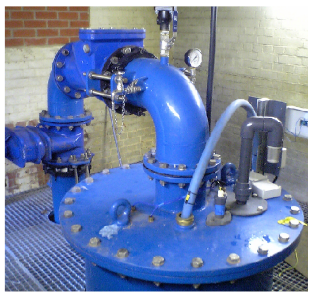

BLACK ROCK FARM

HYDROGEOLOGICAL IMPACT APPRAISAL
IN SUPPORT OF ABSTRACTION LICENCE APPLICATION

REVISED NOVEMBER 2020

PROJECT NO. 18190510

NRW REF. PPN-00375

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HYDROGEOLOGICAL IMPACT APPRAISAL

Black Rock Farm
Cross Lanes
Wrexham
LL13 0TF

Origin	Name
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Report researched and produced by B. A. Hydro Solutions Limited (BAHS Ltd) on the instruction of Elliott (Agriculture) Limited.

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1 Introduction

This Hydrogeological Impact Appraisal has been undertaken by B. A. Hydro Solutions Ltd. (BAHS Ltd.) to support the application for a groundwater abstraction licence at Black Rock Farm, Cross Lanes, Wrexham.

The abstraction is required to support an open-loop ground source heat pump (GSHP) system at the site. The GSHP system will be used to help regulate the temperature within a broiler poultry housing unit. The abstraction will be non-consumptive; once abstracted, water will pass, untreated, through a heat exchange system before being returned to ground by means of a re-injection borehole.

The abstraction volumes sought by this licence application are as follows:

- 103,109 cubic metres per year (282 m^3/day equivalent)
- 540 cubic metres per day
- 30 cubic metres per hour
- Instantaneous rate of 8.33 litres per second

Consent to undertake test pumping at the site was given by Natural Resources Wales under Consent Number PPN-00375, issued on 11th December 2019. Two 4-day tests were undertaken in June/July 2020 in line with this consent; the first test involved simultaneous abstraction and re-injection, whilst the second test comprised abstraction only.

- Section 2 of this report gives details of the site location
- Section 3 summarises the local and site specific geology
- Section 4 outlines the hydrogeology and local water features
- Section 5 presents and analyses the results of the test pumping
- Section 6 summarises the conclusions of the report

This report was originally issued in September 2020 in support of a groundwater abstraction licence application. It has been revised in November 2020 to take into account comments received by Natural Resources Wales.

2 Site Details and Requirements

The site boundary and the location of the abstraction (ABH) and re-injection (RIBH) boreholes are illustrated in Figure 1. Table 1 gives the National Grid Reference (NGR) and site elevation of the individual boreholes.

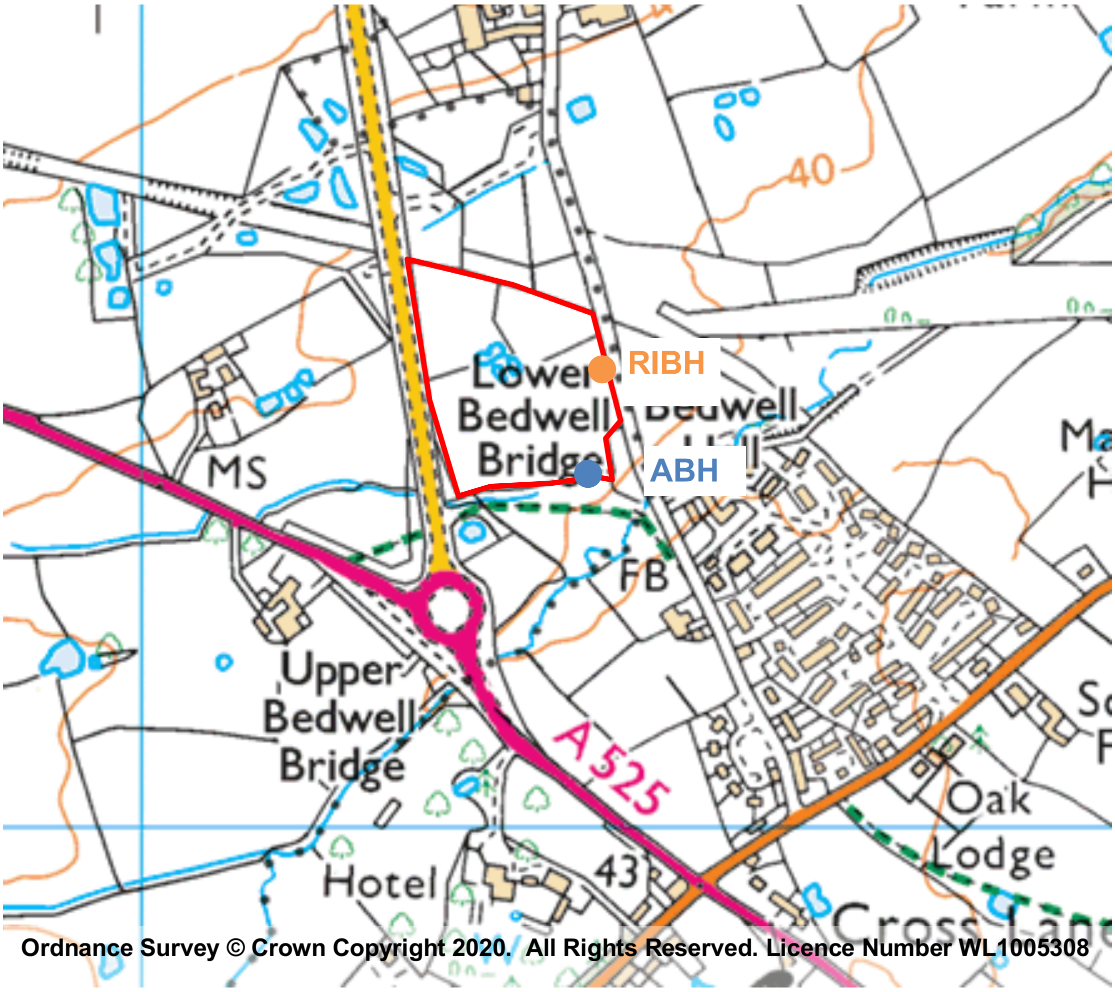

Figure 1: Location Map

Site Address:	Black Rock Farm
	Sesswick Way
	Cross Lanes
	Wrexham
Postcode:	LL13 0TF
NGR borehole position ABH:	SJ 37452 47358
Elevation ABH:	40 metres above Ordnance Datum (maOD)
NGR borehole position RIBH	SJ 37462 47476
Elevation RIBH:	42 metres above Ordnance Datum (maOD)

Table 1: Site details

The two boreholes were drilled in 2018, the construction details are presented in Table 2.

	ABH	RIBH
Completion date	04/06/2018	11/09/2018
Drill depth (mbdat)	80	85
Drilled diameter	300 mm to 12m 250 mm 12 to 80 m	300 mm to 18m 250 mm 18 to 85 m
Casing details	Steel: 250 mm, 0 to 12m Plain PVC:150 mm, 0 to 30m Slotted PVC: 150 mm, 30 to 80m	Steel: 250 mm, 0 to 18m Plain PVC:150 mm, 0 to 30m Slotted PVC: 150 mm, 30 to 85m
Backfill	Gravel: 10 to 80m Grout seal: 0 to 10m	Gravel: 20 to 85m Grout seal: 0 to 20m
Water strike (mbdat)	Strike: 26, 33, 77	Strike: 28, 78
Rest water level on completion (mbdat)	33	33

Table 2. Borehole construction details, Black Rock Farm

The proposed GSHP system is pressurised such that water is re-injected under pressure. High pressure protection is installed in the form of a sensor and switch to prevent the system operating outside of design limits.

3 Geological Setting

3.1 Introduction

The geology mapped at ground level across the local area is illustrated in Figure 2; the location of the property is outlined in red. The site is underlain by a layer of topsoil and Till that covers the rock head formed of the Kinnerton Sandstone Formation. With depth the Salop Formation is encountered; this unit extends to a considerable depth and, as such, is the lowermost unit considered in this report.

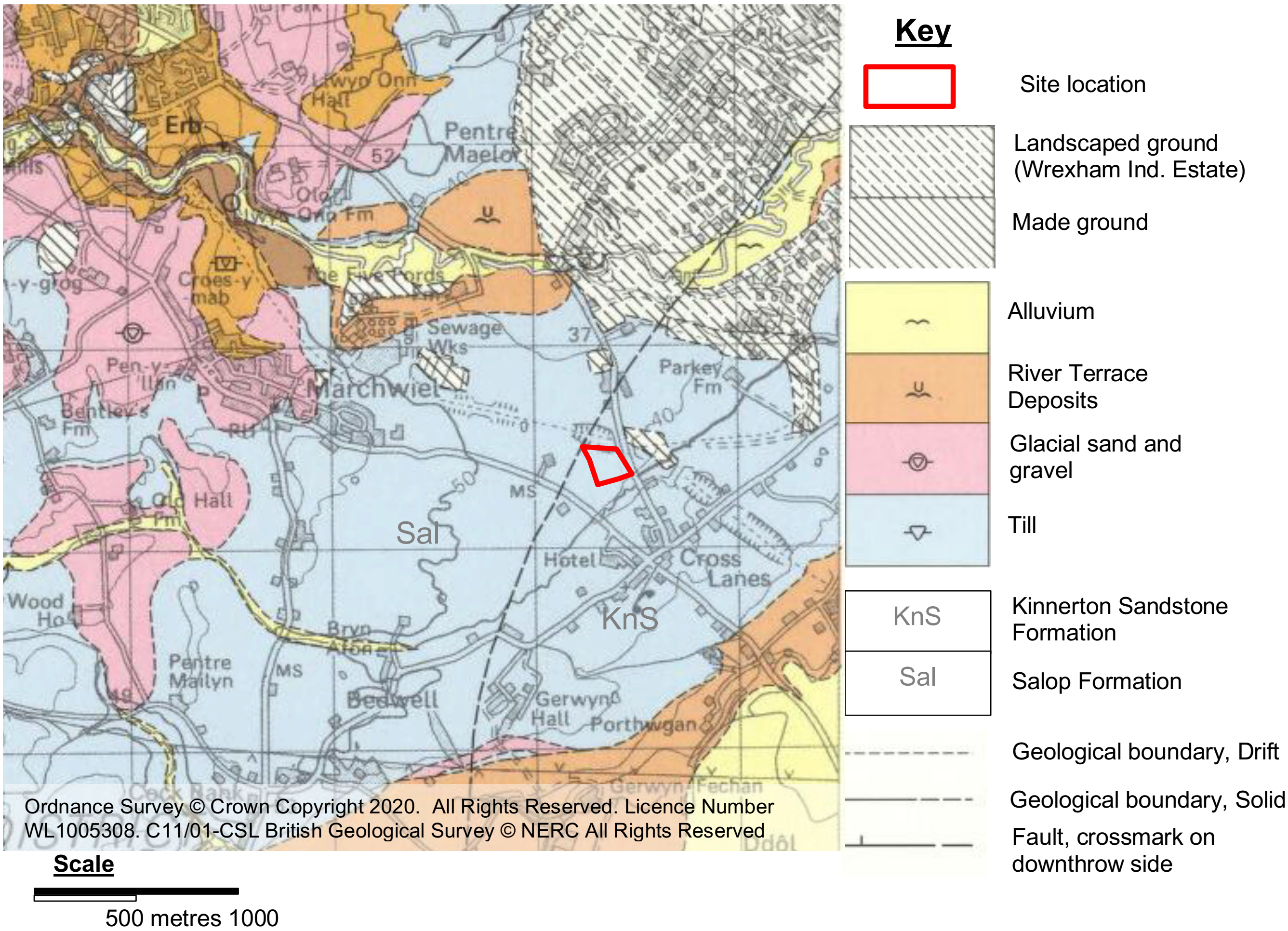

Figure 2: Geological Map

Figure 3 provides a schematic summary of the geological profile from ground level downwards. The lithological characteristics of each horizon are considered in Section 3.2.

