Kinnerton Boreholes - Additional Water Resources Assessment

Prepared for Heidelberg Materials UK

CONFIDENTIAL

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Quality Control Sheet

Title	Additional Water Resources Assessment
Client	Heidelberg Materials UK
Issue Date	22/02/2024
Reference	3490192 Hanson Padeswood (P22-064) \ RPT Additional Water Resources Assessment

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Revision History

Revision	Details	Prepared by	Checked by	Approved by	Issue Date
REV01	Review by authors & client	JED	DT		20/02/2024
REV02	Final draft for internal review	JED	PH	PH	22/02/2024
REV03	Final issue	JED		PH	23/02/2024
REV04					

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1 INTRODUCTION

1.1 Background

Envireau Water has submitted an application to NRW on behalf of Heidelberg Materials (formerly Hanson), to vary two existing abstraction licences to authorise an increase in licensed abstraction from the Kinnerton Boreholes from 60 m^3/hour (1,500 m^3/day, 136,500 m^3/year) to 165m^3/hour (3,960 m^3/day, 1,445,400 m^3/year), an increase of 105 m^3/hour (2,460 m^3/day, 1,308,900 m^3/year). The increase is necessary to support the Padeswood CCS project, a nationally significant carbon capture project within Wales and the UK. The location of the site is shown on Figure 1.

The application was supported by a detailed technical report, dated March 2023, which provides details of a 4 day pumping test conducted on the Kinnerton boreholes under Groundwater Investigation Consents (GIC) WA/067/0009/0001 and WA/067/0009/0002, issued by Natural Resources Wales (NRW) in December 2022.

In determining the application, NRW has raised concerns that the technical report does not address issues related to groundwater / surface water interaction in the wider hydrogeological setting, and that the impact of the proposed variation on the regional groundwater flux and the concomitant cumulative effects of the proposed changes together with other large abstractions from the groundwater catchment have not been considered.

A meeting was held between NRW, Heidelberg Materials and Envireau Water on 28th September 2023 during which the concerns were discussed, and it was agreed that a scope of work for an additional desk based water resources assessment to assist in the determination of the application, would be provided.

1.2 Objectives

The objective of the additional water resources assessment is to collate hydrogeological information on the wider / regional groundwater catchments both up gradient and down gradient of the Kinnerton boreholes, in order that catchment scale effects can be considered. In particular (but not exclusively) the assessment should consider:

- Groundwater / Surface water interaction with the River Dee and its tributaries;
- Assessment of the groundwater flux that the Kinnerton boreholes intercept and the effects of the increase in abstraction;
- Development of a water balance including recharge, that takes account of the proposed increase in abstraction; and
- The presentation of a qualitative impact assessment in a standard format (e.g. Greenleaves III or similar).

This report presents the conceptual model, numerical analysis and impact assessment, and is designed to support the test pumping report.

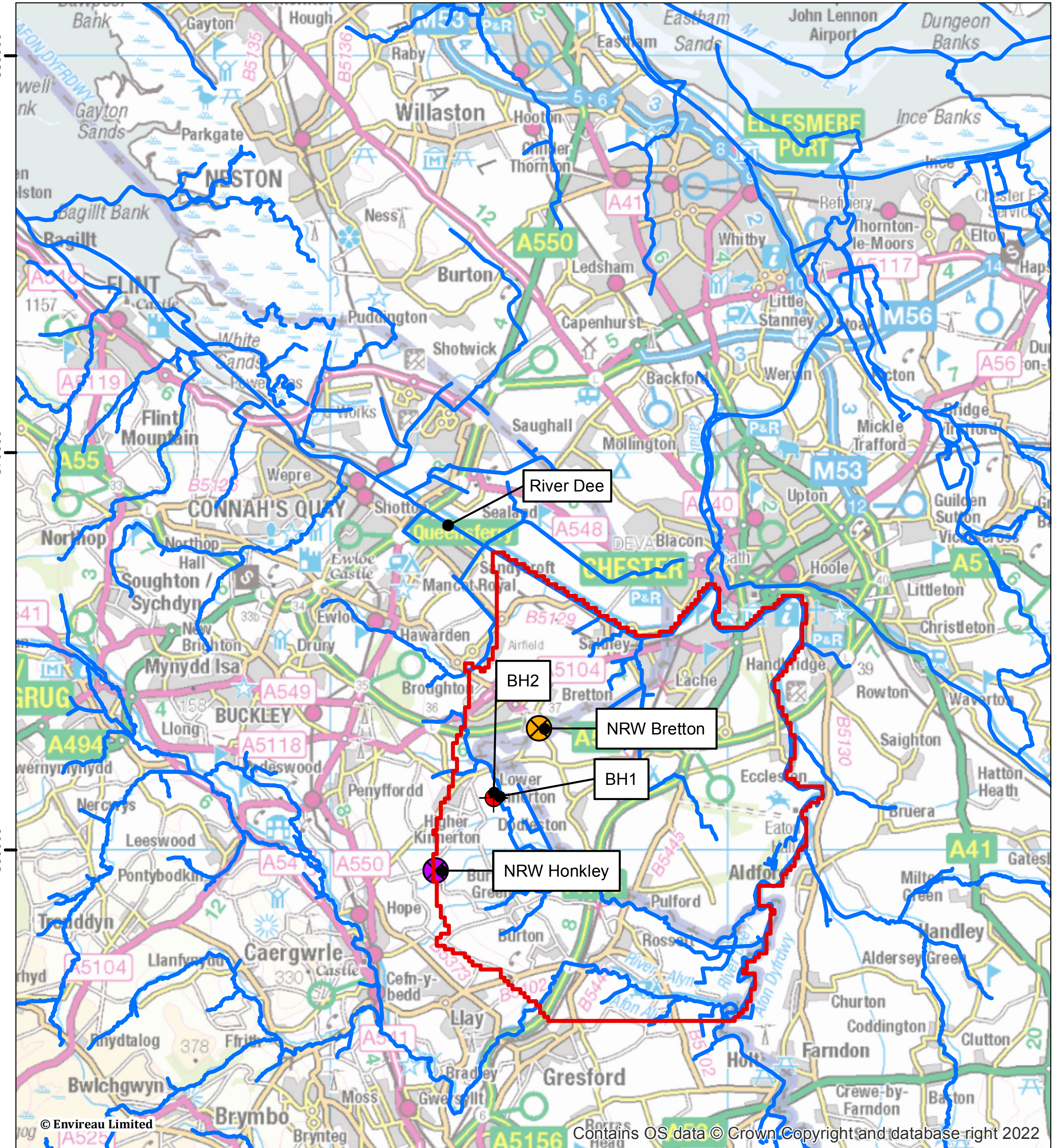
1.3 Data Sources

The information and assessments in this report are based on:

- A comprehensive literature review by JH Groundwater;
- Numerical analysis by Groundwater Science;
- Hydrogeological analysis & risk assessment by Envireau Water; and
- British Geological Survey (BGS) and Ordnance Survey mapping.

Figure 1: Site Location and Setting

Padeswood, Flintshire



Model Boundary

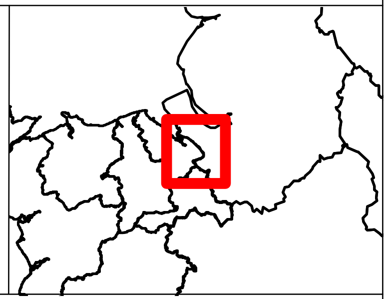
Kinnerton Abstraction

- BH1 Licence Ref. 24/67/9/0137
- BH2 Licence Ref. 24/67/9/0126

Monitoring Locations

- NRW Bretton
- NRW Honkley
- Watercourse

Notes:



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NGR: 335,125 E / 366,898 N

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Ref: Site Setting

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2 LITERATURE REVIEW

A literature review has been undertaken which has considered 22 literature sources which discuss the properties and characteristics of the Permo-Triassic aquifer in the Cheshire and Wirral region. The review included many documents requested by NRW. Focus has been given to the hydraulic interaction between bedrock and overlying glacial superficial deposits. The review considers the geology and hydrogeology, a review of rainfall recharge and the anticipated interaction between groundwater in the superficial glacial deposits (drift), sandstone bedrock and surface water. A full list of the sources is provided in the reference list at the end of this report.

