

RICK BRASSINGTON
Consultant Hydrogeologist

Hydrogeological Assessment of impact of the
proposed Wasperton sand & gravel quarry

For The Barford Residents Association

Rick Brassington *Consultant Hydrogeologist*
12 Culcheth Hall Drive
Culcheth
Warrington
Cheshire
WA3 4PS

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Separate documents accompanying this report:

Druid, S. 2022 *Comparing Groundwater Drawdown with Estimated Influence Radius – A Case Study of Infrastructural Projects in Sweden*. Degree Project at the Department of Earth Sciences, University of Uppsala

Kendon, K.J., Fischer, E.M. & Short, C.J. 2023 Variability conceals emerging trend in 100 year projections of UK local hourly rainfall extremes. *Nature Communications* published online March 2023

Summary

Smiths Concrete Ltd have proposed to excavate a sand and gravel quarry that covers an area of some 53.5 ha in a site of 89.5 ha and it will extend over a period of 10 to 15 years. The application to Warwickshire County Council omits many details that makes an assessment of the likely environmental impact by an independent expert very difficult indeed.

The application falls short in the ways described below:

- relevant data is limited to a summary of the borehole logs with the full logs not being provided.
- groundwater levels have been recorded in nine piezometers that cover a 53.5 ha site have also presented and are limited to a period of twelve months. A longer period is needed to evaluate the range of the changes in the water levels so that the impact off the site can be properly assessed.
- information on site specific values of the hydraulic properties of the river terrace materials should be provided. This is easily done based on at least four drawdown and recovery tests with a minimum of two observation boreholes being used in each test. This would allow estimates of the inflows to be made far rather than to rely on guessed values for hydraulic conductivity. The site investigation boreholes could have been used instead of being backfilled.
- dewatering details for the twelve cells has not been provided other than stating that there will be a pumping sump and that the water will be settled before it is discharged into the local surface water system.
- it is stated that the need for a discharge will be limited to the start of the quarrying. However, there are no calculations provided to support this profoundly optimistic claim. It is likely that pumping will be required for most of the period when the site is being worked.
- In view of the importance of pumping to the success of the quarrying operation he does not provide any measures that will be put in place to maintain the pumping and keep the quarry dry. Calculations to provide estimates should be provided.
- an abstraction licence is expected to be required, granted by the Environment Agency (EA) although the documents do not indicate what the EA's views are on this matter.
- other aspects of the proposal that require the EA's agreement include the operation of the site as a landfill.
- fails to provide sufficient detailed and site-specific information to determine the effects of the works on local groundwater. He does indicate that these effects will

extend beyond the site boundary and it would be unsafe to determine the application without additional data.

- does not provide adequate calculations to demonstrate the drawdown in the terrace materials beyond the site boundary. The equations used only apply to unconfined aquifers whereas this sand and gravel is currently confined. Therefore the results are totally unreliable. In addition, the actual calculations are not shown.
- fails to provide detailed operational plans however it can be inferred that 24 hour working by up to 3 pumps will be required throughout the operational life of the quarry (up to 15 years). This will cause not only significant noise pollution but potentially also CO₂ emissions (the power source for the pumps is not given although it is assumed to be diesel).
- The backfilling for restoration using a total of 1,000,000 m³ of inert wastes must be regarded as a landfill and subject to the regulations managed by the EA. This requires a comprehensive description of the site and special measures are required where the landfill is in a sensitive area. These are defined by, amongst other things, as where the inert wastes are tipped below the water table and also in an area where groundwater provides a direct pathway to other sensitive receptors such as surface waters. This is the case where the local groundwater currently flows towards the River Avon.
- the lack of information on the rockhead outside the site between it and the River Avon. This information would indicate whether or not that river water will be drawn into the site by the pumping.
- fails to explain where suitable inert fill will be sourced. Inert fill has become a valuable resource and is very likely to be in increasingly short supply. It is suggested that a full application would demonstrate the availability of the infill material as this totally controls the ability of the operator to restore the site in the way described.
- “inert landfill” usually attracts the lowest level of regulatory scrutiny because of the supposed low risk, that results in a considerable reliance upon ‘Operator Self-Monitoring’ to reduce the regulatory burden. This could mean that the operator does not restrict the backfill material to inert wastes due to the difficulties in obtaining it.
- the application proposes to change the local landscape by leaving the settlement lagoons as mitigation for possible flooding. It is known that there will be flooding caused by the proposal from obstructing the local groundwater flow so that the water comes to the ground surface making flooding more certain. In addition climate change is expected to increase the number of >20 mm/hour storms that will result in local flooding.
- The proposal to leave the settlement lagoons in place will reduce the amount of good quality farm land that is currently used for short term salad crops and the like.

1. Introduction

- 1.1 Smiths Concrete Ltd are proposing to extract all the sand and gravel resources beneath fields to the south of Barford, Warwickshire except for areas that lie along certain existing boundary lines. The location of the site is shown in Figure 1.1. The boundary of the site to which the applicant has access extends to some 89.5 ha and is shown in red and includes the proposed unquarried areas along the internal boundary lines together with those parts of the site that are not underlain by sand and gravel. The area where it is proposed to excavate all the sand and gravel extends to 53.5 ha in total.
- 1.2 An application (No. WDC/22CM008) has been made to Warwickshire County Council for a planning consent to permit this quarry to proceed. It is proposed to work the site in a series of cells with the entire process taking some 10-15 years. The applicant states that he intends to have up to three cells open at any one time.
- 1.3 The proposal is to use the fine-grained washings from the gravel treatment process together with the overburden and imported inert waste materials to allow the excavation to be restored to the original ground levels. It is very likely that importing the inert materials will be regarded by the EA as waste disposal and the site as a landfill which will also require an environmental permit. An environmental permit will also be required for the discharge of the abstracted water to the local surface water system. Neither permits have been applied for as yet.
- 1.4 The water pumped from the quarry will be discharged into the existing streams and ditches for disposal and the applicant states that he proposes that the discharge will all be in the initial part of the development. The dewatering will require a significant rate of pumping to lower the groundwater in each cell as it will also extend into neighbouring areas. Such abstractions have required an abstraction licence from the Environment Agency (EA) since 2018.
- 1.5 Local people are concerned about the environmental impact that the proposed workings will have and this report deals with those aspects that affect the groundwater system and related topics in the proposals.
- 1.6 The Barford Residents Association has instructed Professor Rick Brassington to investigate the hydrogeology of the site and related issues and to prepare a report that is contained in this document.
- 1.7 Warwickshire CC Planning Department has asked the Environment Agency (EA) for its views on the proposals and the EA has replied in a letter dated 7th February 2023.
- 1.8 I visited the local area on 24th May 2023 and was shown the location of the proposed quarry by Dr Malcolm Eykyn and a number of his colleagues from the Barford Residents Association.

Information used for this report

- 1.9 The information used to produce this report include that which is contained in the planning application and has been accessed from the Warwickshire County Council's planning webpage. These data includes the letter from the EA and consultancy documents prepared by Hafren Water Environmental Water Management.
- 1.10 The other sources of information used are as listed below.

Reports etc

Crow, P. 2005 *The Influence of Soils and Species on Tree Root Depth*. Information Note Forest Research Forestry Commission Edinburgh

Druid, S. 2022 *Comparing Groundwater Drawdown with Estimated Influence Radius – A Case Study of Infrastructural Projects in Sweden*. Degree Project at the Department of Earth Sciences, University of Uppsala

Edmonds, E.A., Poole, E.G., Wilson, V., Bullerwell, W. & Williams, B.J. 1965 Geology of the country around Banbury and Edge Hill. Explanation of sheet 201. Memoirs of the Geological Survey of Great Britain, England and Wales (Sheet - New Series) British Geological Survey, Nottingham

Environment Agency, 2013 Warwickshire Avon abstraction licensing strategy. Published by the Environment Agency, Bristol

Kendon, K.J., Fischer, E.M. & Short, C.J. 2023 Variability conceals emerging trend in 100 year projections of UK local hourly rainfall extremes. *Nature Communications* published online March 2023

Mitchell, A. and Jobling, J. 1984. *Decorative trees for country, town and garden*. HMSO, London.

Old, R.A., Sumblar, M.G., Ambrose, K., Brewster, J., Jones, A.R.L., Rushton, A.W.A., Carruthers, R.M., Murti, P.K., Calver, M.A., Riley, N.J., Warrington, G., Harrison, R.K., Strong, G.E., Ivimey-Cook, H.C. 1987 Geology of the country around Warwick, Memoir for 1:50000 geological sheet 184 (England & Wales) Memoirs of the Geological Survey of Great Britain, England and Wales (Sheet - New Series) British Geological Survey, Nottingham

Pyatt, G., Ray, D. and Fletcher, J. 2001. An ecological classification for forestry in Great Britain. *Forestry Commission Bulletin 124*. Forestry Commission, Edinburgh.

Skiadaresis, G, Schwarz, J, Stahl, K, & Bauhus, J. 2021. Groundwater extraction reduces tree vitality, growth and xylem hydraulic capacity in *Quercus robur* during and after drought events. *Scientific Reports* **11**, Article number: 5149

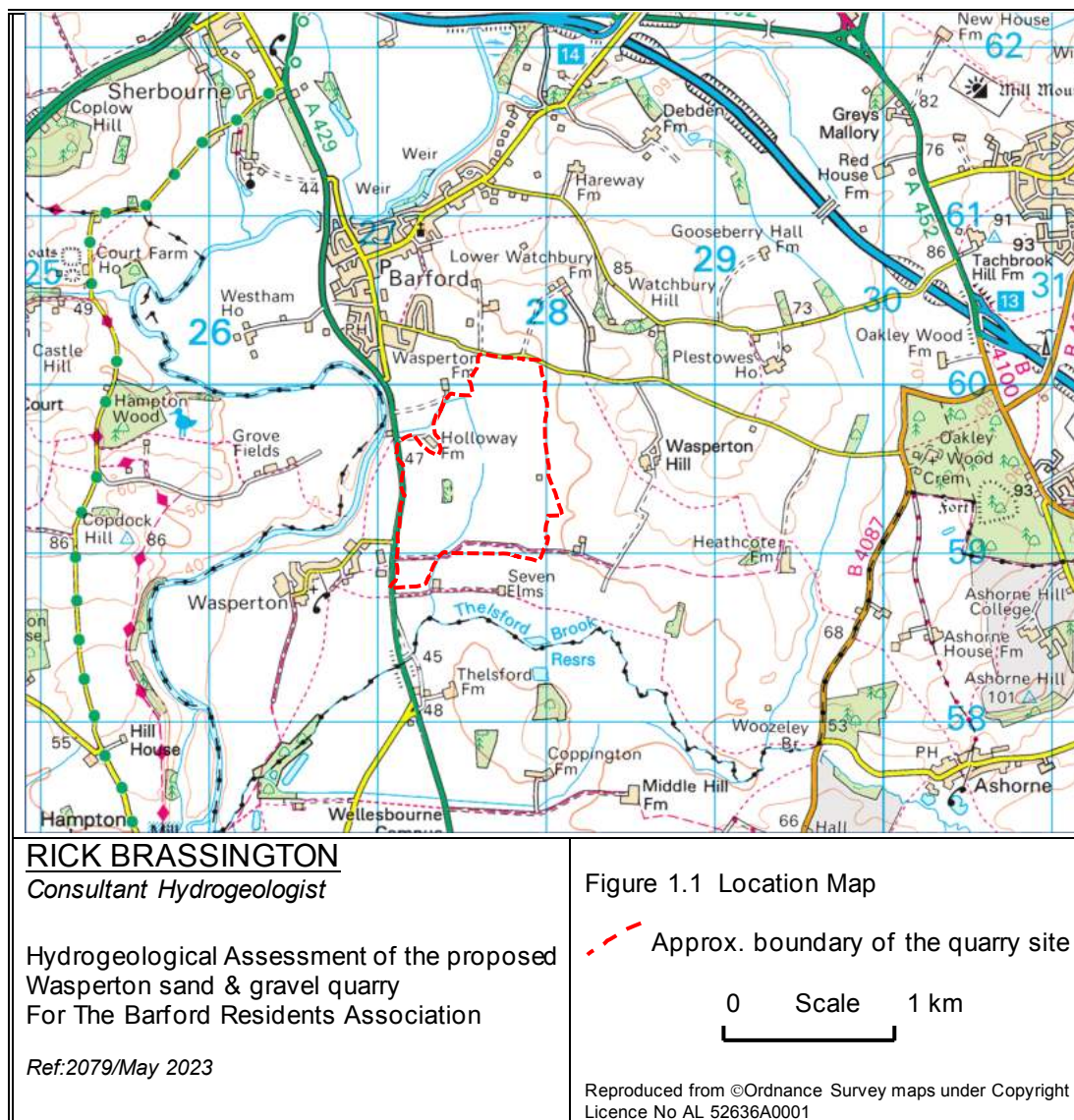
Maps

OS Explorer 221 - Coventry, Warwick, Royal Leamington Spa & Kenilworth
OS Explorer 205 - Stratford upon Avon, Evesham & Alcester
BGS Sheet 184 Warwick Solid with Drift on 1:50 000 scale
BGS Sheet 201 Banbury Solid with Drift on 1:50 000 scale

BGS Sheet SP25NE on 1:10,000 scale
BGS Sheet SP26SE on 1:10,560 scale (coloured)

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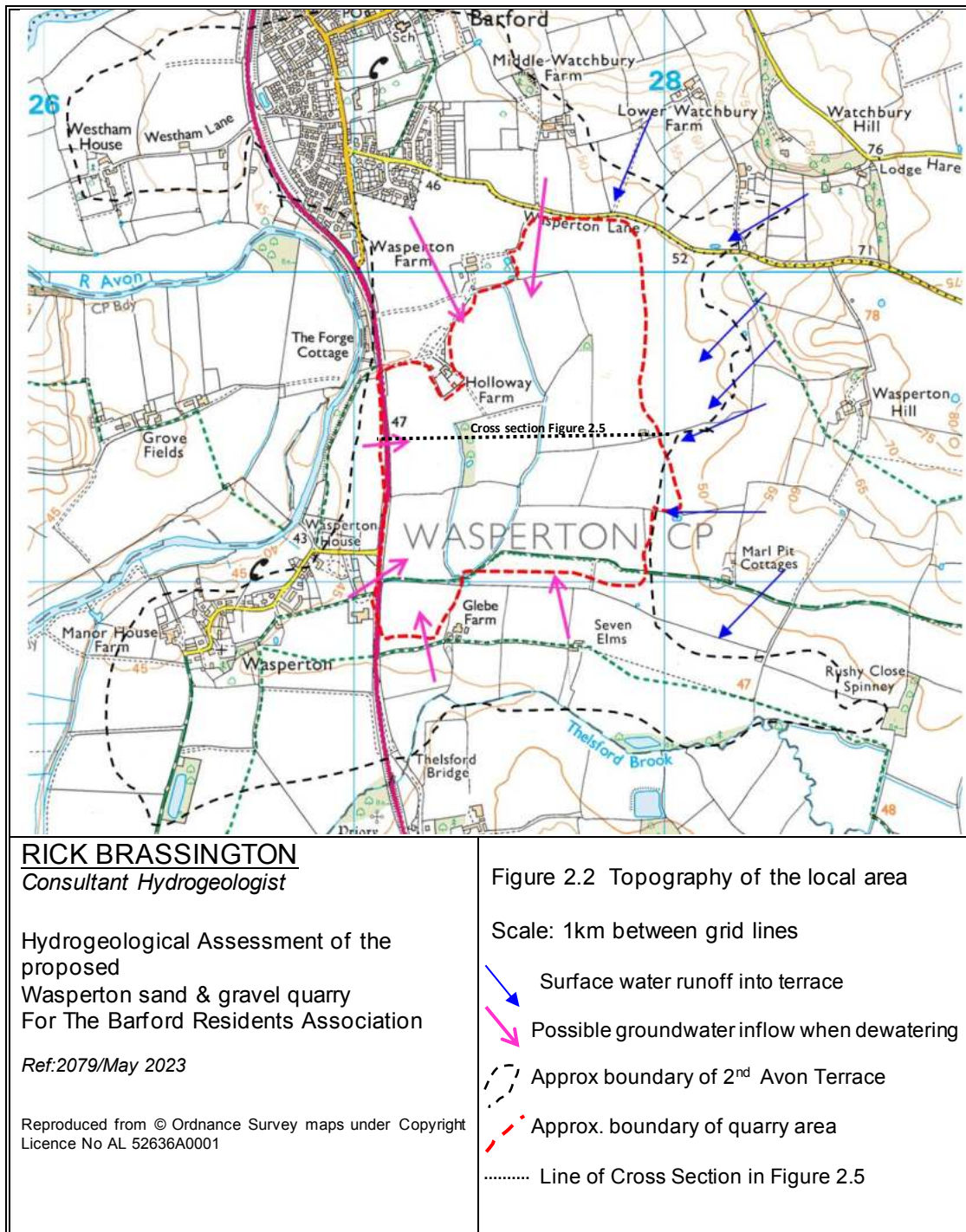
2. Topography and Geology

