0.0002
Unsaturated zone thickness							
Base case	4.45	5.99	5.70	5.16	4.58	3.99	3.15
Groundwater level at Bromsberrow North							
Base case	31.55	32.85	32.59	32.01	31.42	30.84	30.00

The predicted peak contaminant concentrations are presented in Table 5.15 the Site Boundary receptor; in Table 5.16 for groundwater at the PWS and Table 5.17 for the abstraction at the PWS; the EAL for each determinand is also included. A comparison of the data presented in these tables to the relevant EALs indicates that the restoration scheme poses no significant risk to environmental waters.

It should be noted that since lead is heavily retarded the maximum concentration is reached after 10,000 years so there is a notable difference between the maximum concentration and the highest concentration at 10,000 years shown in the tables presented here.

Sulphate is the only determinand predicted to exceed the EAL at the Site Boundary where the peak concentration is predicted by 10 years. The 50th percentile concentration for sulphate is approximately equal to the background concentrations and all data presented for sulphate at the Site Boundary receptor are below the UKDWS of 250 mg/l. The 95th percentile concentration for sulphate in groundwater at the PWS is just above the EAL whilst the 95th percentile concentration in the abstraction is approximately 2 mg/l.

Dilution is the key processes for sulphate. Ammoniacal nitrogen concentrations are reduced by degradation, but this is less significant than dilution as the travel time along the pathway is relatively short (of the order of the modelled half-life). Retardation is the dominant process for the metals, and the peak concentrations at the groundwater receptors are significantly delayed.

It should be noted that the minimum and maximum probabilistic distributions for the difference in hydraulic head used to calculate the hydraulic gradients along the pathways are based on recent high and low groundwater conditions. For each simulation the probabilistic gradient is applied for the full duration of the model. Thus, the 95th percentile concentrations for sulphate will derive from a simulation that assumes the hydraulic gradient is at the minimum for the duration of the model which an overly conservative assumption.

Table 5.15 Predicted peak contaminant concentrations in groundwater at the Site boundary

		Arsenic	Total Chromium	Lead	Nickel	Copper	Cadmium	Sulphate	Ammoniacal nitrogen
EAL		0.005	0.005	0.005	0.02	0.006	0.0004	55	0.17
Det: Highest @ timeslice (years)		4.89E-5 @ 4171	4.35E-5 @ 7733	2.13E-8 @ 100000	1.28E-5 @ 31275	8.07E-5 @ 24748	7.10E-6 @ 9442	**65.0 @ 7.1**	0.057 @ 28.5
95th	**Maximum**	2.09E-4	1.42E-4	7.30E-6	4.77E-5	3.80E-4	3.31E-5	**126**	0.082
	Highest @ timeslice (years)	1.74E-4 @ 1000	1.05E-4 @ 4000	1.42E-11 @ 10000	4.09E-5 @ 8000	3.10E-4 @ 6000	2.41E-5 @ 2000	**120 @ 10.0**	0.074 @ 40.0
50th	**Maximum**	4.30E-5	3.59E-5	8.10E-9	1.14E-5	6.99E-5	5.92E-6	55.3	0.036
	Highest @ timeslice (years)	2.11E-5 @ 4000	2.26E-5 @ 8000	1.20E-37 @ 10000	2.05E-7 @ 10000	4.40E-6 @ 10000	3.10E-6 @ 8000	54.5 @ 10.0	0.031 @ 60.0

Results shown in **bold** indicate the EAL has been exceed.

Table 5.16 Predicted peak contaminant concentrations in groundwater at the Bromsberrow PWS

		Arsenic	Total Chromium	Lead	Nickel	Copper	Cadmium	Sulphate	Ammoniacal nitrogen
EAL		0.005	0.005	0.005	0.02	0.006	0.0004	55	0.17
Deterministic: Highest @ timeslice (years)		2.38E-5 @ 4171	2.12E-5 @ 7734	1.04E-8 @ 100000	6.22E-6 @ 31276	3.93E-5 @ 24748	3.46E-6 @ 9442	31.6 @ 7.9	0.025 @ 29.8
95th	**Maximum**	1.03E-4	7.18E-5	3.62E-6	2.32E-5	1.85E-4	1.63E-5	**63.5**	0.035
	Highest @ timeslice (years)	8.37E-5 @ 1000	5.21E-5 @ 4000	6.63E-12 @ 10000	2.05E-5 @ 8000	1.50E-4 @ 6000	1.19E-5 @ 2000	**61.7 @ 10.0**	0.032 @ 50.0
75th	**Maximum**	4.09E-5	2.98E-5	2.10E-7	1.02E-5	6.51E-5	5.73E-6	40.1	0.022
	Highest @ timeslice (years)	2.25E-5 @ 2000	2.17E-5 @ 6000	1.79E-26 @ 10000	2.57E-6 @ 10000	3.19E-5 @ 10000	3.55E-6 @ 6000	39.2 @ 10.0	0.020 @ 50.0
50th	**Maximum**	2.04E-5	1.74E-5	4.00E-9	5.53E-6	3.40E-5	2.89E-6	26.6	0.015
	Highest @ timeslice (years)	1.02E-5 @ 4000	1.10E-5 @ 8000	6.10E-38 @ 10000	9.62E-8 @ 10000	2.16E-6 @ 10000	1.49E-6 @ 8000	26.3 @ 10.0	0.012 @ 60.0

Results shown in **bold** indicate the EAL has been exceed.