2.1 Overview of geology and hydrogeology

A general overview of the Permo-Triassic (Sherwood Sandstone Group) sequence is included in Griffiths et al (2002), who summarise the bedrock geology in the West Cheshire and Wirral region. The sequence consists of channels sands, silts and mudstones, together with some wind-blown deposits. The Kinnerton Sandstone into which the abstractions are installed comprises aeolian deposits. ESI (2006) reiterates the depositional environment of the Kinnerton Sandstone, which comprises cross-stratified aeolian sediments and sits at the base of the Sherwood Sandstone Group sequence. It most likely spans the boundary between the Permian and Triassic systems and has an estimated thickness of between 10 to 380m.

Allen et al (1997), notes that aquifer properties of the Permo-Triassic sandstones are greatly affected by their sedimentary structure and by post-depositional diagenesis. Fine-grained layers within the Permo-Triassic sandstone have lower permeabilities and can act as confining layers. However, Streetley (2023) noted that the predominantly aeolian, Permian deposits (i.e. the Kinnerton Sandstone) have relatively low proportions of fine-grained material and are cross-bedded on a metre rather than decimetre scale which is more typical of the fluvial deposits.

Robins and Davies (BGS, 2016) conclude that significant yields are abstracted from the Triassic Kinnerton Sandstone Formation in the Dee catchment and that for the most part the aquifer is concealed by thick glacial deposits. ESI (2006) note that drift deposits extend over about 60% of the area. Robins and Davies further note that that there are a number of silty horizons in the Permo-Triassic bedrock as a whole which impede vertical flow but, as seen above, such horizons may be limited in the Kinnerton Sandstone.

Griffiths et al (2002), summarise the superficial drift geology for the West Cheshire and Wirral region. They note that the area underwent extensive glaciation and this has smoothed the topographic surface of the bedrock and has resulted in substantial thicknesses in places as is evident locally. Earp et al (2002) estimated that greater than half of the area is overlain by at least 2m of clay drift, although this is mapper to be considerably thicker in the area around the boreholes. The till limits recharge and confines the underlying aquifer.

Much of the discussion in the literature covers the wider West Cheshire and Wirral region. However, LWRC (2000) discuss the geological and hydrogeological conditions within the Chester sub-unit. They note that over 95% of the Chester unit is often covered with very thick drift. This includes the area where the boreholes are located within the deep rockhead channel to the west of the River Dee at the western edge of the unit. LWRC (2000) conclude that the drift is broadly separated into a characteristic sequence of boulder clay, sands, gravels and basal clays. However, the drift clays which represent lacustrine deposits or clay tills derived from the Welsh hills are thick in the western part of the unit and as a consequence substantial confined heads of 5 - 10 metres develop in the drift sands below them particularly in the Dodleston area.

Consideration of the detail of the drift sequence was given by Simpson & Partners (1996). They described the classical nomenclature of Lower Boulder Clay overlain by Middle Sands and then Upper Boulder Clay and in places Upper Sands. WMC (2003) also notes a three-component drift sequence; Lower Boulder Clay, Middle Sands and Upper Boulder Clay, which weas historically categorised by Hull (1864).

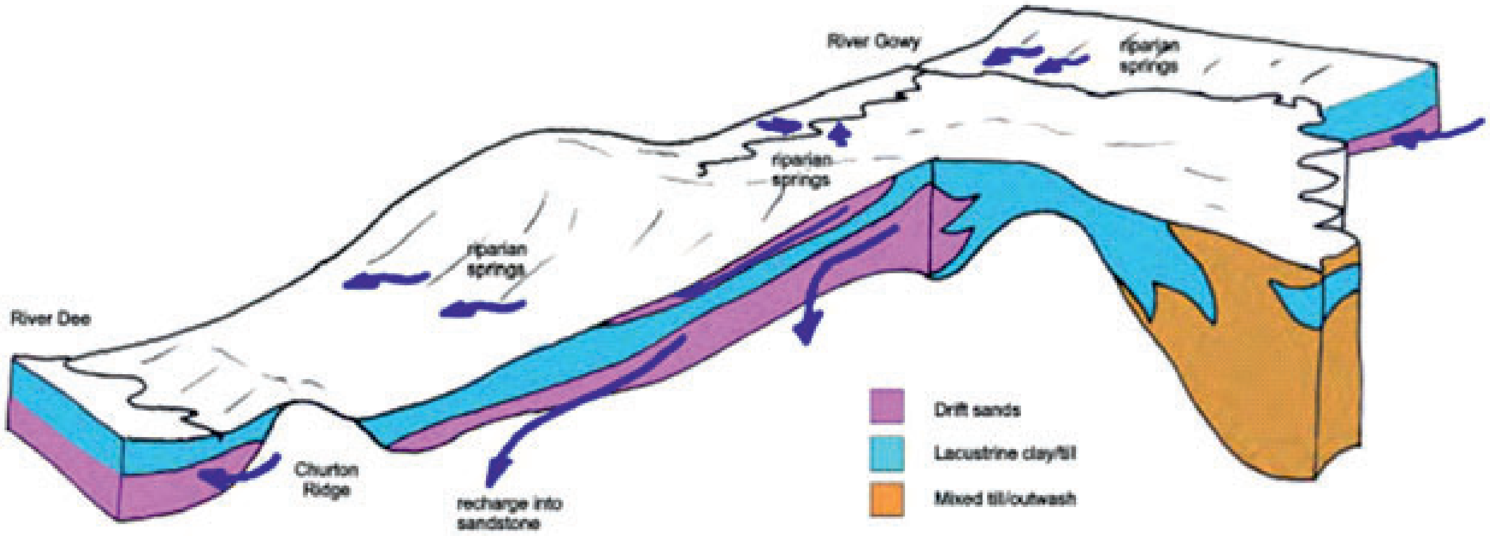
The Middle Sands were thickest in the extreme northern and southern parts of the area. In general, the Middle Sands were said to be 30 - 40 m thick and often covered by Upper Boulder Clay.

Simpson & Partners (1996) report stated that the most extensive drift deposit was the Upper Boulder Clay. This was overlain by glacial sand and gravel in places, although this is not shown to be the case locally.

LWRC (2000) also summarise the characteristics of the drift deposits. The thickness of the deposits locally is shown to be significant and at least 50m thick. The drift is composed of layers of deposits ranging from very high permeability sands and gravels to very low permeability lacustrine clays and tills. The site is located on the latter. The permeable deposits are normally interleaved between lower permeability clays and till and horizontal or lateral hydraulic contact will often be better than vertical hydraulic because of this clay. Where present, permeable deposits within the drift can be in good but discrete hydraulic continuity with the rockhead below and are also discretely exposed at ground surface. These receive recharge from rainfall and from surface runoff. However, the abstraction boreholes are shown to be located on low permeability till. LWRC (2000) further note that in the River Gowy catchment, whilst there is good contact where permeable drift overlies the bedrock, upstream of Huxley and downstream of Bridge Trafford superficial clays and tills become thicker and hydraulic contact with the main surface watercourse is poor (Figure 2).

Simpson & Partners (1995) made an implicit distinction between the till and the Sands and Gravels stating that “the till deposits contain little or no groundwater” and concluding that “the main hydrogeological significance of the till is its ability to limit groundwater recharge to the underlying sands and gravels”. In this sense it echoes the conclusions of Vines (1984). He stated that the drift deposits consisted largely of Boulder Clay and would be characterised by low permeabilities. The distribution of permeabilities was skewed strongly to the lowest end of the range and clays proved to be predominantly over consolidated and this characteristic was said to be typical of the Boulder Clays of the region as a whole.

Mapping at 1:50 000 scale reproduced at BGS (2024) shows that the area around the abstraction boreholes is covered with boulder clay. The closest outcrop of sands and gravels is situated at a distance of more than 1.5km to the west of the site, with another area approximately 2km to the south. The thickness of those sand and gravel outcrops has not been established. An area of lacustrine clay and silt is located approximately 250m to the east. Like the boulder clay this is considered to be low permeability.



A View of aquifer blocks with anterior sections removed

Figure 2: Drift in the Upper Dee area (LWRC 2000)

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Project No. 3490192 Hanson Padeswood

Client: Heidelberg Materials

Drawn by: JED

Ref: 3490192 Hanson Padeswood \ Figure 2

Simpson & Partners (1995) identified the glacial sands and gravels as an aquifer within the Quaternary deposits. The description of their physical form and characteristics implied that the Quaternary deposits were randomly distributed both spatially and vertically. Where present, sands and gravels were described as being generally over 25 m thick in hollows or buried valleys but could be up to 50m thick.