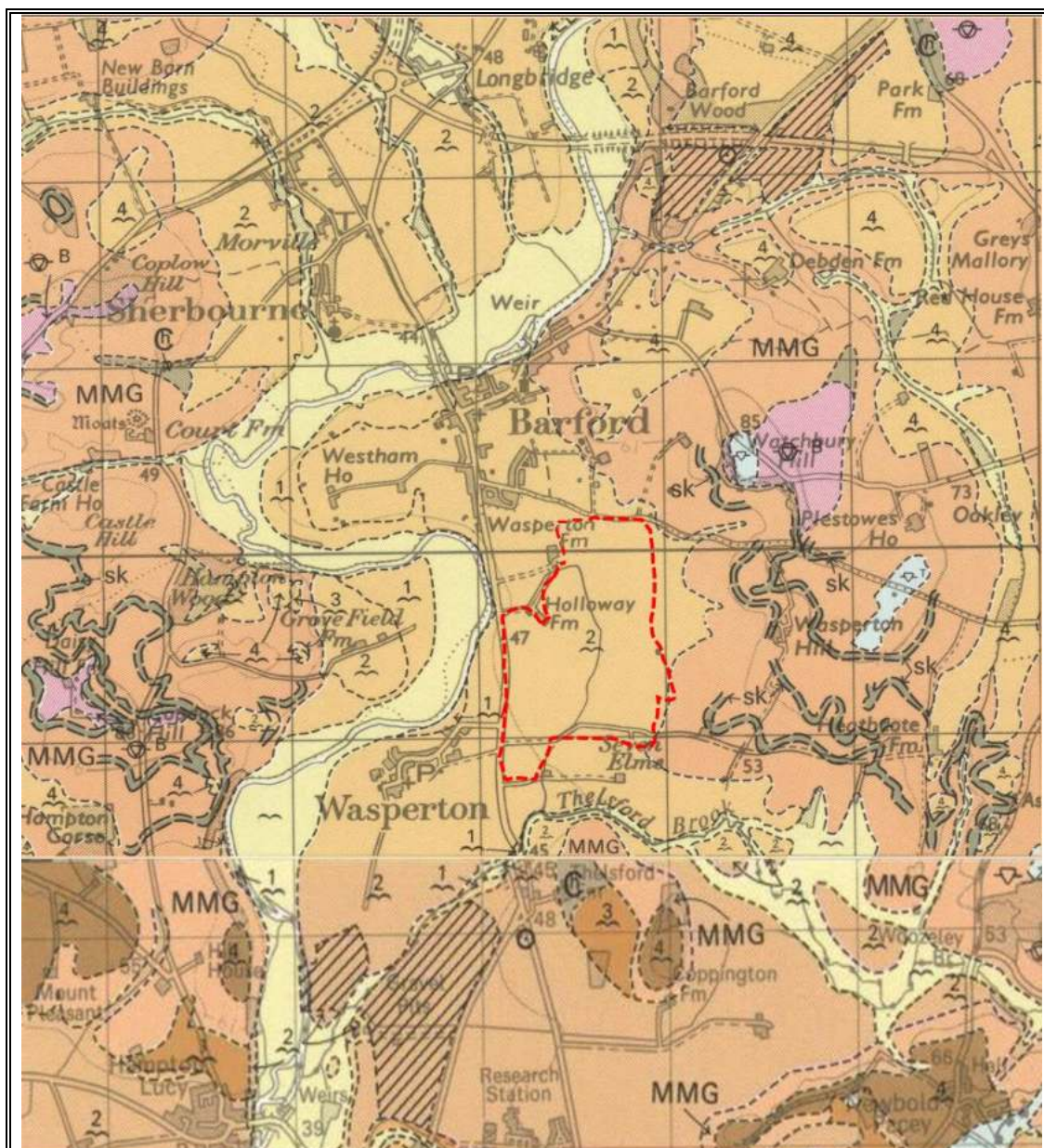
- 2.1 The local topography around the site has a low hill on the eastern side that comprises Watchbury Hill in the northeast that is joined by high land to Wasperton Hill in the south and lies due east of the site. Watchbury Hill achieves an elevation of just over 85 mOD and the Wasperton Hill is to a similar elevation. The elevation of the proposed quarry is 45 mOD next to the main road and extends to 46.9 mOD on the eastern boundary. The site has a general slope to the west towards the River Avon. A tributary of the Avon, the Thelsford Brook lies about 300 m to the south of the southern boundary. A system of minor watercourses crosses the site that, with a number of ditches, provides the local drainage. The main drainage is towards the Thelsford Brook with the northern part of the site draining to another minor watercourse that is a tributary of the Avon. The onsite drainage system is shown in Figure 2.1, a diagram taken from the Hafren Water hydrogeology report. The map also shows the locations of licensed surface water abstractions.
- 2.2 The northern boundary of the site lies along a short stretch of Wasperton Lane that runs towards the east from Barford village. The boundary runs to the south just below the 50 mOD contour for about 1 km before turning towards the west and running along a farm lane before turning towards the southwest again to run round Glebe Farm. When it reaches the A429 it runs to the north following the road until it reaches the access to Holloway Farm when it runs in a general northeasterly direction to meet up with the Wasperton Lane and has bends to avoid Holloway Farm and the neighbouring Wasperton Farm. This can be seen on the large scale OS map in Figure 2.1 that also shows the minor watercourses and ditches on the site and round its boundaries. A number of the site boundaries are defined along these ditches.
- 2.3 Figure 2.2 shows the potential direction of groundwater entering the site during dewatering pumping and the surface runoff that enters the site from the area above the site on the side of the Watchbury/Wasperton hill. It should be noted that the surface runoff into the terrace gravels occurs all along its eastern boundary and is the main source of recharge to the groundwater that is outside the site that will be affected by dewatering.
- 2.4 This area of Warwickshire is underlain by rocks of the Mercia Mudstone which are mainly mudstone with some interbedded siltstones and occasional interbedded thin very fine- to fine-grained sandstones that are referred to as 'skerries'. These skerry sandstones form minor aquifers where they are sufficiently thick. The British Geological Survey have not indicated any beneath the proposed quarry site although this could be because the overlying river terrace materials hides the possible subcrop. In addition the boreholes logs provided by the applicant do not record any Mercia Mudstone although it is clear that the boreholes penetrated the full thickness of the river terrace materials would have encountered the mudstone at the base of each borehole. It is noted that other similar boreholes in the area prove sand and gravel lying directly on the Mercia Mudstone. The map in Figure 2.3 shows the superficial deposits in the area which are predominantly terrace gravels that are proposed to be quarried. The key to the BGS map drift deposits is shown in Figure 2.4.

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- 2.6 The nature of the materials that are described in the borehole logs provided by the applicant are 'overburden' and 'mineral' and they give impressions of either the hydraulic conductivity of these materials or the thickness of the layers that may be different if the full logs had been provided.





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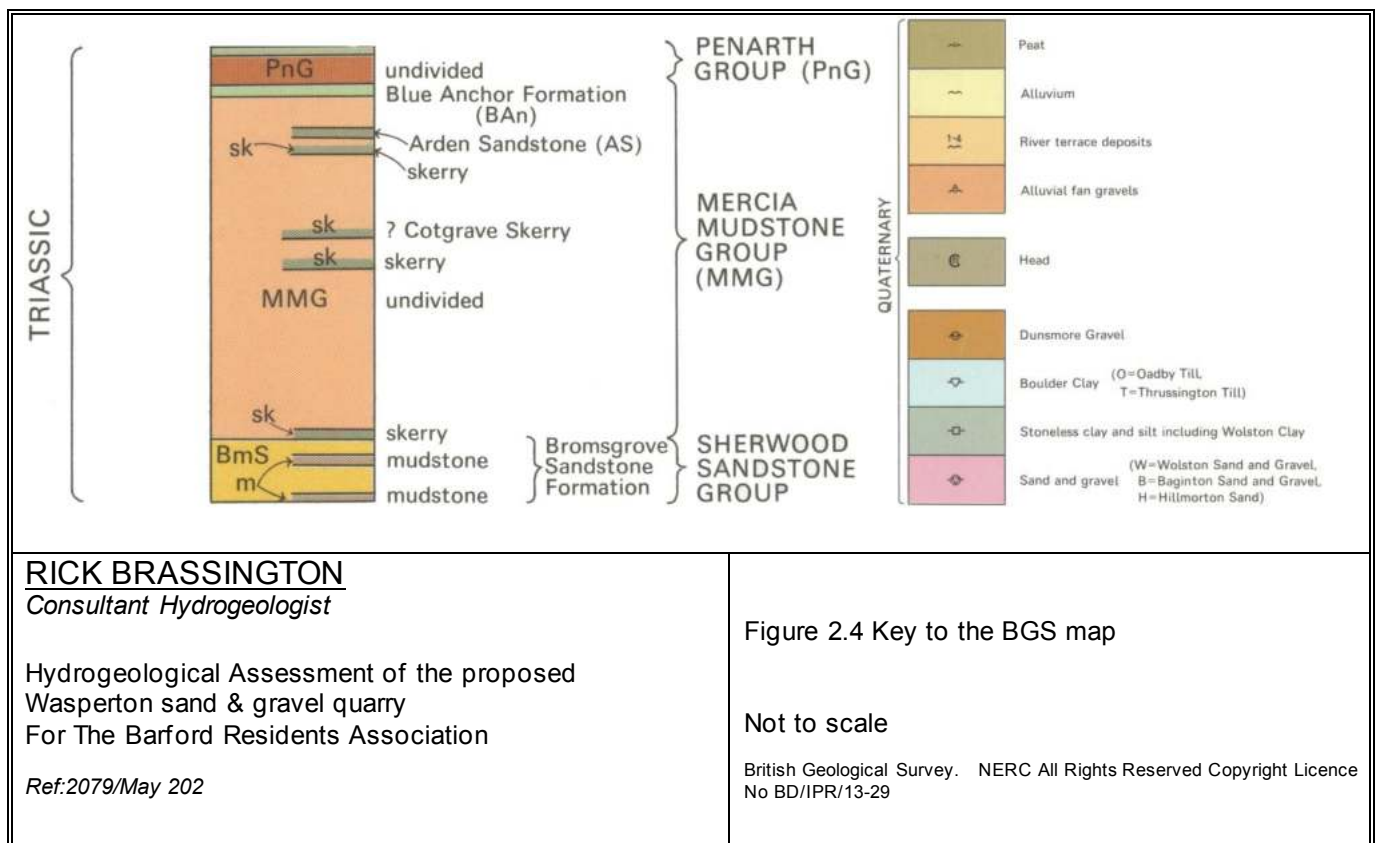
Ref:2079/May 2023

Figure 2.3 – Geology map

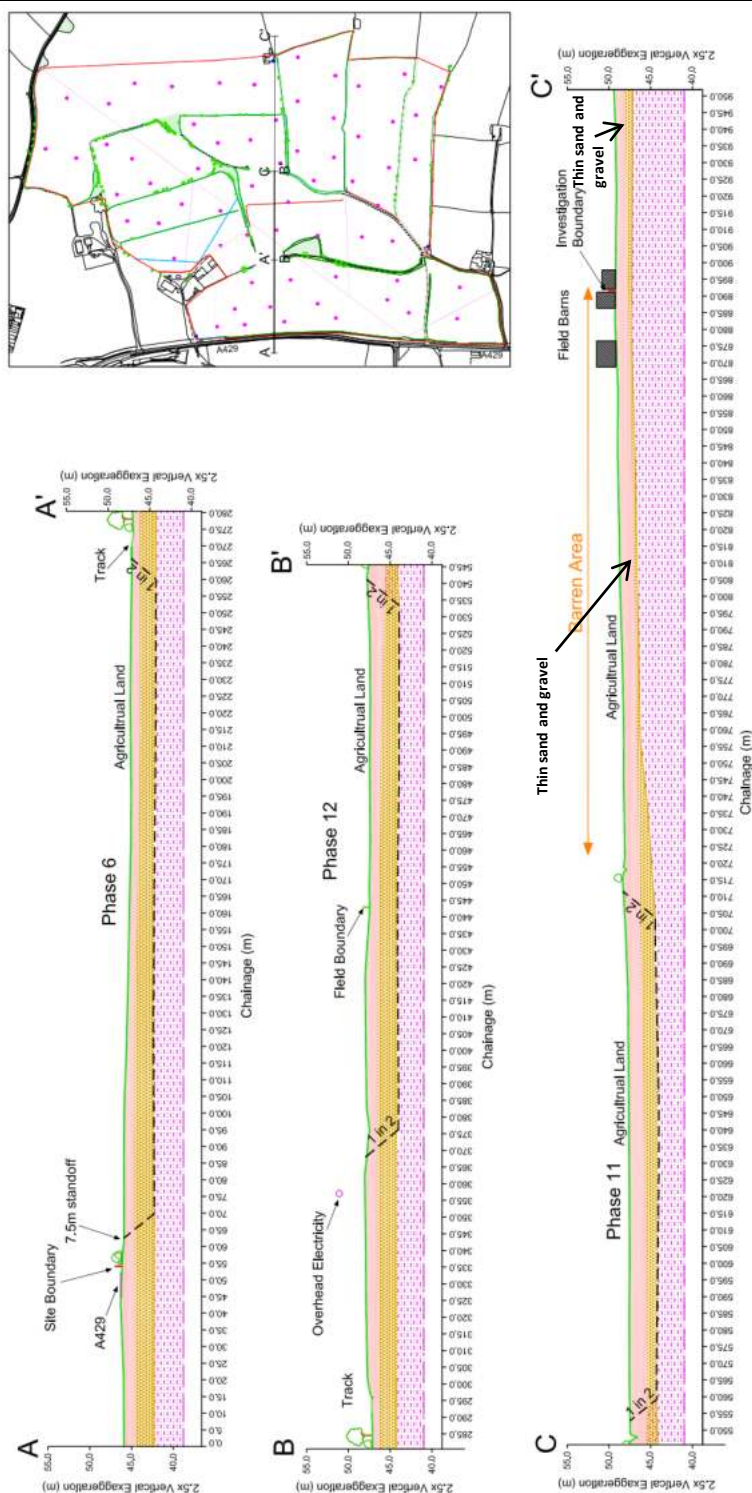
Scale: The grid lines are 1 km apart

--- Boundary of quarry area

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- 2.7 A cross section provided by the applicant and shown in the application documents as Plan WSP 22-6 Cross Section is shown below as Figure 2.5. The three elements are to be put together and show the gentle slope of the ground surface (green), the rockhead (as a pink hatched block), then sand and gravel (as a gold coloured block), and the thickness of the overburden (as a salmon pink block).
- 2.8 The section shows a thin layer of sand and gravel in the area marked on other maps provided as “barren”, a term that may suggest that there is no sand and gravel. This thin layer provides an important role in allowing surface runoff from the hillside to the east to enter the sand and gravel as recharge,
- 2.9 The land surface to the east of the site quickly rises to 70 mOD within 650 m from the end of the section. This slope has an average gradient of 1 in 9.3 which may also be stated as 0.31 or 31%. This is sufficiently steep to encourage heavy rain to runoff down the slope being concentrated in the valleys shown by the ground contour shapes, from where it will recharge the river terrace gravels. This is in contrast with the proposed restoration where the material that it is proposed to replace the sand and gravel will be material with a low effective porosity and will not be able to absorb the water in the same way therefore causing the groundwater levels to rise and the prospect of flooding increased.



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Copied from diagram in Hafren Water report

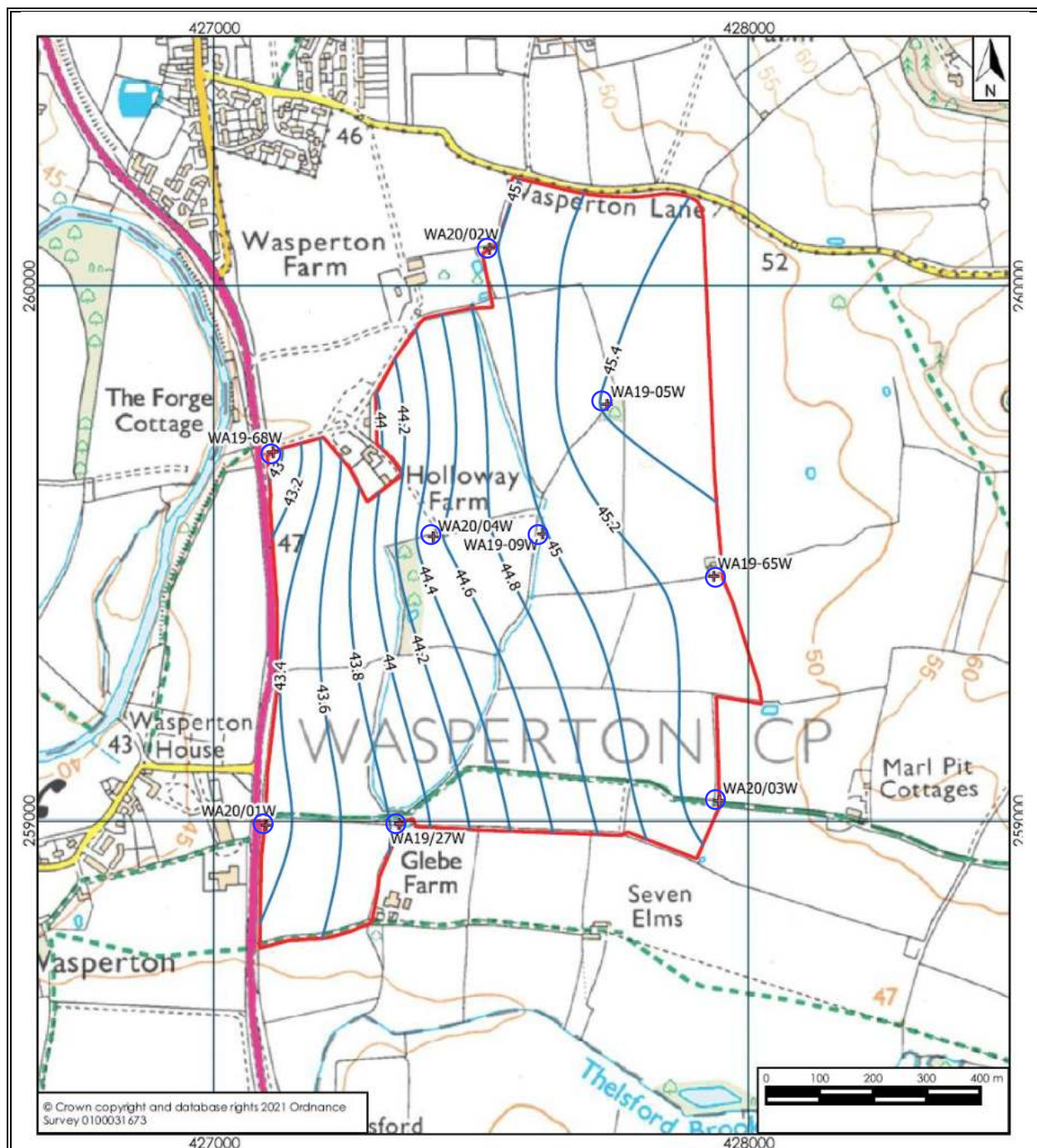
Figure 2.5 Cross section

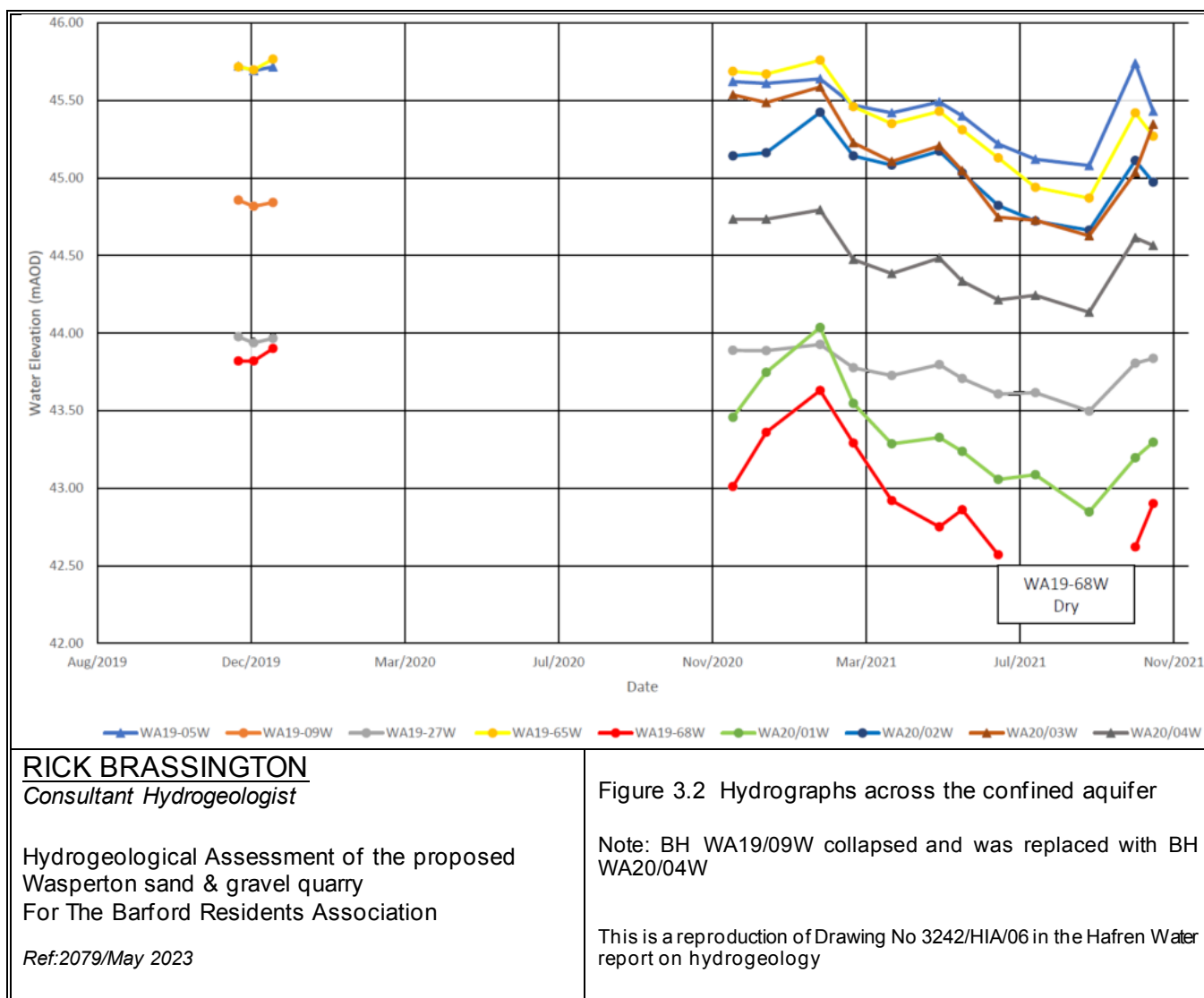
Key

- Current Topography
- Overburden
- Mineral
- Mudstone/Clay Bedrock
- Investigation Boundary
- Proposed Extraction Design