Table 5.17 Predicted peak contaminant concentrations at the Bromsberrow PWS

		Arsenic	Total Chromium	Lead	Nickel	Copper	Cadmium	Sulphate	Ammoniacal nitrogen
EAL		0.005	0.005	0.005	0.02	0.006	0.0004	55	0.17
Deterministic: Highest @ timeslice (years)		9.17E-7 @ 4171	8.15E-7 @ 7734	4.00E-10 @ 100000	2.40E-7 @ 31276	1.51E-6 @ 24748	1.33E-7 @ 9442	1.2 @ 7.9	9.52E-4 @ 29.8
95th	**Maximum**	3.95E-6	2.50E-6	1.32E-7	8.74E-7	7.19E-6	5.74E-7	2.1	1.35E-3
	Highest @ timeslice (years)	3.25E-6 @ 1000	1.86E-6 @ 4000	3.20E-13 @ 10000	7.77E-7 @ 8000	5.58E-6 @ 6000	4.27E-7 @ 2000	2.0 @ 10.0	1.25E-3 @ 30.0
75th	**Maximum**	1.50E-6	1.12E-6	8.37E-9	3.73E-7	2.41E-6	2.14E-7	1.5	8.82E-4
	Highest @ timeslice (years)	9.01E-7 @ 2000	8.31E-7 @ 6000	6.79E-28 @ 10000	9.73E-8 @ 10000	1.22E-6 @ 10000	1.44E-7 @ 6000	1.5 @ 10.0	7.52E-4 @ 60.0
50th	**Maximum**	8.14E-7	6.61E-7	1.47E-10	2.07E-7	1.27E-6	1.10E-7	1.1	5.70E-4
	Highest @ timeslice (years)	3.95E-7 @ 4000	4.34E-7 @ 8000	2.62E-39 @ 10000	3.60E-9 @ 10000	7.67E-8 @ 10000	6.03E-8 @ 8000	1.0 @ 10.0	4.76E-4 @ 60.0

Results shown in **bold** indicate the EAL has been exceed.

Table 5.18 Predicted dilution factors for hazardous substances at the Water Table receptor

	Det	95th	90th	75th	50th	25th	5th
Base case dilution factor							
Water table (instantaneous dilution)	0.2112	0.3406	0.3244	0.2692	0.1910	0.1055	0.0365
Breakout (instantaneous dilution)	0.0012	0.0023	0.0021	0.0018	0.0013	0.0008	0.0003

The results for the hazardous substances at the water table are presented in Table 5.19 and are compared to the EAL (Table 5.10). Retardation in the AEGB is the key process as the dilution factor presented in Table 5.18 indicates the 95th percentile dilution factor will reduce source term concentrations by 35%. The peak concentration for arsenic at the water table is approximately 30 times lower than the EAL and is predicted to occur at around 1,000 years. Chromium and lead concentrations are also below the EAL values and are predicted to reach the peak concentrations after thousands of years, as they are both heavily retarded.

Table 5.19 Predicted contaminant concentrations for the hazardous substances at the Water Table receptor

Water Table		Arsenic	Total Chromium	Lead
EAL		0.005	0.005	0.005
Deterministic: Highest @ timeslice (years)		1.70E-4 @ 4169	1.51E-4 @ 7732	7.43E-8 @ 100000
95th	**Maximum**	7.26E-4	4.76E-4	2.38E-5
	Highest @ timeslice (years)	6.09E-4 @ 1000	3.43E-4 @ 4000	6.16E-11 @ 10000
75th	**Maximum**	2.78E-4	2.04E-4	1.60E-6
	Highest @ timeslice (years)	1.69E-4 @ 2000	1.53E-4 @ 6000	1.24E-25 @ 10000
50th	**Maximum**	1.49E-4	1.24E-4	2.77E-8
	Highest @ timeslice (years)	7.32E-5 @ 4000	8.06E-5 @ 8000	4.81E-37 @ 10000

Results shown in **bold** indicate the EAL has been exceed.

Concentrations for the breakout pathway indicate no risk is posed by breakout from the surface of the restoration material infiltrating through the unsaturated zone. Instantaneous dilution is only process considered on this pathway and is sufficient to reduce the concentrations to levels below the EAL as the low hydraulic conductivity of the waste means that any breakout flux is small compared to surface run-off across the Site.

Table 5.20 Predicted contaminant concentrations for the breakout pathway

		Arsenic	Total Chromium	Lead	Nickel	Copper	Cadmium	Sulphate	Ammoniacal nitrogen
EAL		0.005	0.005	0.005	0.02	0.006	0.0004	55	0.17
Deterministic: Highest @ timeslice (years)		5.23E-5 @ 1.14E-4	8.72E-5 @ 1.14E-4	1.31E-4 @ 1.14E-4	1.05E-4 @ 1.14E-4	5.23E-4 @ 1.14E-4	1.74E-5 @ 1.14E-4	1.3 @ 1.14E-4	1.74E-3 @ 1.14E-4
95th	**Maximum**	1.11E-4	1.89E-4	2.81E-4	2.21E-4	1.12E-3	3.69E-5	2.8	3.74E-3
	Highest @ timeslice (years)	1.06E-4 @ 10.0	1.80E-4 @ 10.0	2.67E-4 @ 10.0	2.10E-4 @ 10.0	1.07E-3 @ 10.0	3.55E-5 @ 10.0	2.7 @ 10.0	3.56E-3 @ 10.0
75th	**Maximum**	8.03E-5	1.34E-4	1.95E-4	1.58E-4	7.84E-4	2.65E-5	2.0	2.70E-3
	Highest @ timeslice (years)	7.79E-5 @ 10.0	1.27E-4 @ 10.0	1.87E-4 @ 10.0	1.54E-4 @ 10.0	7.48E-4 @ 10.0	2.56E-5 @ 10.0	1.9 @ 10.0	2.60E-3 @ 10.0
50th	**Maximum**	5.66E-5	9.24E-5	1.40E-4	1.12E-4	5.46E-4	1.84E-5	1.4	1.89E-3
	Highest @ timeslice (years)	5.47E-5 @ 10.0	8.99E-5 @ 10.0	1.35E-4 @ 10.0	1.08E-4 @ 10.0	5.26E-4 @ 10.0	1.77E-5 @ 10.0	1.4 @ 10.0	1.82E-3 @ 10.0

Results shown in **bold** indicate the EAL has been exceed.