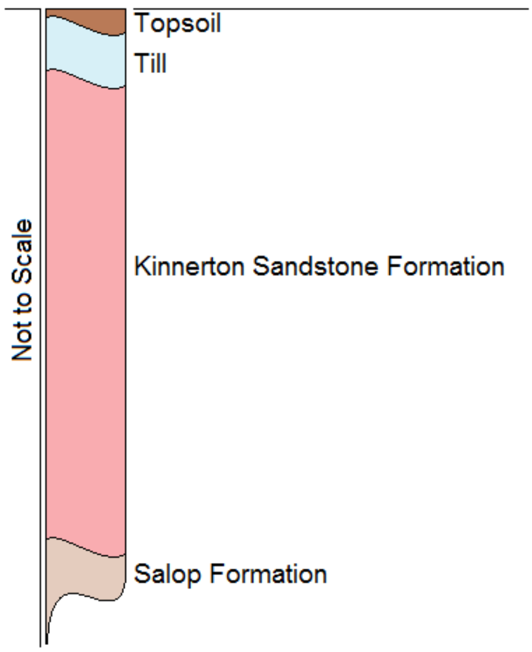

Figure 3: Lithological Log

3.2 *Lithology*

3.2.1 Drift

The uppermost layer across the site is a thin topsoil. The soil is classified as seasonally wet, slowly permeable, slightly acid but base-rich, loamy and clayey.

Underlying the soil is variable thickness of Till (also referred to as Boulder Clay). The Till is glacial in origin; locally glacial deposits comprise Upper Boulder Clay overlying Middle Sands, in turn overlying Lower Boulder Clay. The Upper Boulder Clay generally comprises a stoneless red calcareous clay. The Middle Sands comprise deposits of sand and gravel with thin bands of laminated clay. The Lower Boulder Clay is patchily developed and generally obscured, where present below the Middle Sands it usually comprises hard red or occasionally grey clay till containing numerous stones, often of considerable size.

3.2.2 Kinnerton Sandstone Formation

The Kinnerton Sandstone (previously referred to as the Lower Mottled Sandstone) comprises red-brown to yellow, generally pebble-free, fine- to medium-grained, cross-stratified sandstone. The formation is dominantly aeolian in provenance and tends to be free of mudstones.

3.2.3 Salop Formation

The Salop Formation (formerly referred to as the Erbistock Formation) is the uppermost unit of the Warwickshire Group. The formation comprises red and red-brown mudstone, and red-brown sandstone containing beds of pebbly sandstone and conglomerate. Thin limestone beds occur towards the bottom of the formation. Local borehole logs record alternating bands of red marl and sandstone; marl being the dominant lithology.

3.3 Structure

No faults are mapped within 2 kilometres of the site; a south-west to north-east trending fault that downthrows to the north is located some 2.2 kilometres north of the site and the north-south trending Wrexham Fault is located 3.6 kilometres to the west.

3.4 Site Specific Geology

Details of the strata encountered during the drilling of the abstraction and re-injection boreholes are presented in Table 3Table 4 and **Error! Reference source not found.** and Figure 5.

Abstraction Borehole		
Description of strata	**Thickness (m)**	**Depth (mbgl)**
Top soil	1.00	1.00
Clay with gravel	4.00	5.00
Gravel and Sand	3.00	8.00
Weak red sandstone	2.00	10.00
Red sandstone	70.00	80.00

Table 3. Abstraction borehole, description of strata (mbgl = metres below ground level).

Re-injection borehole		
Description of strata	**Thickness (m)**	**Depth (mbgl)**
Red Clay	9.00	9.00
Gravel	3.00	12.00
Red Sandstone	73.00	85.00

Table 4. Re-injection borehole, description of strata (mbgl = metres below ground level).

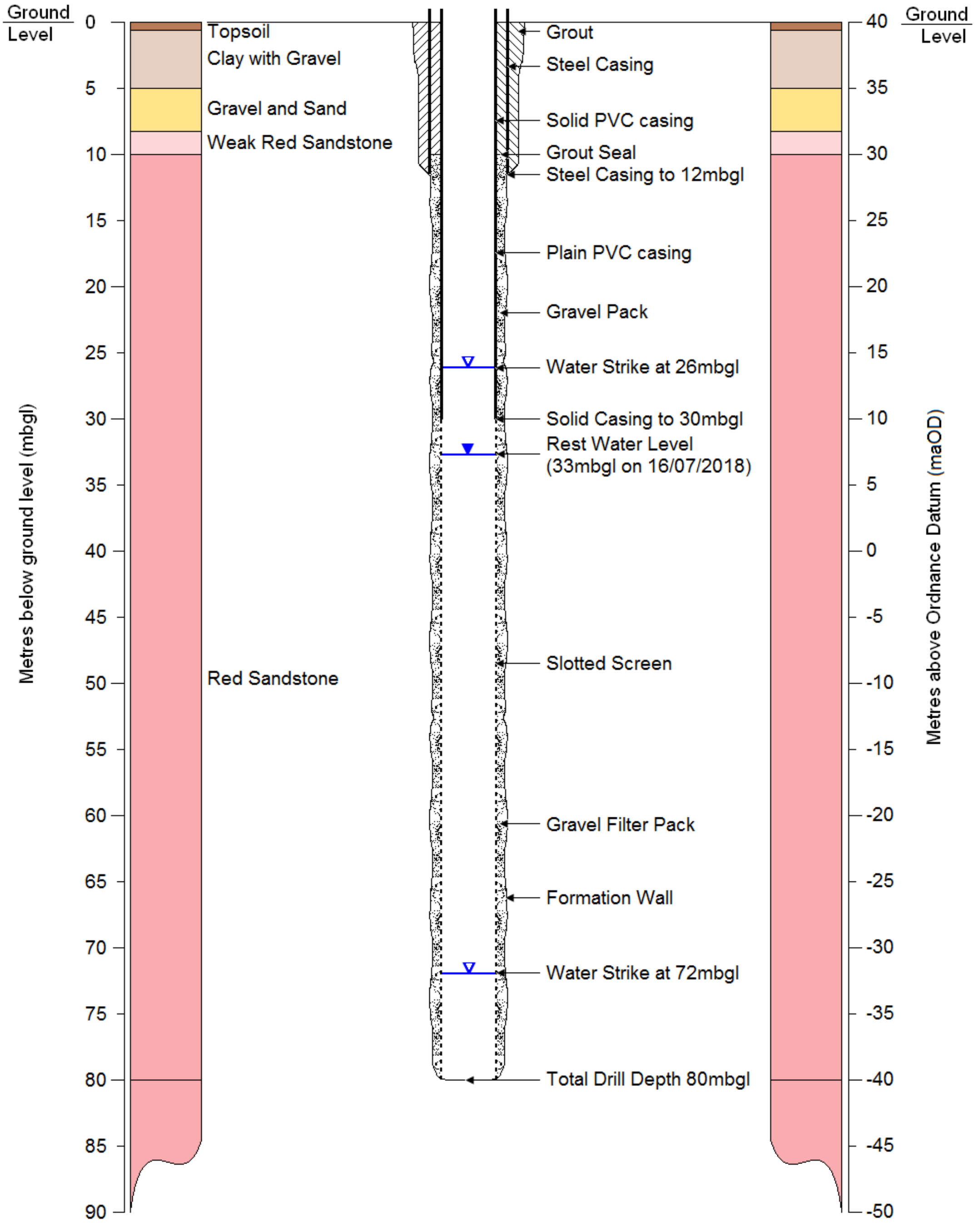

Figure 4. Black Rock Farm abstraction borehole (ABH)

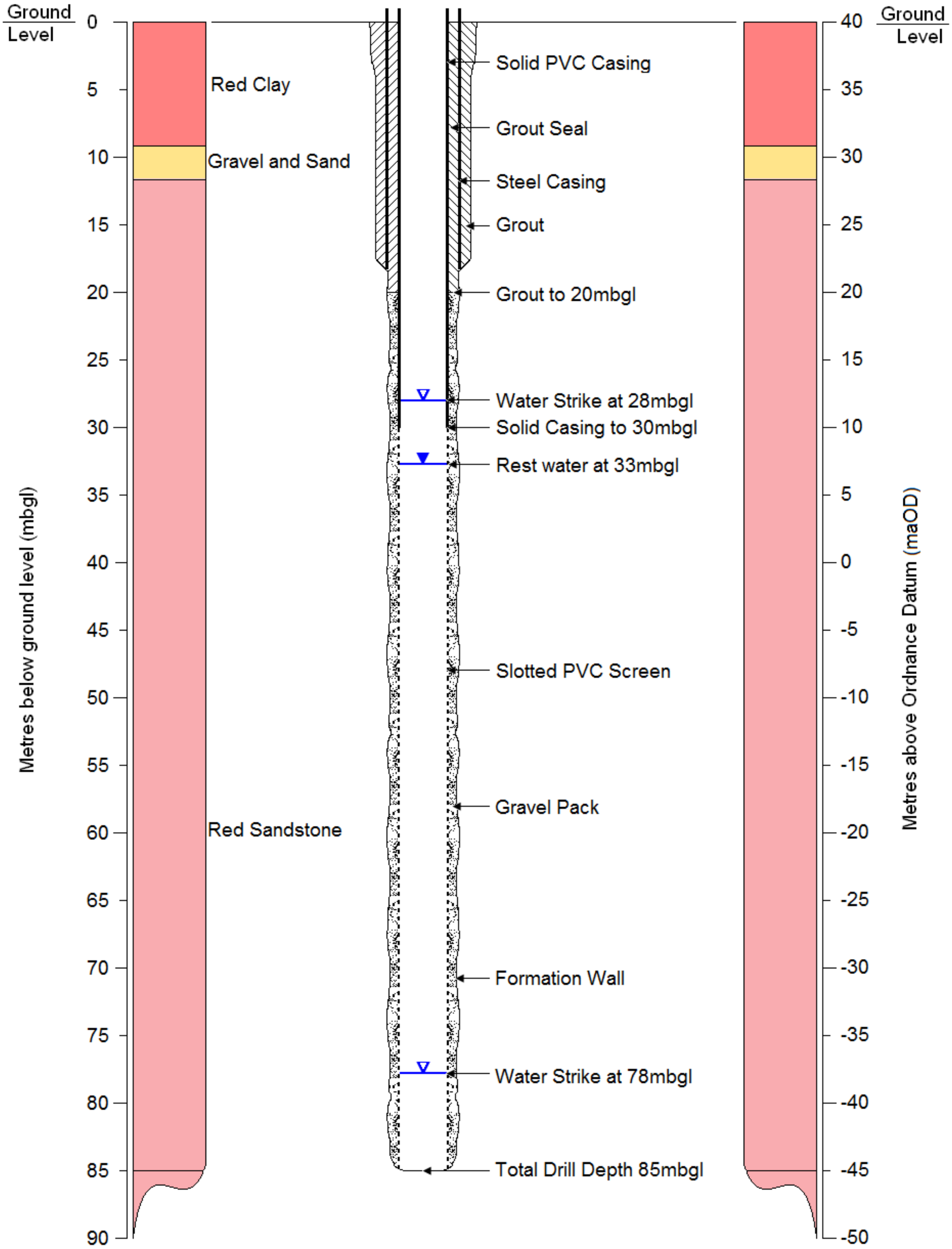

Figure 5. Black Rock Farm re-injection borehole (RIBH)

The thickness of drift deposits is variable between the two boreholes, being 8 metres at the ABH and 12 metres at the RIBH. The drift descriptions are consistent with Till, the unit being dominated by clay (Upper Boulder Clay) in the RIBH, less so in the ABH. Both boreholes record a 3 metre layer of gravel/gravel and sand consistent with the Middle Sands; no underlying clay layer (Lower Boulder Clay) is recorded.

The red sandstone encountered in both boreholes is consistent with the Kinnerton Sandstone Formation. However, the description is limited in detail and, given the proximity of the boreholes to the outcrop boundary with the Salop Formation (inferred to be 280 metres to the west), it is possible that the 'red sandstone' also includes some of the Salop Formation.

4 Hydrogeology and water features

4.1 Hydrogeology

The Till underlying the site is considered a Secondary Aquifer. Clay layers within the unit are of low permeability and may act to confine, and limit recharge to, underlying strata. The sand and gravel noted within the Black Rock Farm boreholes are of higher permeability and have the potential to store and transmit water. However, drilling records and records for other local boreholes show the glacial deposits to be dry for the most part.

The Permo-Triassic sandstones, of which the Kinnerton Sandstone Formation is the lowermost unit, are considered a Principal Aquifer. Saturated groundwater flow in the sandstone formations occurs by a combination of intergranular and fracture flow. Discontinuities include bedding-plane fractures, inclined joints of either tectonic or diagenetic (i.e. dissolution of vein infills) origin, and solution-enlarged fractures. They can provide preferential flow paths and have a significant effect on the physical properties of the aquifer.

The fractured Permo-Triassic sandstones are often described as a 'dual permeability system', at least with regard to borehole behavior (Allen et al., 1997). The majority of the total storage capacity of the system is provided by the rock matrix, and significant regional transport occurs in both the fractures and the rock matrix. Water flows through the matrix and the fractures towards a borehole.