3. Hydrogeology

- 3.1 The river terrace sand and gravel deposits are designated by the EA as an aquifer although the applicant states that there are no current abstractions across the proposed quarry area. The terrace deposits lie on a rockhead of Mercia Mudstone which is poorly permeable and can be regarded as an effective base to the aquifer.
- 3.2 A piezometric map (showing groundwater contours) has been provided by consultants Hafren Water on behalf of the applicant and is shown in Figure 3.1. These contours have been checked and within the limited distribution of the data point they seem to be reasonably accurate. The limited number of data points does not enable the small watercourses in the centre of the site to be picked up indicating the problem with too few data points.
- 3.3 The farm where the proposed site is located is owned by St Johns College, Oxford that owns further land outside the site boundary and therefore there is no reason why the applicant could not have been allowed to construct boreholes outside the proposed quarry site. This would have allowed the information from the site to be better put into the context of the groundwater system in the surrounding area.
- 3.4 Examination of the water table map shows the water table gradient across the site is about 1.9 m in 800 m or 0.0024 (0.24%). In addition, the depth of water across the site is low i.e. the saturated aquifer is relatively thin. These features show that the sand and gravel of the river terrace deposits are moderately permeable
- 3.5 It is assumed that the material in the overburden is finer-grained than that of the mineral (aquifer) which will mean that a greater proportion of the potential rainfall will runoff to discharge into the River Avon along the system of minor watercourses and ditches on the site. The remainder will either be lost back to the atmosphere as evapotranspiration or will recharge into the aquifer. The main recharge will be surface runoff from the eastern area up the side of the hill.
- 3.6 The aquifer will receive direct recharge from rainfall and occasional snow melting on the ground surface with the recharge being principally during the period from November to April. The applicant has had monthly water level readings taken in the monitoring piezometers that are shown as hydrographs in Figure 3.2. The record from piezometer WA19/09W only exists for the first three readings. The Hafren Water report states that one borehole has been damaged and it is assumed that it is this piezometer as WA20/04W 2020 has been drilled in the general area of this position.
- 3.7 Examination of the hydrographs shows that the greatest annual fluctuations occurs in the water level records from the piezometers at the down-slope locations next to the A429 in piezometers WA19/68W and WA20/01W. These two records show an annual fluctuation of about 0.7 m in the water table elevation.





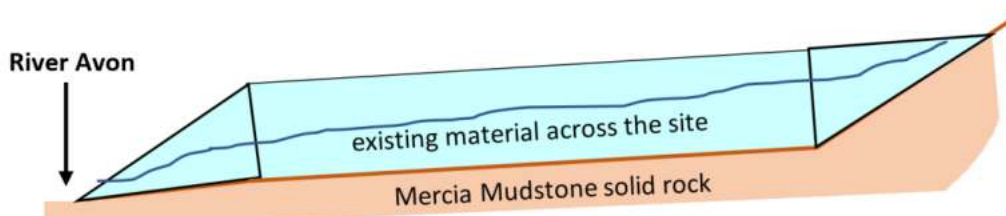
- 3.8 The hydrographs from the piezometers near the eastern edge of the site show smaller fluctuations with WA19/05W and WA19/65W both showing about 0.3 m annual fluctuation, the piezometer in the centre of the proposed quarry site, WA20/04W shows about 0.35 m annual fluctuation, WA20/02W near the northern site boundary shows some 0.4 m fluctuation and WA20/03W near the southern boundary shows a fluctuation of some 0.5 m. The differences between these fluctuations will depend upon differences between the hydraulic properties of the aquifer with the greater responses reflecting lower storativity.
- 3.9 The hydrographs for WA19/68W peaks at 43.6 mOD and WA20/01W peaks at 44.0 mOD. These elevations are significant in terms of the risk to flooding an open cell in the proposed quarry from groundwater flow and also flow from the River Avon through the sand and gravel materials and are discussed in the next section of this report.

4. Potential hydrogeological impact

Impact of the proposed infilled quarry

- 4.1 The proposal is to extract the sand and gravel by dry working the site in 12 phases with each phase being infilled, at least in part, by the very fine- and fine-grained material that has been washed from the sand and gravel, being placed in the previously excavated phase. The short fall is proposed to be made up by inert waste materials brought onto the site that largely consist of clayey materials. Eventually the site will become a largely impermeable block of very fine- to fine-grade materials consisting of clay and silt sized particles with a hydraulic conductivity of 10^{-5} to 10^{-4} m/d or possibly less. There will be narrow flow paths between the different phases of low permeability material along the boundaries between the phases that have been left to support the present drainage system. The hydraulic conductivity will be the same as now in these areas.
- 4.2 This situation is illustrated by Figure 4.1 below. The first case shows the present situation with the sand and gravel aquifer being confined by the overburden and with a groundwater flow system that slopes down towards the River Avon. Note that the groundwater elevations are a piezometric or pressure surface that lies above the aquifer which is full of water almost everywhere. The piezometric surface represents the water pressure in the aquifer and is the level at which groundwater stands at in the monitoring piezometers.

1. Existing case shows water table across the site carrying water to River Avon



2. Quarry area filled with low permeability waste that does not allow significant flow

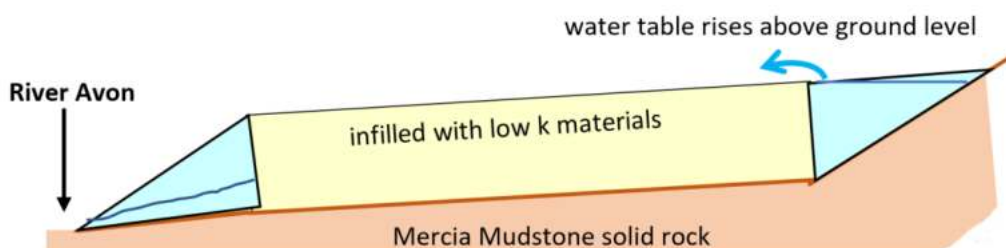


Figure 4.1 – Conceptual model of the impact of the proposed infilled quarry

- 4.3 The second case represents the situation after the quarrying has finished and has been restored by being filled with low hydraulic conductivity materials. These

materials cannot allow any significant groundwater flow and so the water levels on the up flow side of the backfilled quarry will rise and flow over the ground. The capacity of the existing water courses will need to be assessed to ensure that flooding does not take place. These aspects have been ignored in the application.

Groundwater flow through the aquifer system

- 4.4 The applicant has not measured the hydraulic conductivity despite is being a simple measurement to take. It easily fits in with the drilling programme when three piezometers are chosen, one to be the pumping borehole and the other two monitoring boreholes. Groundwater is pumped from the pumping borehole for about a day and the water levels in all three boreholes are carefully monitored, usually with data loggers installed in the boreholes. Monitoring should continue for another day and a half after pumping has ceased and that should provide the recovery data. The data set collected can then be examined using standard methods to calculate the transmissivity and the storativity. Transmissivity is the hydraulic conductivity multiplied by the aquifer thickness and storativity is the volume of water that will drain out under gravity of a unit volume of saturated aquifer expressed as a percentage or a decimal.
- 4.5 Had at least four such measurements been taken across the site representative values for the hydraulic conductivity would have been obtained. Instead values have been 'guesstimated' to lie between 1 m/d and 15 m/d with a 'most likely' value given as 10 m/d. Without any information on the grain size of the material in the aquifer that should have been provided in the details contained in the borehole logs it is not possible to state the value of hydraulic conductivity with any degree of certainty at all. It is noted that smaller values of hydraulic conductivity show a smaller impact on the water environment.
- 4.6 The values for the hydraulic conductivity have been provided in many text books. The United States Department of the Interior has published a Groundwater Manual that includes diagram that has been modified to produce Figure 4.2 shown below. It should be noted that the unit of hydraulic conductivity used in the diagram is m³/day/m² that is simplified to m/day).
- 4.7 The potential values are very variable as can be seen from the scale in Figure 4.2 which extends over ten orders of magnitude, from 0.000005 m/d to 50,000 m/d. It can be seen that the applicant's given values run from the mid-point in fine sand into the low values given for clean sand and sand and gravel on Figure 4.2. The value for sand and gravel is shown on the diagram as extending from about 20 m/d to 200 m/d, values that are greater than shown in Figure 4.2.
- 4.8 The applicant has not calculated the possible groundwater flows through the existing aquifer system. However, this can be done using Darcy's Law that relates the discharge (Q) to the hydraulic conductivity (k), the cross sectional area (A) and the hydraulic gradient (h/l) where h is the reduction in head over the distance (l). Darcy's Law can be written as:
$$Q = k \times A \times \frac{h}{l}$$

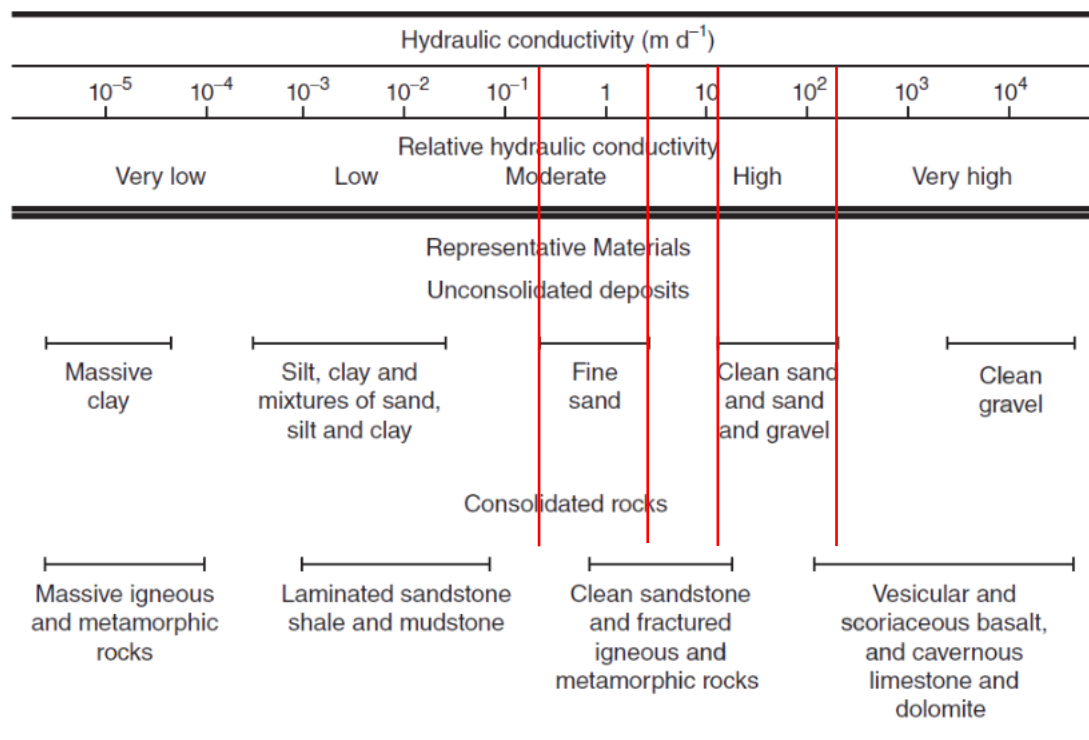


Figure 4.2 – Typical hydraulic conductivity values

4.9 The value for the flow rate is calculated by putting in values for the factors shown above into the equation. It is assumed that the aquifer unit is 1 km wide and is 2 m thick (i.e. high) which gives a cross sectional area of $2,000 \text{ m}^2$. The hydraulic gradient is calculated from the groundwater contours shown in Figure 3.1 and which was used to measure it as 0.0026.

4.10 The values of discharge (Q) calculated using the hydraulic conductivity values is shown in Table 4.1 below that uses the three values chosen by the applicant with an extra value of 20 m/d that marks the low end of the range shown for clean sand and sand and gravel shown in Figure 4.2. The hydraulic conductivity value I have chosen (20 m/d) provides a flow rate of $104 \text{ m}^3/\text{d}$.

$$Q = 20 \times 1000 \times 2 \times 0.0026 = 104 \text{ m/d}$$

Hydraulic conductivity (m/d)	Discharge through aquifer (m^3/d)
1	5.2
10	52
15	78
20	104

Table 4.1 – Discharge values

4.11 It can be seen that the range of discharges though the sand and gravel deposit is very sensitive to the value of hydraulic conductivity. This emphasises the need for the applicant to have carried out field tests to assess the hydraulic conductivity at the site.

4.12 In addition to the flow rate through the sand and gravel it is also possible to estimate the volume of water stored in the aquifer.

4.13 The length of the aquifer is approximately 1 km and so is its width. Its thickness is some 2 m. The specific yield (that is the water that can be released expressed as a percentage of the material and is the same as storativity in a water table aquifer) of the sand and gravel is some 26% estimated from Table 4.2 below. The specific yield is always less than the total porosity as a proportion of the water will always remain because it is attracted to the grains in the aquifer material by adhesion and capillary forces. The specific retention (the proportion of water remaining in the aquifer) is inversely proportional to the grain size meaning that the specific yield reduces as the grain size reduces.

4.14 The volume of water stored beneath the whole aquifer beneath whole the site is:

$$1,000 \times 1,000 \times 2 \times 0.26 = 520,000 \text{ m}^3.$$

4.15 Therefore, the volume of groundwater stored in the total area of the confined aquifer beneath the site has been estimated to be around 520,000 m³ and the flow rate through it under present conditions is up to 260 m³/d, with both estimates calculated in this report. This figure does not include direct rainfall.

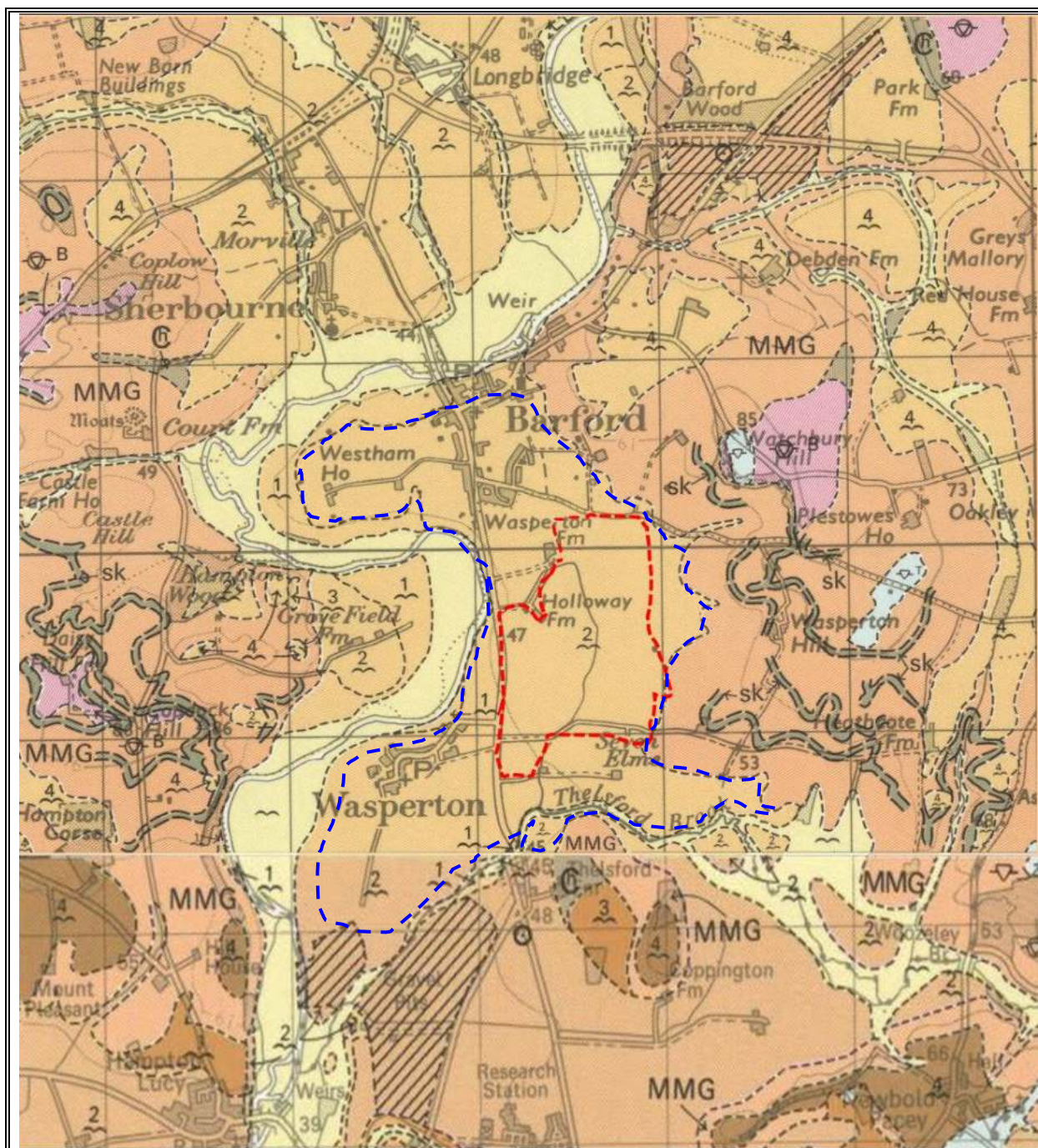
Material	Porosity (%)	Specific yield (%)
Coarse gravel	28	23
Medium gravel	32	24
Fine gravel	34	25
Coarse sand	39	27
Medium sand	39	28
Fine sand	43	23
Silt	46	8
Clay	42	3

Adapted from USGS Water Supply Paper 1839-D (Column 1) & USGS Water Supply Paper 1662-D (Column 2)

Table 4.2 – Porosity & specific yield

4.16 In their report, Hafren Water states that *a groundwater inflow rate of 6.2 l/s (538.5 m³/day) has been calculated, including rainfall incident to these phases gives an annual average inflow rate of 9.9 l/s (855.4 m³/day). It should be noted that the aquifer is of limited extent and the majority of water will be derived from aquifer storage, therefore inflow rates are likely to decrease following commencement of dewatering.*

4.17 Presumably this estimate refers to the abstraction rate necessary for dewatering. The pumping rate is expected to decrease during the period of quarrying although pumping must continue otherwise the particular quarrying phase will flood. In fact, the aquifer extends in all directions outside the site boundary (see Figure 4.3) and once the groundwater piezometric surface has been lowered within the site a potential flow will be developed from these areas to the pumping location thereby starting the influence of the quarry on the surrounding area.