5.4.1.1 Summary

Dilution and declining source are the key parameters for the non-hazardous pollutants at the groundwater receptors (Site boundary and PWS).

Retardation and travel time in the AEGB are the key parameters for the hazardous substances at the water table.

As discussed above, probabilistic modelling is conservative when considering ranges on water-balance parameters as these are applied for the duration for the model during each realisation. Thus, the 95th percentile sulphate concentrations will originate from a realisation that uses the highest source-term concentration and the lowest dilution factor. In reality the dilution factor which will vary significantly over duration of the model due changes in groundwater levels and rainfall.

5.4.2 Sensitivity results

The sensitivity of the model to key parameters was assessed using the sensitivity cases described in Section 5.3.5. The sensitivity models and results are presented in Appendix E.

As discussed in Section 5.4.1, since lead is heavily retarded the maximum concentration is reached after 10,000 years so there is a notable difference between the maximum concentration and the highest concentration at 10,000 years shown in the tables presented here.

5.4.2.1 Impact on groundwater regime

The dilution factors presented in Table 5.21 show that Sensitivity 1 (AEGB) has the most significant impact on the dilution factor as the higher hydraulic conductivity of the AEGB significantly increases the flux that can pass through the barrier.

The thickness of the unsaturated zone is reduced in Sensitivity 3 (Rebound); here the 5th percentile value is 0.71 m, some 2.44 m lower than the base case value. This would does not include the impact of climate change but it is likely that the net impact of climate change over the next 100 years would be to decrease groundwater levels, and any increase trend would be temporary. Note that the thickness of the unsaturated zone underneath the Site is not represented in the model.

Table 5.21 Comparison of predicted dilution factor, unsaturated zone thickness and groundwater levels at Bromsberrow North for Base Case and sensitivity models

	Deterministic	95th percentile	90th percentile	75th percentile	50th percentile	25th percentile	5th percentile
Dilution factor for Site Boundary receptor							
Base case	0.06	0.11	0.10	0.08	0.05	0.03	0.01
Sensitivity 1 AEGB	0.19	0.27	0.26	0.22	0.20	0.17	0.15
Sensitivity 2 Rogue load	0.06	0.11	0.10	0.08	0.05	0.03	0.01
Sensitivity 3 Rebound	0.07	0.12	0.11	0.09	0.06	0.03	0.01
Sensitivity 4 Climate change	0.06	0.11	0.10	0.08	0.06	0.03	0.01
Unsaturated zone thickness							
Base case	4.45	5.99	5.70	5.16	4.58	3.99	3.15
Sensitivity 1 AEGB	4.45	5.99	5.70	5.16	4.58	3.99	3.15
Sensitivity 2 Rogue load	4.45	5.99	5.70	5.16	4.58	3.99	3.15
Sensitivity 3 Rebound	2.14	3.56	3.27	2.72	2.14	1.56	0.71
Sensitivity 4 Climate change	4.45	5.99	5.70	5.16	4.58	3.99	3.15
Groundwater level							
Base case	31.55	32.85	32.59	32.01	31.42	30.84	30.00
Sensitivity 1 AEGB	31.55	32.85	32.59	32.01	31.42	30.84	30.00
Sensitivity 2 Rogue load	31.55	32.85	32.59	32.01	31.42	30.84	30.00
Sensitivity 3 Rebound	33.86	35.28	35.02	34.44	33.85	33.28	32.44

	Deterministic	95th percentile	90th percentile	75th percentile	50th percentile	25th percentile	5th percentile
Sensitivity 4 Climate change	31.55	32.85	32.59	32.01	31.42	30.84	30.00

A comparison of the rainfall parameters for the Base Case and Sensitivity 4 (Climate change) is given in Table 5.22. As described in Section 5.3.5.4, the climate change parameters are used to define a probabilistic distribution for the monthly LTA values of rainfall and actual evapotranspiration. The differences between the base case and sensitivity values presented in Table 5.22 are less than might be expected based the fractional change data presented in Table 5.13 because the monthly LTA values generated during the simulation are independent parameters. This approach was deemed appropriate as defining a correlation between the monthly LTA values assumes the change in climate be consistent over the 10,000 years rather than the climatic extremes currently predicted.