Regionally, based on core samples, the Kinnerton Sandstone Formation's matrix hydraulic conductivity ranges from 3.7×10^{-5} to 10 m/d, with an interquartile range of 0.13 to 1.8 m/d (Allen et al., 1997). The lower hydraulic conductivity values result from the sampling of fine-grained layers and the influence of mudstone lenses, rather than cementation, which is poor in the Kinnerton Sandstone Formation. Bulk hydraulic conductivities, converted from pumping test transmissivity data, range from 0.16 to 46 m/d, with a geometric mean and median of 2.5 m/d; the higher values supporting the importance of fracture flow contributions within the aquifer.

A review of the pumping test for 763 Permo-Triassic sandstone sites by Allen et al, 1997, concluded that the Permo-Triassic sandstones tend to behave as confined or semi-confined aquifers even when confining layers are absent: pumping test analyses yield confined storage coefficient values, and boreholes often exhibit barometric efficiency. A typical unconfined Permo-Triassic sandstone aquifer gives a delayed yield response to pumping in which an initial confined response lasts for hours to months, followed by a transition period in which the drawdown data depart from the confined type curve, showing smaller than expected values (Figure 6). This is then often followed by an increase in drawdown rate towards an unconfined response after a few days, weeks or months. However, a complete double curve, (with both the confined and fully unconfined response), is rarely seen. When analysed (using the Theis or Boulton methods) a confined storage of 10^{-3} to 10^{-4} is often obtained, but it is virtually never possible to analyse the end of the curve for specific yield. Thus, when even obviously unconfined Permo-Triassic sandstone aquifers are pumped, a characteristic confined response curve is seen.

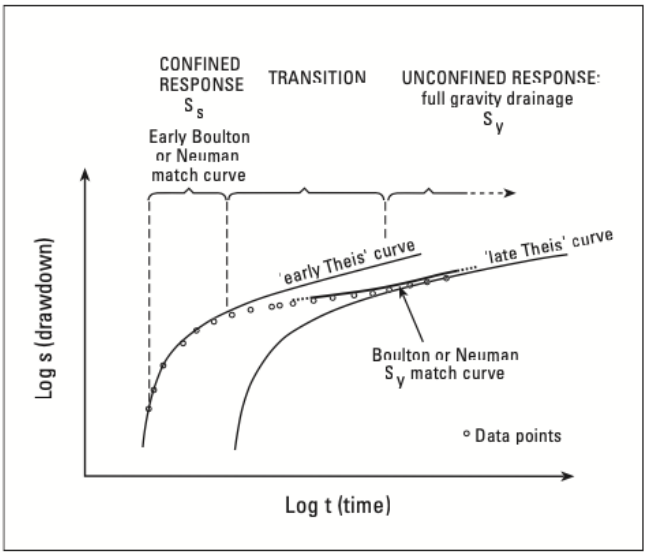

Figure 6. Characteristic time-drawdown response of Permo-Triassic sandstone aquifer to pumping (Allen et al., 1997)

Allen et al concluded that the most likely explanation of aquifer behaviour is its anisotropic nature. After the initial confined response of the aquifer, vertical hydraulic gradients are set up across the less permeable layers as more water flows out of the permeable layers so reducing their head. The propagation of this head change to the surface for an unconfined water table response is slowed down by the low vertical hydraulic conductivity layers of the aquifer. Retardation of vertical flow by the less permeable horizons means that the interlayers effectively confine the aquifer. The drawdown response in longer tests, where the upturn of the curve is seen towards the end of pumping, is typical of anisotropic unconfined aquifers.

Other explanations which have been invoked to account for the confined response of the Permo-Triassic sandstones on pumping are the effects of boundaries, superficial strata and fractures. However, while each may contribute to specific test responses, they cannot explain the widespread nature of the effect.

The fractured nature of the aquifer is also likely to contribute to its unusual behaviour. The dual permeability nature of the system is likely to result in changes to the gradient of the drawdown curve as different components of the system come into play (for example the accessing of storage from deeper parts of the aquifer). However, the characteristic times of these responses are unknown and, at present, unpredictable.

A further possibility is that dewatering of fractures could provide the low storage values, later followed by a matrix contribution. The values of storage obtained from pumping tests are however too low even for fracture storage and they can only be attributed to confined storage. However, there is some component of fracture flow and this dominates the transmissivity in some areas. Fractures may contribute low storage values in pump tests. Generally, however, throughout the Permo-Triassic sandstones the annual storage of the aquifer appears to be controlled by a high-matrix specific yield, even in areas where fractures are important in transporting water and give high borehole transmissivity.

The Aquifer Properties Database (Allen et. al 1997) includes transmissivities for the Permo-Triassic Sandstone from 138 sites in the Cheshire region (including Wrexham). The site transmissivity values range from 0.90 to 4900 m^2/d, with an interquartile range of 120 to 530 m^2/d. Fracture flow is particularly significant at high values. The values show an approximately normal distribution, the geometric mean is 220 m^2/d and the median is 250 m^2/d.

The Database has storage coefficient records at 53 sites in the Cheshire region. The site averages range from confined values of $1.2x\ 10^{-5}$ through semi-confined values to rare low unconfined values of up to 0.09. The distribution of storage coefficient data shows an approximately log-normal distribution, with a geometric mean of $1.1x10^{-3}$. The interquartile range is $3.6x\ 10^{-4}$ to $2.8\ x10^{-3}$. There is no correlation from the data between pumping test length and storage coefficient value.

Rest water levels beneath the site are around 10 to 15 maOD, the water table sits within the sandstone aquifer with an unsaturated zone above. The regional groundwater flow direction is to the north.

4.2 Groundwater Quality

After construction in 2018, a pumped sample was taken from the abstraction borehole (ABH) and tested for a range of parameters. The results are summarised in Table 5.

Parameter	Result	UK limit (Drinking Water Standards)	Unit
Calcium	117	-	mg/l
Magnesium	57.6	-	mg/l
Sodium	39.5	200	mg/l
Chloride	26.0	250	mg/l
Sulphate	34.2	250	mg/l
Bicarbonate	584	-	mg/l
Nitrate (as NO3)	0.8	50	mg/l
Iron (total)	0.09	0.2	mg/l
Copper	<0.01	2	mg/l
Manganese	0.01	0.05	mg/l
Total Dissolved Solids	604	-	mg/l
Electrical Conductivity	863	2500	µS/cm
pH	7.2	6.5-9.5	pH units
Turbidity	2.36	4	NTU

Table 5. Water quality, abstraction borehole

The groundwater quality is good with all determinands being within UK limits. The groundwater is of calcium-bicarbonate type with subsidiary magnesium and sulphate and minor sodium and chloride. Manganese and iron are relatively low, consistent with oxidising conditions.

4.3 Water Features

A number of small pond and surface drains are located within the vicinity of the site. These sit on the glacial drift deposits (Till) and are likely hydraulically isolated (perched) from the Kinnerton Sandstone by varying amounts of clay.

The River Dee is located around 1.56 kilometres south-east of the Black Farm abstraction borehole (ABH).The river flows south-west to north-east past the site, before heading north to Chester.

The Water Features Survey undertaken in October 2019 (Form WRC submitted October 30th 2019), identified three operational boreholes within 2 kilometres of the site (Figure 7, Table 6).

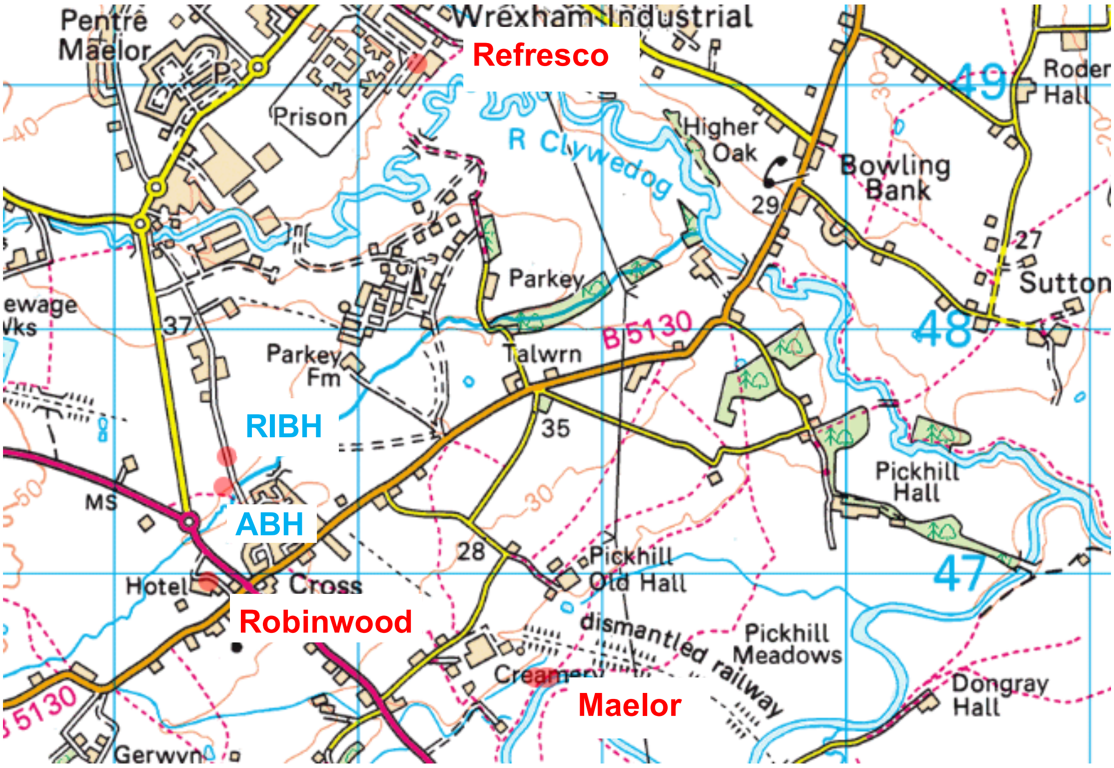

Figure 7. Operational boreholes within 2 kilometres of Black Rock Farm

Site	NGR	Distance from ABH (m)	Licence Number	Construction details
Robinwood Activity Centre	337390 346970	390		Depth: 77 metres, plain cased to 36 metres, slotted casing below. RWL: c. 28 mbd
Maelor Foods ABH	338728 346712	1440	WA/067/0007/0015	Depth: 171.5 metres. Plain cased to 77.5m RWL c.11 mbd, PWL c.35 mbd.
Refresco Drinks	338240 349090	1900	WA/067/007/006	-

Table 6. Operational boreholes within 2 kilometres of Black Rock Farm, identified during Water Features Survey.

As shown in Figure 8, the Black Rock Farm boreholes are located within Source Protection Zone 2 of the Refresco (Cott Beverages) production borehole, there are no Source Protection Zones associated with the Maelor production borehole or the Robinwood site.

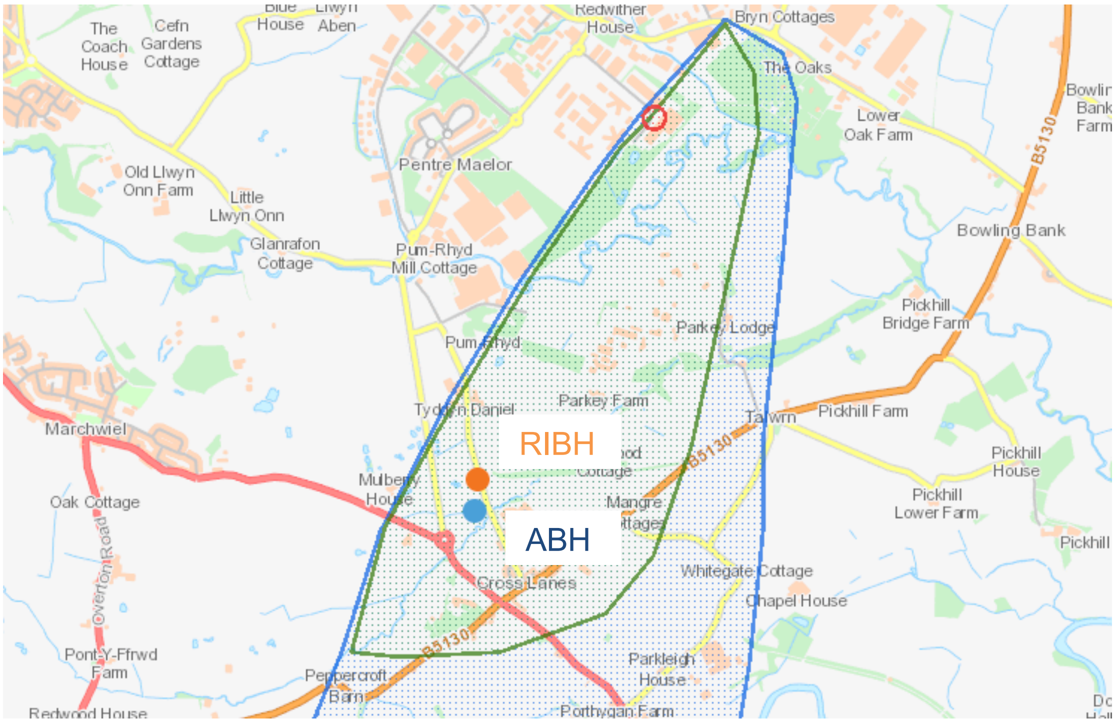

Figure 8. Source Protection Zones. Red= Zone 1, Green=Zone 2, Blue=Zone 3 (total catchment). From Natural Resources Wales Map Viewer

During the completion of the Water Features Survey the Local Authority confirmed there were no private water supplies in the local area.

