Ground Source Energy Feasibility Report

Raby Castle

County Durham, DL2 3AH

On Behalf of

Renewable Energy Alliance Ltd.

Quality Management

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Data Sources

- Ordnance Survey (OS) maps for the site;
- BGS Geological Map, 1:50,000 Series Sheet 32, Barnard Castle, Solid (1969);
- BGS Geological Map, 1:50,000 Series Sheet 32, Barnard Castle, Drift (1969);
- BGS Hydrogeological Map, 1:625,000, Sheet 1, Hydrogeological Map of England and Wales (1977);
- BGS Lexicon of named rock units (online);
- BGS Borehole Records (online);
- The physical properties of minor aquifers in England and Wales, Technical Report WD/00/04, BGS and Environment Agency (2000);
- Catchment Area Management Strategy (CAMS), Tees Abstraction Licensing Strategy (2019);
- Environment Agency Catchment Data Explorer (online);
- BGS Memoir, The geology of the county around Barnard Castle: Explanation of one-inch geological sheet 32 (New Series) (1976).

Disclaimer

Hydrogeo Limited has undertaken a groundwater abstraction prognosis on behalf of the client. A desk study review of available information has been carried out by an experienced hydrogeologist and the results of this work are displayed in this report. No responsibility can be accepted for the local conditions which alter the interpretation and predictions of the published data.

The prognosis has been prepared based on limited geological and hydrogeological information. Although we have applied our experience and expertise to the interpretation of the data available, no guarantee can be made as to the amount or quality of water obtained. Development of groundwater sources has an inherent risk. Developers should be aware that it is possible that an insufficient volume or poor quality of water could be encountered.

It is the responsibility of the contractor to check for buried services and underground obstructions, including drainage systems prior to drilling.

Current and Proposed Development

- The site is occupied Raby Castle comprising approximately 230ha of historic structures, parkland, gardens and woodland.
- The site address is Raby Castle, County Durham, DL2 3AH. The National Grid Reference (NGR) for the site is 412769, 522034. The main site entrance is situated off the A688.
- The site is located immediately north of the village of Staindrop and its walled northern boundary is formed by Burnt Houses Lane. The wall continues along Keverstone Bank, the eastern boundary, and along the southern boundary with Staindrop. The western boundary of the area here registered is formed by the western edge of Bath Wood, the eastern edge of Sandy Bank Wood, a track between Sandy Bank Wood and Kennel Wood, the western edge of Kennel Wood, and a line through North Wood to the west of The Folly.
- The site is situated at an elevation of 230 meters above ordnance datum (mAOD) to the north, generally sloping gently to the south to an elevation of 108mAOD at the sites southern boundary.
- A borehole supply capable of providing 12 l/s for a 200kW load and 27 l/s for a 600kW load in an open loop ground source system.
- A closed loop ground source system is also discussed as an alternative.

Local Hydrology and Environment

- Several water features are present on and within the vicinity of the site.
- The nearest named watercourse is Langley Beck which flows eastwards generally along the sites southern boundary. The watercourse flows for approximately 500m within the site boundary (in the south-west of the site) before flowing parallel to the site boundary for 650m, separating the site from the town of Staindrop.
- Moor Beck is present some 275m south of the site boundary and merges with Sudburn Beck approximately 625m south of the site boundary. Sudburn Beck flows into Langley Beck approximately 1.5km south-east of the site.
- Several unnamed watercourses and drainage ditches are located within the site boundary.
- A drain is marked as present between North Wood and Kennel Wood, towards the north of the site.
- A drain is marked running across the centre of the site to the north of Raby Gardens, near the Nursery, parallel to the road running towards the North Lodge gate.
- Further drainage is marked across the centre of the site, running from the Kennel Wood Cottages in the west to the East Middle Lodge Wood. The watercourse is shown to be fed by several springs and issues before merging with Langley Brook 180m south-east of the site.
- A series of drains are marked within Bath Wood to the south-west of the site, these are fed by a series of issues both on site and to the west. This drainage network flows into Langley Brook at the south-western border of the site.
- Further drainage is marked to the north of the site surrounding Cockfield.
- Two large ponds are present within the site boundary named Low Pond and High Pond, with their nearest points located approximately 450m and 625m south of the existing borehole, respectively.
- A covered reservoir and pump house is located to the west of the site, near North Wood.
- Several small ponds are present within 1km of the site including two to the north (250m N and 975m NE); three to the west (245m NW, 785m W and 350m W); two to the south (750m S and 630m SE); and one to the east (850m E).
- Several springs are marked within 500m of the site including two beyond the site boundary near South Lodge (106mAOD) feeding into Langley Brook; one beyond the east of the site boundary near East Middle Lodge Wood (121mAOD); one approximately 425m east of the site near New Raby Wood (130mAOD); and one marked 50m west of the site to the south of Dandy Bank Wood (135mAOD).

- Ordnance Survey mapping shows three wells within 1km of the site. The first is associated with Ivy Cottage and is located approximately 280m north of the site. A second is located near Mount Slowly in Burnt Houses, some 730m north-west of the site. An additional well is shown on OS 1:25,000 mapping some 630m north of the site however is not marked on smaller scale mapping.
- The site is not situated within a Nitrate Vulnerable Zone (NVZ), the nearest NVZ is located 1.9km to the east of the site boundary.
- The site is not situated within 5km of any Site of Special Scientific Interest (SSSI), Special Areas of Conservation (SAC), or Special Protection Area (SPA). The nearest protected area is situated 6.4km to the west.