Table 5.22 Comparison of predicted Rainfall, Run-off and Effective Rainfall at Bromsberrow North for Base Case and Climate change sensitivity model

	Deterministic	95th percentile	90th percentile	75th percentile	50th percentile	25th percentile	5th percentile
Rainfall (mm)							
Base case	848.20	848.20	848.20	848.20	848.20	848.20	848.20
Sensitivity 4 Climate change	848.20	879.16	869.45	853.28	835.42	816.44	792.54
Run-off (mm)							
Base case	127.23	166.22	161.62	148.49	127.68	106.66	89.01
Sensitivity 4 Climate change	127.23	163.59	159.38	146.41	126.13	104.99	87.71
Effective rainfall (mm)							
Base case	260.68	283.60	280.85	272.59	260.42	248.80	238.89
Sensitivity 4 Climate change	253.62	286.55	277.10	263.82	247.53	233.65	211.47

5.4.2.2 Impact at the groundwater receptors

The results of the sensitivity runs are presented in Table 5.22 to Table 5.24 for the Site Boundary receptor (Deterministic, 95th percentile and 50th percentile respectively); and Table 5.25 for the 50th percentile concentrations at the PWS groundwater receptor. The results are below EAL unless stated otherwise.

It should be noted that for all the runs the maximum concentration for lead is reached after 10,000 years.

Inspection of the data indicates that Sensitivity 1 (AEGB) shows the most significant increase in concentrations due to the increase in the dilution factor, although with the exception of sulphate, ammoniacal nitrogen is the only determinand to slightly exceed the EAL (0.2mg/l compared to 0.17 mg/l for the 95th percentile concentration) whilst this still below the UKDWS of 0.39mg/l.

An additional scoping model run was carried out using a AEGB hydraulic conductivity of $1x10^{9}$m/s (stated as being the maximum value in the supporting permitting documents, including the ESSD (Stantec, 2024c) and SOP (Stantec, 2024d)). The model results are not reported here as they are very similar to the results from the Sensitivity 1 model; this is because the flux through the AEGB is not limited and hence the dilution factor is the same for both values of AEGB hydraulic conductivity. The range of hydraulic conductivities used in the base case model originates from samples of Blue Lias Clay taken from in situ landfill engineering (Appendix D) and so is representative of the properties AEGB that will be installed at the Site. Furthermore, the AEGB and the waste material at the base of the void will be further compressed as the Site is progressively filled, further reducing the hydraulic conductivity.

Ammoniacal nitrogen is the only determinand to be impacted by Sensitivity 2 (Rogue Load); as discussed in Section 5.3.5.2 this is because the maximum concentration of 25 mg/l is overly conservative for the total waste mass. The other results for the remaining determinands for the Rogue Load sensitivity run are not greatly different to the base case results with the exception of arsenic which has increased by a factor of approximately 10 but is still below the EAL.

Sensitivity 3 (Rebound) and 2 (Climate change) have results similar to the base case.

Table 5.25 indicates sulphate concentration for Sensitivity 1 (AEGB) is the only determinand with 50th percentile concentrations slightly greater than the EAL for the groundwater receptor at the PWS with concentrations of 97 mg/l compared to the EAL of 55 mg/l; this concentration is significantly below the UK DWS of 250 mg/l. The 95th percentile concentration for sulphate at the PWS abstraction is of the order of 5 mg/l (Appendix F).

Table 5.23 Predicted deterministic concentrations (mg/l @ years) at the Site Boundary for the sensitivity cases presented in Section 5.3.5

	Arsenic	Total Chromium	Lead	Nickel	Copper	Cadmium	Sulphate	Ammoniacal nitrogen
EAL	0.005	0.005	0.005	0.02	0.006	0.0004	55	0.17
Base Case	4.89E-5 @ 4171	4.35E-5 @ 7733	2.13E-8 @ 100000	1.28E-5 @ 31275	8.07E-5 @ 24748	7.10E-6 @ 9442	**65.0 @ 7.1**	0.057 @ 28.5
Sensitivity 1 AEGB	1.82E-4 @ 1233	1.62E-4 @ 2284	5.36E-6 @ 100000	4.75E-5 @ 9229	3.01E-4 @ 7303	2.64E-5 @ 2788	**203 @ 3.5**	**0.18 @ 10.7**
Sensitivity 2 Rogue Load	7.60E-6 @ 4171	4.35E-5 @ 7733	1.33E-9 @ 100000	2.84E-6 @ 31275	8.07E-5 @ 24748	7.10E-6 @ 9442	**69.4 @ 7.1**	**0.31 @ 28.5**
Sensitivity 3 Rebound	5.64E-5 @ 4171	5.01E-5 @ 7734	2.46E-8 @ 100000	1.47E-5 @ 31276	9.31E-5 @ 24748	8.19E-6 @ 9442	**74.9 @ 7.4**	0.063 @ 29.0
Sensitivity 4 Climate change	4.91E-5 @ 4171	4.37E-5 @ 7733	2.14E-8 @ 100000	1.28E-5 @ 31275	8.12E-5 @ 24748	7.14E-6 @ 9442	**65.4 @ 7.1**	0.058 @ 28.5

Results shown in **bold** indicate the DWS has been exceeded and in *italic* indicate the baseline has been exceeded. Exceedances are also shaded red for ease of identification.

Table 5.24 Predicted 95th Percentile concentrations (mg/l @ years) at the Site Boundary for the sensitivity cases described in Section 5.3.5.