5 Test Pumping

5.1 Introduction

As per Consent Number PPN-00375, issued on 11th December 2019, two 4-day tests were undertaken in June/July 2020. Test 1 (19/06/20 to 23/06/20) involved the simultaneous abstraction of water from the abstraction borehole (ABH) and recharge of water into the re-injection borehole (RIBH). Test 2 (29/06/20 to 03/07/20) involved abstraction only from the ABH. The tests were undertaken in this order due to engineering considerations on site.

Details of the tests are summarised in Table 7.

TEST 1. SIMULTANEOUS ABSTRACTION AND RE-INJECTION	
Date and time of test:	19/06/2020 14:34 to 23/06/2020 14:34
Duration test:	96 hours (4 days)
Rest water level (ABH)*:	25.57 mbdat
Average abstraction rate:	26.119 m^3/hour (626.9 m^3/day)
Water level at end of test (ABH):	30.47 mbdat
Method of discharge measurement:	Flow meter
Discharge arrangements:	Discharged direct to re-injection (recharge) borehole (RIBH)
Date and time of recovery test:	23/06/2020 (14:34 to 16:54)
Duration of recovery test:	140 minutes
Equipment Failure:	None

TEST 2. ABSTRACTION ONLY	
Date and time of test:	29/06/2020 14:00 to 03/07/2020 14:00
Duration test:	96 hours (4 days)
Rest water level (ABH):	25.55 mbdat
Average abstraction rate:	22.585 m^3/hour (542.0 m^3/day)
Water level at end of test (ABH):	31.22 mbdat
Method of discharge measurement:	Flow meter
Discharge arrangements:	Discharged to pond 130 metres to north-west (NGR 337360 347460)
Date and time of recovery test:	03/07/2020 (14:34 to 16:54)
Duration of recovery test:	140 minutes
Equipment Failure:	None

Table 7: Details of Black Rock Farm pumping tests.
***ABH datum used during tests = top of dip tube (17 cm above ground level)**

A number of sites, identified in the Water Features Survey (Form WRC submitted October 30th 2019), were monitored before, during and after the tests; these are detailed in
Table 8 below. Unfortunately no data has been made available by Refresco (Section 4.2).

Site	**(NGR) Dist. from source (m)**	**Comments (incl. e.g. Depth, RWL, PWL)**	**Type of monitoring**
Black Rock Farm Abstraction borehole (ABH)	NGR 337452 347358	Depth: 80 metres, plain cased to 30 metres, slotted casing to 80 metres	Manual
Black Rock Farm Re-injection borehole (RIBH)	NGR 337462 347476 (120 m north of ABH)	Depth: 85 metres, plain cased to 30 metres, slotted casing below. RWL 23.7 mbd	Diver and manual
Robinwood Activity Centre abstraction borehole	NGR 337390 346970 (390 m south of ABH, 500 m south of RIBH)	Depth: 77 metres, plain cased to 36 metres, slotted casing below. RWL: c. 28 mbd	Manual (logger access not possible)

Maelor ABH (licensed source WA/067/0007/0015)	NGR 338728 346712 (1440 m south east of ABH)	Depth: 171.5 metres. RWL c.11 mbd, PWL c.35 mbd.	Logger (3rd party)
River Dee Deep OBH	NGR 338778 346574 (1550 m south east of ABH)	Depth: 90 metres, slotted casing 75m to 90 mbd	Logger (3rd party)
River Dee Shallow OBH	NGR 338770 346572 (1550 m south east of ABH)	Depth: 20 metres, slotted casing 10 to 20 mbd	Logger (3rd party)

Table 8. Groundwater monitoring points

Additionally, rainfall data for the period of monitoring have been sourced from the UK Water Resources Portal for the Dee at Manley (station 67015). The monitoring station is located around 10 kilometres south-west of the site; some local variation in rainfall would be expected, however, in the absence of a closer monitoring point, it is considered useful as a reference. Flow data for the River Dee at Manley (upstream of the site) have also been downloaded.

Charts showing water levels for the various monitoring points before, during and after the tests are presented on the following pages (Figure 9,Figure 11 andFigure 12 and 12).

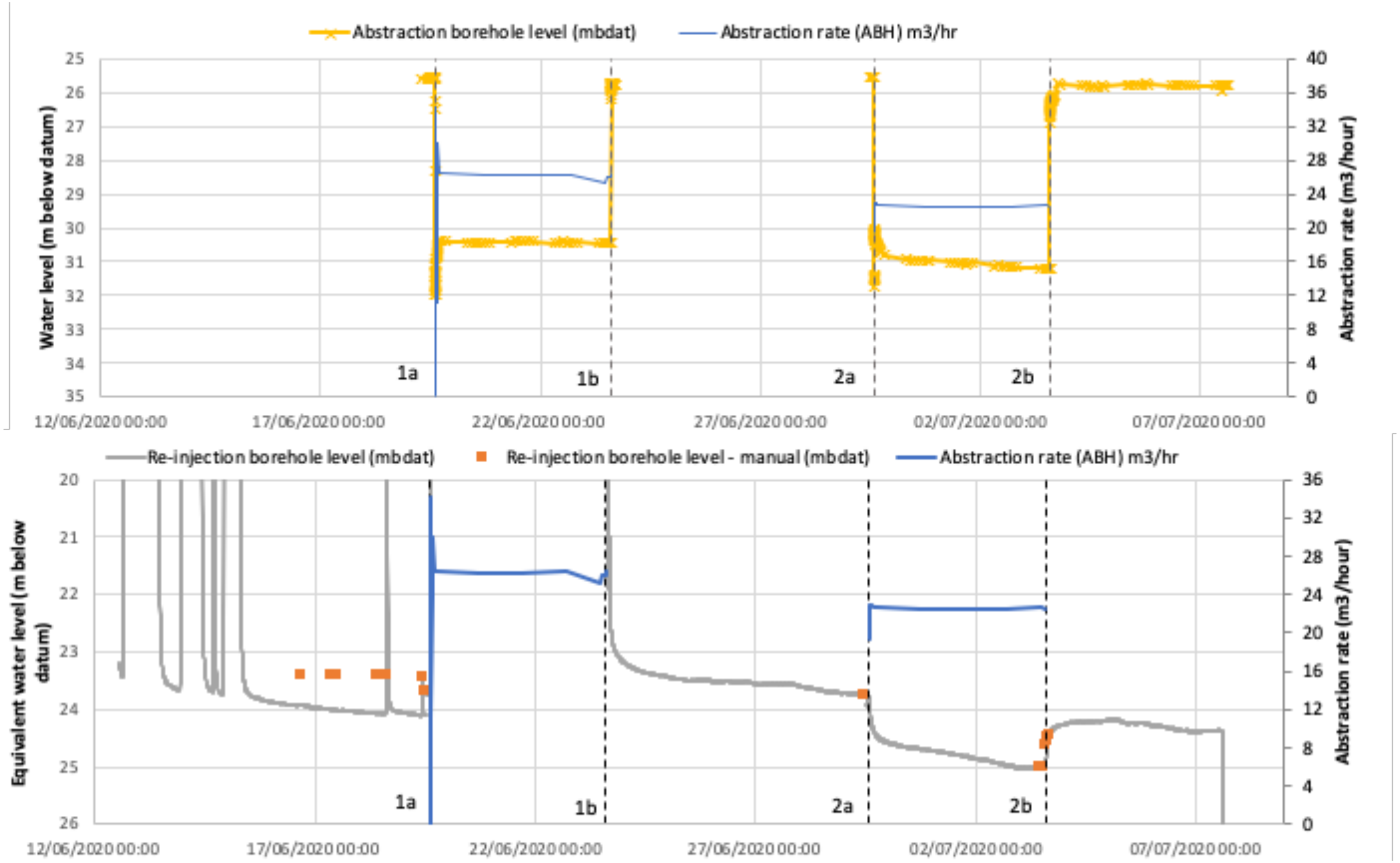

Figure 9. Water levels and flow rates within ABH and RIBH. 1a = start of Test 1, 1b= end of Test 1, 2a- start of Test 2, 2b= end of Test 2

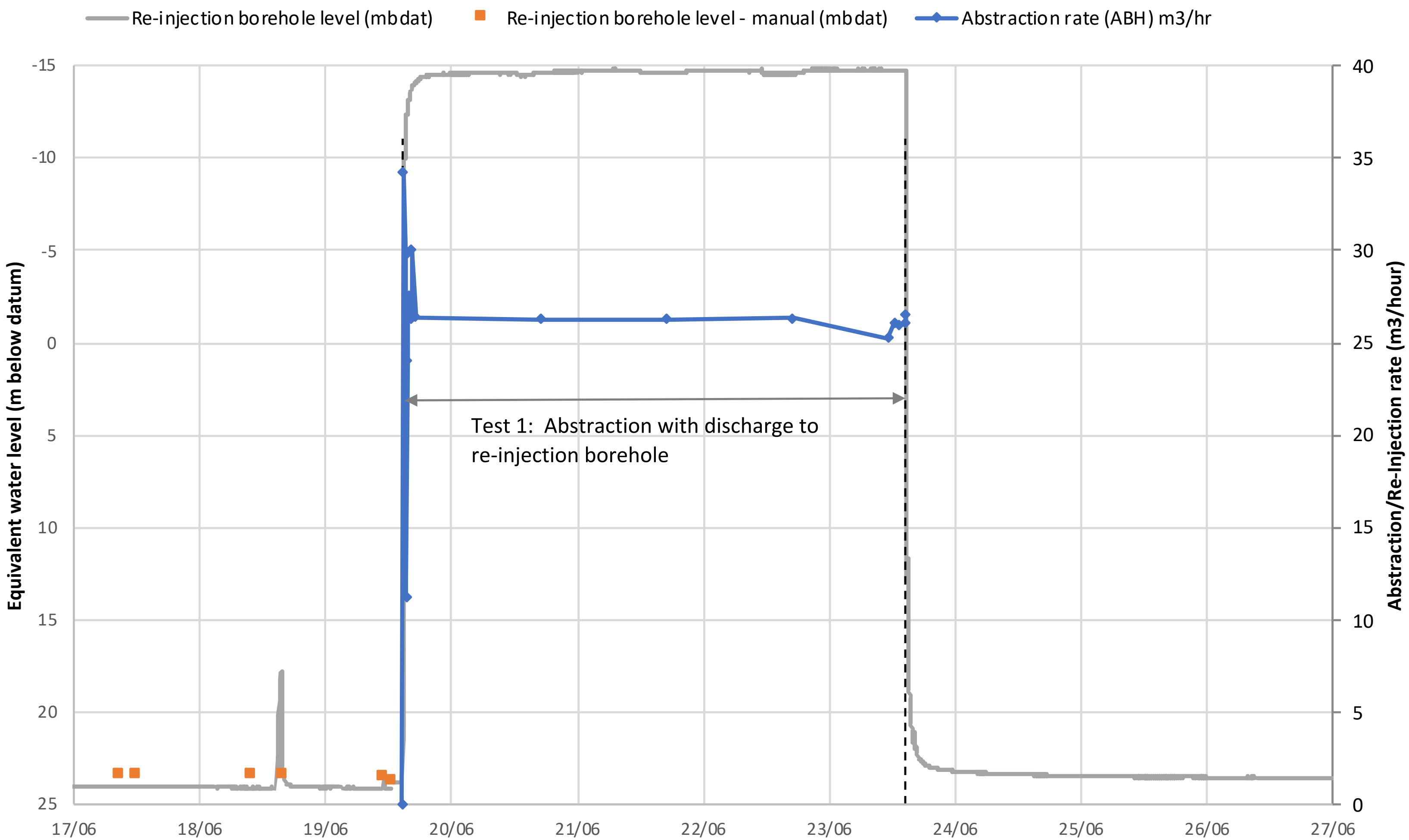

Figure 10. Water level within RIBH during Test 1 (abstraction from ABH with discharge to RIBH).