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Figure 4.3 The total river terrace deposit

 Total catchment potentially draining to the
pumping quarry

Scale: 1 km between grid lines

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- 4.18 It is difficult to estimate the distance from the proposed quarry site that the impact will extend because the aquifer is confined before the pumping starts with an increasing part of it becoming unconfined as the effect stretches away from the pumping location.
- 4.19 The area of the second terrace beneath both villages of Barford and Wasperton extends to more than twice the area that lies within the site boundary (see Figure 4.3 above). Lowering the elevation of the piezometric surface/water table to that of the Mercia Mudstone rockhead will cause groundwater to flow towards the pump location and will result in a much larger area of influence caused by the dewatering than that calculated by the applicant. This result demonstrates the inaccuracy caused by using an equation that does not apply in confined aquifers, as exists here. These aspects are discussed further below.
- 4.20 A further aspect of the dewatering that needs to be considered is the replacing the quarried sand and gravel with low permeability inert waste materials (i.e. with both a low hydraulic conductivity and storativity). This will cause the groundwater to flow round each block of the low permeability material and follow convoluted flow paths along the materials left untouched along the boundaries between the individual phases.
- 4.21 The main change however, will occur once the site has been restored and pumping will cease is that the blocking of the natural groundwater flow paths will raise groundwater levels to above the ground surface that will result in much more surface water in the area of the proposed quarry. When the proposed quarry is completed the recharge from direct precipitation and from runoff from the steep land above the proposed quarry area would need a ditch system with an increased capacity than at present to carry the water away to avoid flooding. This is discussed further under the heading of flood risk and is an aspect not considered by the applicant.

Extent of the impact caused by pumping

- 4.22 Hafren Water has attempted to calculate the extent of the drawdown that the dewatering pumping will have on the piezometric levels in the area beyond the proposed quarry and to define the radius of influence. This is a very difficult estimate to make with any accuracy and it also needs to have a hydraulic conductivity value that can be relied on rather than an estimate that is 'plucked out of the air'.
- 4.23 There are a number of different formulas that allow an estimate to be made of the radius of influence for an aquifer. Almost all of these formulas assume that the pumping is from a well rather than a far larger structure such as one of the quarry phases proposed by the applicant. All make assumptions about the hydrogeology with some assuming unconfined conditions and some confined conditions. The groundwater system at the proposed Wasperton Quarry site is an aquifer that overlies the very low permeability Mercia Mudstone and

overlain, by a layer that includes clay and acts as a confining layer in most places.

- 4.24 The data provided in *Table 7.2 - Borehole Details in the Planning Statement* submitted in document *Planning Application Planning Statement* is not sufficiently detailed to allow an understand the groundwater conditions in sufficient detail to calculate the radius of the impact caused by the dewatering. Information from Table 7.2 is included in Appendix 1 of this report. As has been pointed out before in this report, there are no details of the actual materials encountered in the boreholes that are normally given in drilling logs provided by the driller, neither are there details of water levels that were encountered in the boreholes during drilling.
- 4.25 Table 7.2 in the Planning Statement does not record any information on WA19/37, WA20/01W, WA20/02W, WA20/03W, and WA20/04W. It should be noted that the final four boreholes are in the network of monitoring piezometers that constitutes a total of only nine boreholes, a density of one borehole per 9.94 ha.
- 4.26 It appears that the aquifer is confined over most of the area based solely on WA19/05W, WA19/09W and WA19/65W and is not confined at points defined by WA19/27W and WA19/68W. The latter two locations are close to surface watercourses, the Thelsford Brook at WA19/27W and the River Avon discharge to the river along an unnamed watercourse at WA19/68W. No data has been provided by the applicant for WA20/01W, WA20/02W, WA20/03W and WA20/04W. The information from the applicant's Table 7.2 is summarised in Table 4.3 below.
- 4.27 The groundwater contours are based on readings for November 2021. It should be noted that there were significant differences between November 2021 and the earlier record that started in November/December 2020.

Piezometer	WA19/05W	WA19/09W	WA19/27W	WA19/65W	WA19/68W	20/01	20/02	20/03	20/04
GL (mOD)	46.386	45.507	44.783	46.504	45.610	No data provided			
Base overburden	43.59	43.51	44.18	45.30	44.41				
Water level	45.7	44.8	43.9	45.7	42.9				
Amount of confining	2.1 m	1.3 m	-	0.4 m	-	undetermined			
Unconfined/confined	Yes	Yes	No	Yes	No				

Table 4.3 – Details of monitoring piezometers

- 4.28 The piezometric surface lies within the confining layer meaning that the groundwater in the aquifer is under a pressure above atmospheric. The greatest confining pressure is recorded at WA19/05W which lies just within the worked quarry on the eastern side. The next highest confining pressure is at WA19/09W in the central part of the site towards Holloway Farm and the least confined pressure is on the eastern boundary about half way along it (WA19/65W).

- 4.29 The applicant's plan is to have up to three phased pits open at any one time. This is more likely to require pumping all the time (i.e. day and night) as otherwise ground water will flow into the excavation and will have to be pumped out the following day before work can recommence.
- 4.30 To work out the distance of the drawdown in the groundwater levels from the quarry Hafren Water has assumed that the abstraction will be subject to a hands-off-flow (HoF). Inquires made by me to the EA has shown that the EA is unlikely to apply a HoF in this instance. They say that it is their experience that water arising from dewatering operations and abstracted water for mineral washing processes, which is classified as a low-loss use, is returned back to local watercourses following appropriate settlement treatment. This return usually compensates for the impacts of abstraction and so a HoF on the license(s) is usually not required.
- 4.31 It is not known whether or not the EA will continue with this view once they have evaluated the application. However, common sense says that it is inappropriate to limit the abstraction when its main purpose is to dewater the excavation.
- 4.32 At the end of the Hafren Water report is a brief review of the explanation of Dupuit-Forchheimer formula together with an explanation of the Sichardt formula that are both based on a number of assumptions.
- 4.33 The Dupuit-Forchheimer assumptions hold that groundwater flows horizontally in an unconfined aquifer and that the groundwater discharge is proportional to the saturated aquifer thickness. It was formulated by Jules Dupuit and Philipp Forchheimer in the late 1800s to simplify groundwater flow equations for analytical solutions. It is valid for unconfined flow rather than the confined conditions that currently exist in the aquifer contained within the 2nd Avon river terrace.
- 4.34 The difficulty of using the Dupuit-Forchheimer formula is that the aquifer is confined and will remain so until the pumping has lowered the groundwater levels below the top of the aquifer. Even then much of the aquifer beyond the site boundary will still be confined.
- 4.35 The Sichardt formula (also known as the Turner Formula although it was created by Weber) describes the radius of influence in terms of drawdown, hydraulic conductivity and a constant 'C' that is equal to 3,000 when the radius of influence is given in metres. This formula also applies to unconfined conditions and assumes that the abstraction is from a single abstraction point.
- 4.36 The aquifer is overlain by the overburden and the piezometric surface that represents the groundwater level in a borehole, making it a confined aquifer. As pumping continues the groundwater will be derived from further afield and the aquifer will become unconfined close to the area of pumping. It is expected that the unconfined sand and gravel will extend further and further from the quarry face although the water pumped from the quarry will eventually all have been derived from the confined part of the aquifer.

- 4.37 The diagram shown in Figure 4.4 below is to illustrate the development of the cone of depression as the pumping continues. Initially, there will be a drawdown and the groundwater piezometric surface will remain within the overburden confining layer. In 'A' after pumping for a short time the cone will be moved away from the quarry and an unconfined part of the aquifer will start to be formed. In 'B' the pumping has been for a much longer period and the piezometric surface is lower in the confining layer as well as the unconfined part of the aquifer being much larger.

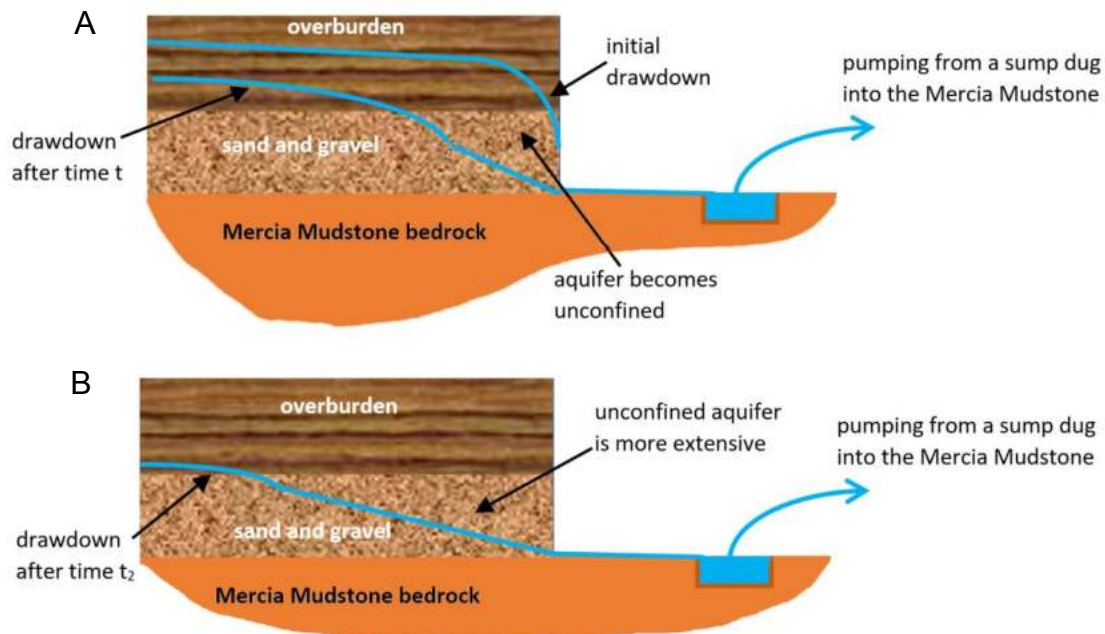


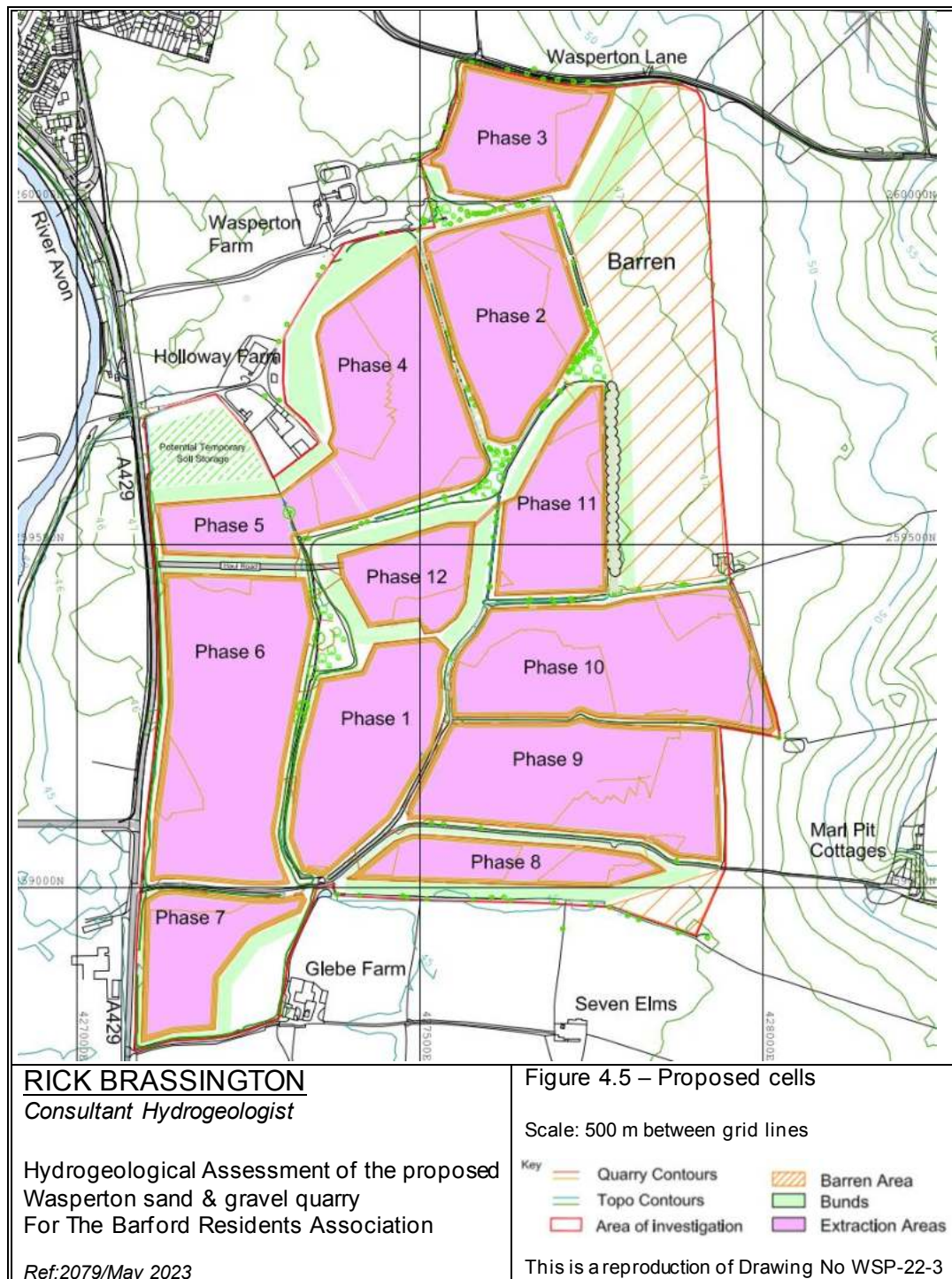
Figure 4.4 – The development of the cone of depression

- 4.38 The sand and gravel aquifer will go from confined to unconfined conditions as the piezometric level is lowered and at locations some distance from the quarry boundary the aquifer will remain confined making it very difficult to estimate the extent of the impact of causing a flow from the aquifer beneath the adjacent land.
- 4.39 A proportion of the abstracted water is to be used for washing the mineral and in the application it states that the need for a discharge from the site will be limited to the initial setup period. The only losses from the settlement lagoons is through evaporation and some water will be carried in the mineral products as they are taken from the site. It is considered that the site operator will need to discharge water from the site at least several times a week and possibly more frequently. The applicant did not present any calculations that support his contention of there being only one initial discharge.
- 4.40 The water management on the site is to circulate it round a number of clean water lagoons. The discharges to the River Avon will be undertaken by pumping the water initially into a central system of settling lagoons and from there into the local minor watercourses and ditches as required. The proposal is to leave

the current surface water drainage system in place and so the abstracted water that is pumped into these ditches will ultimately discharge into the River Avon.

- 4.41 The application makes it clear that the abstraction will be the subject of an abstraction licence that are granted by the Environment Agency. Although the Environment Agency is referred to on a number of occasions there is no mention of either a formal approach or an informal approach being made at this stage to assess the prospect of this licence being granted. This is surprising as continuous pumping is a vital part of this application to ensure that the quarry is worked 'in the dry' as the applicant states the workings will be.
- 4.42 The most significant aspect is that the river terrace will require water being pumped from each cell from almost the whole time when the sand and gravel are being extracted at that location. Although the application sets out how each cell will be managed there are no details provided showing how it is proposed to manage the water onsite. In my view this is a very serious deficiency in the application.
- 4.43 The cells are large with the sides usually being a few hundred metres long. The water table is less than a metre below ground level and so almost from the beginning of the operation in each cell it will be necessary to pump the water out in order that the sand and gravel can be dug in dry conditions. The applicant's proposed phases are shown in Figure 4.5 below.
- 4.44 The only mention of a water management scheme simply says that a pumping sump will be constructed in each cell and that the water will be treated followed by settlement and then will be discharged.
- 4.45 The first thing to consider is the volume of water already beneath the site and for simplicity we assume that a typical cell is 100 m by 100 m. The sand and gravel is overlain by the overburden which is typically 1.4 m thick based on an average of the data given in the table of borehole results in Appendix 1. If the thickness of the sand and gravel is assumed to be 2 m and the specific yield (volume of water that is contained in a unit volume of aquifer see Table 4.2) is, say, 26%, the volume of water to be removed is 5,200 m³.
- $$100 \times 100 \times 2 \times 0.26 = 5,200 \text{ m}^3$$
- 4.46 At a pumping rate of some 500 m³/day it will take 18 days to remove this volume of water. However, the quarrying operation will take the base of the quarry down in stages so the lowering of the groundwater elevation will be managed in steps removing the need for the water table to be lowered to the bedrock in one operation. This pumping will also cope with the water that flows into the cell both from outside it and also beyond the borders of the site.
- 4.47 When excavation commences the soil and much of the overburden (sandy, silty clay) above the water table may be removed without any dewatering. In order to dig below the groundwater level a temporary pumping sump will need to be dug at different elevations as work continues to enable the groundwater level to be lowered. The overburden that was below the groundwater level can then be

extracted once the water level is at a controlled level. The sand and gravel can then be removed in a similar way with the water table being lowered by a number of temporary sumps as the excavation continues to the bedrock. No such detail is given in the application.



4.48 Once the bedrock is reached there will be water ingress along the contact between the sand and gravel and the mudstone beneath with a seepage face above the bedrock. This water may be collected by temporary ditches dug into the bedrock around the cell boundary to carry the groundwater to a pumping sump. This action will prevent water from flowing in an uncontrolled way over

the surface of the mudstone resulting in the base being reduced to mud as vehicles track across it. This is not mentioned at all in the application for permission to work this extensive site that is all below the local groundwater level. It is clear that the proposal would involve a high rate of pumping water from the site and the permeable nature of the aquifer would cause the drawdown to extend a great distance away from the site.