95th Percentile		Arsenic	Total Chromium	Lead	Nickel	Copper	Cadmium	Sulphate	Ammoniacal nitrogen
EAL		0.005	0.005	0.005	0.02	0.006	0.0004	55	0.17
Base Case	Maximum	2.09E-4	1.42E-4	7.30E-6	4.77E-5	3.80E-4	3.31E-5	**126**	0.082
	Highest @ timeslice (years)	1.74E-4 @ 1000	1.05E-4 @ 4000	1.42E-11 @ 10000	4.09E-5 @ 8000	3.10E-4 @ 6000	2.41E-5 @ 2000	**120 @ 10.0**	0.074 @ 40.0
Sensitivity 1 AEGB	Maximum	8.40E-4	4.80E-4	2.60E-5	1.77E-4	1.48E-3	1.23E-4	**306**	**0.22**
	Highest @ timeslice (years)	6.78E-4 @ 300	4.27E-4 @ 1000	6.07E-6 @ 10000	1.31E-4 @ 4000	1.26E-3 @ 1200	1.03E-4 @ 600	**258 @ 10.0**	**0.20 @ 20.0**
Sensitivity 2 Rogue load	Maximum	1.07E-3	1.40E-4	3.08E-6	3.00E-5	4.06E-4	3.35E-5	**126**	**0.75**
	Highest @ timeslice (years)	7.13E-4 @ 1400	1.07E-4 @ 4000	7.98E-12 @ 10000	2.21E-5 @ 10000	3.07E-4 @ 6000	2.43E-5 @ 2000	**120 @ 10.0**	**0.66 @ 40.0**
Sensitivity 3 Rebound	Maximum	2.38E-4	1.62E-4	8.22E-6	5.42E-5	4.31E-4	3.77E-5	**143**	0.089
	Highest @ timeslice (years)	1.99E-4 @ 1000	1.19E-4 @ 4000	1.66E-11 @ 10000	4.69E-5 @ 8000	3.48E-4 @ 6000	2.78E-5 @ 2000	**138 @ 10.0**	0.080 @ 30.0
Sensitivity 4 Climate change	Maximum	2.08E-4	1.44E-4	7.39E-6	4.72E-5	3.73E-4	3.36E-5	**129**	0.083
	Highest @ timeslice (years)	1.78E-4 @ 1000	1.07E-4 @ 4000	1.43E-11 @ 10000	4.19E-5 @ 8000	3.13E-4 @ 6000	2.43E-5 @ 2000	**121 @ 10.0**	0.076 @ 40.0

Results shown in **bold** indicate the DWS has been exceeded and in *italic* indicate the baseline has been exceeded. Exceedances are also shaded red for ease of identification.

Table 5.25 Predicted 50th Percentile concentrations at the Site Boundary for the sensitivity cases described in Section 5.3.5.

50th Percentile		Arsenic	Total Chromium	Lead	Nickel	Copper	Cadmium	Sulphate	Ammoniacal nitrogen
EAL		0.005	0.005	0.005	0.02	0.006	0.0004	55	0.17
Base Case	Maximum	4.30E-5	3.59E-5	8.10E-9	1.14E-5	6.99E-5	5.92E-6	55.3	0.036
	Highest @ timeslice (years)	2.11E-5 @ 4000	2.26E-5 @ 8000	1.20E-37 @ 10000	2.05E-7 @ 10000	4.40E-6 @ 10000	3.10E-6 @ 8000	54.5 @ 10.0	0.031 @ 60.0
Sensitivity 1 AEGB	Maximum	1.88E-4	1.62E-4	4.90E-6	4.94E-5	3.06E-4	2.76E-5	**202**	0.14
	Highest @ timeslice (years)	1.01E-4 @ 1400	1.09E-4 @ 2000	4.42E-17 @ 10000	2.91E-5 @ 8000	1.68E-4 @ 8000	1.26E-5 @ 4000	**167 @ 10.0**	0.12 @ 20.0
Sensitivity 2 Rogue Load	Maximum	1.33E-4	3.62E-5	2.34E-9	4.49E-6	6.59E-5	6.04E-6	49.5	**0.22**
	Highest @ timeslice (years)	4.87E-5 @ 4000	2.28E-5 @ 8000	3.76E-38 @ 10000	6.04E-8 @ 10000	4.45E-6 @ 10000	2.98E-6 @ 10000	48.4 @ 10.0	**0.18 @ 80.0**
Sensitivity 3 Rebound	Maximum	4.95E-5	4.13E-5	9.28E-9	1.31E-5	8.02E-5	6.76E-6	**63.4**	0.038
	Highest @ timeslice (years)	2.45E-5 @ 4000	2.58E-5 @ 8000	1.40E-37 @ 10000	2.34E-7 @ 10000	5.02E-6 @ 10000	3.56E-6 @ 8000	**62.5 @ 10.0**	0.033 @ 60.0
Sensitivity 4 Climate Change	Maximum	4.32E-5	3.60E-5	8.18E-9	1.15E-5	7.08E-5	5.99E-6	**56.2**	0.037
	Highest @ timeslice (years)	2.13E-5 @ 4000	2.29E-5 @ 8000	1.22E-37 @ 10000	2.05E-7 @ 10000	4.54E-6 @ 10000	3.14E-6 @ 8000	55.0 @ 10.0	0.031 @ 60.0

Results shown in **bold** indicate the DWS has been exceeded and in *italic* indicate the baseline has been exceeded. Exceedances are also shaded red for ease of identification.

Table 5.26 Predicted 50th Percentile concentrations (mg/l @ years) in groundwater at the PWS for the sensitivity cases described in Section 5.3.5.