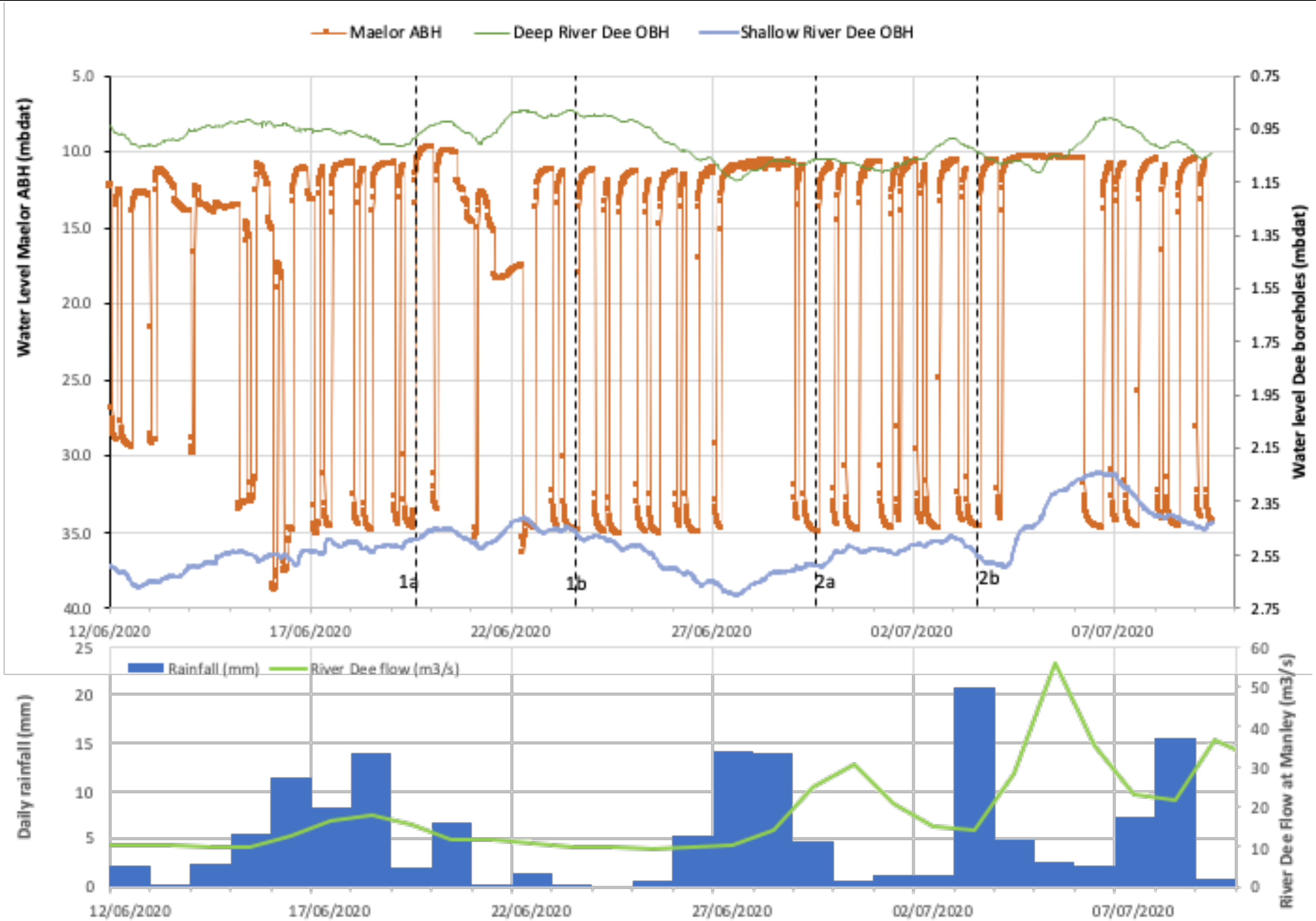

Figure 11. Water levels within Maelor production borehole and River Dee Observation boreholes. Data provided by Maelor. Rainfall and flow for River Dee at Manley plotted for reference.

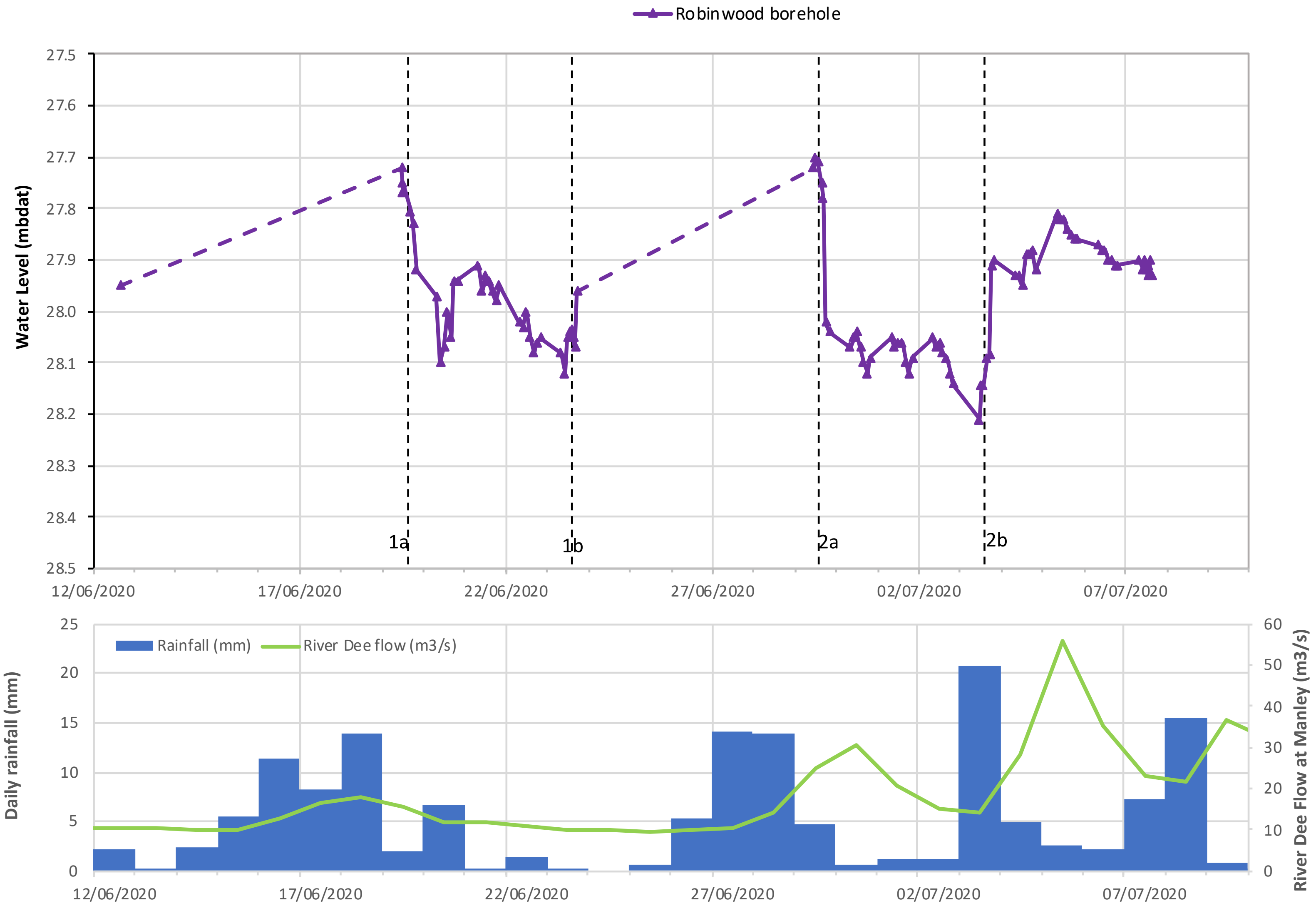

Figure 12. Water levels within Robinwood Activity Centre borehole. Rainfall and flow for River Dee at Manley plotted for reference.

5.2 Response within on-site boreholes

Test 1, comprising 4 days of constant abstraction and re-injection, commenced on June 19th at 14:34, the rest water level within the ABH was 25.57 metres below datum (mbdat). Abstraction began initially at around 34 m^3/hour dropping over the course of the first two hours before settling to a relatively constant rate of between 25.2 and 26.5 m^3/hour. The average abstraction rate over the course of the test was 26.1 m^3/hour. The drawdown in water levels within the abstraction borehole peaked at 6.4 metres at around 9 minutes in response to the initially high abstraction rate before settling at around 4.9 metres (30.46 mbdat) for the remainder of the test. On cessation of pumping, water levels within the abstraction borehole recovered to within 5% within the first 9 minutes.

During the test abstracted water was simultaneously discharged into the re-injection borehole. The rest water level within the re-injection borehole at the start of the test was 23.7 metres below datum. Pressure within the borehole rose quickly, reaching an equivalent water level of 14.44 metres above datum within 5 hours (Figure 10). Thereafter the pressure rose more slowly, eventually stabilising 36 hours after the start of the test at 14.72 metres above datum, an increase of 38.4 metres relative to the rest water level. On cessation of abstraction (and injection), water levels within the re-injection borehole recovered to within 5% within 95 minutes.

Test 2, comprising 4 days of constant abstraction, commenced on June 29th at 14:00. Abstraction rates were high for the first 10 minutes of the test and settled down after around 20 minutes pumping at a rate of between 22.51 m^3/hour and 23 m^3/hour for the remainder of the test. The average flow rate for the test was 22.58 m^3/hour. The drawdown in water levels within the abstraction borehole peaked at 6.2 metres in the first minute in response to the initially high abstraction rate before rising then steadily declining, flattening out at 5.67 metres for the final 2.5 hours of the test. On cessation of pumping, water levels within the abstraction borehole recovered to within 5% within 23 hours.

Prior to the commencement of Test 2, the water level within the re-injection borehole was at 23.78 mbdat. With the onset of pumping, water levels declined, sharply at first, then more gradually flattening out at 25.02 mbdat after 80 hours and remaining as such for the remainder of the test, a total drawdown of 1.24m.

5.3 Response within off-site boreholes

5.3.1 Maelor Production borehole

The Maelor Production borehole was operational throughout the testing period and this is evident in the hydrograph. When operational, pumping water levels within the borehole are at around 35 mbdat, rest water levels are at around 11 mbdat.

The start of Test 1 coincides with the Maelor borehole being shutdown. The borehole operated on each day of the test and was in operation at the end of the test. Rest water levels and pumping water levels during the test are consistent with those either side of the test.

The Maelor borehole was operational at least once a day during Test 2. As in Test 1, rest water levels and pumping water levels during the test are consistent with those either side of the test.

The testing at Black Rock Farm does not appear to impact on water levels within the Maelor Production borehole.

5.3.2 River Dee Observation Boreholes (OBHs)

The River Dee Observation boreholes are located around 150 metres from the Maelor Production borehole and are monitored as part of the Maelor abstraction licence. Between June 12th and July 9th the water levels with the boreholes have a similar profile; the level within the shallow borehole fluctuated by 0.5 metres, and within the deep borehole by 0.23 metres. Water levels are consistently higher within the deep borehole as compared with the shallow.

The water level was rising in the Shallow OBH prior to the onset of Test 1. This rise continued with the onset of the test on June 19th, peaking on June 22nd. Thereafter the water level dropped, and continued to drop after cessation of the test, reaching a minimum on June 28th. The level rose slightly during Test 2. Between July 4th and July 7th the water level rose steeply within the borehole; this coincided somewhat with a period of non-operation of the Maelor ABH and also followed a high rainfall event and peak flow in the River Dee.

The water level within the deep borehole follows a similar, albeit muted, profile to the shallow borehole, with a minimum water level on June 27th and maximum on July 7th, both outside the testing period.

Water levels show no obvious response to the testing at Black Rock Farm.

5.3.3 Robinwood Borehole

The Robinwood borehole was manually dipped over the period of testing, there being insufficient access for the installation of a data logger. The borehole is used for the top up of a large pond at the site. The pump operates for short periods at a time pumping only a small quantity of water. Whilst the Robinwood activity centre was closed during the monitoring period, the borehole was still in operation.

Unfortunately background data for the site are limited in extent. Over the course of the monitoring period water levels ranged between 27.70 mbdat (June 29th) and 28.21 mbdat (July 3rd).