Site Location Map

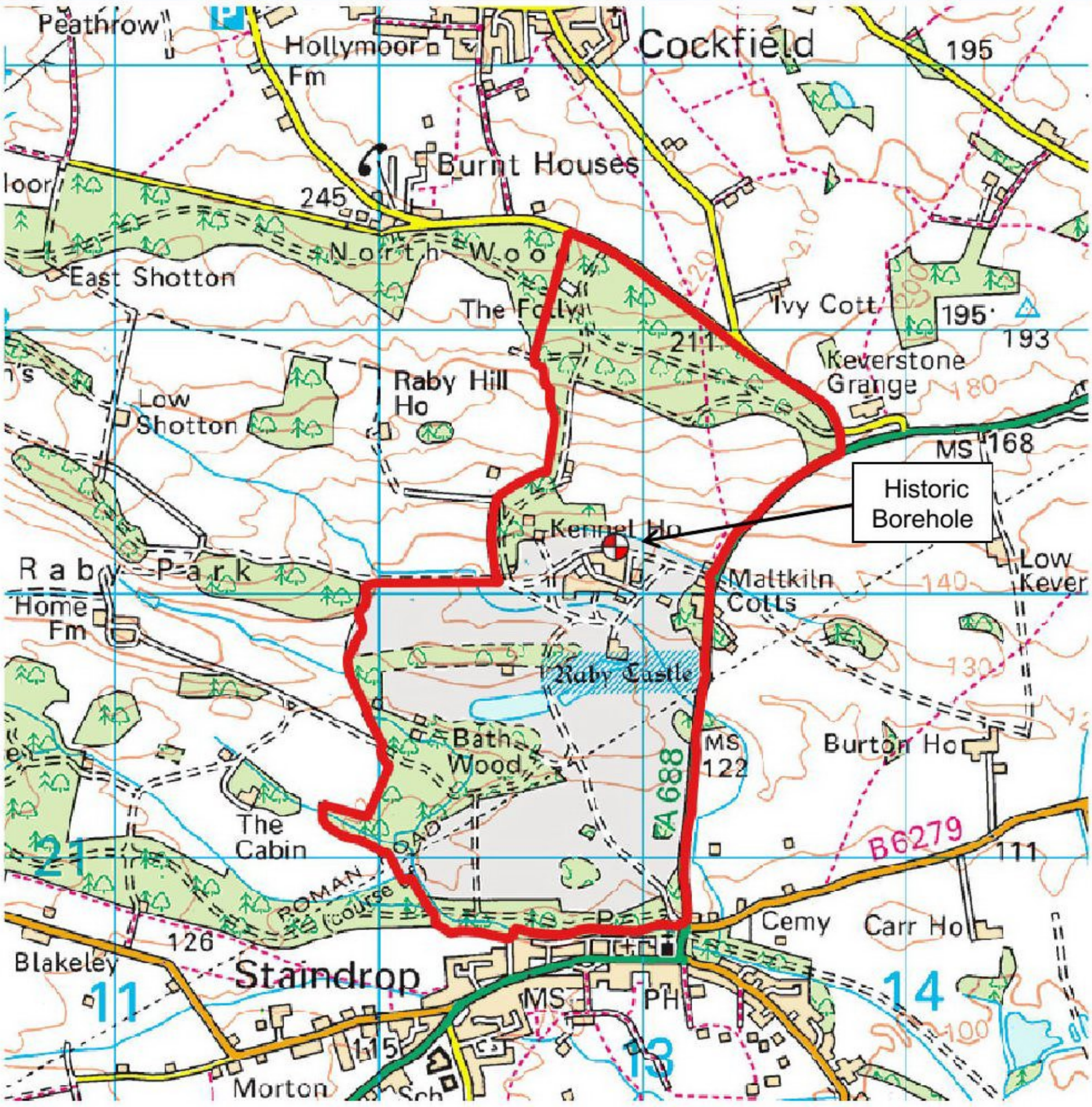


Figure 1- Ordnance Survey Map of Site Location. Crown copyright reserved, Licence No. 100047852

Historic Development

- Historic Ordnance Survey (OS) mapping for the site dated from 1860 to present has been reviewed as part of this report. Mapping from 1860 appears to show the site in a similar state to present.
- The northern extremity of site land ownership is located in an area of historic coal mining with areas of the site designated Development High Risk Areas (DHRA).
- The north of the site occupied by North Wood is shown to be underlain by Coal and Fireclay deposits with a small area of the site near to Long Lane marked as having been worked underground.
- A permitted waste site is located within the site boundary. The waste site is shown to be along the sites northern boundary, within North Wood, near Long Lane, the former site of a sandstone quarry. The sites status is shown to be 'closure' and was previously a 'landfill taking non-biodegradable wastes'.

Water Availability & CAMS (Catchment Area Management Strategy)

- The site is located within the 'Langley Beck from source to Sudburn Beck' area of influence, part of the Tees Middle Operational Catchment within the Tees Management Catchment.
- The site is included within the Tees Abstraction Licensing Strategy, last updated in March 2019.
- In areas of the Tees Management Catchment area, groundwater is licenced separately from surface water, with the catchment split into separate Groundwater Management Units (GWMU).
- The site is located in the Tees Middle catchment, with restricted water available for licensing during Q30, Q50, and Q70 conditions. During Q95 conditions, water is available for licensing.
- There are four groundwater bodies within the Tees catchment. The site is located upon the Tees Carboniferous Limestone and Millstone Grit GWMU (GB40302G700300).
- At present, only the Skerne Magnesian Limestone is impacted by existing abstractions, restricting water availability. There are no restrictions on the underlying GWMU.
- The site is not situated within an Environment Agency (EA) Source Protection Zone (SPZ). The nearest Zone III – Total Catchment is located 4.8km to the east.
- Any application for a new groundwater abstraction licence will be treated on a case by case basis. Applications will be assessed as to their impact upon on designated sites such as wetlands, water course and other groundwater users. Abstraction restrictions would be dependent aspects such as aquifer type, the depth of the borehole, proximity to surface water courses and designated sites and the proposed use.
- At the current stage, it appears that a consumptive groundwater abstraction license could be granted.

Geology

Artificial Ground

- Artificial ground consists of any areas where ground conditions have been significantly modified by man. These include excavations, infilled ground and made up ground.
- No artificial ground is shown to be present on BGS geological mapping, however a veneer of made ground is likely across areas of the site.
- It is known that an area in the north of the site boundary has been infilled through use as a landfill.

Superficial Geology

- An extract from the BGS paper map of superficial deposits present across the site and surrounding area can be seen in Figure 3.
- Superficial Deposits consist of near surface unconsolidated (loose) sedimentary deposits which have not

yet become solid rock.

- The BGS has recorded both Devensian Till and Alluvium as present beneath the site.
- The site is primarily covered by Devensian Till deposits of diamicton with small areas marked as being covered by Alluvium or by no superficial deposits. Areas of Alluvium are associated with watercourses in the south-west of the site.
- Glacial (Devensian) Till consists of a poorly sorted sedimentary deposit ranging from gravelly, sandy silty clay to sandy clayey gravel, with individual clasts ranging up to boulder size.
- Quaternary Alluvium consists of variable sediment of mud, sand and gravel with some peat in places.