- 4.49 In addition, the application only provides site information of the type that a quarry operator would require to work the site and none for a technical appraisal of the proposed scheme. The information provided consists of borehole logs for 67 of the 68 boreholes drilled in 2019 (details for WA19/37 are missing) and in addition no information is provided from the four boreholes drilled in 2020 which is a significant weakness.
- 4.50 The first 67 boreholes drilled in 2019 across the site are listed in Appendix 1 with the information given being limited to the borehole reference number, grid reference, elevations of the ground level at the borehole location, elevation of the base of the unusable overburden, elevation at the base of the borehole, and thicknesses of the overburden and the quarryable minerals. The four boreholes drilled in 2020 to provide additional piezometers have not been included in the table although these boreholes are shown on maps that depict borehole locations.
- 4.51 The information provided on the boreholes does not constitute the borehole logs which are the typed up version of information gathered in the field. If this information is looked at in more detail than the applicant has undertaken it may be plotted across the site to show the rockhead, the thickness of the sand and gravel, and the thickness of the total materials that make up the river terrace. This information along with the water table can be used to visualise the geological material that it is proposed to remove by quarrying and how it relates around the edges of the site to the groundwater on the outside of this boundary.
- 4.52 The data from the boreholes has been used to construct a rockhead map in this evaluation of the application. This is shown on a map in Figure 4.6 with elevations shown in metres above Ordnance Datum. This information shows that the elevation of the rockhead falls in a southwestwardly direction although it is a slightly more complex with small upstanding areas across the site.
- 4.53 The rockhead elevations shown in Figure 4.6 indicate that the lowest values are at 40.21 mOD. The River Avon is at elevations along its length from a point opposite the entrance to Wasperton Farm to near Wasperton village lies at values just below 40 mOD which indicates that flow from the River Avon through the sand and gravel deposits into open quarried cells may not be possible except during a time of flood. Again the applicant does not provide any information on this aspect.
- 4.54 Other data from the table has been used to plot the variations in mineral thickness, i.e. the sand and gravel that lies on the rockhead with the data shown on a map in Figure 4.7. The average thickness has been calculated by the applicant from the whole data set as 2.25 m and this value has been used to

calculate the volume of minerals removed from the site as 1,203,750 m³. This is clearly a 'guesstimate' as there are variations from 1.0 m to 3.4 m across the site. If the silt sized particles are taken into account the volume of minerals to be removed from the site after processing is about 1,000,000 m³. The applicant's plan is for this volume to be replaced by inert waste brought on to the site.

- 4.55 The thicknesses of the sand and gravel has a general trend of thickening towards the west. However, there are many locations where this trend is reversed and it is concluded that the terrace deposits were land down by the proto-Avon in its meanders across the site which accounts for the random nature of the deposits thickness together with the variations in the rockhead. The sand and gravel lies directly on the rockhead and so there will be a direct connection between the most permeable part of the river terrace and that in the river terrace outside the area available to the applicant.
- 4.56 The thickness of the total river terrace deposits is shown in Figure 4.8. This value includes the thickness of the over burden which being a finer-grade material than the sand and gravel will have a lower hydraulic conductivity and also the storativity. Such lower values will influence the rate of flow through the overburden compared with the higher hydraulic conductivity of the sand and gravel. Pumping tests may be designed to determine these differences in hydraulic conductivity.
- 4.57 The implications of the variations in rockhead and the thickness of the deposits are that it will better enable the impact of the proposed dewatering to be calculated.
- 4.58 The whole site extending to 89.5 ha must be considered in the assessment of the impact on the local environment and this area must be extended to include the surrounding area that will inevitably be impacted. The main information required to calculate the possible impact are all site specific yet only general. In the application documents it is stated that the saturated thickness of the sand and gravel has been determined from the borehole logs and monitoring data for the site and is assumed to be 2 m in all phases. The calculation assumes that all phases will be dewatered at once, therefore giving a worst-case estimate the extent of drawdown. Due to the lack of site-specific data generic hydraulic conductivity values have been used, based on the presence of clay bands and the clay content of the sand and gravel. These generic values are likely to differ significantly from what is actually there.
- 4.59 The information required for meaningful calculations to be made about the extent of the impact on the local water table in the river terrace from Barford to the Thelsford Brook are the hydraulic conductivity (k) (a term that means the permeability of the formation materials with respect to water), and the storativity (S) (a term that refers to the volume of water that can drain under gravity from a unit volume of aquifer). Knowledge of the hydraulic conductivity at the site would allow calculations of the extent of the drawdown and the cone of depression developed when the groundwater level has been drawn down to the rockhead. Knowledge of the storativity would allow the volume of water in the aquifer to be calculated.

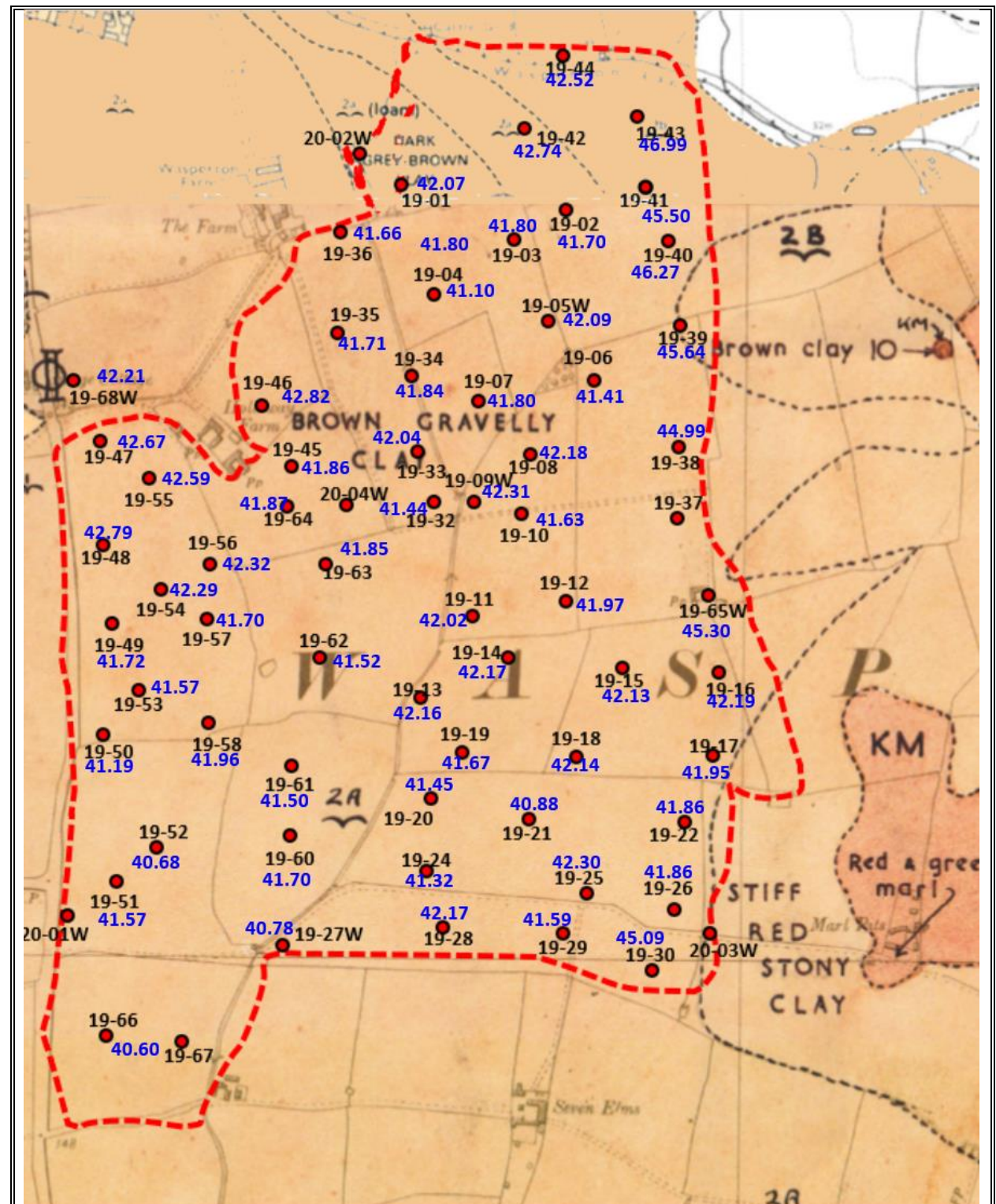
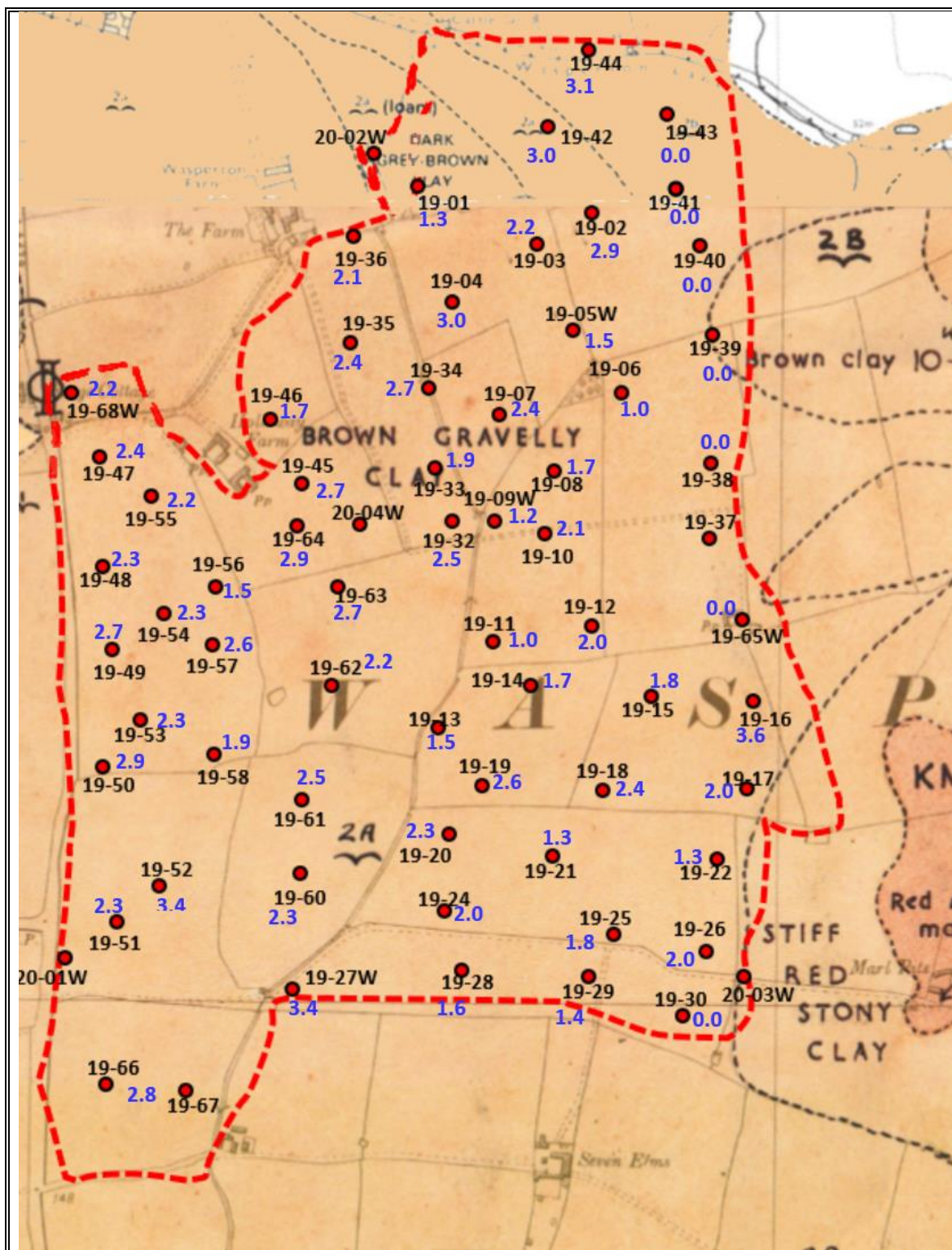


Figure 4.6 Rockhead elevations

Scale: 1 km between grid lines

The elevations in mOD have been taken from the data supplied in the application documents



RICK BRASSINGTON

Consultant Hydrogeologist

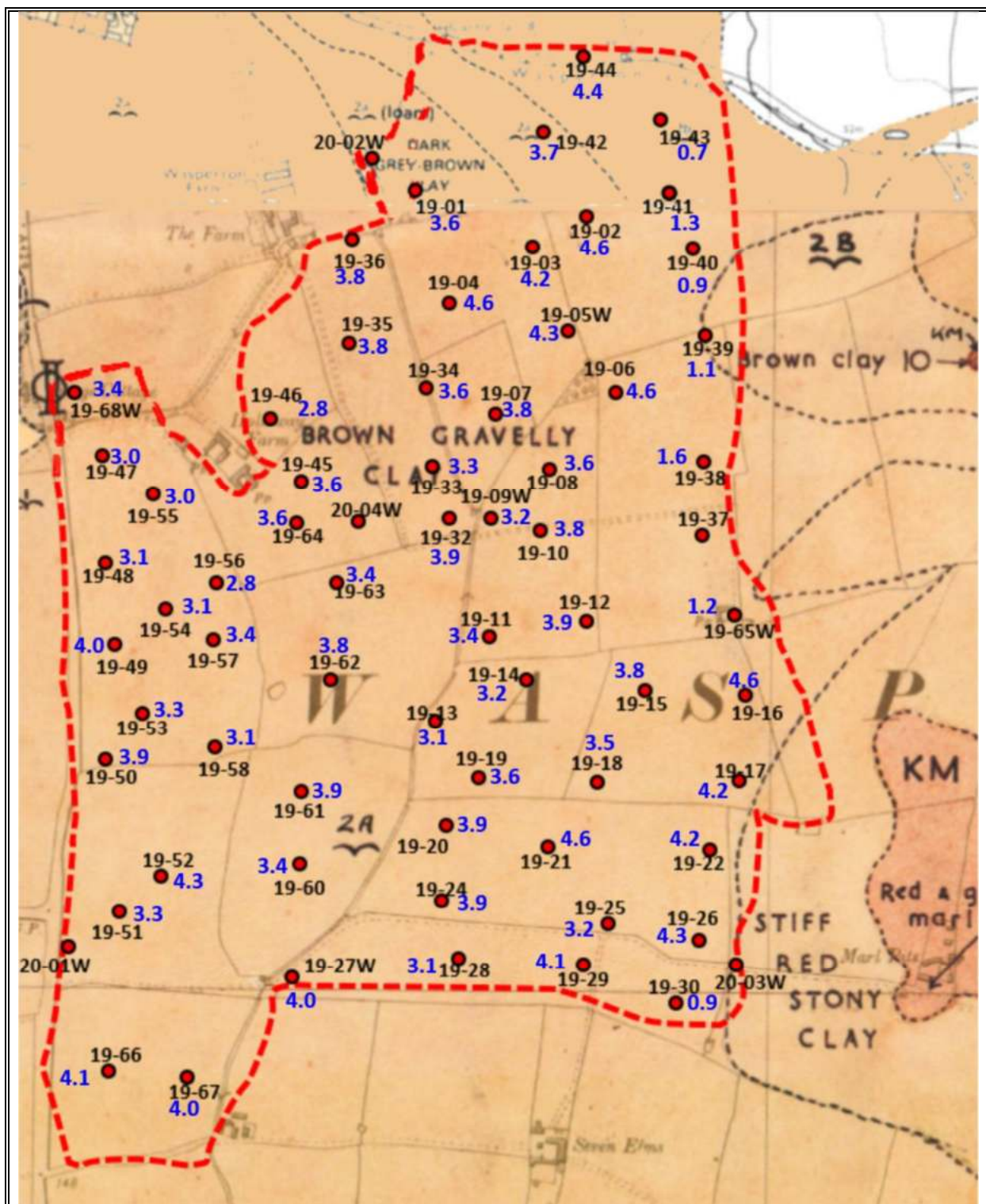
Hydrogeological Assessment of the proposed
Wasperton sand & gravel quarry
For The Barford Residents Association

Ref:2079/May 2023

Figure 4.7 Thicknesses of sand & gravel

Scale: 1 km between grid lines

The thicknesses in metres were taken from the data
supplied in the application documents.
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Figure 4.8 Thicknesses of total river terrace deposit

River terrace includes overburden and minerals

Scale: 1 km between grid lines

The thicknesses in metres were taken from the data supplied in the application documents.
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- 4.60 Neither of these values has been provided yet they are easily available from simple pumping tests. Each test would involve pumping from a borehole over a period of at least 8 hours for up to 24 hours, and to monitor the fall in water levels in the pumped borehole and at least two others acting as monitoring boreholes. It would also be necessary to monitor the recovery in all three boreholes to provide more data to calculate these hydraulic properties. Once the data from these tests has been obtained it may then be analysed using well established methods to provide local values for k and S . It should be borne in mind that the values calculated will vary by some degree. This is caused by variations in geological factors that influence the hydraulic properties and is why as many values as possible must be obtained in order to add credence to the values calculated from the test data.
- 4.61 Bearing in mind that the total site is 89.5 ha (221 acres), these tests should be carried out at a minimum of four locations across the site and the data obtained then used to evaluate the k and S values. This data collection should be extended to areas outside the site bearing in mind the land ownership. The values obtained could then be used to calculate the likely extent of the impact of pumping in the river terrace outside the limits of the site. It is firmly believed that an application that is not backed by site specific scientific data should be refused a planning application.
- 4.62 The point was made in the previous section of this report that the same landowner has land outside the area made available to the applicant so it would have been possible for the pumping tests to extend to beyond the site itself.
- 4.63 The applicant proposes to commence the restoration of each cell during the process of digging the sand and gravel. The material to be used will be the overburden that will have been stripped and stored at the start of quarrying in each cell together with the fine-grained material that has been washed from the mineral deposit as it is processed. The missing volume has been calculated as totalling some 1 million cubic metres.
- 4.64 The applicant plans to make up the difference between the available low hydraulic conductivity materials and the sand and gravel that has been removed but he has not provided any information on the availability of such materials.
- 4.65 The previous practice of restoring a quarry by filling it with waste materials has long since been abolished making excavated materials such as clay and silt that are proven to be uncontaminated are extremely valuable as fill.
- 4.66 The relevant government web site defines inert waste as waste that does not undergo any significant physical, chemical or biological transformations. It will not dissolve, burn or otherwise physically or chemically react, must not biodegrade or adversely affect other matter that it comes into contact with in a way likely to cause environmental pollution or harm to human health. The total leachability and pollutant content of the waste and the ecotoxicity of the leachate must be insignificant and not endanger the quality of surface water or groundwater. Examples of these wastes include metal, wood, bricks, asphalt or concrete, and other building construction materials such as shingles, insulation,

tiles and glass. Many of these materials are recyclable which is a better use than being used as common fill.

- 4.67 As a result, it is expected that inert materials are relatively rare and therefore the applicant may not be able to procure sufficient inert wastes to enable the cells to be restored in the way that he plans. He should produce evidence for the planning authority to evaluate on the volume and nature of these inert materials. If it arises after the quarrying commences the planning authority and the EA will have to accept that other wastes may be used to restore the site or the proposed land form after restoration will be changed to include larger areas of water.
- 4.68 Nothing in the planning application refers to the proposal of leaving the settlement ponds in place and its significance on the landscape. A number of aspects are relevant here including the loss of agricultural land, the attraction of water birds and the relevance of large birds to the flight path to Birmingham International Airport.

The need for field testing in determining the radius of influence

- 4.69 Druid (2020) published a paper based on the work he had carried out at Uppsala University. He recognises the number of formulas that are available to calculate the radius of influence for an excavation that goes below the water table or piezometric surface. Part of the study was to calculate the radius of influence using several formulas for two specific sites where a number of observation boreholes had been constructed and to compare the theoretical results with the actual readings. He then followed these calculations by a sensitivity analysis.
- 4.70 The formulas identified by Druid (2022) are listed in Table 4.4 below. The formulas used in the two site studies are Thiem-Confined and Sichardt in case study 1 and in the second case study was Thiem-Marinalli. A condition of being able to apply these formulas is to have obtained a hydraulic conductivity value and a storativity value from field tests.
- 4.71 Druid (2020) then carried out a sensitivity analysis using all the formulas shown in the Table 4.4. The results of these sensitivity analyses is shown in Figure 4.9.
- 4.72 The sites chosen for the study were two specific construction projects in Sweden. The first at Lomma, a small town that lies on the west coast just to the north of Malmö in the southern county of Skåne. The project was to construct two tunnels beneath an important rail route carrying goods to the town of Malmö, one for vehicles and people and the second only for people.
- 4.73 The ground at Lomma consists of a thick layer of clayey till, overlain by about 6 m of sandy clayey silt. This layer consists of interbedded sand and clay lenses of varying thickness. The water-bearing layer at this location was interpreted within the sand, effectively forming an unconfined aquifer of some 1 m thickness presumably because the clay being in lenses and would not continue laterally.