A manual dip taken on 12th June prior to testing was 27.95 mbdat, the rest water level at the start of Test 1 was somewhat higher at 27.77 mbdat. Within the first 17.5 hours of pumping water levels had declined to 28.10 mbdat (33 cm drawdown), levels then rose to a peak of 27.91 mbdat before steadily declining to 28.12 mbdat (35 cm drawdown) at 10:04 on June 23rd. For the final 4.5 hours of the test, water levels rose slightly such that the water level at the end of the test was 28.04 mbdat (27 cm drawdown). Water levels continued to rise on cessation of the test, however the data post-testing is limited.

Immediately prior to Test 2, the water level within the Robinwood borehole was at 27.71 mbdat. Water levels fell on the commencement of pumping, steeply at first before fluctuating at around 28.07 mbdat. A further drop occurred near the end of the test, water levels reaching a minimum of 28.2 mbdat at 10:45 on July 3rd. The water level then started to rise and continued to rise on cessation of pumping peaking at 27.81 mbdat on July 5th before steadily declining until monitoring ended on July 7th.

At the end of the monitoring period, rest water levels were still below those recorded at the start of Test 2, though still within the background range for the borehole.

The data appear to suggest a drawdown in the Robinwood Borehole of 0.27 metres in response to Test 1, and 0.44 metres in response to Test 2, however the lack of background data hinders this determination. The fluctuations in water level observed in the Robinwood borehole during the tests (particularly during Test 2 when a fairly regular rise and fall was seen) are likely associated with the operation of the Robinwood borehole itself.

5.3.4 Wrexham Observation borehole

Water level data has been made available by Natural Resources Wales for an observation borehole at a site in Wrexham (SJ34/57B), located some 2.2 kilometres north-east of the Black Rock Farm ABH, outside of the search area for the Water Features Survey. The borehole is completed within the Salop Formation, the Kinnerton Sandstone Formation being absent in the area. No impact from the testing is apparent (Figure 13); over the month-long period of the monitoring data, water levels fall only very slightly in line with a regional summer regression.

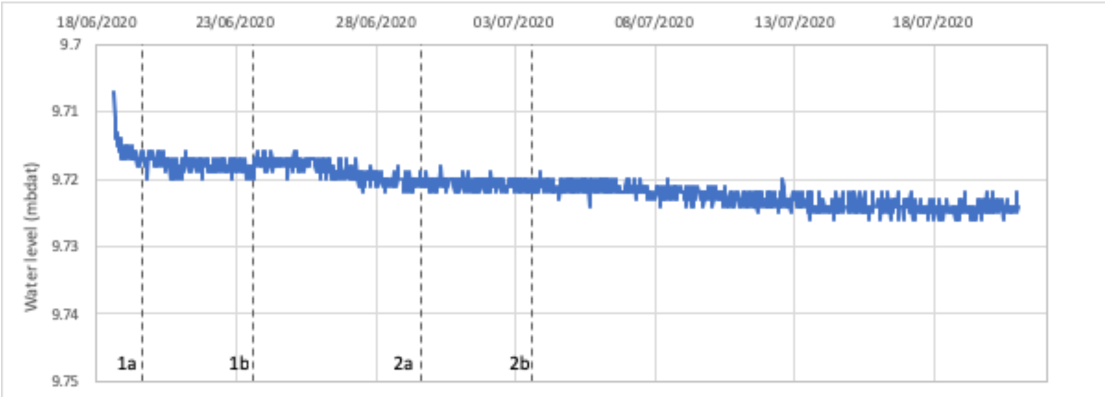

Figure 13. Groundwater levels with Wrexham Industrial Estate OBH SJ34/57B

5.4 Test analyses

5.4.1 Test 2

Plots of drawdown against time for the ABH and RIBH for Test 2 (ABH abstracting, no re-injection) are shown in Figure 14.

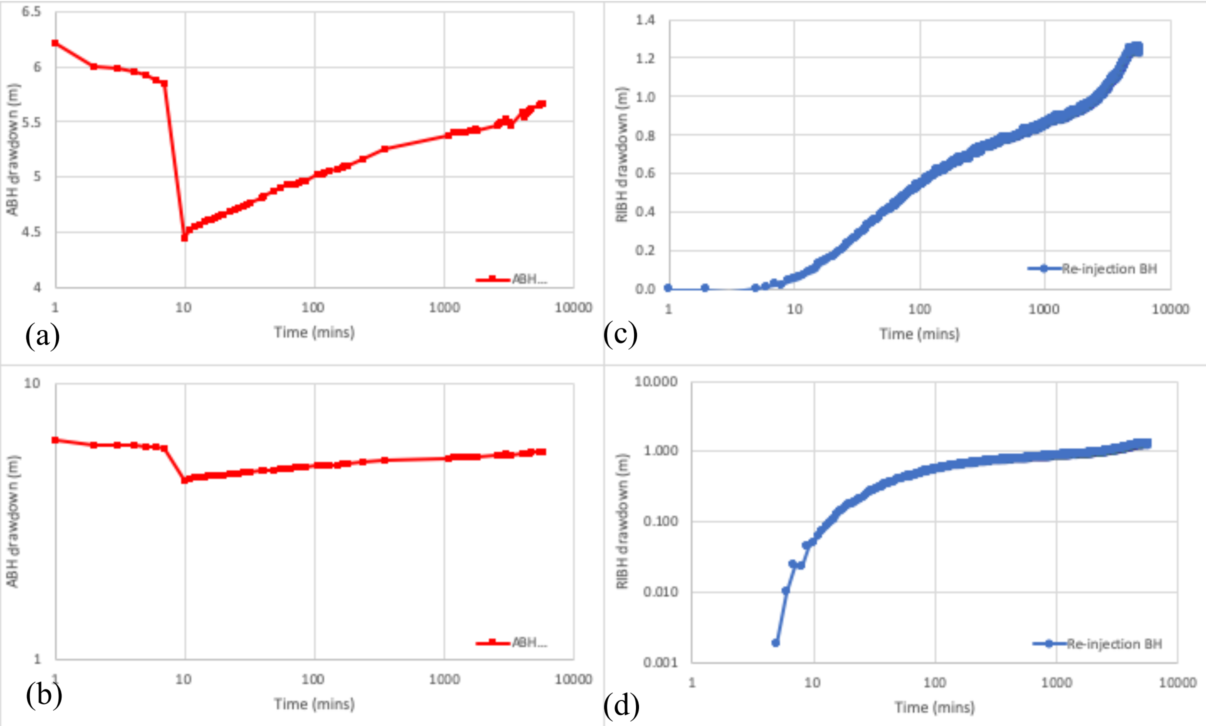

Figure 14. Semi-log and log-log plots of drawdown against time for the ABH and RIBH.

The response in the abstraction borehole (a,b) is masked by the initially high abstraction rate, thereafter drawdown steadily increases with time. A slight flattening in the rate of drawdown occurs after around 350 minutes followed by an increase in the rate of drawdown after around 3200 minutes, drawdown is stable at the end of the test. Much of the response seen within the re-injection borehole (c, d) is typical of the behaviour noted in Section 4.1. Within the early stages, up to around 230 minutes, a confined response is observed. There then follows a transition period in which the drawdown data depart from the confined type curve, showing smaller than expected values; this likely reflects a component of vertical flow as drainage takes place from saturated material within the cone of depression (delayed yield). As pumping continues the rate of drawdown again increases as the cone of depression expands more slowly and the drainage of pores within the cone is able to catch up and keep pace with the growth of the cone.

AquiferWin32 was used to plot and analyse the logger data in the abstraction borehole for the constant rate tests and recovery data.

Modelling Test 2 (abstraction only, no re-injection), Figure 15 shows the Cooper and Jacob approximation (confined aquifers), which gave a transmissivity value of 254 m^2/day.

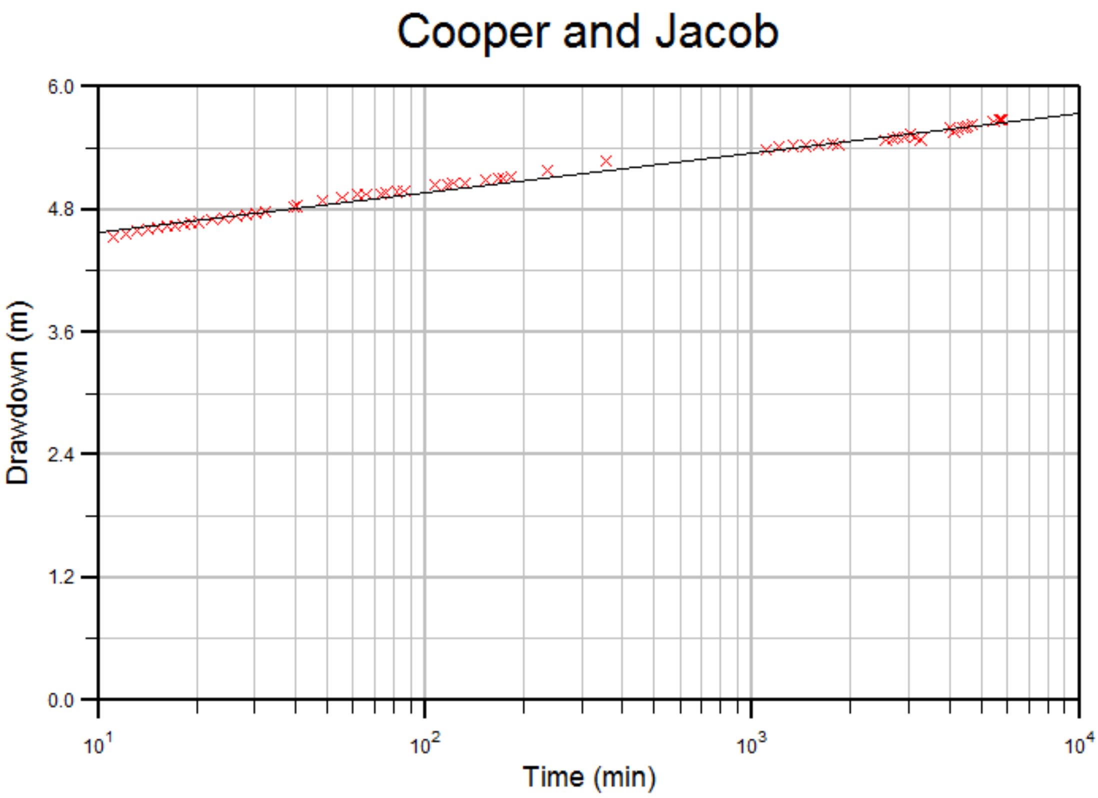

Figure 15. Cooper-Jacob plot, ABH data, Test 2

Using the Theis (confined) method, a transmissivity of 254 m^2/day was also calculated (Figure 16).

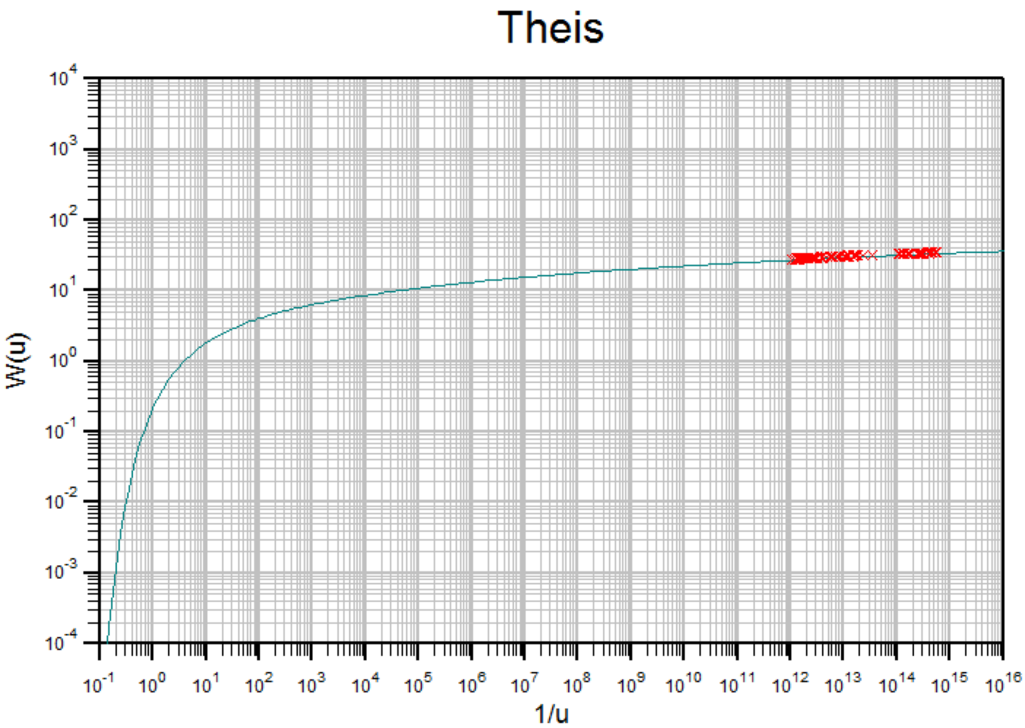

Figure 16. Theis analysis, ABH data, Test 2

Recovery data produced different gradients at early and late time, which can be seen in following figures. The early time data (Figure 17) produced a T value of 153 m^2/day, and a transmissivity value of 8 m^2/day was derived from the late time data (Figure 18).