LWRC (2000) suggest that in general the hydraulic characteristics of both the sandstones and the drift produce a slow response to changes in abstraction or recharge. Vertical flows will dominate the western part of the unit in the deep sandstone. They note that the groundwater system is multi-layered. Flows will be more rapid in the thick drift sands which fill the buried channel west of the River Dee driven by steep hydraulic gradients created in the Wrexham Sands and the large volumetric inflows of groundwater from the Upper Dee and Peckforton areas.

Robins and Davies (BGS, 2016) state that regionally groundwater flow in the bedrock is essentially longitudinal towards Chester, but local flow in the glacial deposits may be lateral towards the River Dee. It is noted elsewhere that throughflow in the glacial deposits represents a high component of shallow flow in the more permeable sands and gravels. Vines (1984) noted that boreholes penetrating the buried channel have artesian pressure and that the channel may be acting as a hydraulic barrier to vertical flow resulting in large drawdowns in pumping boreholes within the channel.

2.2 Interaction between drift and bedrock

The role and complexity of hydraulic performance of the drift deposits was noted by Streetley (2023), who summarised that much of north western UK has a thick and complex sequence of Devensian (glacial) and Holocene (postglacial) deposits overlying the subcrop of the Permo-Triassic Sandstone. These strata may control both recharge to the aquifer and discharge from it to surface waters. Unfortunately, owing to their complex nature in three dimensions and the generally low levels of available borehole data of adequate quality, it is often very difficult to constrain the spatial distribution and properties of these deposits to a satisfactory degree. One of the first areas in which this was attempted in detail was West Cheshire. The preliminary conceptual model study (LWRC 2000) concluded that the superficial deposits were so complex that the available data would not allow their distribution and properties to be constrained to an adequate degree. As a result, the Environment Agency decided that such a model should not be developed for the regional modelling exercise.

However, Streetley and Shepley (2000) examined the drift domains used in the East Shropshire model and concluded that although the superficial deposits in East Shropshire were complex, there were sufficient data to justify modelling the variability of these. They broadly concluded that where there a clay dominant sequence recharge potential to the aquifer was generally poor with high degree of runoff or shallow throughflow. Only when the sequence had greater than 50% sand and gravel was there any reasonable chance for aquifer recharge, although even then this required good hydraulic connectivity of the formations in the drift.

Griffiths et al (2002), note that glacial sands and gravels permit direct and indirect recharge via hydraulic connection with rivers, except where they are till covered. They further note that the till limits recharge and confines the bedrock aquifer.

2.3 Aquifer recharge

Vines and Brassington (1981) presented a conceptual model of the aquifer in their West Cheshire Saline Groundwater Investigation. The study concluded that the major outcrop areas with the highest groundwater levels showed recharge zones in the east of the region. Where present, drift cover, described as Boulder Clay, was viewed as acting as a confining or semi-confining layer. It was considered that boreholes penetrating this layer and installed into the sandstone below would be artesian under natural conditions. Like many others, Brassington found that the complex nature of the superficial deposits were problematical from the point of view of estimating recharge.

Vines, Lucey & Campbell (1983) followed up on earlier work by Vines and Brassington (1981) and raised the conceptual view that the Quaternary deposits might "sometimes act as an extension of the main sandstone aquifer and give rise to semi-confined groundwater conditions over a large part of the area".

LWRC (2000) note that the majority of effective rainfall leaves the area as surface runoff via the river network. Although large areas of the Wirral and West Cheshire aquifer are not covered by the existing surface runoff hydrometric network LWRC (2000) concluded that for all the gauging stations none could be described as heavily groundwater supported rivers, neither are they flashy clay catchments. It therefore appears that the underlying Permo-Triassic sandstones exert no significant effect on gauged baseflows, implying that the drift runoff characteristics are dominant. Evidence from excavations in the Chester area (Strahan, 1882) suggest that groundwater in a lodgement till at the base of the drift can act as a barrier to groundwater flow into the River Dee.

The schematic illustration of hydrogeological processes operating in the study area (shown in Figure 1.11.2, LWRC, 2000 and reproduced herein as Figure 2) suggest that there is predominantly lateral freshwater discharge operating within the drift deposits with potentially some downwards leakage locally. Areas where there is assumed to be good hydraulic contact with the river network is located to the south of the site.

LWRC (2000) consider that the River Dee is likely to be influent over all of its length and receives groundwater from drift sands. Groundwater heads are reduced upstream and laterally from the main river by leakage through the drift into surface watercourses. However, in their modelling report Gebbett & Johnson (2002), aquifer-river interaction was only considered where the rivers were directly overlaying the aquifer. LWRC (2000) notes that groundwater flows funnelled into the Chester unit probably begin to rise vertically through the drift to discharge into surface watercourses in the Eccleston area and westwards, an area located to the north of the site.

Whilst not within the study catchment, Gellatly et al (2012) studied a wetland area (Marsh Farm lakes) within the Wirral block. They note that direct recharge to the sandstone aquifer occurs on the higher ground mainly to the north and east of Inner Marsh Farm. Recharge rates are generally higher in areas of sandstone outcrop, with a greater proportion of surface water runoff (and hence lower recharge) occurring where the sandstone is overlain by glacial till. Recharge pulses are often dampened significantly as they pass through the drift, particularly through the glacial till, because low-permeability deposits can restrict downward movement of water, making the actual recharge less than the potential recharge (Rushton 2005). In their model they state anecdotal evidence suggesting that the strong hydraulic connection between the sandstone and drift aquifers is present beneath the Inner Marsh Farm lakes, due to the presence of a high permeability layer penetrating the otherwise low permeability glacial clays.

3 HYDROGEOLOGICAL SETTING

The hydrogeological conceptual model relating to the Kinnerton Boreholes was summarised in Envireau Water 2023 as:

- The Kinnerton Boreholes target the Kinnerton Sandstone Formation, which is part of the Sherwood Sandstone Group, and is at least 200m thick at the Site.
- The Sherwood Sandstone Group is overlain ~47m of low permeability superficial deposits, which acts as a confining layer and provides hydraulic separation between groundwater in the sandstone bedrock and surface water features.
- Groundwater flow is predominantly to the north. Flow occurs as intergranular and fracture flow. At the Kinnerton Boreholes fissuring within the sandstone is a key flow mechanism.
- Recharge to the sandstone aquifer occurs where the formation outcrops, via infiltration through superficial deposits where they thin, and via fault induced pathways.
- Groundwater levels at the Kinnerton Boreholes are artesian.
- Historic test pumping data shows the Kinnerton Boreholes are capable of delivering at least 150m^3/hour.

The conceptual model has been extended to cover a larger area and to incorporate interaction with the River Dee and its tributaries, as well as groundwater outflow to the north, to the sea.

The wider conceptual model is based on the regional geology shown on Figures 3 and 4 (Superficial and Bedrock Geology). The wider geology confirms the distribution of low permeability drift lying below the tributaries to the River Dee and below the River Dee itself. The literature review has demonstrated the hydraulic disconnect between the Sherwood Sandstone and the surface water system, and the importance of a gravel interburden in terms of discharge.

The Hydrogeological Map of Clwyd and the Cheshire Basin (BGS, 1989) provides useful information on the hydrogeology of the area. An extract from the map is presented as Figure 5. The hydrostratigraphy comprises the superficial deposits overlying (generally) the Sherwood Sandstone & Collyhurst Sandstone, overlying the Coal Measures which comprise sandstones and marls (the 'Barren Measures') underlain calcareous sandstones of the Coed-yr-alt Beds, which in turn are underlain by the largely marls/mud rocks of the Ruabon Marl.

The sandstones have low permeabilities, which is enhanced by fracturing. Figure 4 shows that immediately west of the site the Sherwood Sandstone is underlain by Lower Coal Measures, the Gwespyr Sandstone Formation and the Bowland Shale. The more arenaceous units within these formations comprise aquifer systems with intergranular permeability which is enhanced by fracturing and decalcification. There is therefore hydraulic connection to recharge areas to the west and higher elevation land. It is this elevation change that creates the groundwater head for the artesian conditions at the borehole.