Formula	R Lomma (m)	R Hova (m)
■ Theis	8	59
■ Jacob 0	11	88
■ Jacob 0.3	11	80
■ Thiem Confined	34	74
■ Thiem Unconfined	91	80
■ Todd	151	73
■ Marinelli & Nicolli (M & N)	153	82
■ Thiem-Marinelli Thiem-M&N)	88	82
■ Sichardt	31	7
■ Elongated	55	44
■ Cashman & Preene (C & P)	18	4
■ Kusakin	6	2
■ Aravin & Numerov (A & N)	15	6
■ Weber	32	12
■ Lembke	27	35
■ Liedholm	81	27
■ S-Q	67	19

Table 4.4 – Formulas used to calculate area of influence after Druid (2022)

- 4.74 The second site is at the village of Hova in the county of Västergötland in central southern Sweden. The project was to construct a bridge for a main highway over a rural road. The geology is sandy silty clay overlying a silty sand that forms a confined aquifer some 2 m in thickness.
- 4.75 The radius of influence was calculated using all 17 formulas and the results were summarised on the diagrams in Figure 4.9 below with the radius of influence calculated in the formula(s) used shown on each diagram for unconfined and confined conditions.
- 4.76 The most accurate formula used in the unconfined conditions is the Sichardt with the formulas calculated by Weber being close calculation.
- 4.77 In the confined conditions most of the theoretical formulas were fine and the empirical ones were all a long way off.
- 4.78 Part of the reasons for accuracy and inaccuracy is that with real life examples they do not completely meet the conditions about for example, being fully confined or unconfined.
- 4.79 The Druid (2022) conclusions are the initial estimations made for the two sites matched the measured groundwater levels and can be considered successful. Based on the two projects, no clear trend as to which type of formula that yields the most accurate results could be found, but differed greatly between the cases. Although the Thiem-Confined method was the single formula that presented the most accurate results for radius of influence, a larger study of more projects and cases with documented groundwater levels would be required in order to

hopefully evaluate each formula's overall accuracy. It does seem as though the accuracy of the formula increases with the number of parameters, as the theoretical formulas performed slightly better in this study.

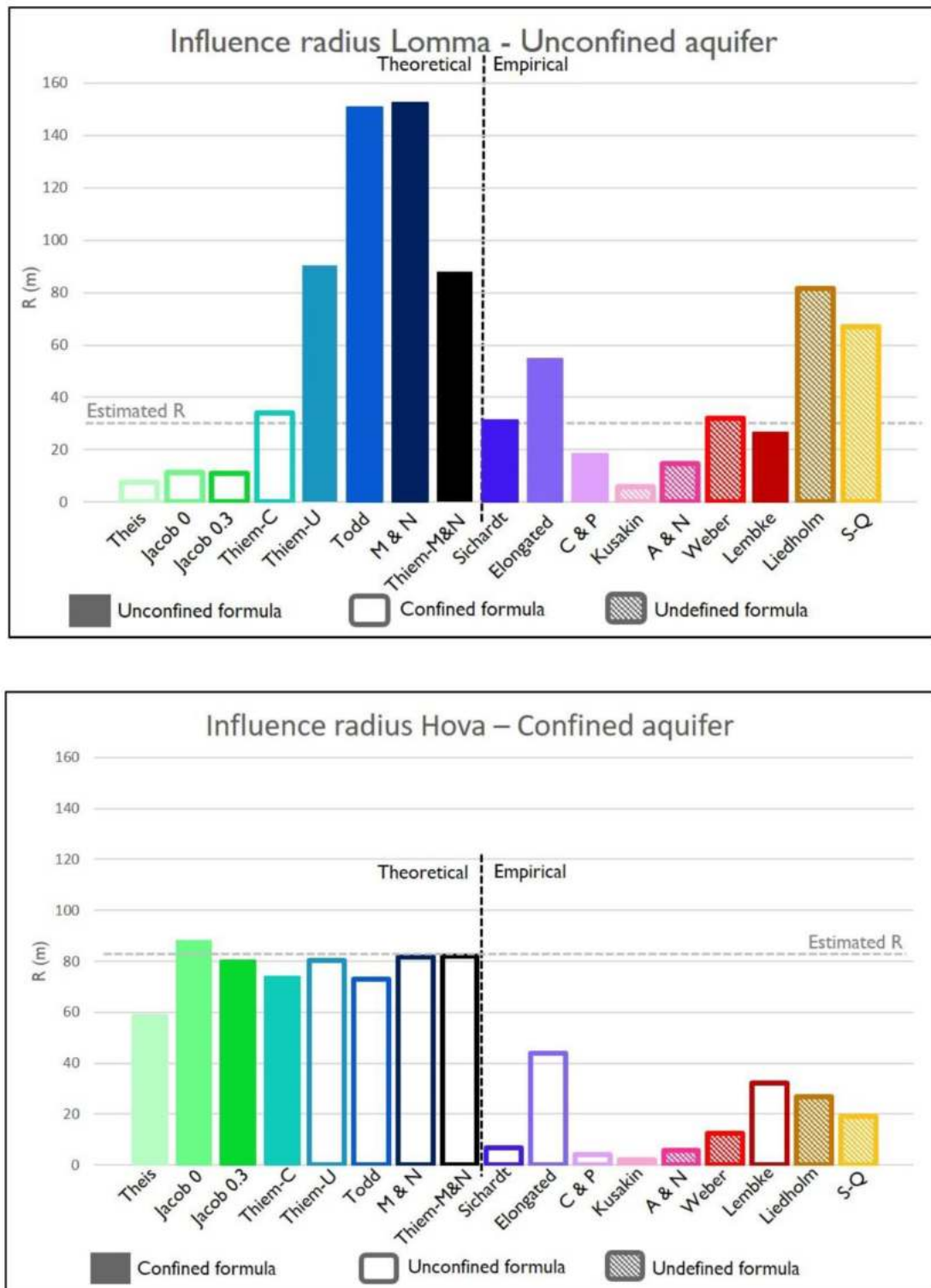
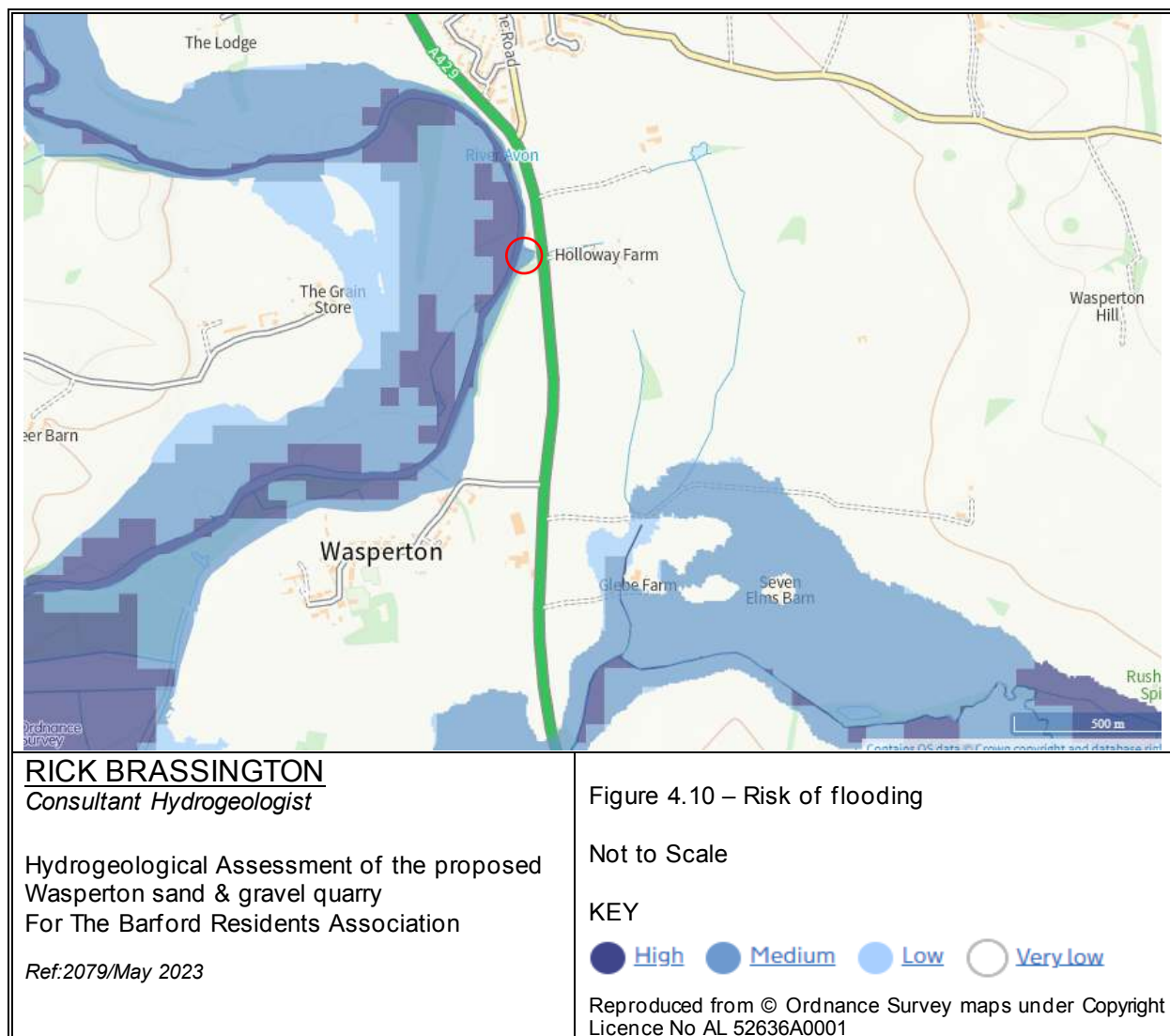


Figure 4.9 – Accuracy of the formulas in calculating the radius of influence

- 4.80 The formulas using the same input parameters gave large ranges in output, and the choice of formula for estimation of the influence radius is crucial. The possibility of different formulas resulting in wildly different values for influence radius needs to be taken into consideration when performing estimations.
- 4.81 The sensitivity was found to be very different not only for different formulas and input parameters, but also for different ranges of input parameters. As possible input ranges is related to aquifer properties, the type of aquifer in each specific case is important when dealing with uncertain input parameters. Hydraulic conductivity, due to its prevalence and relatively high range of possible values, is one of the more uncertain parameters. This emphasises the need for several field measurements of the hydraulic properties to be made in order to have a satisfactory range of values for the formula to calculate a satisfactory radius of influence.

Potential increase in flooding

- 4.82 Examination of the rockhead topography using the rockhead information shown in Figure 4.6 indicates that when the river is in flood it will be able to reach Phases 5 and 6 and possibly further when they are open excavations.
- 4.83 Figure 4.8 shows flood areas adjacent to the site with the are close to the Holloway Farm entrance showing flood water elevations are over 40 mOD when compared to the elevations on an OS map (e.g. Figure 2.2). This indicates that flooding could take place if the quarry was in operation at the time. It should be borne in mind that the map in Figure 4.10 is based on previous flooding events and that it does not necessarily include changes in rainfall intensity that result from climate change.
- 4.84 If planning permission were to be granted and Smiths was able to start quarrying they would commence in early 2024. Assuming that the quarry would take some 15 years to complete it would be 2039 before it was finished. This periods is long enough for changes in rainfall intensity to have increased and cause flooding problems in the quarry.
- 4.85 The Meteorological Office records rainfall and is the main source of information on future trends to changes in rainfall patterns. In a paper by Kendon *et al* (2023) the changes in rainfall events with an intensity of 20 mm/hour or more are examined. Intensities of 20 mm/hour or more have been chosen because they are likely to result in local flooding.
- 4.86 The authors used records with 100-years return period for the computer model from 1981 to 2080. This enabled the model to predict that changes in rainfall intensity exceeding 20 mm/hour causing flash floods are four times as frequent by the 2070s as in the period 1981 to 2014. With every degree of regional warming, the intensity of extreme downpours increases by 5-15%. However, these changes are not realised as a smooth trend. Instead, as a result of internal variability, extreme years with record-breaking events may be followed by decades with no new local rainfall records. A period of 15 years for working this quarry is sufficient for more intense flooding events to occur.



- 4.87 The results of this study show that rainfall intensity is increasing which will mean that the risks of flooding from the creation of the proposed infilled quarry extending over most of an area of 89.5 ha will be significantly increased by the effects of climate change resulting in flooding from direct rainfall and the River Avon of the open workings during the active quarrying phase. During the period after quarrying has finished when the groundwater within the former workings will no longer exist, flooding will impact more frequently on the infilled quarry and surrounding area.
- 4.88 The applicant in the Planning Statement submitted as part of its application for planning consent states that the lagoons that will be used for the settlement of the water used for processing the mineral product during the life of the proposed quarry will be retained post-restoration and the storage capacity within these will be sufficient to offset the increase in run-off due to the placement of inert fill. It is unlikely that the retaining of these water bodies will fully mitigate the flooding particularly over the areas outside the proposed quarry site.

Potential impact on local trees

- 4.89 A paper by Skiadaresis *et al* (2021) describes a study carried out by the authors to examine the impact of changing groundwater levels on the growth of trees, particularly the English oak, *Quercus robur*. The study examined differences in stem growth and xylem hydraulic architecture of 216 oak trees from sites with contrasting groundwater availability, including sites where groundwater abstraction has led to reduced water availability for trees over several decades. Compared to sites with no groundwater abstraction, trees at sites with groundwater abstraction and therefore a lowered water table, showed both reduced growth and hydraulic capacity during periods of moderate and extremely low soil water availability. Trees of low vigour, which were more frequent at sites with groundwater abstraction, were not able to recover growth and hydraulic capacity following drought periods that points towards prolonged drought effects.
- 4.90 In another publication Crow (2005) relates the root depth and spread to the soil types in which trees grow. It is well known that different soil types and their properties are an important factor in determining the rooting habit of a tree. Crow (2005) reviews the available published information to produce a guide of plausible rooting depth ranges for a selection of species on soils with different characteristics. Table 4.5 shows the likely rooting depths for mature trees in different soil types.
- 4.91 The soil types are described by Crow (2005) and are adapted from Mitchell and Jobling (1984) and Pyatt *et al* (2001) and comprise:
- (1) Loose, deep well-drained soils. Some sands with large pore spaces are most likely to promote greater root depths as they are well aerated and may provide less resistance to root penetration. Examples include Littoral soils.
 - (2) Shallow soils over rock. These are also well drained, but bedrock occurs at less than 1 m. If the rock is chalk or a similar soft rock, some local root penetration may occur. Rendzinas and Rankers are common examples of this class.
 - (3) Intermediate loamy soils. These retain more moisture than groups 1 and 2, but still allow considerable root development. Examples include Brown Earths that can vary greatly in their constituents and water content.
 - (4) Impervious subsoils. Soils with a large particle size that are restricted by an impervious layer. These soils may be seasonally waterlogged. Podzols, with a cemented iron pan formed within 1 m of the soil surface, are the main soil type in this class.
 - (5) Soils with moisture retaining upper horizons. These soils are seasonally waterlogged in the top 40 cm due to poor slowly permeable surface horizons. In such soils, there may be little need for deep root development. Surface water gleys are the most important type of soil in this class.

Species		Soil groups							
Scientific name	Common name	1	2	3	4	5	6	7a	7b
<i>Abies grandis</i>	Grand fir ^a	**	!		!				*
<i>Abies procera</i>	Noble fir ^a	**	!	!	!	!	!	*	*
<i>Acer campestre</i>	Field maple	**	**		**	!	!	**	***
<i>Acer pseudoplatanus</i>	Sycamore	*	**		!	!	!	!	**
<i>Alnus glutinosa</i>	Alder ^a	**	!		!		!	!	!
<i>Betula pubescens</i>	Downy birch ^a	*	!		!	!	!	!	!
<i>Carpinus betulus</i>	Hornbeam ^a	*	!		!			!	***
<i>Castanea sativa</i>	Sweet chestnut ^a	*	!		**	**	**	!	***
<i>Fagus sylvatica</i>	Beech	**	!		!	!	!	**	***
<i>Fraxinus excelsior</i>	Ash	*	**		**	*	*	!	***
<i>Juglans regia</i>	Walnut ^a	*	!		**		!	**	***
<i>Larix decidua</i>	European larch		!		!	**	**	!	**
<i>Larix kaempferi</i>	Japanese larch ^a	**	!	!		!	!	!	*
<i>Malus sylvestris</i>	Apple ^a		!		!		!	!	*
<i>Picea abies</i>	Norway spruce	*	!		!		!	!	*
<i>Picea sitchensis</i>	Sitka spruce ^a	*							
<i>Pinus contorta</i>	Lodgepole pine ^a		!				!		
<i>Pinus nigra</i> var. <i>maritima</i>	Corsican pine		!				!	!	***
<i>Pinus sylvestris</i>	Scots pine ^a				*	***	***	!	***
<i>Populus alba</i>	White poplar ^a	**	**		!		!	**	**
<i>Populus tremula</i>	Aspen ^a	*	!					!	*
<i>Prunus avium</i>	Wild cherry	**	**		!	!	!	!	*
<i>Pseudotsuga menziesii</i>	Douglas fir ^a	*	**		*	*	*	!	***
<i>Quercus robur</i>	Pedunculate oak ^a	*			!			!	***
<i>Salix alba</i>	White willow ^a	**	!	!	!	!		!	!
<i>Thuja plicata</i>	Western red cedar	*	**	!	!			!	*
<i>Tilia cordata</i>	Small leaved lime	!	!		!	!	!	!	***
<i>Tsuga heterophylla</i>	Western hemlock ^a	*	**		!		!	!	***

Reproduced from Crow (2005)

^a Unlikely if soils are calcareous.

*** Conditions not recommended for growth.

** Not ideal and growth may be impeded (will vary from site to site).

* Not ideal for growth but some values published.

! Values are conjectural (all others values are from database).

Probable rooting depth range for mature trees

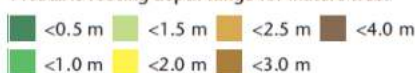


Table 4.5 - Probable rooting depth ranges for selected tree species.

(6) Soils with wet lower horizons. Examples such as Groundwater gleys occur within or over permeable materials that allow periodic waterlogging by a fluctuating water table. These waterlogged horizons may determine the root depth.

(7) Organic rich soils. These include peat soils of varying type and origin. A distinction has been made between those that are drained (7a), and those that are predominantly waterlogged (7b).

- 4.92 The soil types at the proposed quarry site are shown below in Figure 4.11 are taken from the Cranfield Soil and Agrifood Institute website.