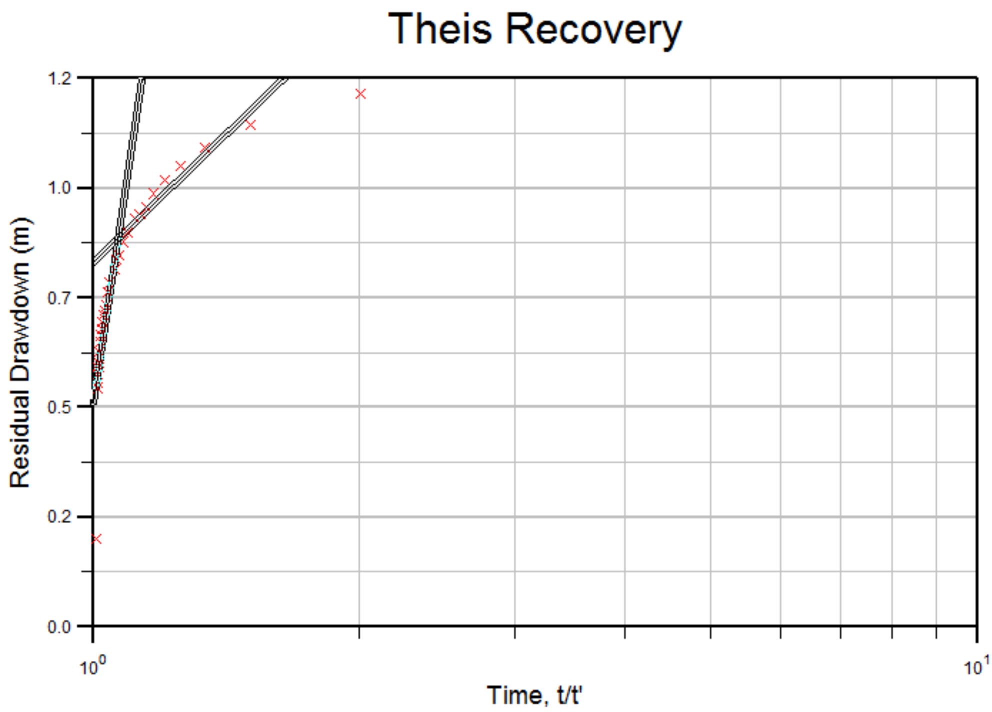

Figure 17. Theis analysis of early recovery data, ABH, Test 2

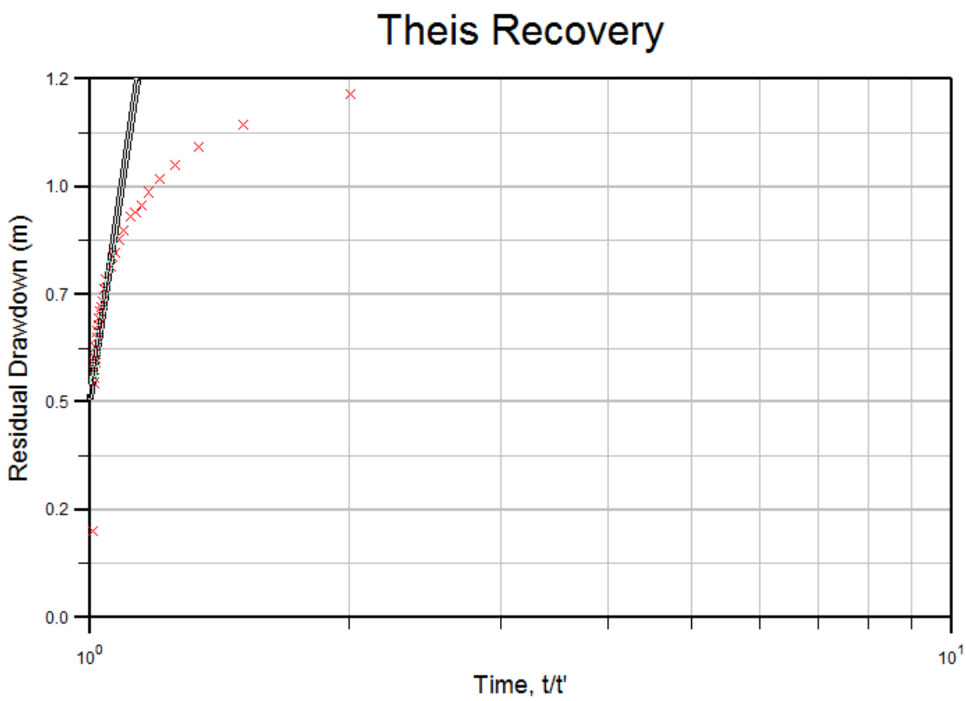

Figure 18. Theis analysis of late recovery data, ABH, Test 2

Time-drawdown analysis of the data from the re-injection borehole has been undertaken applying the Cooper-Jacob method (Figure 19). Early data give a transmissivity of 187 m^2/day and a storage coefficient of 2.0 x 10^{-4}, consistent with a confined response in the early data. Late data give a transmissivity of 95 m^2/day and a storage coefficient of 3.3 x 10^{-3}.

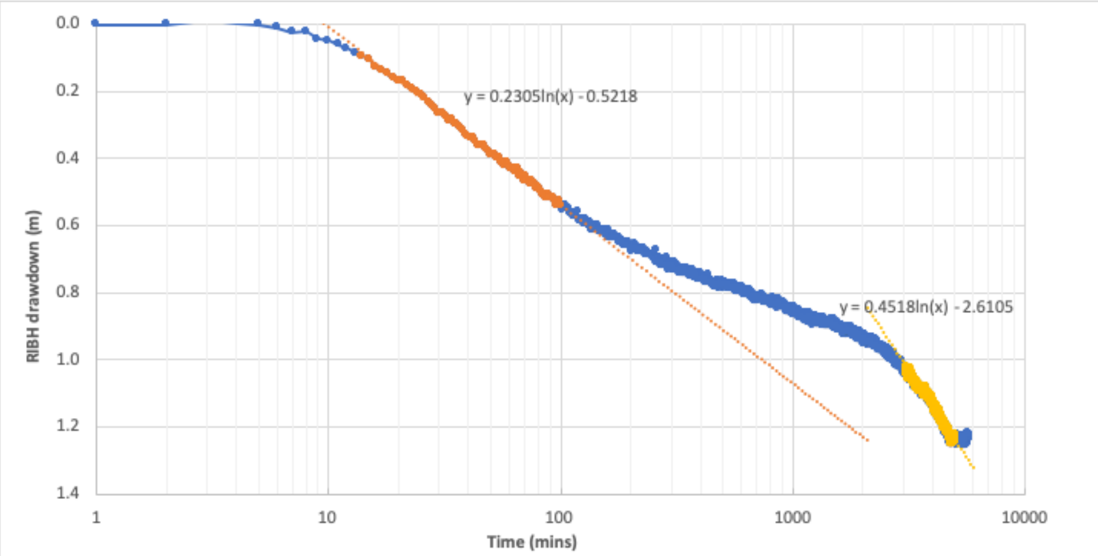

Figure 19. Time-drawdown plot for Cooper-Jacob analysis of RIBH data, Test 2

Theis analysis of the RIBH drawdown data is presented in Figure 20. A transmissivity of 231 m^2/day and a storage coefficient of 4.0 x 10^{-4} were calculated.

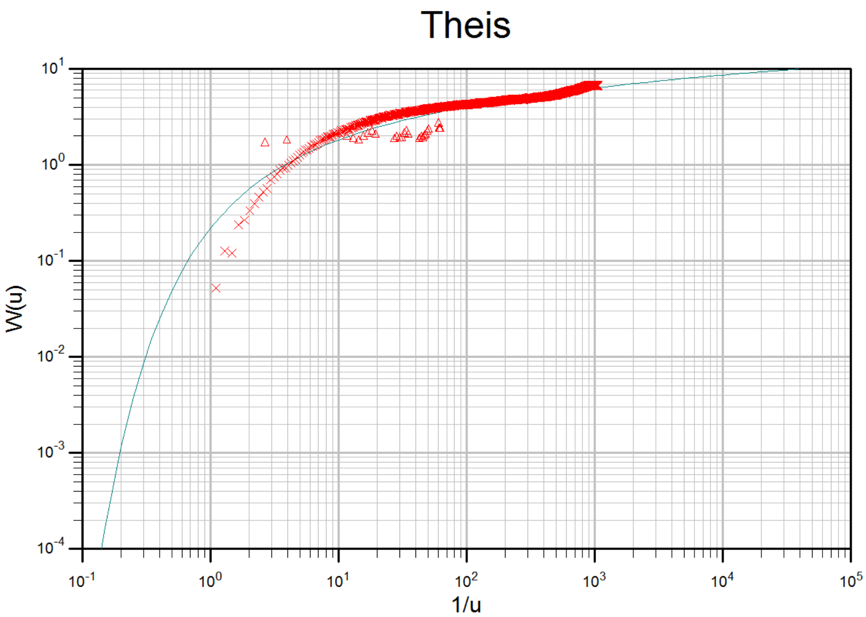

Figure 20. Theis analysis, RIBH data, Test 2

The drawdown at the end of Test 2 observed at Robinwood and the RIBH is plotted as a function of distance in (Figure 21).

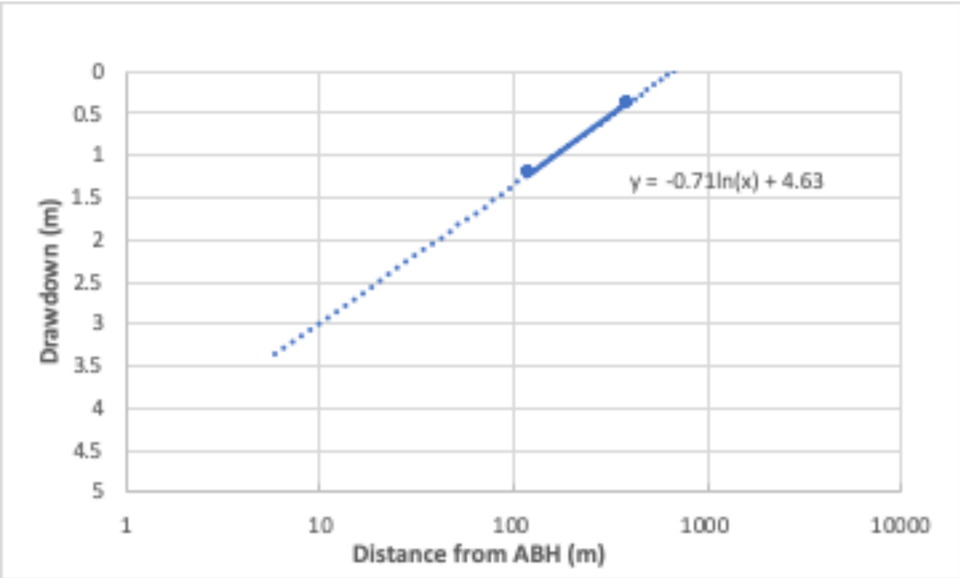

Figure 21. Distance drawdown plot for RIBH and Robinwood OBH

Applying the Cooper Jacob method to distance-drawdown, gives a transmissivity of 121 m^2/day and a storage coefficient of 2.5 x 10^{-3}. The storage coefficient is within the range calculated for the Permo-Triassic sandstones within the region.

5.4.2 Test 1

Time-drawdown analysis of the data from the re-injection borehole for Test 1 (abstraction and re-injection) has been undertaken applying the Cooper-Jacob method.

Early, mid- and late data for the injection phase of the test give transmissivity values of 3, 10 and 286 m^2/day respectively (Figure 22).