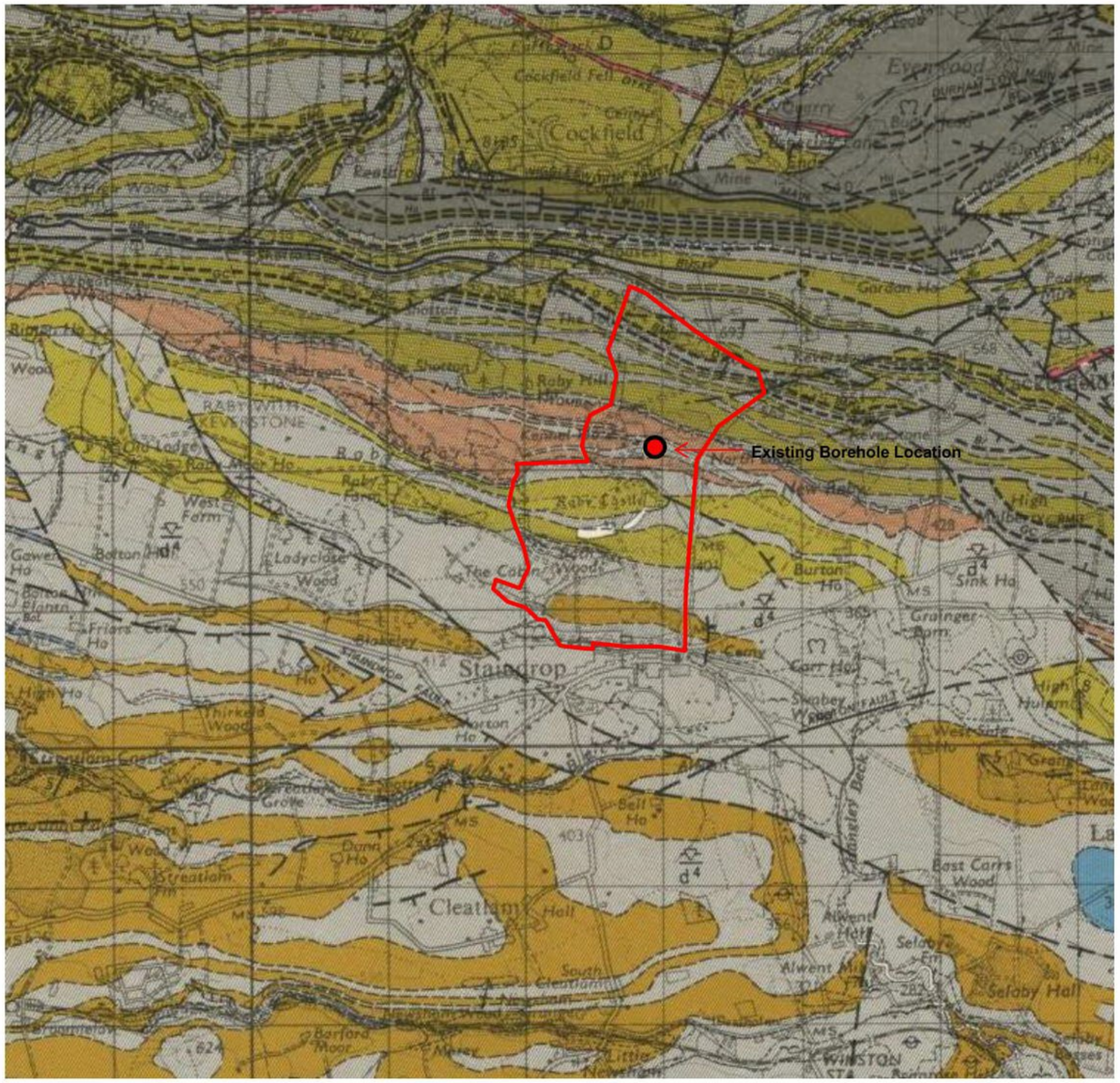
Bedrock Geology

- An extract from the BGS paper map of bedrock present across the site and surrounding area can be seen in Figure 2. Figure 2 uses obsolete rock unit names.
- An updated digital map of the bedrock across the site and surrounding area is included as **Drawing 1**.
- **Drawing 2** shows a conceptual cross-section of the site. The drawing shows the expected sandstone beds found beneath the site.
- The uppermost stratigraphy of bedrock beneath the site consists of the Pennine Coal Measures Group. The group is widespread across the region and is described by the BGS as an "*alternation of sandstone, grey siltstone and grey mudstone, with frequent coal seams and seatearth horizons. Note that, definitions for the base of the Pennine Coal Measures Group and the bases of the Middle and Upper Formations are those of Stubblefield and Trotter (1957), but the top of the Pennine Coal Measures Group is newly defined here on a purely lithostratigraphical basis*".
- The site is positioned at the very edge of the Pennine Coal Measures Group upon the lowermost Pennine Lower Coal Measures Formation, generally comprising "*interbedded grey mudstone, siltstone and pale grey sandstone, commonly with mudstones containing marine fossils in the lower part, and more numerous and thicker coal seams in the upper part*". The Pennine Lower Coal Measures Formation is Langsettian (Westphalian A) in age (~318 to 319 million years ago).
- Outcropping beneath the southern portion of the site and positioned stratigraphically below the Pennine Coal Measures Group is the Yoredale Group, a series of limestones, mudstones, siltstones and sandstones. The Group was deposited during the Carboniferous Period approximately 313 to 335 million years ago. The group is subdivided into the Alston Formation and Stainmore Formation.
- The Stainmore Formation (formerly Millstone Grit) is the uppermost constituent of the Yoredale Group beneath the site and is described by the BGS as a "*Cyclical repetition of sandstones, siltstones, mudstones, thin limestones and some coals*". The Stainmore Formation is anticipated to be 383.6m thick below the site and is thought to have formed approximately 319 to 329 million years ago.
- The Stainmore Formation is broadly equivalent to the Millstone Grit of the central and south Pennines.
- The Alston Formation (formerly Alston Group) is situated stratigraphically beneath the Stainmore Formation and consists of "b*ioclastic limestones, sandstones, mudstones, siltstones and rare coals typically in regular cyclothemic sequence.*" formed some 328 to 337 million years ago. The Alston Formation is anticipated to be 186.3m thick beneath the site.

Geological Structure

- The site is situated upon the southern boundary of the coalfield.
- The BGS map (Barnard Castle, Sheet 032) shows the area to be dipping at approximately 8° to the north with some minor faulting to the north. (**Drawing 02)**.
- **Drawing 02** shows how the geological structure beneath the site will allow for the targeting and abstraction of groundwater from selected sandstone stratigraphic layers.