50th Percentile		Arsenic	Total Chromium	Lead	Nickel	Copper	Cadmium	Sulphate	Ammoniacal nitrogen
EAL		0.005	0.005	0.005	0.02	0.006	0.0004	55	0.17
Base Case	Maximum	2.04E-5	1.74E-5	4.00E-9	5.53E-6	3.40E-5	2.89E-6	26.6	0.015
	Highest @ timeslice (years)	1.02E-5 @ 4000	1.10E-5 @ 8000	6.10E-38 @ 10000	9.62E-8 @ 10000	2.16E-6 @ 10000	1.49E-6 @ 8000	26.3 @ 10.0	0.012 @ 60.0
Sensitivity 1 AEGB	Maximum	9.18E-5	7.95E-5	2.37E-6	2.42E-5	1.50E-4	1.37E-5	**97.0**	0.057
	Highest @ timeslice (years)	4.96E-5 @ 1400	5.29E-5 @ 2000	2.04E-17 @ 10000	1.41E-5 @ 8000	8.13E-5 @ 8000	6.11E-6 @ 4000	**82.5 @ 10.0**	0.048 @ 20.0
	Maximum	6.43E-5	1.76E-5	1.17E-9	2.22E-6	3.19E-5	2.94E-6	23.8	0.092

50th Percentile		Arsenic	Total Chromium	Lead	Nickel	Copper	Cadmium	Sulphate	Ammoniacal nitrogen
Sensitivity 2 Rogue load	Highest @ timeslice (years)	2.40E-5 @ 4000	1.09E-5 @ 8000	1.77E-38 @ 10000	2.93E-8 @ 10000	2.17E-6 @ 10000	1.43E-6 @ 10000	23.1 @ 10.0	0.075 @ 80.0
Sensitivity 3 Rebound	Maximum	2.37E-5	2.01E-5	4.58E-9	6.37E-6	3.95E-5	3.32E-6	30.7	0.016
	Highest @ timeslice (years)	1.18E-5 @ 4000	1.28E-5 @ 8000	7.02E-38 @ 10000	1.11E-7 @ 10000	2.50E-6 @ 10000	1.73E-6 @ 8000	30.4 @ 10.0	0.013 @ 60.0
Sensitivity 4 Climate change	Maximum	2.06E-5	1.74E-5	4.03E-9	5.56E-6	3.43E-5	2.88E-6	26.8	0.015
	Highest @ timeslice (years)	1.02E-5 @ 4000	1.10E-5 @ 8000	6.18E-38 @ 10000	9.63E-8 @ 10000	2.18E-6 @ 10000	1.51E-6 @ 8000	26.4 @ 10.0	0.012 @ 60.0

Results shown in **bold** indicate the DWS has been exceeded and in *italic* indicate the baseline has been exceeded. Exceedances are also shaded red for ease of identification.

5.4.2.3 Impact at the Water Table receptor and Breakout Pathway (hazardous pollutants)

The results of the sensitivity runs are presented in Table 5.26 and Table 5.27 for the Water Table receptor and Table 5.28 and Table 5.29 for the Breakout Pathway (Deterministic, and 95th percentile respectively). The results are below EAL unless stated otherwise.

For both the Water Table receptor and the Breakout Pathway a similar pattern is observed as for the groundwater receptors, in that Sensitivity 1 (AEGB) has the most significant impact on the predicted concentrations due to increase in the dilution factor; whilst arsenic is seen to increase for Sensitivity 2 (Rogue Load).

Table 5.27 Predicted deterministic concentrations (mg/l @ years) at the Water Table for the sensitivity cases presented in Section 5.3.5

	Arsenic	Total Chromium	Lead
EAL	0.005	0.005	0.005
Base Case	1.70E-4 @ 4169	1.51E-4 @ 7732	7.43E-8 @ 100000
Sensitivity 1 AEGB	6.34E-4 @ 1232	5.64E-4 @ 2283	1.87E-5 @ 100000
Sensitivity 2 Rogue load	2.65E-5 @ 4169	1.51E-4 @ 7732	4.62E-9 @ 100000
Sensitivity 3 Rebound	1.70E-4 @ 4169	1.51E-4 @ 7732	7.43E-8 @ 100000
Sensitivity 4 Climate change	1.74E-4 @ 4169	1.54E-4 @ 7732	7.57E-8 @ 100000

Results shown in **bold** indicate the DWS has been exceeded and in *italic* indicate the baseline has been exceeded. Exceedances are also shaded red for ease of identification.

Table 5.28 Predicted 95th Percentile concentrations (mg/l @ years) for the hazardous pollutants at the Water Table for the sensitivity cases described in Section 5.3.5.

95th Percentile		Arsenic	Total Chromium	Lead
EAL		0.005	0.005	0.005
Base Case	Maximum	7.26E-4	4.76E-4	2.38E-5
	Highest @ timeslice (years)	6.09E-4 @ 1000	3.43E-4 @ 4000	6.16E-11 @ 10000
Sensitivity 1 AEGB	Maximum	2.80E-3	1.68E-3	8.66E-5
	Highest @ timeslice (years)	2.30E-3 @ 300	1.48E-3 @ 800	2.01E-5 @ 10000
Sensitivity 2 Rogue load	Maximum	3.46E-3	4.77E-4	1.03E-5
	Highest @ timeslice (years)	2.58E-3 @ 1000	3.41E-4 @ 2000	2.86E-11 @ 10000
Sensitivity 3 Rebound	Maximum	7.26E-4	4.76E-4	2.38E-5
	Highest @ timeslice (years)	6.09E-4 @ 1000	3.43E-4 @ 4000	6.16E-11 @ 10000
Sensitivity 4 Climate change	Maximum	7.43E-4	5.00E-4	2.46E-5
	Highest @ timeslice (years)	5.98E-4 @ 1000	3.57E-4 @ 4000	6.36E-11 @ 10000

Table 5.29 Predicted deterministic concentrations (mg/l @ years) for Breakout Pathway for the sensitivity cases presented in Section 5.3.5