While faulting is important in controlling the geology, faulting in the vicinity of the site is primarily in the Sherwood Sandstone, where it is generally considered to enhance permeability. Thus, the faults are not considered to form barriers, and will increase flow in a northerly direction.

Figure 6 shows hand drawn groundwater contours supplied by the Environment Agency which were developed in 2017 for the Sherwood Sandstone. These confirm movement of groundwater from the west in the vicinity of Kinnerton, with a flow component toward the north and north east. At the site, groundwater flow is toward the north, and thus the groundwater flux is discharging to the Dee Estuary and tidal River Dee.

Figure 7 draws the hydrogeological setting into a conceptual model, shown as a cross section.

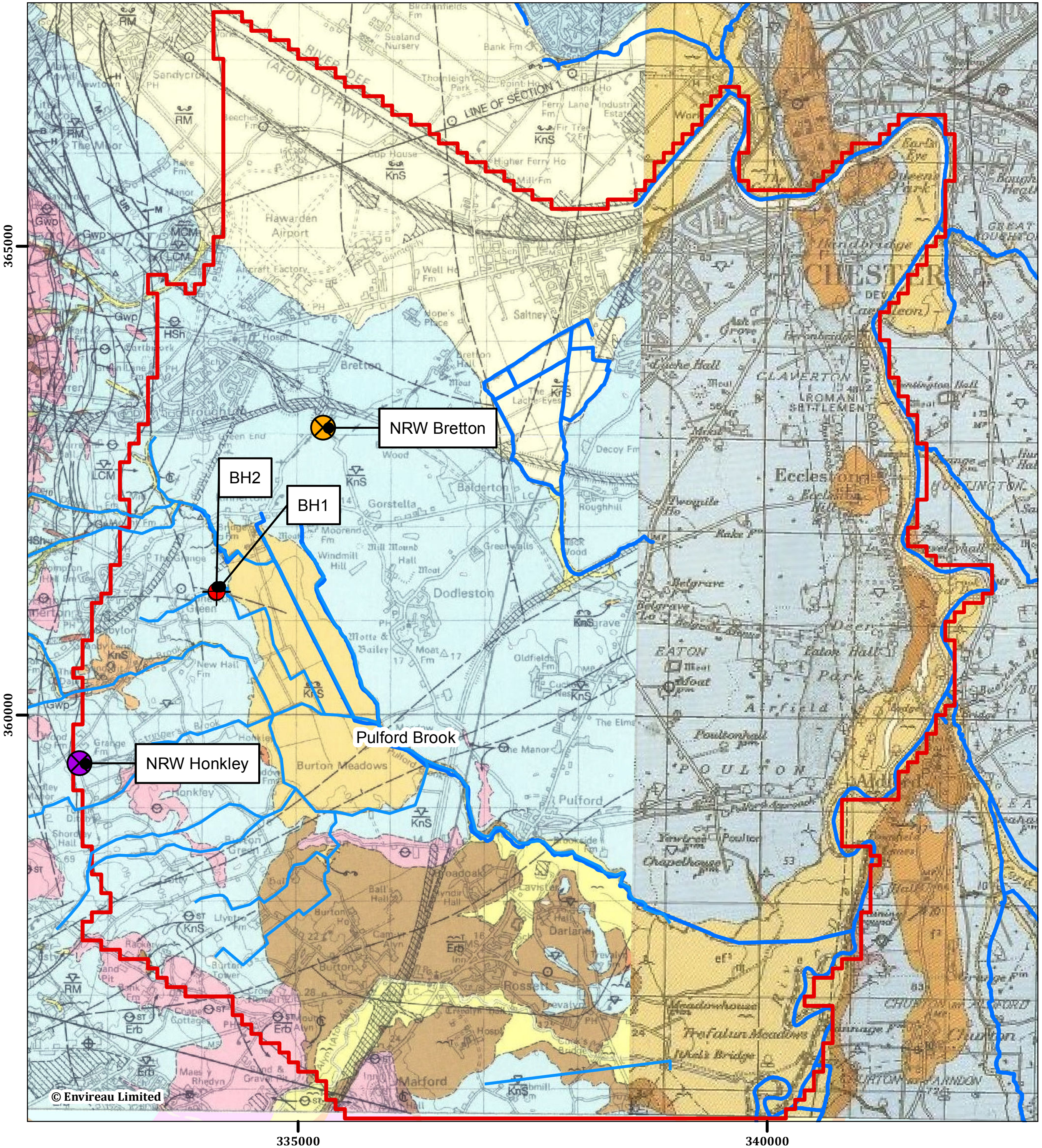

Figure 3: Superficial Deposits

Padeswood, Flintshire

Model Boundary

Kinnerton Abstraction Boreholes

BH1 Licence Ref. 24/67/9/0137

BH2 Licence Ref. 24/67/9/0126

Monitoring Locations

NRW Bretton

NRW Honkley

Watercourses

Linear Features

Fault

** For bedrock geology key, see Figure 4*

Superficial Deposits

ARTIFICIAL DEPOSITS

- Made Ground on original ground surface
- Infilled Ground, former excavations which are either wholly or partially backfilled

DRIFT

QUATERNARY : PLEISTOCENE AND HOLOCENE

Postglacial Deposits

- Foundered Strata
- Landslip
- Blown Sand
- Tufa
- Peat
- Marine Deposits, undifferentiated, organic-rich clay, silt, sand and gravel
- Raised Marine Deposits, storm beach sand and gravel
- Lacustrine Deposits, organic-rich clay and silt
- Alluvium, gravels,sands and silty clays
- River Terrace Deposits, undifferentiated, sand and gravel
- Alluvial Fan Deposits, sand and gravel
- Older Alluvial Fan Deposits, sand and gravel
- Scree, angular gravel
- Head, gravelly and sandy clay

Glacial Deposits

- Glaciolacustrine deposits, silts and clays
- Glaciofluvial Ice Contact Deposits, sand and gravel
- Glaciofluvial Sheet and Glaciolacustrine Delta Deposits, sand and gravel
- Glaciofluvial Deposits undifferentiated, sand and gravel
- Till, stoney clay

Notes:

0 1,000 2,000 3,000 Meters

Scale: 1:62,000 at A4

07 February 2024

NGR: 337,500 E / 361,633 N

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Drawn by: JH

Ref: Superficial Deposits

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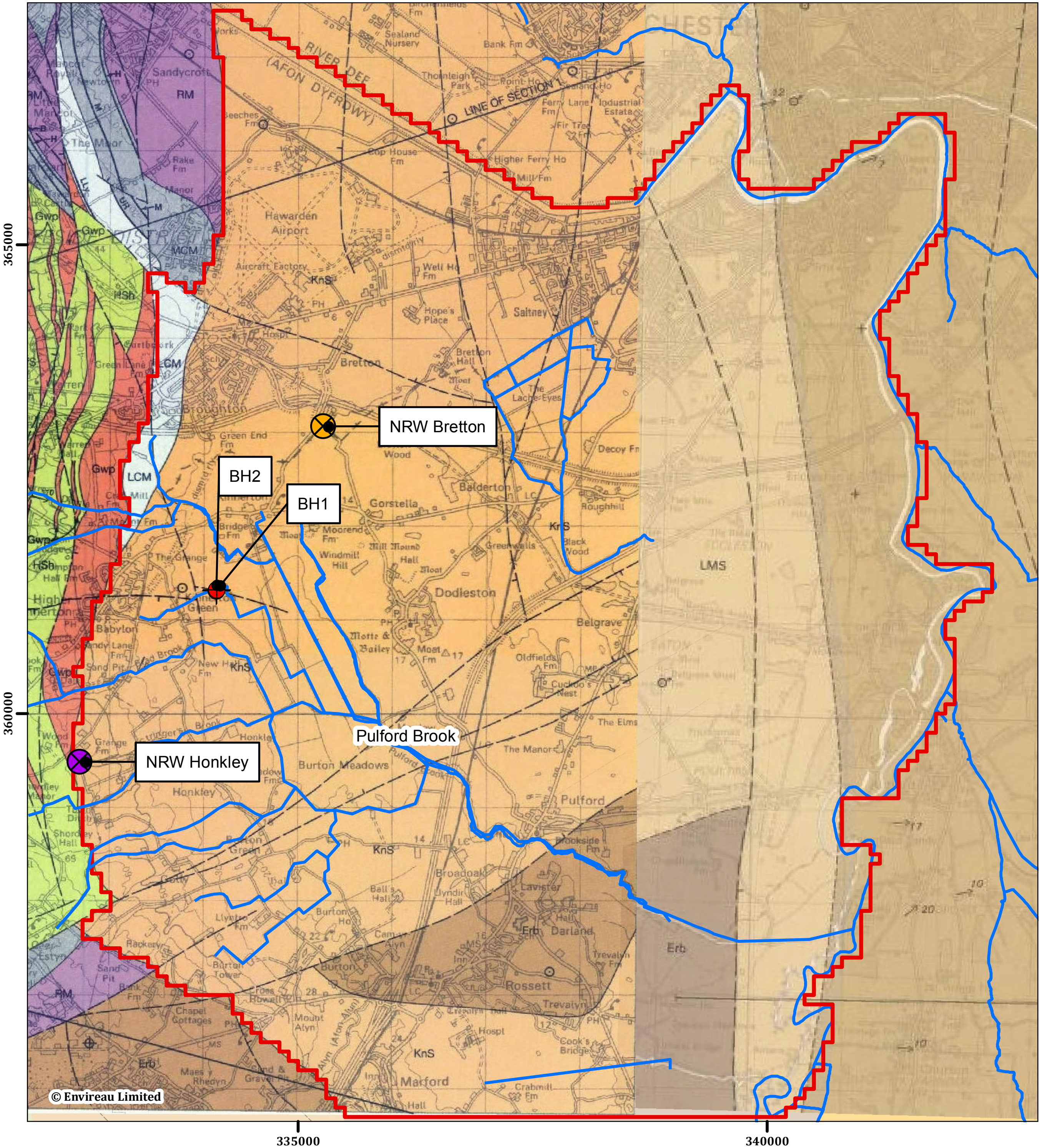
Figure 4: Bedrock Geology

Padeswood, Flintshire



Model Boundary

Kinnerton Abstraction Boreholes

BH1 Licence Ref. 24/67/9/0137

BH2 Licence Ref. 24/67/9/0126

Monitoring Locations

NRW Bretton

NRW Honkley

Watercourses

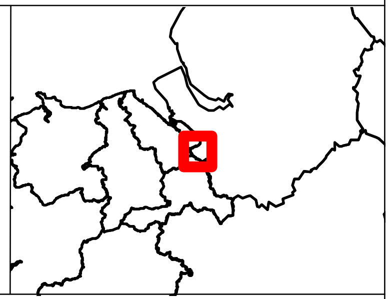
Bedrock Geology

Sherwood Sandstone Group	KnS	Kinnerton Sandstone Formation
Warickshire Group	Erb	Salop Formation *(formerly Erbistock Formation)*
	RM	Etruria Formation *(formerly Ruabon Marl Formation)*
Coal Measures	MCM	Middle Coal Measures
	Ho	Hollin Rock
	LCM	Lower Coal Measures
Millstone Grit Group	Gwp	Gwespyr Sandstone Formation
	Hsh	Bowland Shale Formation *(formerly Holywell Shales Formation)*
	CfS	Cefn-y-Fewd Sandstone Formation
		Namurian - Dinantian

Linear Features

Fault

Notes:



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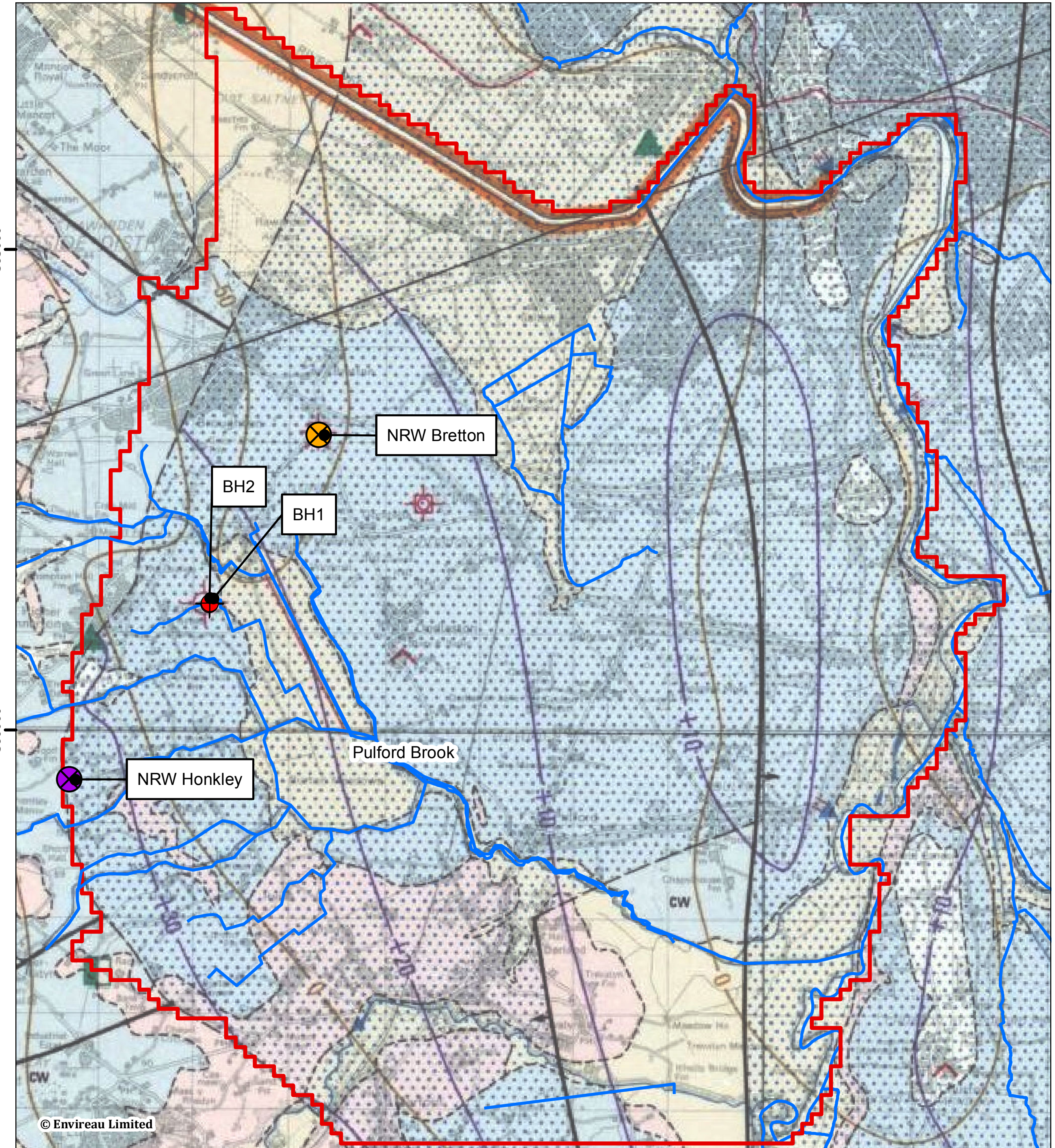


Figure 5: Hydrogeological Map

Padeswood, Flintshire

Model Boundary

Kinnerton Abstraction Boreholes

BH1 Licence Ref. 24/67/9/0137

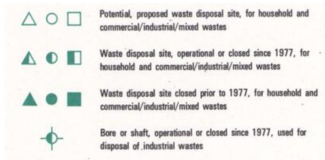
BH2 Licence Ref. 24/67/9/0126

Monitoring Locations

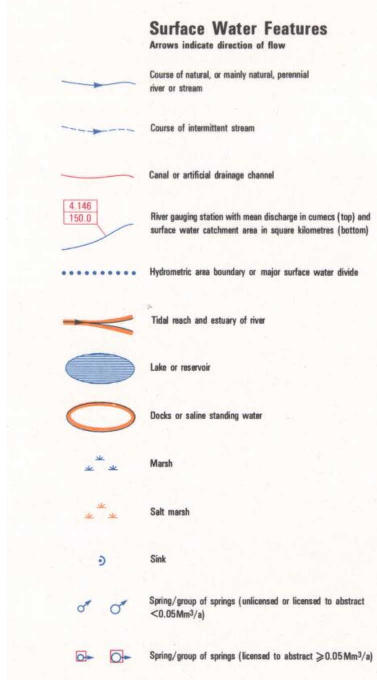
NRW Bretton

NRW Honkley

Watercourses



Hydrogeolgial Key



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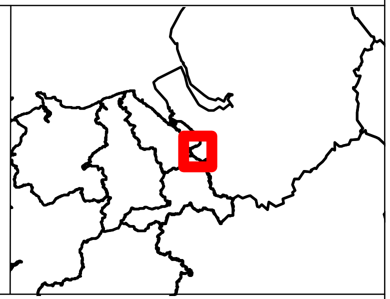