Paper Geological Map Extract – Bedrock Geology



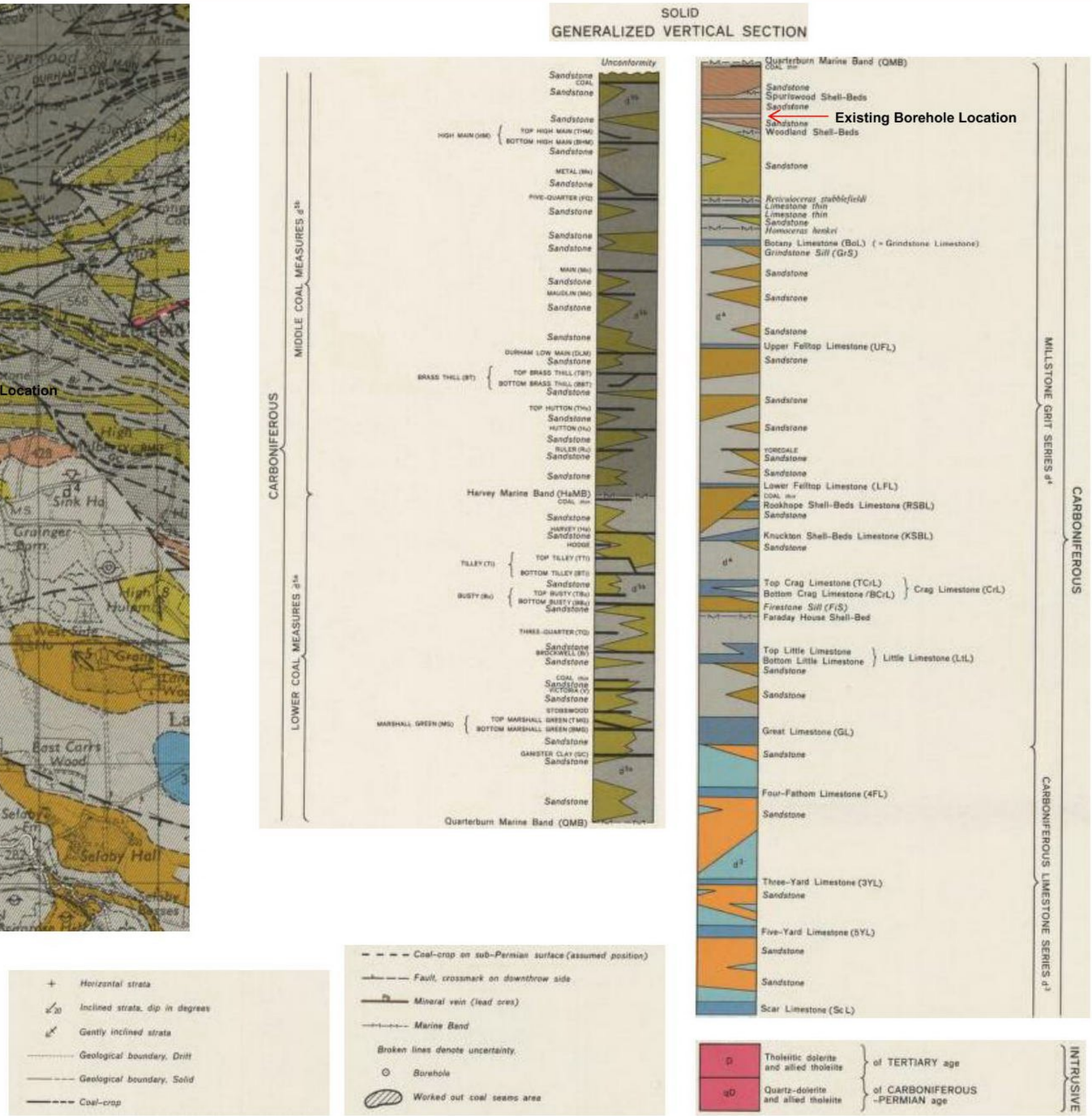
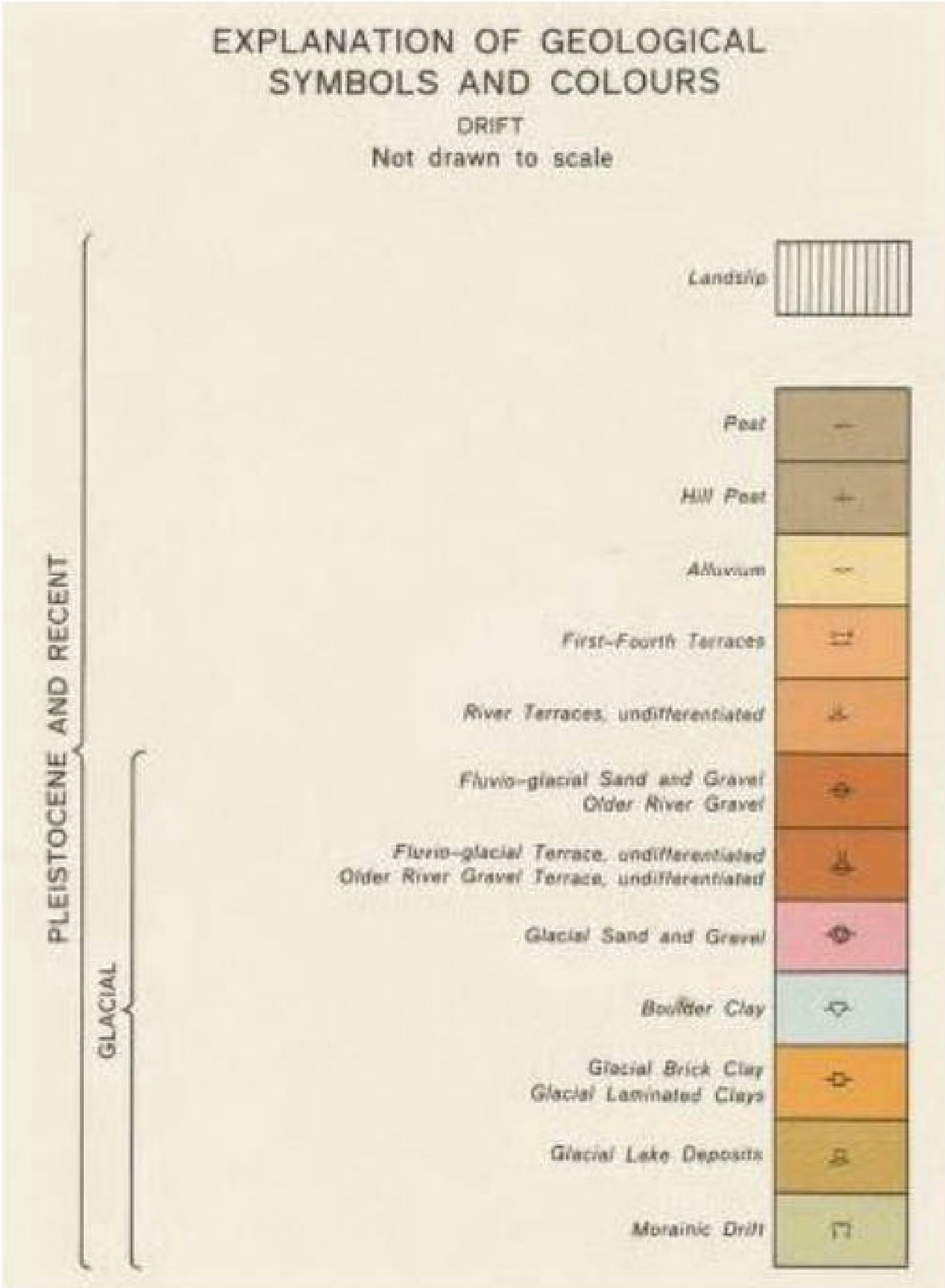
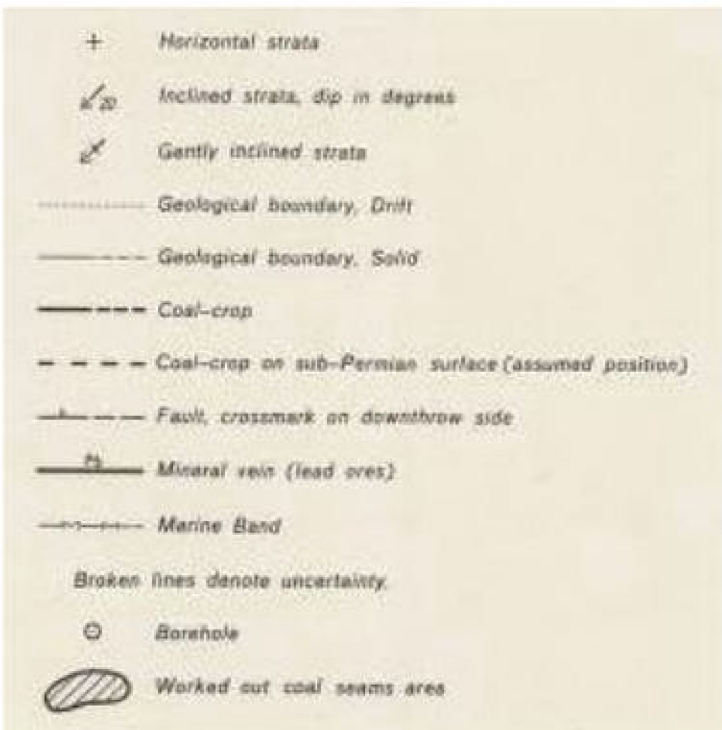