	Arsenic	Total Chromium	Lead
EAL	0.005	0.005	0.005
Base Case	5.23E-5 @ 1.14E-4	8.72E-5 @ 1.14E-4	1.31E-4 @ 1.14E-4
Sensitivity 1 AEGB	No breakthrough	No breakthrough	No breakthrough
Sensitivity 2 Rogue load	8.14E-6 @ 1.14E-4	8.72E-5 @ 1.14E-4	8.14E-6 @ 1.14E-4
Sensitivity 3 Rebound	5.23E-5 @ 1.14E-4	8.72E-5 @ 1.14E-4	1.31E-4 @ 1.14E-4
Sensitivity 4 Climate change	5.36E-5 @ 1.14E-4	8.93E-5 @ 1.14E-4	1.34E-4 @ 1.14E-4

Results shown in **bold** indicate the DWS has been exceeded and in *italic* indicate the baseline has been exceeded. Exceedances are also shaded red for ease of identification.

Table 5.30 Predicted 95th Percentile concentrations (mg/l @ years) for Breakout Pathway for the sensitivity cases described in Section 5.3.5.

95th Percentile		Arsenic	Total Chromium	Lead
EAL		0.005	0.005	0.005
Base Case	Maximum	1.11E-4	1.89E-4	2.81E-4
	Highest @ timeslice (years)	1.06E-4 @ 10.0	1.80E-4 @ 10.0	2.67E-4 @ 10.0
Sensitivity 1 AEGB	Maximum	No breakthrough	No breakthrough	No breakthrough
	Highest @ timeslice (years)	No breakthrough	No breakthrough	No breakthrough
Sensitivity 2 Rogue load	Maximum	7.53E-4	1.88E-4	1.96E-4
	Highest @ timeslice (years)	7.26E-4 @ 10.0	1.81E-4 @ 10.0	1.89E-4 @ 10.0
Sensitivity 3 Rebound	Maximum	1.11E-4	1.89E-4	2.81E-4
	Highest @ timeslice (years)	1.06E-4 @ 10.0	1.80E-4 @ 10.0	2.67E-4 @ 10.0
Sensitivity 4 Climate change	Maximum	1.20E-4	2.00E-4	2.96E-4
	Highest @ timeslice (years)	1.15E-4 @ 10.0	1.91E-4 @ 10.0	2.82E-4 @ 10.0

5.5 Hydrogeological completion criteria

Completion is considered to occur once the Site no longer poses a threat to the environment. The risk assessment shows that the discharges from the Site will not pose a threat either to groundwater in the Bridgnorth Sandstone or to the Bromsberrow Heath PWS. We believe that a five-year period of monitoring following termination of the operational phase will suffice to demonstrate completion.

Given that there is no engineered cap or artificial sealing liner on the inert cells at the Site, there will be no managed phase following the end of restoration

Site monitoring data will be evaluated on an annual basis. The Hydrogeological Risk Assessment for the site will be reviewed in line with EA guidance. These reviews will help establish whether the Site performance is as predicted by the site Hydrogeological Risk Assessment.

Following Site closure, the Site will continue to be monitored for a further 5 years in order to confirm that it is performing as predicted by the site Hydrogeological Risk Assessment. If it is, steps will then be taken to surrender the permit.

5.6 Review of technical precautions

Accidental inclusion of hazardous substances or high concentrations of non-hazardous pollutants in materials proposed to be deposited will be controlled by standard procedural checks on the content of materials arriving at the Site. Controls are based on the Waste Acceptance Criteria defined in the Landfill Regulations.

Groundwater monitoring will continue at Bromsberrow North boreholes (BH01, BH02, BH03 and BH04 as shown in Figure 2.8) until completion in order to protect the Bromsberrow Heath PWS. Inspection of the monitoring network will be routine and maintenance will be carried out promptly to ensure that monitoring is continuous and can detect any changes in groundwater quality and identify rising trends in water levels. The monitoring measurements and schedules are presented in the Site Monitoring Plan (Stantec, 2024b).

Control levels and compliance limits have been derived for the Site and are presented in Section 6.1.2.1.

Operational procedures will ensure that run-off from the in-situ imported materials will not migrate to unlined excavated areas (Stantec, 2024d). Trends in groundwater levels at the site and at the EA and PWS boreholes will be continually assessed and the level to which the active area of the site will be excavated could be increased should groundwater level data indicate that water levels will rise to within 1 m of the proposed excavation elevation.

If any contaminants are leached from the material, attenuation within the AEGB as well as instantaneous and groundwater dilution, retardation and attenuation in the saturated zone are deemed effective in reducing the concentration of such contaminants to levels below the current baseline concentrations.

6 Requisite Surveillance

Requisite surveillance is for the Site is detailed in Stantec (2024b) whilst the proposed calculated groundwater Control Levels and Compliance Limits for the Site are presented in Section 6.1.

Monitoring locations are shown in Figure 2.8.

6.1 Groundwater compliance limits

Groundwater quality data for sulphate, nickel and ammoniacal nitrogen have been assessed to set Control Levels and Compliance Limits for the Site. Arsenic is not currently being monitored at the Bromsberrow North or South sites but has now been included in the proposed monitoring suite (Stantec, 2024b).

Where concentrations have been found below the level of detection, the level of detection concentration has been used in the assessment.

The time-series charts the determinands listed above for the monitoring locations at Bromsberrow North have been reviewed and to identify outliers. Based on this assessment the maximum value of sulphate of 191 mg/l was removed from the dataset.