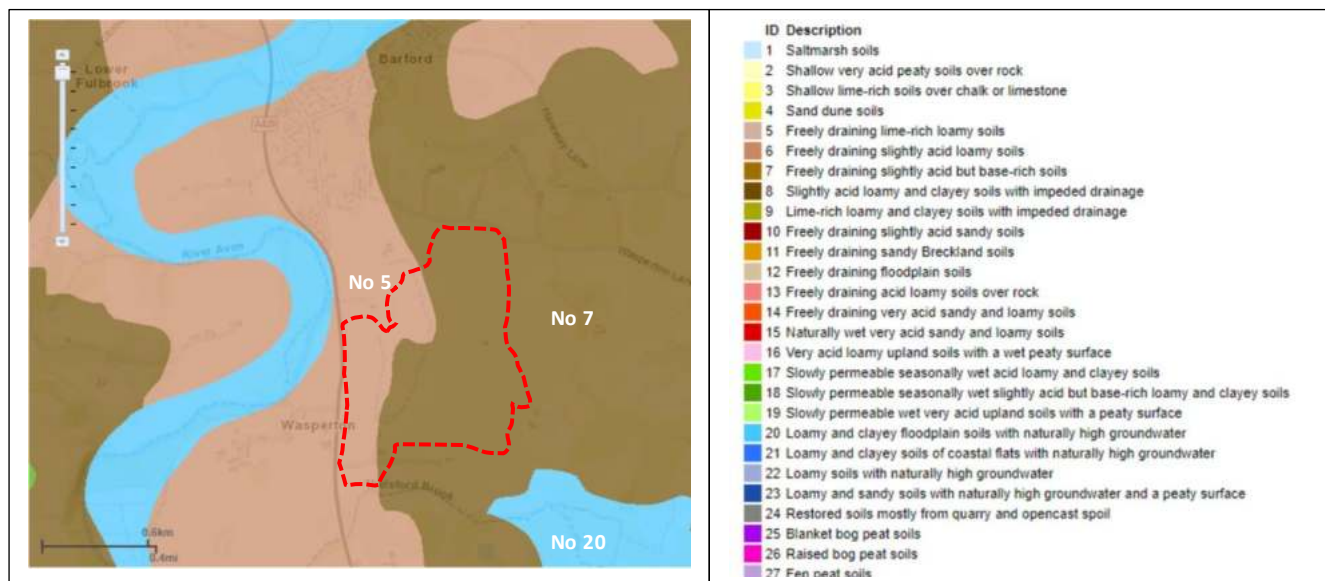


Figure 4.11 – Soil types at proposed Wasperton Quarry site

- 4.93 The soil types on the map in Figure 4.11 from the east are No 7 - freely draining slightly acid but base-rich soils and No 5 - freely draining lime-rich loamy soils. These are equivalent to Category 1 - Loose, deep well-drained soils, and Category 3 - Intermediate loamy soils shown in paragraph 4.76 above.
- 4.94 There are a number of mature trees across the proposed quarry site, particularly common oaks that will be subject to a reduction in the water supply resulting from the dewatering activities. This impact is expected to cause damage to the trees and where they are located in areas that are adjacent to the proposed backfilling with low permeability wastes can be expected to suffer in the long term with some slowly being killed. Trees take a time to die through being faced with a reduced water supply as natural mechanisms will kill it from the leaf tips and is likely to take more than a decade or two to die completely.
- 4.95 Where a tree is in an area that is subject to flooding where there is currently none there is a danger that it will die from drowning.
- 4.96 The lane that runs through the small village of Wasperton is lined by trees on both sides as it leaves the A429 main road. The western part of this group of trees fall in the Wasperton Conservation Area which gives them protection against any damage. To carryout any work on the trees a consent is required from Warwick District Council. The conservation document states that *it is an offence to cut down, uproot, lop, top or wilfully damage or destroy any tree in a Conservation Area, except with the consent of the District Council*. These features are shown in Figure 4.12 with the location of the trees and their species.

- 4.97 Clearly these trees are potentially threatened and the District Council needs to consider the potential damage to them from the proposed quarrying and associated changes to the local drainage system.

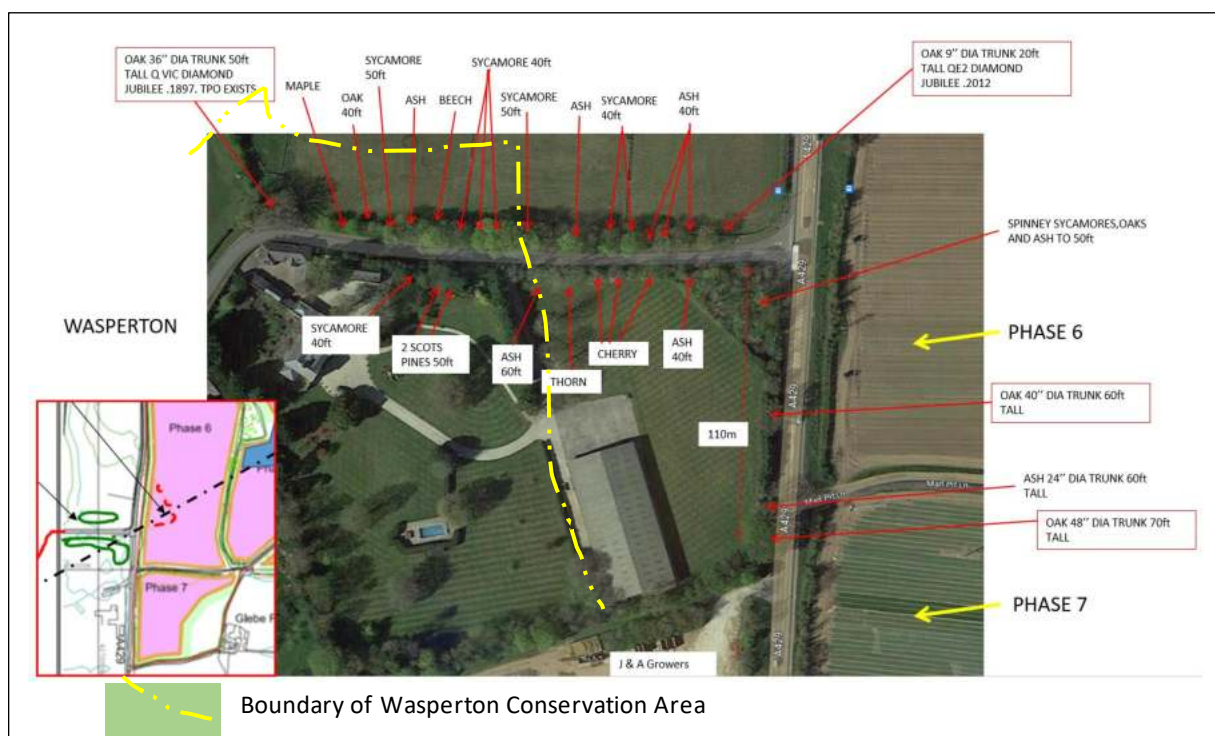


Figure 4.12 – Details of trees in Wasperton Lane

Changes to the local landscape

- 4.98 The proposal by the applicant to leave the existing surface water drainage system in place makes it appear that there will be no change to the landscape caused by the quarrying. However, the plan includes leaving the settlement lagoons that are in Phase 12 of the proposal in place to act as a receptor for flood water. It is left unstated that in the event of the site operator not being able to acquire sufficient inert waste to restore the remainder of the site it is just a matter of leaving other open quarry phases open to increase the area of open surface water across the site.
- 4.99 The landscape will be already changed by the settlement lagoons being left and the only albeit unstated mitigation for the lack of availability of inert wastes will be to create more surface water that will be at the expense of a reduction in the area of good quality farm land.

Potential impact on the University of Warwick Wellesbourne Campus

- 4.100 The University of Warwick took over the former National Vegetable Research Station in 2004 and since that time has run a number of experiments including different crop types as well as into insects such as bees.

- 4.101 The University confirmed that there is only one borehole on the campus site that taps into the deep Sherwood Sandstone aquifer that lies beneath the Mercia Mudstone. It is located in the southern part of the site at SP 2678 5644 and shown on Figure 4.13.
- 4.102 The deep borehole into the Sherwood Sandstone will not be affected by the proposed quarrying as it is protected by the Mercia Mudstone that is recorded as being some 143 m thick in this location.
- 4.103 It is understood that the University has employed consulting engineers to assess the potential impact on its assets and research work although I have not seen this report. It is not known if the University will make any representations regarding this planning application.

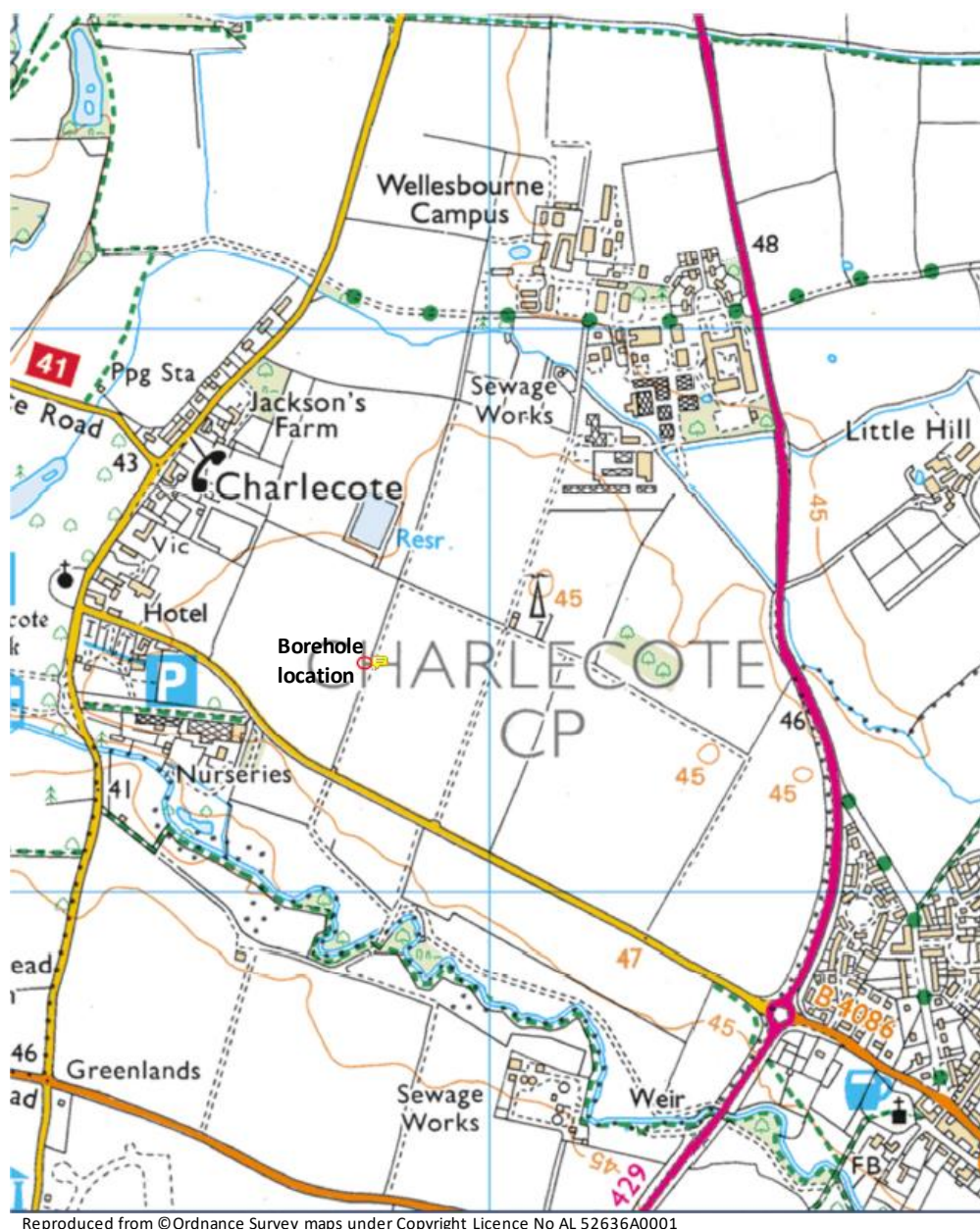


Figure 4.13 – Wellesbourne campus and borehole location

5. Adequacy of information provided in the application

- 5.1 This section summarizes the omissions from the planning application made to Warwickshire County Council for a proposal for a large working quarry. There are many aspects of the application where essential information has been omitted from the documentation provided to support the application.
- 5.2 This application does not provide the information necessary for the planning authority to be assured that the impact of 10 to 15 years of dewatering pumping will have on the local groundwater in the river terrace aquifer that extends from north of Barford to the south of Wasperton has been properly understood.
- 5.3 The only relevant data is limited to a summary of the borehole logs that is restricted to the information the applicant needs to assess the mineral reserves. The borehole logs have been interpreted by the applicant to provide the thicknesses of overburden and sand and gravel which severely devalues the data set to hydrogeological interpretation. The full log of each borehole should have been provided as this will provide information on the nature of the materials that have been allocated to overburden and mineral and is important for the planning authority to determine the planning consent.
- 5.4 The measurements of groundwater levels in nine piezometers over a period of twelve months have also been presented, although again, this information was needed for the applicant to assist with his planning the dewatering aspect. The data provided in the hydrographs shows annual changes of more than a metre during the period of 12 months that runs from November 2020. A longer period is needed to evaluate the range of the changes in the water levels so that the impact of the site can be assessed.
- 5.5 The applicant should have provided site specific values of the hydraulic properties of the river terrace materials based on at least four drawdown and recovery tests with a minimum of two observation boreholes being used in each test. No such data has been provided.
- 5.6 The assessment of the distance of the drawdown in the groundwater body has been made using an equation that only applies to unconfined groundwater conditions where a water table exists. This is not the case at the site where the groundwater is confined at the moment although it will become unconfined as the dewatering goes on. As a result the complicated situation means that the estimates made by the applicant are wrong and cannot be used in this context.
- 5.7 It may be deduced that the objective in the dewatering programme is to lower the groundwater levels to the Mercia Mudstone rockhead and maintain them at that level in each of the open cells for a year or two. This will require pumping that will remove the groundwater in the sand and gravel that lies within the cell that will cause the groundwater piezometric surface to be lowered in the confined aquifer that surrounds the site. As the lowered groundwater level will be required in the various cells as they move round pumping must continue and not stop for a significant period. As a result the radius of influence will be more extensive.

- 5.8 With this deduction in mind it does not make any sense to assume that the applicant is correct in his assertion that the discharge to the River Avon along the existing watercourses and ditches will be for only a short period at the start of the quarrying process. In order to lower the water table to the bedrock pumping must be continuous throughout the quarrying period that is estimated to be up to 15 years long.
- 5.9 The manner in which each of the twelve cells is to be dewatered has not been provided. The information is limited to stating that there will be a pumping sump and that the water will be settled before it is discharged into the local surface water system.
- 5.10 In view of the importance of pumping to the success of the quarrying operation he does not provide any measures that will be put in place to maintain the pumping and keep the quarry dry such as temporary ditches dug into the Mercia Mudstone surface.
- 5.11 The application states that an abstraction licence may be required to permit the abstraction that would be granted by the Environment Agency although there is no indication about what the EA's views are on this matter. .
- 5.12 Similarly there are other aspects of the proposal that require the EA's approval that are the operation of the site as a landfill and the nature of the inert materials that can be use to restore the land to its original form. Truly inert wastes are in great demand for various uses on landfills and it is likely to prove very difficult for the applicant to obtain the 1,000,000 m³ that will be required to restore the site to the current levels.
- 5.13 The EA's guidance on the requirements for landfills for inert wastes, which in this case will require a total volume of some 1,000,000 m³ of inert wastes requires a comprehensive risk assessment to identify the potential risks to surface water and groundwater. Special measures are required where the landfill is in a sensitive area that are defined by, amongst other things, as where the inert wastes are tipped below the water table and also in an area where groundwater provides a direct pathway to other sensitive receptors such as surface waters. This is the case here, where the local groundwater currently flows towards the River Avon. Additional precautionary measures include the lining of the landfill site to protect the local groundwater system in the case of non-inert wastes being placed in the quarry.
- 5.14 The EA in its letter to the planning department makes it clear that it requires a groundwater monitoring scheme to be installed, an emergency pollution plan is developed, a scheme for detailed restoration of the site that provides habitats that are satisfactory for various water dwelling wildlife and it should include objectives and a time table for restoration to take place. The EA mentions eels, Greater Water-parsnip and otters as species that need to be considered.
- 5.15 The EA also notes that the southern boundary partially falls in Flood Risk Zones 2 & 3 and requires compensatory storage to be provided. The analysis of the

rainfall data by Meteorological Office scientists indicate that the >20 mm short term rainfall events that cause local flooding will continue to increase. This will cause the flooding at the site to increase. The mitigation proposed by the applicants to leave the settlement lagoons in place will not provide a long term solution to this problem especially outside the site.

- 5.16 The EA notes that the site may require Environmental Permits under the Environmental Permitting (England and Waters) Regulations 2016 and states that any pollution prevention measures will be enforced under these permits. Quarry sites where fine-grained and very-fine-grained materials are washed out of the mineral are known to give problems of pollution in local surface water systems due to the difficulty of settling out these very small particles.
- 5.17 The application as it stands, falls short of providing sufficient information in many aspects that does not allow a comprehensive assessment of the potential impact to be made. It is also wrong in a number of aspects such as the prediction of the extent of the radius of influence as the equation for water table conditions is used whereas the groundwater over much of the site is in a confined state.
- 5.18 The application:
- fails to provide sufficient detailed and site-specific information to determine the effects of quarrying on local groundwater. These effects will extend far beyond the site boundary and it would be unsafe to determine the application without addition data.
 - the groundwater data provided together with the borehole logs is inadequate to obtain a proper understanding of the groundwater condition across the site.
 - does not provide any reliable calculations to demonstrate the drawdown in the terrace materials beyond the site boundary. The equations it appears to have used only apply to unconfined aquifers whereas this sand and gravel is currently confined over much of the site. This makes the values given in the application useless. In addition, the actual calculations are not shown in order that they can be checked.
 - the values that are given for the radius of influence are based on a calculation with a guessed value for the hydraulic conductivity which is lower than the values published for these materials by the United States Department of the Interior. In addition he uses a formula that does not apply to the confined groundwater condition found across this proposed quarry site. These calculations are meaningless and cannot be used to assess the radius of influence.
 - the application does not provide information of site specific measurements of hydraulic conductivity from local pumping tests.

- acknowledges the need for an abstraction license but there is no evidence of any discussion with the Environment Agency. Nor is there any mention of the need for a landfill license from the EA. The EA is a statutory consultee which has give it an opportunity to review the application and to form planning conditions that the County Council must include in the event that it decides not to reject this application.
- fails to provide detailed operational plans however it can be inferred that 24 hour working by up to 3 pumps will be required throughout the operational life of the quarry (up to 15 years). This will cause not only significant noise pollution but potentially also CO₂ emissions (the power source for the pumps is not given although it is assumed to be diesel).
- fails to explain where the required 1,000,000 m³ of suitable inert fill will be sourced. Inert fill has become a valuable resource and is expected to be in short supply.
- does not include any proposed schemes for the abstraction licence and the landfill environmental permits.
- the data collected by the applicant is limited to the confines of the quarry site itself. However, the impact will extend far beyond the boundary and it is strongly considered that the applicant should have extended its data collection on groundwater monitoring and data on the aquifer hydraulic properties that extend beyond the site. This is made more bewildering in that the site owner possesses land beyond these boundaries.
- the likelihood is that flooding will increase as a result of the quarry because the flow paths for water to cross to the River Avon will have been lost across the site. This may be mitigated at least to some extent by increasing the size of the ditches across the site. However, yet again this is something that has not been addressed by the applicant.
- the most likely scenario comprises the site being given planning permission and the necessary volume of inert wastes not being found leaving the applicant to apply for the planning application conditions to be revised to leave larger surface water bodies. The plan currently is to create a new surface water body or bodies in the centre of the site but in the event that only 75% of the necessary volume of inert wastes can be found then two or three phases will need to be left as open water. This will significantly alter the nature of the local landscape.