Figure 2 - British Geological Survey bedrock map of site and surrounding area, Sheet 32 **Barnard Castle** (1969). Licence number [C10/018-CSL] © NERC. All rights reserved.

Paper Geological Map Extract – Superficial Geology





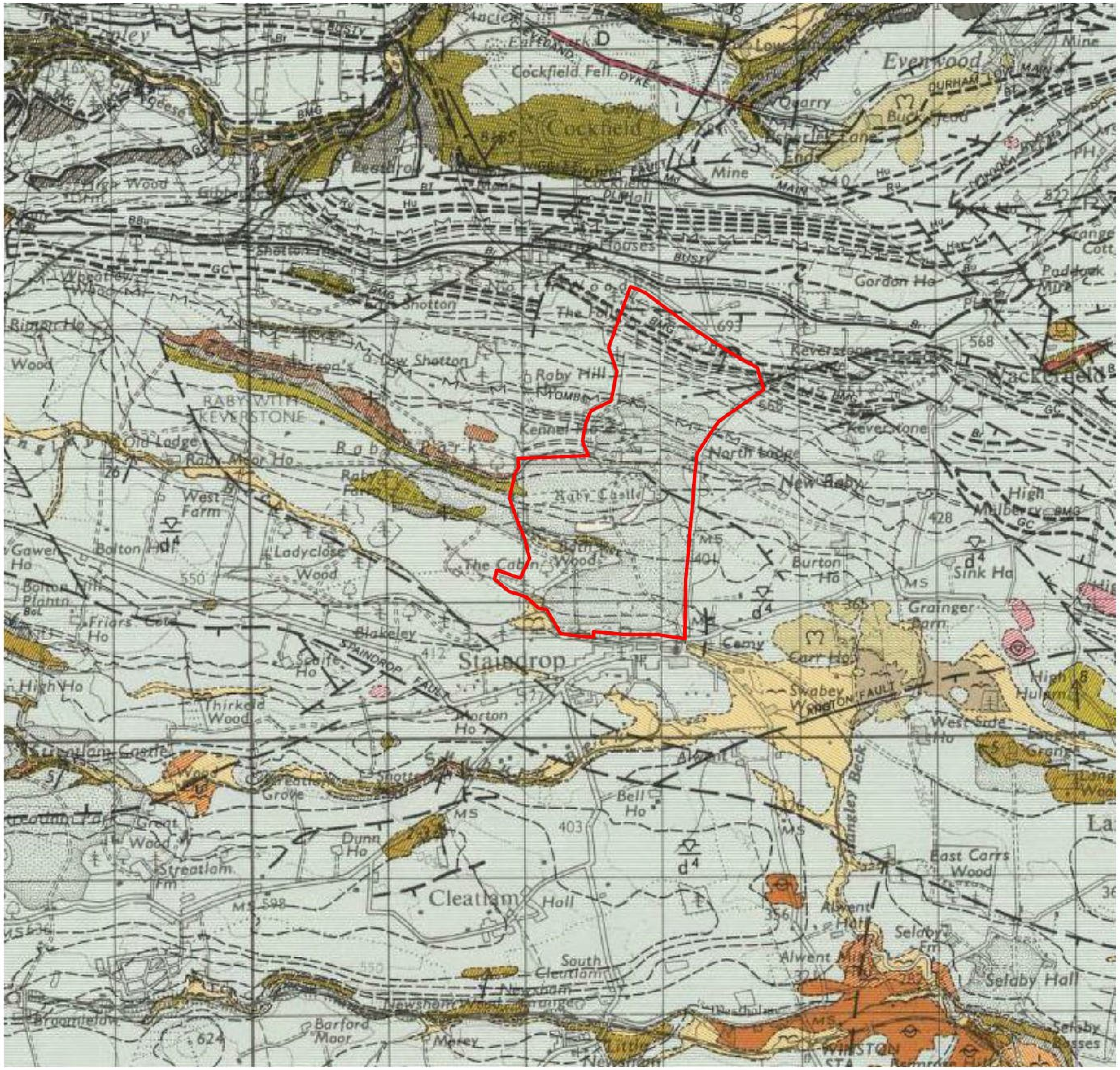


Figure 3 - British Geological Survey superficial map of site and surrounding area, Sheet 32 **Barnard Castle** (1969). Licence number [C10/018-CSL]

Resource Assessment

Yoredale Group (Stainmore Formation) – Secondary A Aquifer

- The Stainmore Formation and wider Yoredale Group are classified as Secondary A Aquifers. Secondary A Aquifers are permeable layers of rock capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers. The Stainmore Formation in particular is noted to be broadly equivalent to the Millstone Grit of the central and south Pennines.
- The BGS and EA publication *The physical properties of minor aquifers in England and Wales* has been used to determine the following values.
- The geology comprises interbedded thick, massive grit, sandstone and limestone horizons separated by mudstones and shales. Individual grit horizons are often named.
- The sandstone and limestone aquifers are separated by mudstone and shale acting as aquicludes or aquitards creating a multi-layered aquifer.
- Groundwater storage and movement in the generally well cemented grits, sandstones and limestones is predominantly through joints and fractures with only minor contributions from the rock matrix.
- Flow in the Millstone Grit aquifers of the East Pennines to the south tend to decrease rapidly with depth and sandstones commonly well cemented.
- Initial high flow rates found in broadly equivalent Millstone Grit to the south found initially high flow rates from fracture zones declined with time and depth, when exceeding 200m flow ingress was generally insignificant.
- The broadly equivalent Millstone Grit present in the Pennines to the south have been used to determine hydraulic properties for the site.
- Porosity values range from 6% to 23%, with arithmetic mean and median values of about 14%.
- Permeability values range from $3x10^{-4}$ to 0.7m/d, with an arithmetic mean and median values of $5x10^{-3}$ to $4x10^{-2}$m/d.
- The above values were obtained from samples of weathered rock are likely higher than those applicable at depth.
- Pump testing results for Namurian strata (Stainmore Formation) in northern England (north of Darlington) are for four sites around Armathwaite in Cumbria recording specific capacities that were highly variable, ranging from 10 to 289m^3/d/m.
- Pump testing within the equivalent Millstone Grit of the Middle and South Pennines are concentrated on the margins of the outcrop approximately along the line of the River Lune to north-east Lancaster. Sites are sparsely distributed to the north of Leeds and not considered representative of the site.
- Due to the highly variable nature of the geology, transmissivity are known to vary over short distances. Transmissivity is recorded to range between 0.6 and 1059m^2/d with an arithmetic mean of 93m^2/d and median value of 26m^2/d. The 25th and 75th percentile of transmissivity is 7 and 80m^2/d, respectively.
- Specific capacity (yield per m drawdown) is recorded to range between 0.54 and 9092m^3/d/m. The highest values are distinctly anomalous with only two other values exceeding 560m^3/d/m. There appears to be no discernible geographic distribution of yield. The median value is recorded as 21m^3/d/m. The 25th and 75th percentiles are recorded as 8 and 76m^3/d/m.
- Borehole yields are dependent on the number and size of fractures encountered in a productive horizon. The groundwater potential of the main water bearing horizons is very variable and some horizons may only be of local importance. The aquifer is considered relatively unpredictable.
- Few boreholes have been progressed in the area to exploit the groundwater recourses. Of those few drilled, water supply yields of the order of 25m^3/d have been achieved.
- Drawdown creep is fairly typical of Millstone Grit abstractions and is commonly ascribed as a depletion of storage over time.
- The BGS shows that there are 10 water wells within 5km of the site boundary, of which 3 are provided