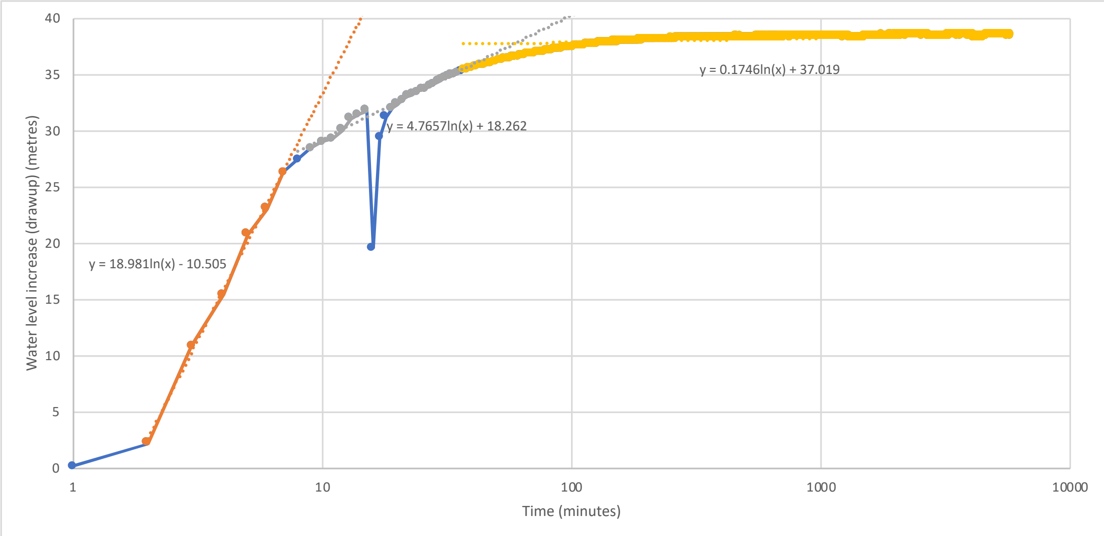

Figure 22. Time – drawdown Cooper Jacob plot. RIBH,injection phase of Test 1.

Early, mid- and late data for the recovery phase of the test give transmissivity values of 7, 16 and 190 m^2/day respectively (Figure 23).

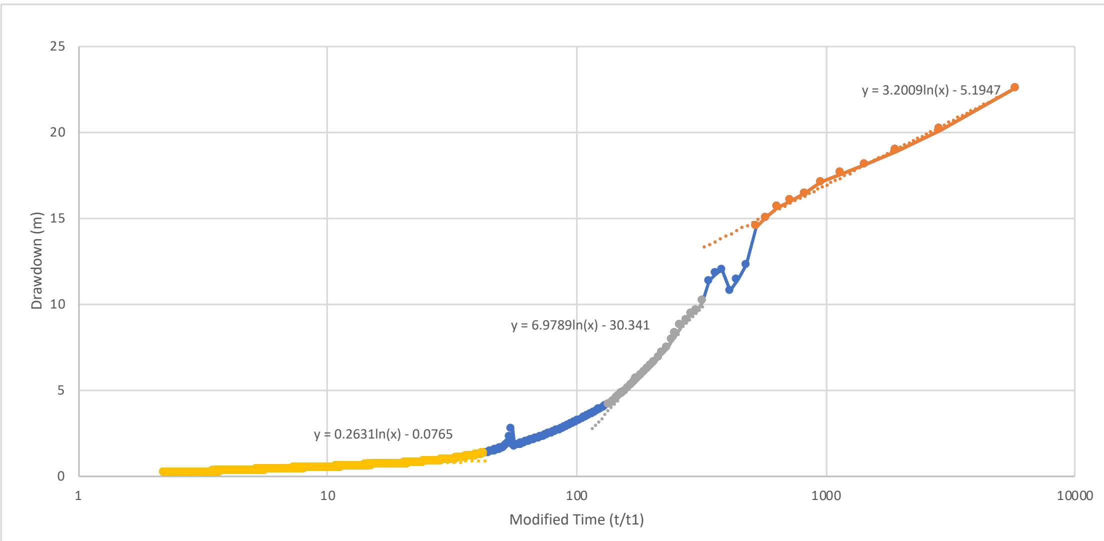

Figure 23. Time – drawdown Cooper Jacob plot. RIBH,recovery phase of Test 1.

The analyses are summarised in Table 9.

Analysis	Transmissivity (m^2/day)	Storage Coefficient
Test 2, ABH, Cooper-Jacob	254	N/A
Test 2, ABH, Theis	254	N/A
Test 2 Recovery, ABH, Copper-Jacob	153 (early), 8 (late)	N/A
Test 2, RIBH, Cooper-Jacob	187 (early), 95 (late)	$2.0x10^{-4}$ (early), $3.3x10^{-3}$ (late)
Test 2, RIBH, Theis	231	$4.0x10^{-4}$
Test 2, RIBH & Robinwood, Cooper--Jacob	121	$2.5x10^{-3}$
Test 1, RIBH, Cooper-Jacob	3 (early), 10 (mid-), 286 (late)	N/A
Test 1 Recovery, RIBH, Cooper-Jacob	7 (early), 16 (mid-), 190 (late)	N/A

Table 9. Summary of hydrogeological parameters determined from test analyses.

Based on analyses of the test data, the Kinnerton Sandstone Formation beneath the site has a transmissivity in the range 100 to 200 m^2/day and a storage coefficient of the order 10^{-4} to 10^{-3}.

5.5 Temperature Data

A temperature probe was installed in the injection borehole at a depth of around 35 metres, within the screened section of the borehole and around 12 metres below rest water level. The probe measured water temperature at one minute intervals throughout the test period. The temperature data are plotted in Figure 24.

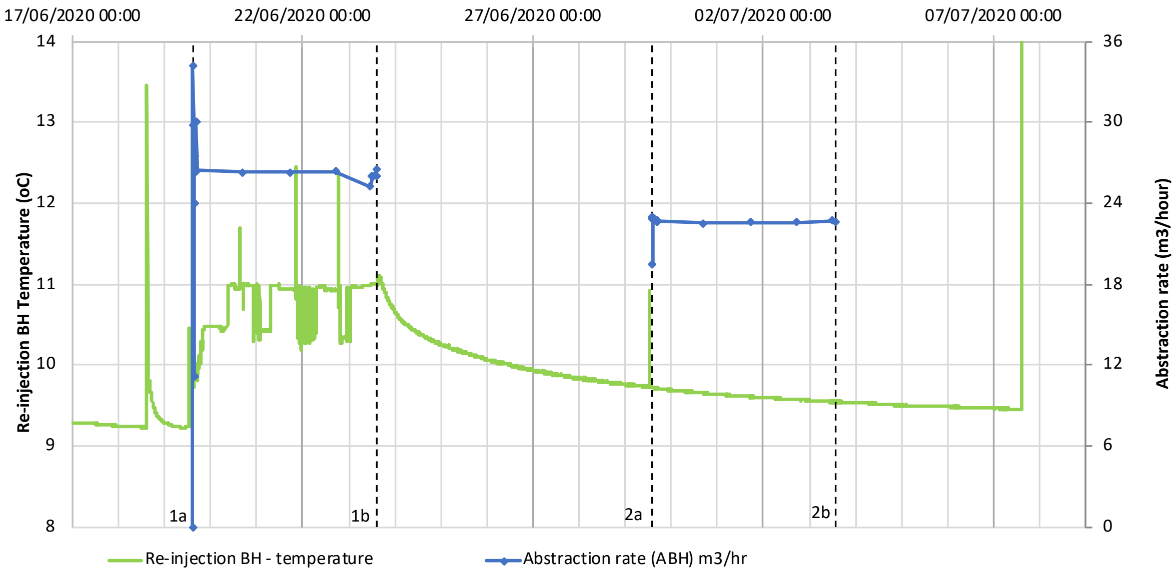

Figure 24. Re-injection borehole, temperature profile.

Prior to the first test, the background water temperature as measured by the probe was around 9.2°C; this reflects the temperature of the water column within the uppermost screened section of the borehole and is not truly representative of the temperature of groundwater within the aquifer. During the first test, water abstracted from the abstraction borehole passed through the GSHP system prior to being discharged to the re-injection borehole. *However, the heat exchangers were not operational during the test.* On commencement of re-injection, the temperature within the re-injection borehole increases, plateauing at around 10.9°C with occasional spikes to 12.4°C and some daily periods of fluctuation down to around 10.3°C. On cessation of re-injection, the temperature within the borehole is seen to decay steadily; there is no impact from the test pumping of the abstraction borehole (with the exception of a small spike around the start of the test).

The temperature of water re-injected to the borehole is representative of the temperature of groundwater within the Kinnerton Sandstone aquifer freshly abstracted via the abstraction borehole. This is slightly warmer than the temperature of the relatively undisturbed water within the re-injection borehole.

6 Conclusions

During Test 1 (abstraction and re-injection), the Black Rock Farm abstraction borehole (ABH) operated for 4 days at an average rate of 26.12 m^3/hr (626.9 m^3/day). During Test 2 (abstraction only), the average rate of abstraction was 22.58 m^3/hr (545.0 m^3/day). In both tests a steady state was achieved whereby the water level within the abstraction borehole was stable in the latter stages of the tests (total drawdown of 4.9 m for Test 1, and 5.7 m for Test 2).

A clear response to abstraction from the ABH was seen within the re-injection borehole during Test 2, a drawdown of 1.24 metres being recorded at the end of the test. As with the ABH, water levels were stable in the RIBH at the end of the test.

The Maelor production borehole (1440 m from the ABH) and River Dee observation boreholes (1550 m distant) showed no apparent response to the testing at Black Rock Farm.

The borehole at Robinwood Activity Centre, 390 metres from the ABH, appeared to show some response to testing; a drawdown of 0.27 metres was recorded at the end of Test 1 and a drawdown of 0.44 metres at the end of Test 2. Unfortunately, background monitoring data are limited for the site, furthermore the borehole itself was operating intermittently throughout the test period. As a worst case scenario, it is thus assumed that the change in water level during the tests is entirely attributable to the testing.

Water levels within the Robinwood borehole had fully recovered from Test 1 prior to the start of Test 2 (unfortunately there are insufficient data points to determine how long this recovery took). When monitoring ended on July 7th, 4 days after the cessation of Test 2, water levels within the borehole were still lower than at the start of the test, though within the background range for the borehole. Again, due to their being insufficient background data it is unclear if this is fully attributable to the test. In any case, the conditions of Test 2 (abstraction only with no re-injection) are not representative of the planned non-consumptive scheme (abstraction and re-injection).

Extrapolating the drawdown observed in the RIBH and Robinwood borehole, the radius of influence associated with the Test 2 is around 660 metres. The Robinwood borehole is the only known operational borehole within this area of influence. Surface water features within the area tend to be perched above the water table within the Kinnerton Sandstone aquifer; the Upper Boulder Clay offering a degree of hydraulic isolation from underlying strata.

The proposed abstraction is to be non-consumptive; abstracted groundwater will be discharged back into the same aquifer. The response seen in the Robinwood borehole to the simultaneous abstraction and recharge test (Test 1), was an apparent drawdown in water level of 0.27 metres. Whilst the Robinwood borehole is 390 metres from the ABH, it is approximately 500 metres from the point of re-injection (RIBH); the apparent drawdown seen at Robinwood in Test 1 is thus a factor of drawdown associated with the ABH offset by re-injection at the more distal RIBH.

The rate of abstraction/re-injection during Test 1, equated to 626.9 m^3/day, some 86.9 m^3/day (16 %) more than the daily rate being sort by this licence application (540 m^3/day). The impact at Robinwood is thus likely to represent a maximum impact at the site; with lower abstraction rates the impact would likely be reduced. It is unlikely that the drawdown noted would have an impact on the operation of this small source. Furthermore the need for pond top up water is likely to be greater in the summer months, whilst the demand for the GSHP system will be greater in the winter months.

Black Rock Farm sits within Source Protection Zone 2 of an abstraction at Refresco (Cott Beverages). Unfortunately monitoring data has not been made available for the site. However, given that no response was seen at the Maelor boreholes (1440 metres distant), the Refresco site (1900 metres distant) is thought to be outside the radius of influence of the abstraction. Furthermore, the Refresco abstraction is closer to the point of re-injection than it is to the point of abstraction; north of the RIBH re-injection is likely to have a greater influence on groundwater levels than abstraction.

Based on the results and analysis, B. A. Hydro Solutions Ltd. recommends the client be licensed to abstract the proposed yield of 30 m^3/hour / 540 m^3/day / 103,109 m^3/year.

References

Allen, D.J, Brewerton, L.J., Coleby, L.M., Gibbs, B.R., Lewis, M.A., MacDonald, A.M., Wagstaff, S.J. and Williams, A.T. 1997. The Physical properties of major aquifers in England and Wales.