Following this, the mean + 2 standard deviations (SD) and the mean + 3 SD are calculated for each determinand. These are then assessed against background groundwater quality and the relevant EALs to determine whether they are suitable for the Control Levels and Compliance Limits as the time-series charts indicate groundwater quality varies both spatially and with time, which is to be expected given groundwater flow will be influenced by the daily abstraction at Bromsberrow PWS.

The proposed control and trigger levels for the downgradient boreholes BH02 and BH03 for Bromsberrow North are presented in Table 6.1. The assessment is presented in Appendix G.

It is proposed that the average of the groundwater concentrations at BH02 and BH03 should be compared to the Control Levels and Compliance Limits in line with Statistical Control theory (Oakland, 2003). Using the average of a sample prevents the Control Levels and Compliance Limits being triggered by rare spikes in groundwater quality.

Table 6.1 Proposed Control Levels and Compliance limits for Bromsberrow North BH02 and BH03

Determinand	Unit	Min	Max	Mean	% > LOD	Standard Deviation	UK DWS	Mean + 2SD	Mean + 3SD	Control Level	Compliance Limit	Comment
Sulphate as SO4	mg/l	16.9	191	42.3	100	19.9	250	82.1	102	**90**	**120**	Control Level based on calculated value; Compliance Limit set to provide distinction from Control Level.
Nickel	µg/l	2.8	21	8.52	100	4.22	20	17	21.2	**18**	**22**	Based on calculated values.
Ammoniacal Nitrogen as N	mg/l	<0.015	0.074	0.012	28	0.0092	0.39	0.030	0.039	**0.05**	**0.08**	High number of non-detects so Control Level set above calculated value and Compliance Limit set to provide distinction from Control Level.

7 Conclusions

In addition to the phased extraction of the remaining mineral reserve at the Bromsberrow North Site, Allstone proposes a joint programme of phased restoration to either agriculture or amenity use, using imported inert material to re-establish original ground levels. A rolling programme of continued sand extraction and phased restoration will be established, and it is estimated that a total of 670,000 m^3 of inert material will be imported. The restoration will comprise filling the void progressively.

This HRA has been prepared to accompany the EP Application to restore the Site by inert landfill. In accordance with the EA pre-application advice received, a probabilistic Risk Assessment has been undertaken in this HRA.

Stantec has reviewed the potential hydrogeological impacts of the continued quarrying operations and subsequent restoration by inert landfill. The conceptual model indicates that local groundwater flows northwards beneath the Site, towards the nearby Bromsberrow PWS. The groundwater level is beneath the base of the proposed excavation and no groundwater abstraction is proposed. No direct disturbance of groundwater levels or flows is anticipated.

Based on this HRA as well as the accompanying FRA (Stantec, 2024a) and ESSD (Stantec 2024c), the following conclusions are made:

- There will be no groundwater inflow into the excavation;
- Potential operational impacts are limited to pollution of groundwater through spillage of liquids within the quarry that will be addressed through the mitigation measures proposed; and
- Potential post-restoration impacts relate to reduced groundwater infiltration and increased runoff from the Site.

The Site is on a Principal aquifer within a Source Protection Zone II. Because the proposal is for restoration by inert landfill, no engineered cap or leachate management system is proposed. However, and in line with the Landfill Regulations, an AEGB with a minimum thickness of 1 m will be constructed across the base and sidewalls of the Site with a maximum hydraulic conductivity of 2×10^{-10} m/s that will serve to limit contaminant flux from the Site. The Site is above the water table and the sensitivity modelling indicates that if abstraction at the PWS is reduced by 20% the Site will remain above the water table. There will therefore be no active long-term management systems required to provide protection to environmental receptors.

The site is acceptable for an inert restoration scheme in terms of its hydrogeological location. To assess the level of risk to groundwater, a quantitative risk assessment has been undertaken using Stantec's RAM software. Processes modelled include advection and attenuation in the geological barrier and the unsaturated zone and dilution, advection, retardation and degradation in the saturated zone.

The risk assessment presented here is based on generic data and data from Bromsberrow South and North nearby boreholes, and these are believed sufficient for a conservative approach to risk assessment. Groundwater monitoring will continue throughout the operation of the Site, including up- and downgradient groundwater level and quality; this is consistent with the approach adopted for the nearby (and now restored) Bromsberrow South landfill. Groundwater monitoring will continue until completion is demonstrated as discussed in Section 5.5.

The model shows that there is no predicted impact on groundwater quality at the Site boundary or at the PWS. A number of sensitivity runs have been undertaken that show that dilution in groundwater is the most significant factor in reducing contaminant concentrations in groundwater, and that the AEGB will control concentrations of hazardous substances at the water table.

The government’s core policies and principles on the most important aspects of land use planning are set out in various Planning Policy Statements (PPS). Planning Policy Statement 23: Planning and Pollution Control sets out the material considerations that should be taken into account in the determination of planning applications that may give rise to pollution. The HRA that has been undertaken has demonstrated that the proposed restoration of the Site would not have an impact on the water environment. Furthermore, the relevant pollution control regime will be properly applied and enforced in the context of an EP.

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APPENDICES

Appendix A

Phased Mineral Extraction and Restoration Details

Appendix B

Groundwater quality charts (electronic)

Appendix C

RAM model (electronic)

Appendix D

Blue Lias Clay data sheet

Appendix E

Climate and rebound calculations (electronic)

Appendix F

Sensitivity models and results (electronic)

Appendix G

Calculation of Control Levels and Compliance Limits (electronic)