with details. Only one record (5km south of the site) is shown as abstracting from the Millstone Grit Series.

- Two historic unlicensed abstractions have been identified within 2.5km of the site. These abstracted 2.27m^3/d and 10m^3/d.
- There are 5 known licensed abstractions within 5km of the site boundary, of which 3 are groundwater abstractions used for 'general farming and domestic' purposes. The nearest groundwater abstraction is 2.7km to the west and abstracts a maximum of 55.45m^3/d, an abstraction 3.7km to the west abstracts 25m^3/d, and an abstraction 3.7km to the south abstracts 50m^3/d.

Groundwater Levels – Site Specific

- The Yoredale Group beneath the site is a multi-layered aquifer comprising productive units separated by aquilucludes or aquitards. The upper Stainmore Formation is considered broadly equivilant to the Millstone Grit.
- The aquifer is considered to be unconfined in areas close to sandstone outcrop, with confined layers present where overlain by mudstones, siltstones or limestones at depth.
- The aquifer is considered to have a sufficient area of recharge given the large, undeveloped nature of much of the outcrop. Recharge may be inhibited by the superficial clayey Till covering vast areas of the outcrop.
- Groundwater is expected to be flowing to the south or south-east, generally in line with the local topography. **Drawing 02** shows the anticipated groundwater levels beneath the site.
- Groundwater level is expected between 105mAOD and 135mAOD given the occurrence of springs locally. This is in-line with historic groundwater level previously recorded within the Raby Castle borehole (129.2mAOD).

BGS Borehole Records

- BGS Borehole records have been reviewed. A total of 48 borehole records are shown within 1km of the site boundary, of which 35 are available for review.
- Excluding the Raby Castle Borehole, a total of two 'water wells' are shown within 2.5km, of which 1 is available for review.
- Very few boreholes were progressed to depth in the vicinity of the site (outside the area of Coal Measures).
- The depth to groundwater may have changed since the construction of these boreholes.
- The existing on-site borehole location can be viewed in Drawing 1 and the details of the abstraction boreholes available are detailed below.

Borehole Name and Location	Borehole Details
NZ12SW6 – RABY CASTLE NGR: 412899,522176 Located on-site	▪ A borehole was sunk in 1943 to a depth of 55.17m to be used as a water supply. ▪ The log provided identifies approximately 3.7m of Boulder Clay superficial deposits (145.7mAOD to 142.0mAOD) followed by 51.5m of Carboniferous Namurian (Millstone Grit Series) bedrock [now Stainmore Formation] to its base (142.0mAOD to 90.3mAOD). ▪ Rest Water Level was recorded as some 16.5mbgl (129.2mAOD). ▪ Pumped Water Level was recorded at 22.9mbgl when pumped 4000g.p.h (5.05l/s or 436.4m^3/d).

Water Quality
▪ Water quality data is unavailable for nearby BGS boreholes. ▪ The nearest borehole with chemical data (NZ01NE3) is located in Barnard Castle 7.3km to the south-west and describes the water quality as '*hard water*'. ▪ Borehole NZ11SW1 was sunk 140m some 7.4km south of the site and includes a chemical analysis of the groundwater encountered; the borehole is located near the base of the Stainmore Formation. ▪ The NZ11SW1 chemical data presents a temporary hardness of 4ppm suggesting that the groundwater is soft and shows a high alkalinity (pH 8.8). ▪ The total solids content was 680ppm (680mg/l), iron content was recorded as 0.24ppm (0.24mg/l) and manganese is not recorded. ▪ There is visual evidence of high iron content in the existing borehole in the form of iron encrustation on the rising main and casing.

Summary of Anticipated Underlying Geology

- The anticipated sequence of geological units beneath the site is displayed in the table below, assuming a borehole position of 412899,522176 and ground level of 145.5mAOD at the site.
- Geological maps and historical BGS borehole records for the area around the site were used to interpret the site geology. Thicknesses and depths are an approximation only.
- Thicknesses of all geological formations have been estimated using available BGS records and structural contours. A best estimate has been made from the available data, but depths in the field may vary. A dip of 8° has been used in all calculations.

Period	Group	Formation		Aquifer	BGS Lithological Description	Estimated Thickness (m)	Depth to base (mBGL)	Elevation of Base (mAOD)
Quaternary (Devensian)	Superficial Deposits	Till Deposits		Secondary (Undi.)	Diamicton	3.7	3.7	141.8
Carboniferous	Pennine Coal Measures	Pennine Lower Coal Measures Formation		Secondary A	Interbedded grey mudstone, siltstone and pale grey sandstone, commonly with mudstones containing marine fossils in the lower part, and more numerous and thicker coal seams in the upper part.	Stratigraphically above BH		
	Yoredale	Stainmore Formation	Mudstone, Siltstone and Sandstone		Cyclical repetition of sandstones, siltstones, mudstones, thin limestones and some coals.	22.5 (proven)	26.2	119.3
			Sandstone			4.6 (proven)	30.8	114.7
			Mudstone, Siltstone and Sandstone			7.0 (proven)	37.8	107.7
			Sandstone (*'upper thick sandstone'*)			32.2 (>17.4 proven)	70.0	75.5
			Mudstone, Siltstone and Sandstone			24.1	94.1	51.4
			Sandstone (*'lower thick sandstone'*)			26.7	120.8	24.7
			Mudstone, Siltstone and Sandstone			262.3	383.6	-237.6
		Alston Formation			Bioclastic limestones, sandstones, mudstones, siltstones and rare coals typically in regular cyclothemic sequence.	186.3	569.9	-423.9

Drilling Risk and Borehole Stability

- **The driller should be made aware of the following risks:**
- Given the local topography and geology, artesian conditions are not expected to be present beneath the site.
- A layer of made ground is expected, although its thickness is unknown. This made ground may be unstable.
- An approximately 3.7m thick layer of Glacial Till (Boulder Clay) is expected. These superficial deposits may be unstable.
- Boreholes progressed through mudstones may be susceptible to borehole deformation and failure, such as 'breakout' and drilling induced fractures, if the hole is left open.
- The sandstone horizons within the underlying geology may be fractured and/or jointed resulting in a potential for loss of drill flush.
- Named coal seams are shown to be present at depth beneath the site by the BGS.
- Coal Mine workings are not believed to be present beneath the Site, however it is possible that workings are encountered this could result in broken ground, loss of drill flush and difficult drilling.
- The geology in the vicinity of the site and the surrounding area has been subjected to faulting which has resulted in a complex geological fault structure. If a fault is encountered this could result in broken ground, loss of drill flush and difficult drilling.