0 | 880 | 1,760 | 2,640 Meters

Scale: 1:62,000 at A4

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NGR: 337,500 E / 361,600 N

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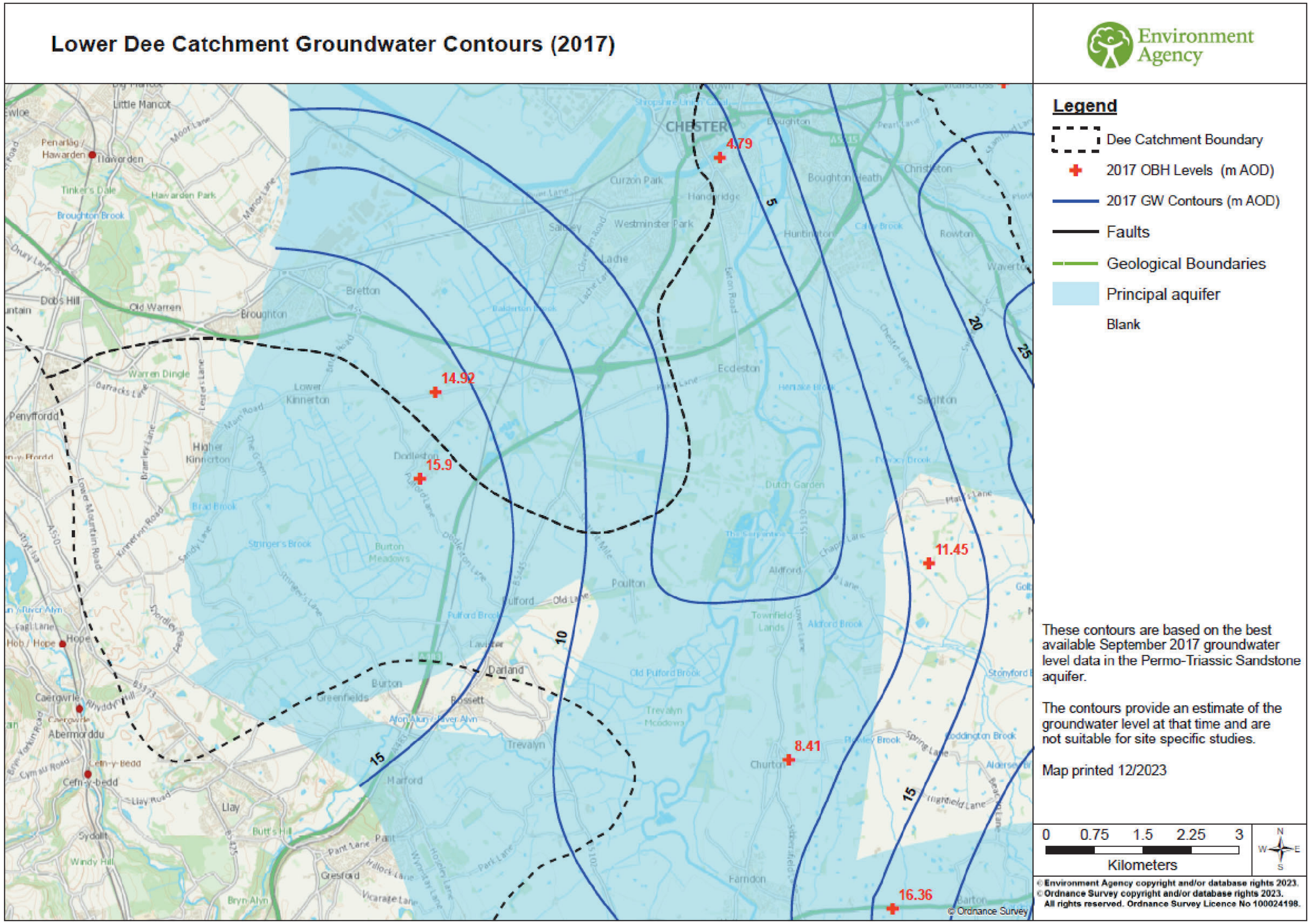
Figure 6: Groundwater Contours



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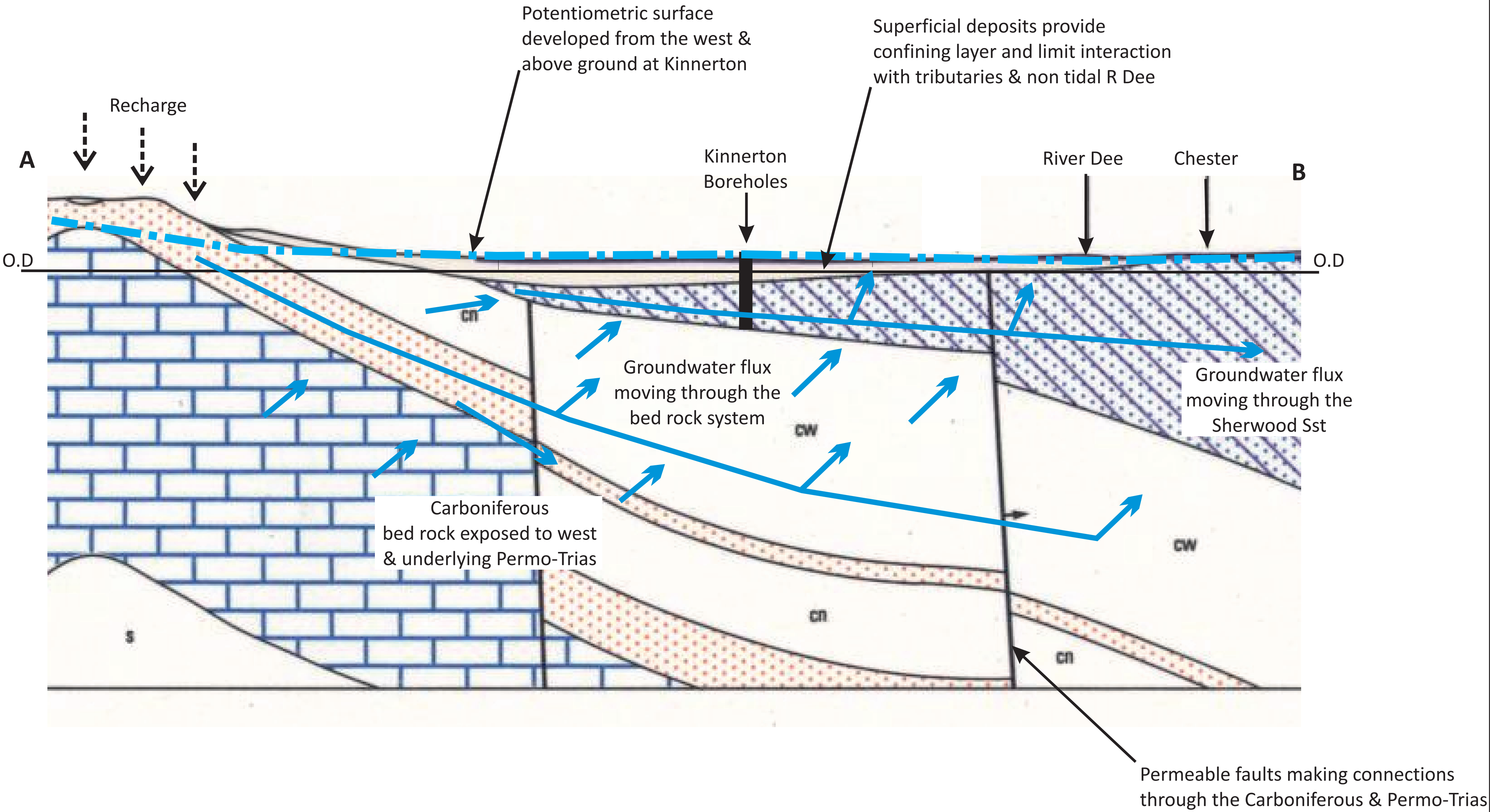

Figure 7 : Hydrogeological Conceptual Model - Section

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Project No.	3490192
Client:	Padeswood
Ref:	Section
Drawn by:	JED

4 NUMERICAL ASSESSMENT

4.1 Purpose

The purpose of the numerical assessment is to provide an assessment of the groundwater flux that the Kinnerton boreholes intercept and the effects of the increase in abstraction; as well as develop a water balance which includes recharge, and that takes account of the proposed increase in abstraction. Combining these elements allows an assessment of the impact of the increased abstraction to be undertaken.