5.19 Due to the many problems with this application for a planning consent for a large sand and gravel quarry Warwickshire County Council is asked to refuse planning permission.

Appendix 1 – List of borehole summary details

BH No	NGR	GL (mOD)	Overburden Thickness (m)	Base Overburden (mOD)	Mineral Thickness (m)	Base of mineral (mOD)	WL (mOD)
WA19/01	SP 27534 59926	45.673	2.3	43.37	1.3	42.07	
WA19/02	SP 27684 59956	46.301	1.7	44.60	2.9	41.70	
WA19/03	SP 27641 59881	46.003	2.0	44.00	2.2	41.80	
WA19/04	SP 27567 59826	45.703	1.6	44.10	3.0	41.10	
WA19/05W	SP 27734 59778	46.386	2.8	43.59	1.5	42.09	45.7
WA19/06	SP 27745 59695	46.006	3.6	42.41	1.0	41.41	
WA19/07	SP 27612 59683	45.596	1.4	44.20	2.4	41.80	
WA19/08	SP 27689 59624	45.783	1.9	43.88	1.7	42.18	
WA19/09W	SP 27614 59537	45.507	2.0	43.51	1.2	42.31	
WA19/10	SP 27697 59526	45.431	1.7	43.73	2.1	41.63	
WA19/11	SP 27628 59437	45.422	2.4	43.02	1.0	42.02	
WA19/12	SP 27757 59450	45.865	1.9	43.97	2.0	41.97	
WA19/13	SP 27576 59336	45.263	1.6	43.66	1.5	42.16	
WA19/14	SP 27664 59386	45.565	1.5	44.79	1.7	42.17	
WA19/15	SP 27813 59385	45.934	2.0	43.93	1.8	42.13	
WA19/16	SP 27945 59384	46.794	1.0	45.79	3.6	42.19	
WA19/17	SP 27890 59272	46.145	2.2	43.95	2.0	41.95	
WA19/18	SP 27763 59277	45.639	1.1	44.54	2.4	42.14	
WA19/19	SP 27645 59275	45.266	1.0	44.27	2.6	41.67	
WA19/20	SP 27573 59221	45.345	1.6	43.75	2.3	41.45	
WA19/21	SP 27708 59203	45.484	1.6	43.88	3.0	40.88	
WA19/22	SP 27859 59202	46.063	2.9	43.16	1.3	41.86	
WA19/23	SP 27501 59144	45.167	1.6	43.57	2.5	41.07	
WA19/24	SP 27614 59111	45.221	1.9	43.32	2.0	41.32	
WA19/25	SP 27752 59100	45.497	1.4	44.10	1.8	42.30	
WA19/26	SP 27895 59064	46.156	2.3	43.86	2.0	41.86	
WA19/27W	SP 27377 58993	44.783	0.6	44.18	3.4	40.78	43.9
WA19/28	SP 27639 59033	45.273	1.5	43.77	1.6	42.17	
WA19/29	SP 27772 59030	45.685	2.7	42.99	1.4	41.59	
WA19/30	SP 27856 58955	45.937	0.9	45.09	0.0	45.09	
WA19/31	SP 27511 59413	45.211	1.2	44.01	1.8	42.11	
WA19/32	SP 27559 59522	45.336	1.4	43.94	2.5	41.44	
WA19/33	SP 27485 59616	45.341	1.4	43.94	1.9	42.04	
WA19/34	SP 27505 59732	45.435	0.9	44.54	2.7	41.84	
WA19/35	SP 27448 59801	45.514	1.4	44.11	2.4	41.71	
WA19/36	SP 27455 59895	45.456	1.7	43.76	2.1	41.66	
WA19/37	No record provided						
WA19/38	SP 27868 59618	46.586	1.6	44.99	0.0	44.99	
WA19/39	SP 27857 59761	46.735	1.1	45.64	0.0	45.64	
WA19/40	SP 27863 59868	47.169	0.9	46.27	0.0	46.27	
WA19/41	SP 27806 59950	46.795	1.3	45.50	0.0	45.50	
WA19/42	SP 27643 60048	46.444	0.7	45.74	3.0	42.74	
WA19/43	SP 27823 60076	47.693	0.7	46.99	0.0	46.99	
WA19/44	SP 27671 60140	46.923	1.3	45.62	3.1	42.52	
WA19/45	SP 27381 59616	45.455	0.9	44.56	2.7	41.86	
WA19/46	SP 27342 59755	45.622	1.1	45.22	1.7	42.82	
WA19/47	SP 27138 59626	45.666	0.6	45.07	2.4	42.67	
WA19/48	SP 27144 59543	45.887	0.8	45.09	2.3	42.79	
WA19/49	SP 27152 59425	45.715	1.3	44.42	2.7	41.72	
WA19/50	SP 27163 59270	45.093	1.0	44.09	2.9	41.19	
WA19/51	SP 27179 59052	44.870	1.0	43.87	2.3	41.57	
WA19/52	SP 27218 59116	44.984	0.9	44.08	3.4	40.68	
WA19/53	SP 27206 59325	45.268	1.0	44.27	2.3	41.57	
WA19/54	SP 27197 59467	45.386	0.8	44.90	2.3	42.29	
WA19/55	SP 27191 59573	45.591	0.8	44.79	2.2	42.59	
WA19/56	SP 27270 59522	45.124	1.3	43.82	1.5	42.32	
WA19/57	SP 27278 59406	45.102	0.8	44.30	2.6	41.70	
WA19/58	SP 27287 59270	45.063	1.2	43.86	1.9	41.96	
WA19/59	SP 27276 59068	44.670	0.8	43.87	2.4	41.47	
WA19/60	SP 27394 59101	45.096	1.1	44.00	2.3	41.70	

BH No	NGR	GL (mOD)	Overburden Thickness (m)	Base Overburden (mOD)	Mineral Thickness (m)	Base of mineral (mOD)	WL (mOD)
WA19/61	SP 27406 59192	45.396	1.4	44.00	2.5	41.50	
WA19/62	SP 27411 59325	45.321	1.6	43.72	2.2	41.52	
WA19/63	SP 27427 59448	45.248	0.7	44.55	2.7	41.85	
WA19/64	SP 27412 59536	45.470	0.7	44.77	2.9	41.87	
WA19/65W	SP 27734 59778	46.504	1.2	45.30	0.0	45.30	45.4
WA19/66	SP 27162 58907	44.696	1.3	43.40	2.8	40.60	
WA19/67	SP 27255 58899	44.598	1.2	43.40	2.8	40.60	
WA19/68W	SP 27109 59689	45.610	1.2	44.41	2.2	42.21	43.8
WA20/01W	No record provided						
WA20/02W							
WA20/03W							
WA20/04W							

Appendix 2 – Selected maps from the application

The following maps provide more of the limited geological information that is contained in the planning application.

Map WSP 22-2 BH Summary shows more information on the distribution of the geological information. Unfortunately the yellow horizontal striped areas show silt and pebbles in the sand and gravel material which is not helpful as these properties provide different effects on the hydraulic conductivity and storativity of the aquifer materials and this devalues the map.

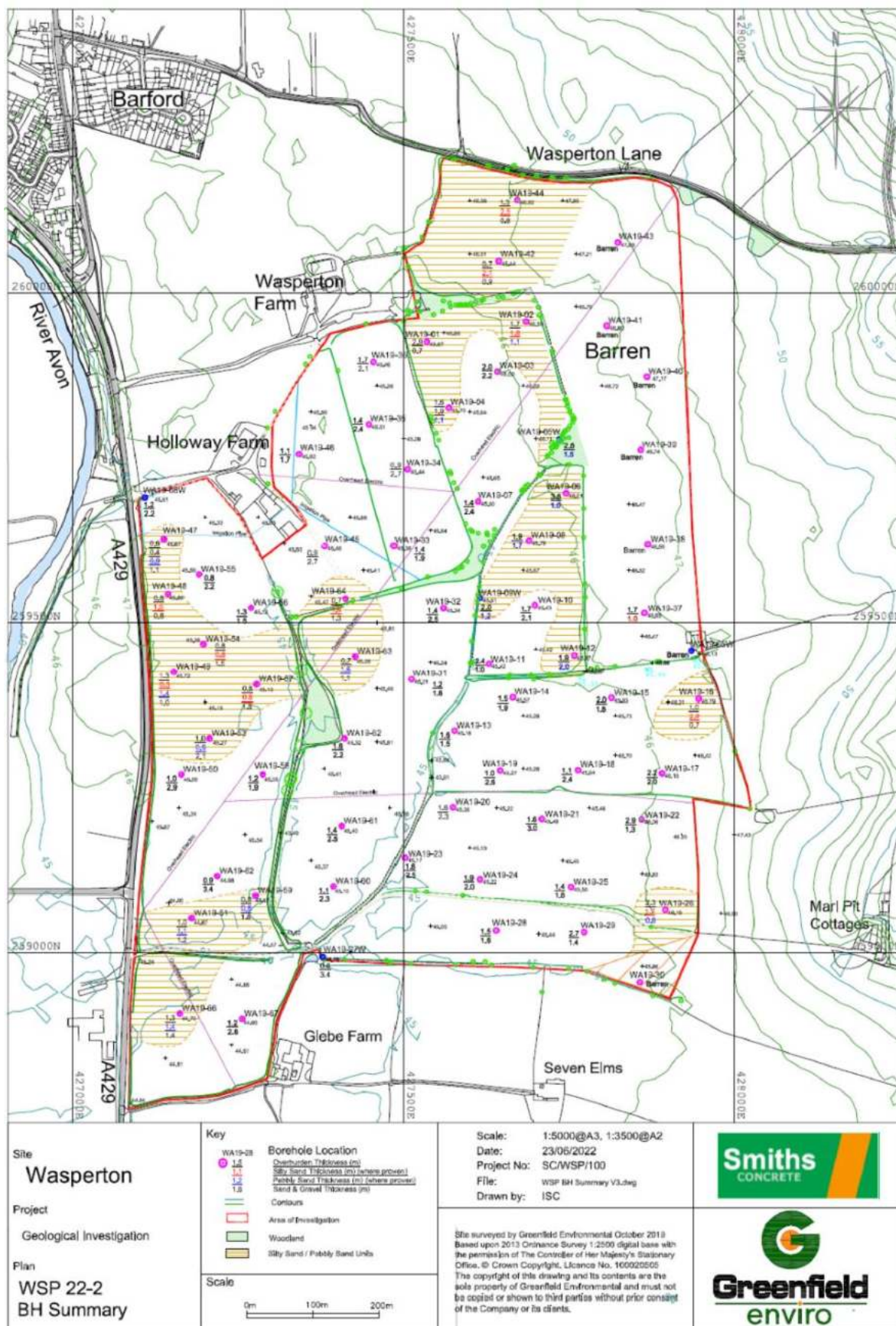
Map WSP 22-3 Extraction design is a general plan showing the approximate areas of each phase of the quarry.

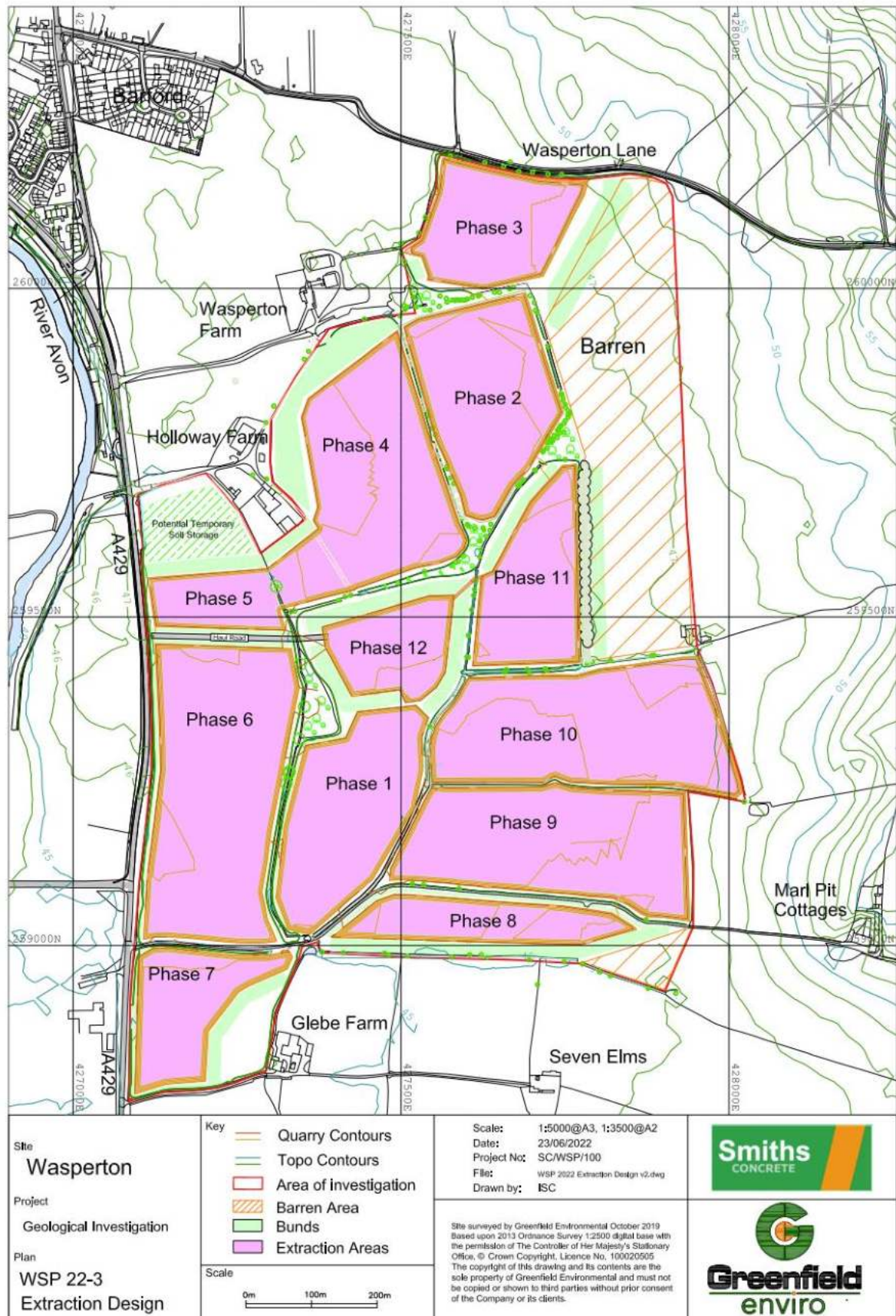
Map WSP 22-4 Mineral Thickness Contours shows the thicknesses in units of 1-2 m, 2-3 m and < 3 m. There is no information on the less than 1 m thickness for the sand and gravel.

Map WSP 22-5 Overburden Thickness Contours shows thicknesses in 0-1 m, 1-2 m and 2-3 m.

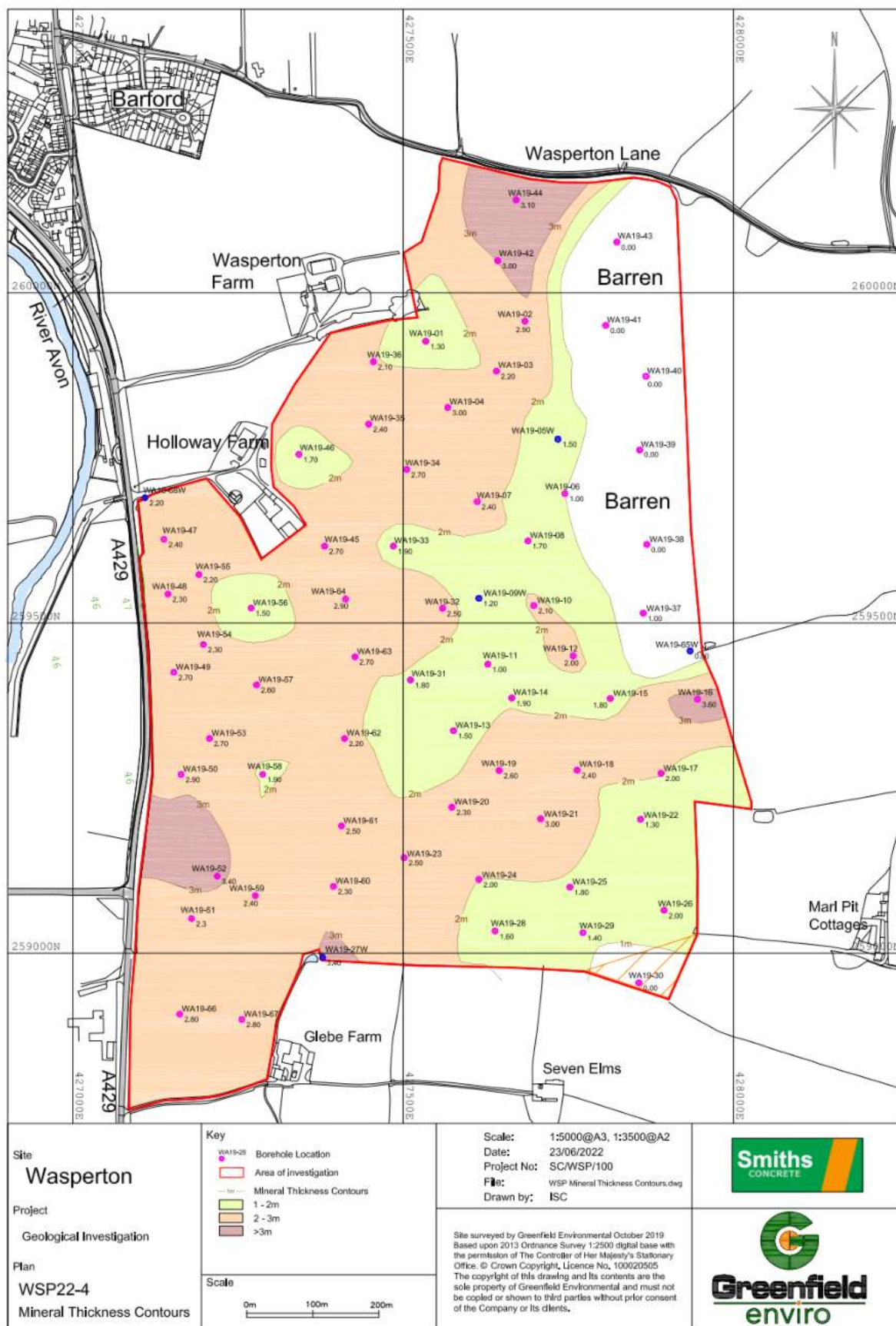
These maps provide some information from the boreholes logs although copies of the actual logs that were provided to the applicant by the driller would have been very much more helpful.

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