Open Loop Assessment

Abstraction Boreholes

- The historic 55m deep borehole present on-site is known to yield 4000g.p.h (5.05 l/s or 436.4m^3/d) with a 6.4m drawdown.
- Using this historic data, a specific capacity (yield per m drawdown) of 68.2m^3/d/m has been calculated for the borehole.
- The above calculated specific capacity is specific to the existing historic borehole record. The calculated value can be applied to further planned boreholes in the vicinity of the existing boreholes, however, due to the probability of encountering a greater proportion of sandstone strata at depth (increased transmissivity) when compared to the existing borehole, it is possible that this specific capacity value is conservative in nature.
- It is important to note that if the water level abstraction drawdown drops below productive (sandstone) horizons, the well may become less efficient. The following calculations are therefore based on minimising the drawdown to no greater than 26.2mbgl (the top of the uppermost recorded sandstone strata). Well efficiency can be tested by a step test in any trial borehole to assess the contribution to yield of this upper sandstone.
- A rest water level of 16.5mbgl has been assumed.
- Using the existing borehole data, the potential drawdowns for abstractions of 12 l/s and 27 l/s have been calculated. The following calculations assume newly installed boreholes to be installed to a similar depth to the existing borehole; however it is recommended that a deeper trial borehole is drilled initially.
- For a yield of 12 l/s (1037m^3/d), two boreholes to 55mbgl each pumping 519m^3/d would be required. These boreholes would experience a drawdown to 24mbgl (drawdown of 7.6m below rest water level).
- For a yield of 27 l/s (2333m^3/d), four boreholes to 55mbgl each pumping 583m^3/d would be required. These boreholes would experience a drawdown to 25mbgl (drawdown of 8.6m below rest water level).

Discharge Boreholes

- In some cases, the volume of water to be injected back to the ground is not supported by the permeability of the strata in which the borehole is located.

- It is recommended that an investigation be carried out into the feasibility of use of the existing borehole as an injection well.
- In periods of high groundwater it may be the case that the volume of water that is able to be discharged to ground may reduce and an 'overflow' option (to surface waters) may be required.
- If any discharge of groundwater to surface waters is required, an investigation into water quality of both the groundwater and surface water into which the discharge will take place is required in order to assess any required treatment, and minimise water flow and quality impacts to the water environment.
- It is recommended that a monitoring study be progressed into the feasibility for the discharge of all or part of the abstracted groundwater into the local surface water network, this should include both flow and water quality baseline monitoring.

Conclusions and Recommendations

Hydrogeo Limited (Hydrogeo) has been commissioned by Renewable Energy Alliance Ltd (the client) to undertake a ground source heating feasibility study.

The feasibility of the water supply was reviewed in terms of the ability of the bedrock beneath the site to provide the yield of water required at the site to meet the required energy demand for an open loop system.

There is a historical record for an abstraction borehole on site which stated a yield of 5 l/s, there is no knowledge or record of the long term performance of this borehole

Open Loop

An open loop system has benefits over a closed loop system requiring fewer boreholes and less ground disturbance during installation.

A trial investigation abstraction/recharge borehole is recommended to support the borehole array design, however based on the on-site historic borehole record test data and boreholes drilled to the same depth as this borehole (55m).

- A flow rate of 12 l/s is expected to require two abstraction boreholes and two discharge boreholes.
- A flow rate of 27 l/s is expected to require four abstraction boreholes and four discharge boreholes.

This is considered to be a worst case estimate as deeper boreholes and well efficiency (pump) testing may prove fewer boreholes and greater drawdowns in the boreholes are required to meet the required yield and energy demand.

A best-case estimate would be one abstraction borehole and one discharge borehole for 12 l/s and two abstraction boreholes and two discharge boreholes for 27 l/s.

It is recommended that a phased approach be taken to the drilling and testing of the required abstraction and discharge borehole open loop scheme as follows:

- Trial borehole advanced to 125mbgl (base of the 'lower thick sandstone').
- CCTV/geophysics testing to determine the depth of productive fissures in order to inform further borehole development. Water quality profiling in the borehole.
- A second (injection) borehole should be drilled (depth dependent on the findings of the first borehole, but max, depth 125m).
- Pumping / injection tests: step test to investigate maximum efficient yield, constant rate test with water quality analysis throughout test. Recovery test. Include monitoring in selected water features.
- Analysis of pump test and recharge test data, calculation of aquifer properties and zone of influence calculations to design additional borehole array (if required), depth and spacing.
- Surface water quality and flow monitoring in the surface water network should be undertaken to baseline conditions and assess the feasibility of discharging water (potentially as an overflow) to the surface water system.

- It is suggested that the area between Raby Gardens and the Gashouse be used for the borehole array with the abstraction wells being positioned to the north of the playing field and injection boreholes being positioned to the south of the playing field. This is based on an estimated groundwater flow direction.
- The distance between boreholes should be determined following testing of the recommended 125m borehole; at this stage a minimum distance of between 50 – 100m would be expected.
- An abstraction over 20m^3/d would require an abstraction license from the Environment Agency and the discharge of groundwater will require further environmental permitting from the EA. Impact assessments will be required to support these applications.

Closed Loop

A closed loop scheme will require a greater number of boreholes installed to meet the energy demand but presents the following advantages over open loop:

- No abstraction or discharge permit and charges are required (fewer Regulatory Issues).
- Injecting water back into an open loop borehole can be problematic over the longer term if there is elevated iron and manganese, encrustation can resulting in clogging and reduced injection borehole efficiency.
- Closed loop has lower long-term operation and maintenance requirements.
- Reduced uncertainty in the long term performance, open loop borehole yields and injection rates can decline over time.
- A single test borehole would be drilled initially for a closed loop, and a thermal response test undertaken to design the borehole number / depth / spacing.

A cost comparison for open loop vs closed loop is recommended.