It is not the intention to develop a detailed and extensive numerical groundwater model. Such an exercise was not considered necessary by Natural Resources Wales and would be inappropriate for the magnitude of the change in the licence.

While a numerical approach has been taken, it is limited in scope (extent) to keep it commensurate with the proposed changes to the abstraction licence.

4.2 Approach

The numerical assessment covers an area of approximately 84 km^2 to the south of Chester, bounded by the River Dee in the north and east, Gresford in the south and the contact between the Sherwood Sandstone and the Millstone Grit Group/ Bowland Shale in the west. The extent of the assessment area is shown on Figure 1.

Only the abstraction from the Kinnerton boreholes has been considered in the numerical assessment, which does not consider other abstractions. Therefore, the results represent the effect of the Kinnerton boreholes on the system and the effects on other abstractors. This is considered appropriate for this level of impact assessment and is in line with what was discussed and agreed with NRW.

A model has been constructed comprising:

- An even rectilinear grid with a cell size of 100 m x 100 m;
- Eight recharge zones delineated based on the surface geology (from the British Geological Survey (BGS) 50k Superficial Geology shapefile) and CORINE land use data from 2018;
- Four layers representing the superficial deposits and the Sherwood Sandstone;
- Drain cells are used to represent the River Dee and its tributaries; and
- General head boundaries along the northern, western and southern boundaries.

Typical recharge rates for each surface geology and land use combination are applied within a given zone. The top surface is the mean topography from the Land-Form PANORAMA digital terrain model (DTM) of the area. The thickness of Layer 1 is based on the BGS Superficial thickness 1 km hex grid dataset. The base of Layer 2 is -80 mAOD and the base of Layer 4 is 200 m below the mean topography, as most groundwater flow occurs in the upper section of the aquifer. The base of Layer 3 is halfway between the base of Layer 2 and the top of Layer 4. The abstraction well is positioned in the lowest layer. The hydraulic properties (shown in Table 1) are based on typical values for the superficial and bedrock geology within the region. Fault zones are digitised in Layers 2, 3 and 4 based on the location of faults in the BGS 50k Bedrock Geology shapefile. Elevated values of hydraulic conductivity are applied in these zones.

Table 1 Hydraulic properties for superficial and bedrock geology in numerical assessment

Layer(s)	Kx (m/d)	Kv (m/d)	Specific storage (m^{-1})	Specific yield
1	0.05	0.005	0.00001	0.1
2, 3 and 4	1.8 (10 in fault zones)	0.09 (10 in fault zones)	0.00001	0.1

Drain cells are used to represent the River Dee and its tributaries. The drain cells are divided into zones based on the predominant underlying geology, and parameterised as shown in Table 2.

Table 2 Drain cell properties

Geology	Hydraulic conductivity for drain cells (m/d)	Drain stage
Tidal flats	0.08	Top surface of Layer 1 (mean topography)
Alluvium	0.0017	
Till and lacustrine deposits	0.0002	

The hydraulic properties given in Tables 1 and 2 have been calibrated within the model by visually comparing output with the measured groundwater levels at Kinnerton and the form of the groundwater contours in Figure 6.

General head boundaries (GHBs) are present along the northern, western and southern boundaries to allow groundwater movement to enter and exit the study area. The elevation of the GHBs is based on groundwater contours from the Hydrogeological map of Clwyd and the Cheshire Basin (BGS, 1989). The hydraulic conductivity for the boundaries is specified depending on the adjacent geology.

Analysis has been undertaken at steady state, which represents an extreme worst case scenario. This is analogous to an analytical approach, but by using a numerical approach more factors can be taken into account.

Three abstraction scenarios have been assessed as detailed in Table 3.

Table 3 Abstraction Rates

Scenario	m^3/year	m^3/day	m^3/hr	Comment
1	136,500	374	16	Equivalent daily abstraction on existing licence
2	616,000	1,688	70	Equivalent daily abstraction for an alternative scenario
3	1,445,400	3,960	165	Rates in variation application

The equivalent daily abstraction rates have been used to represent a long term abstraction, as using the licenced hourly rate would grossly over represent the annual abstraction and therefore impacts. Local, short term impacts have been assessed using the proposed licensed or tested hourly rates.

A 616,000 m^3/year scenario has been included as the impact assessment (Section 5 of this report) identified an impact with an annual abstraction of 1,445,400 m^3/year.

4.3 Results

The model has been run for the three abstraction scenarios detailed in Table 3, and compared to a baseline ('naturalised' environment) in which abstraction is turned off, in order that the effect of the current licence can be seen and that the variation can be put in context (Table 4).

Table 4 Water Balance

Abstraction rate scenario	374 m^3/d		1,688 m^3/d		3,960 m^3/d	
	m^3/d impact relative to Nat	% of abs change	m^3/d impact relative to Nat	% of abs change	m^3/d impact relative to Nat	% of abs change
Tidal reach of Dee	-164	-44%	-737	-44%	-1,730	-44%
River Dee on east of model	-28	-8%	-125	-7%	-287	-7%
Tributaries to River Dee	-15	-4%	-65	-4%	-151	-4%
other	0	0%	0	0%	0	0%
General Head Boundary	-167	-45%	-759	-45%	-1,788	-45%
Impact to non-tidal River Dee and tributaries	-43	-11%	-191	-11%	-438	-11%
Nonimpact (other changes)	-332	-89%	-1,496	-89%	-3,518	-89%

The water balance results have been put in context with the Q95 flow at the Chester Suspension Bridge weir (Weir Number 67033), which is 5.13 m^3/s (443,232 m^3/day). The comparison is shown in Table 5.

Table 5 Comparison with River Dee Q95 (443,232 m^3/day)

Abstraction rate scenario	374 m^3/d		1,688 m^3/d		3,960 m^3/d	
	m^3/d impact relative to Nat	% of Q95	m^3/d impact relative to Nat	% of Q95	m^3/d impact relative to Nat	% of Q95
Tidal reach of Dee	-164	0.04%	-737	0.17%	-1,730	0.39%
River Dee on east of model	-28	0.01%	-125	0.03%	-287	0.06%
Tributaries to River Dee	-15	0.003%	-65	0.01%	-151	0.03%
other	0	0.000%	0		0	
General Head Boundary	-167	0.04%	-759	0.17%	-1,788	0.40%
Impact to non-tidal River Dee and tributaries	-43	0.01%	-191	0.04%	-438	0.10%
Nonimpact (other changes)	-332	0.08%	-1,496	0.34%	-3,518	0.79%

The water balance results demonstrate that:

- The percentage of abstraction attributed to each part of the water balance does not change between scenarios, showing the hydrogeological system is not being disturbed. That is, the sources of water that the boreholes are dependent on now, do not change as a result of the abstraction.
- The vast majority (~90%) of the water abstracted from the boreholes will not reach the non-tidal River Dee or the tributaries. That is, the flux that is intercepted will flow toward the tidal Dee or pass below the River Dee and into the wider groundwater system.
- The source of the water is from the south and west, via recharge on the exposed bed rocks.
- The quantum of the flux that is intercepted that would move to the non-tidal Dee and/or the tributaries ranges from 0.1% to 0.01% depending on the scenarios. In all cases these are extremely low and can be considered as zero in practical terms[1].