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DRAWING 01

Bedrock Geology

KEY

Existing Borehole

Raby Castle (Historic England) Outline

Bedrock Geology

Pennine Coal Measures Group

Pennine Middle Coal Measures Formation - Mudstone, Siltstone and Sandstone

Pennine Middle Coal Measures Formation - Sandstone

Pennine Lower Coal Measures Formation - Mudstone, Siltstone and Sandstone

Pennine Lower Coal Measures Formation - Sandstone

Yoredale Group

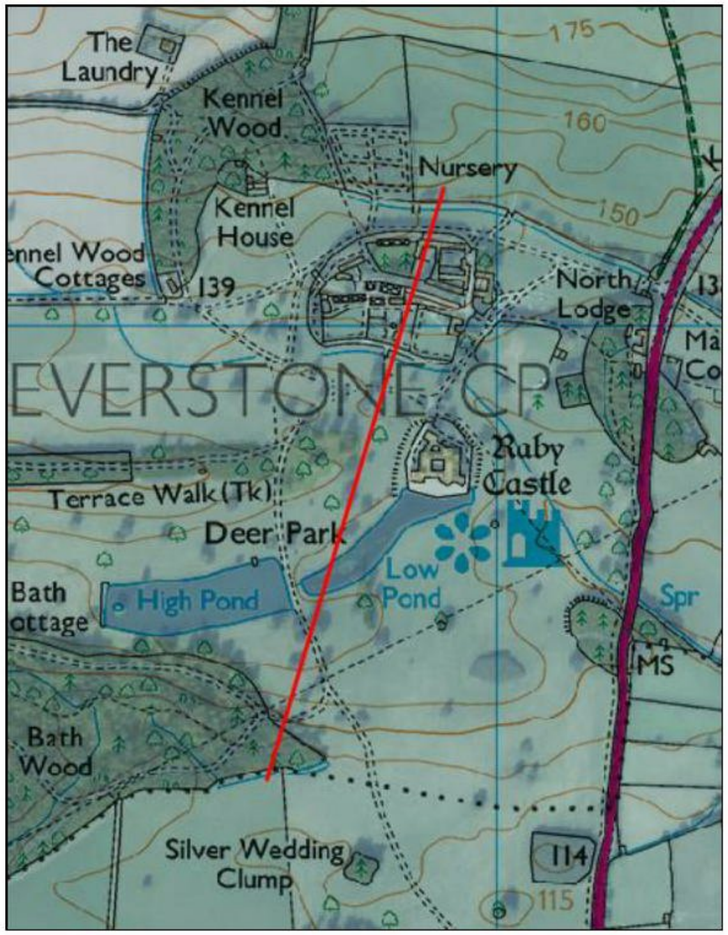
Stainmore Formation - Mudstone, Siltstone and Sandstone

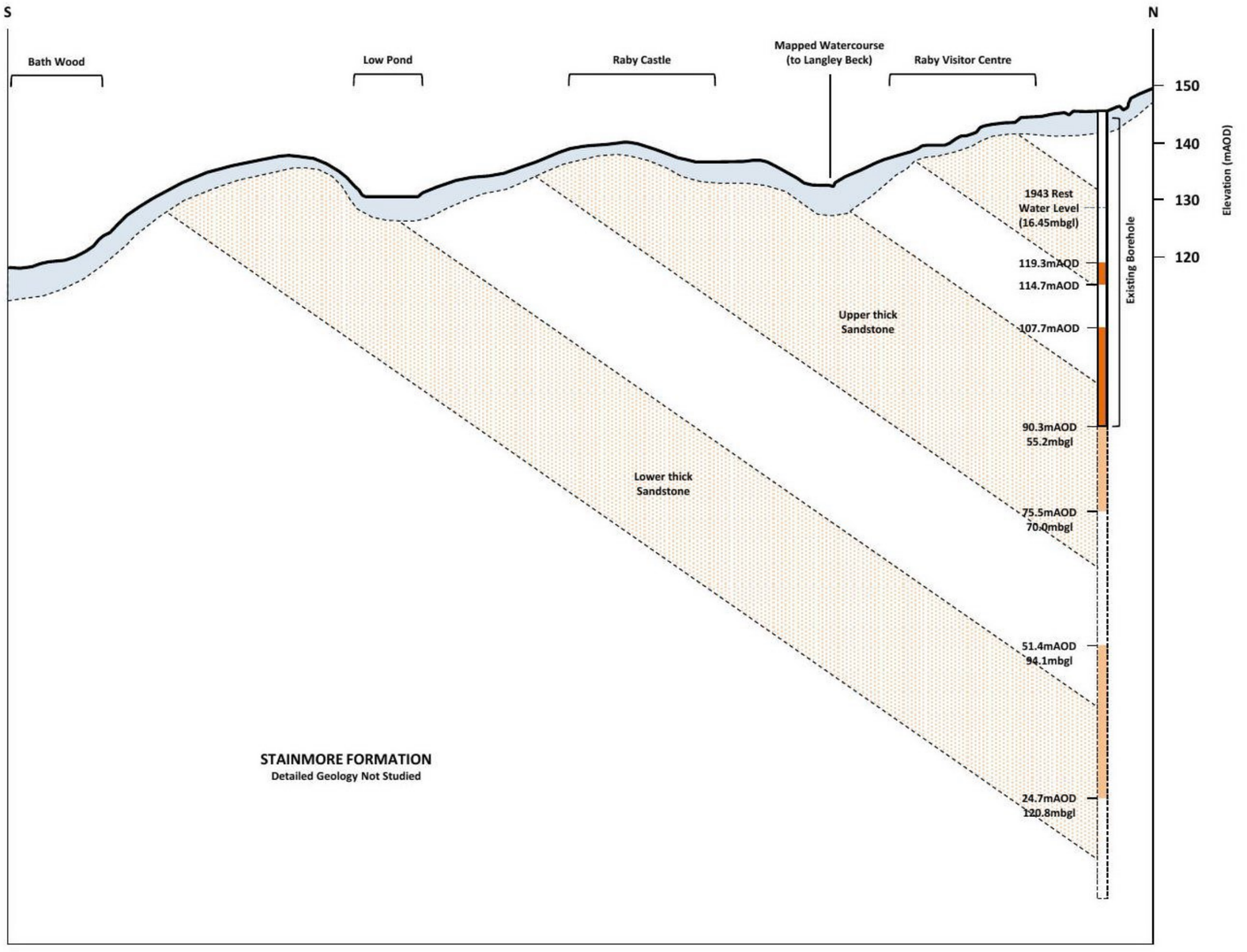
Stainmore Formation - Sandstone

200 0 200 400 600 800 m

N

Date	By	Paper	Scale	Rev
22 04 2021	DD	A3	1:15000	1





MAP KEY

Line of Section

DRAWING KEY

- Glacial Till (Inferred)
- Sandstone Horizon (proven)
- Sandstone Horizon (expected)
- Sandstone Strata (1:50,000 BGS data inferred at 8°N dip)

100m
10m
Note: Vertical Exaggeration (5x)

DRAWING 02 – Conceptual Geological Model

Client: Renewable Energy Alliance Ltd.

Project: Raby Castle, County Durham Ref: HYG899

Date: 06/05/2021 Drawn By: DD Checked: CB

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