4.4 Water Levels

The effect on groundwater levels has been assessed analytically based on the test pumping data. Because the test pumping did not cause a change in water level in the observation boreholes, a value of specific storage (storativity) could not be calculated. Therefore, a value has been estimated using a combination of the step test data analysis and the value of transmissivity calculated from the constant rate test. A prediction of the pumping water level at the end of the constant rate test has been calculated using the Eden – Hazel relationship (Eden & Hazel 1973) for the first 100minutes of pumping, and the Jacob approximation (Jacob 1944) of the Theis solution for the change in drawdown after the first 100minutes of pumping. Using the base parameters in Table 6, a value of 0.0001 m^3/m^3 was obtained for the storativity.

[1] The numerical assessment will always produce an effect on the surface water systems as the model includes a hydraulic connection. i.e. the effect will always be >0. It is considered that a numerical effect of <=0.5% is a reasonable equivalence of zero (0).

Table 6 Base Parameters of Analytical Analysis

Parameter	Value	Unit		Parameter	Value	Unit
T	80	m^2/day		B	0.0902	hr/m^2
Q	164	m^3/hr		C	0.0009	hr^2/m^5
r	0.2	m		RWL	-6.57	mbgl
t	2	days		PWL	45.57	mbgl

Using the calculated storativity and the transmissivity from the base parameters, the drawdown was calculated using the Jacob approximation, for the abstraction rate scenarios. The test pumping rate has been tested at 2 days to represent the test pumping period and provides a calibration / validation of the calculation. A period of 1 year has been taken to represent long term abstraction. The results are presented in Table 7.

Table 7 Water Level Change (drawdown) Calculations

Q (m^3/hr)	Radius (m)				t (days)
	500	1,000	2,500	5,000	
164	13.14	7.72	0.55	-4.87	4
164	30.79	25.37	18.21	12.78	365
15.6	2.93	2.41	1.73	1.22	365
70	13.14	10.83	7.77	5.46	365

The results demonstrate that:

- The zone of influence for the test pumping (run over 4 days) would not have extended to the observation boreholes.
- A significant zone of influence develops with long term abstraction at 164 m^3/hour.
- Abstracting at the existing licensed rate is predicted to produce a drawdown of over 1m at 5km. As this has not been reported, it is concluded that this is an over estimate (see below).
- Abstracting at a reduced effective annual rate of 70 m^3/hour produces a drawdown of ~5.5m at 5km. Again this will also be an over estimate, as a result of the analytical method.

It is important to note that this analysis is unbounded. That is, a drawdown will be calculated at any distance, and will also become negative. Also, the analysis does not take account of recharge or the effects of seasonal and/or intermittent pumping, both of which will reduce the development of a zone of influence and drawdown at distance from the abstraction boreholes. As such the results represent an extreme worst case. That is, the actual drawdown will be less than that predicted, and is highly likely to be significantly less. We would expect that the effective annual rate of 70m^3/hour would create a zone of influence between 2 and 3km in radius, with drawdown at those distances of between 0m and 2m.

5 IMPACT ASSESSMENT

Using the conceptual model and numerical analysis, an impact assessment has been undertaken focussing on the following:

- Reduction in groundwater flux;
- Effects on surface water flows over the superficial cover and on baseflow in the River Dee;
- Effects of down gradient abstractors with respect to direct reduction in groundwater level and effects of reduction in flux; and
- Local direct reduction in aquifer water levels.

5.1 Assessment Methodology

The impact assessment has been carried out using the Source-Pathway-Receptor (S-P-R) approach, and following the principals described in Green Leaves III, and the guidance provided by the Environment Agency in relation to carrying out hydrogeological risk assessments for environmental permits. The use of the numerical assessment represents a Tier 2 assessment which has been developed on a robust understanding of the hydrogeology and groundwater conditions. No proximal high sensitivity receptors have been identified, and therefore the assessment is focussed on effects on the surface water system.

The impact assessment has been carried out based on the identified hazards in accordance with the methodology presented at Appendix A. The impact assessment is set out in the following sections.

5.2 Hazard Identification

The hazards assessed with respect to the proposed abstraction are:

- Reduction in groundwater flux;
- Effects on surface water flows over the superficial cover and on baseflow in the River Dee;
- Effects of down gradient abstractors with respect to direct reduction in groundwater level and effects of reduction in flux; and
- Local direct reduction in aquifer water levels.

The risk of these hazards occurring is considered in the following sections.

5.3 Receptor and Pathway Identification

This assessment is for impacts associated with groundwater abstraction, thus the pathway in terms of the risk assessment comprises hydraulic linkages through the aquifer system. The receptors have been agreed with Natural Resources Wales, as the surface water system and down gradient groundwater abstractors. The water features survey undertaken as part of the test pumping exercise and application process identified the following abstractors within 4km of the Kinnerton Boreholes (Envireau Water, 2022):

- Public Water supply boreholes operated by Dŵr Cymru Welsh Water (DCWW) at Gorstella and Bretton, 2.5km to the northeast. These boreholes target the Permo-Triassic Sherwood Sandstone Group, the same formation as the Kinnerton Boreholes. The boreholes are currently out of use.
- An agricultural borehole at Shordley Hall Farm, located 3.3km southwest of the Kinnerton Boreholes. This borehole targets the Millstone Grit Group, which is a different formation to the Kinnerton Boreholes.

In practical terms, it is considered that these receptors could be at the edge of a zone influence created by the Kinnerton Boreholes.

Historically there were a number of private water supplies in the Kinnerton area. The WFS confirmed that these were abandoned in the 1950's / 1960's following the introduction of mains water to the local area.

As such, the DCWW has been taken as a receptor and direct impacts assessed. Any abstractors from the Sherwood Sandstone that are more distant, have not been assessed directly, but impacts can be inferred from groundwater level change predictions.

5.4 Impact Assessment

5.4.1 Receptor Sensitivity

Receptor sensitivity has been assigned in accordance with Table 1 in Appendix A to the following receptors:

The Sherwood Sandstone Formation aquifer is a principal aquifer providing potable water to a small population in this area and therefore has been a allocated a sensitivity of High.

The tributaries to the River Dee are not in themselves a SAC or SPA but are connected to the River Dee. Therefore they have been allocated a sensitivity of High.

The River Dee upstream from Chester is a SAC/SSSI and has therefore been allocated a sensitivity of Very High.

The DCWW abstraction is a licensed abstraction with a protected right and a protection from derogation. Therefore this has been allocated a sensitivity of Very High.

5.4.2 Magnitude of Impact

The magnitude of impact has been assigned with reference to Table 2 in Appendix A with justifications for the classification given in Appendix B. The magnitude of impacts assigned a range from Medium to Very Low. The magnitude of impact on the non-tidal River Dee and its tributaries has been set at very low. This is in recognition of the fact that the numerical assessment predicts a change, but that change is zero in a practical sense. The drawdown analysis predicts a High impact at the DCWW licensed abstraction, if the 164m^3/hour abstraction rate is assessed.

5.4.3 Potential Significance of Effect

A significance of effect has been calculated from the receptor sensitivity and magnitude of impact described above. A Major significance of effect is assessed for the DCWW licensed abstraction, if the 164m^3/hour abstraction rate is used. Other effects are assessed as Minor or Moderate.

5.4.4 Likelihood of Occurrence with Mitigation

The risk assessment indicates that mitigation is required for the DCWW abstraction. Other risks are either Very Low or None, given the worst case nature of the numerical and analytical analyses.

The following mitigation is proposed to protect the DCWW source and the confined state of the aquifer at the Kinnerton boreholes:

- Reduce average annual abstraction to 616,000m^3/year (equivalent hourly rate 70m^3/hour);
- Control water level in Kinnerton boreholes to 1m higher than top of aquifer. This will protect the confined state, while taking account of borehole hydraulics and inefficiency;
- Monitor water levels electronically at NRW observation boreholes; and
- Provide data analysis and new impact assessment to support abstraction licence renewal.

It is considered that the DCWW abstraction could be close to the zone of influence of an abstraction of 616,000m^3/year at Kinnerton. It is further considered that if drawdown was created at the DCWW boreholes, then it would be small and would not constitute derogation. That is, it would not impact on the ability of DCWW to abstract. Further, while the DCWW boreholes are licensed, they are not operating and it is our understanding that they are inoperable. While the protected right must be protected, the lack of abstraction provides some mitigation.

5.5 Impact Analysis

The results of the impact assessment show that the residual risks, with the mitigation in place, pose an impact ranging from Low to None. Risks to the non-tidal River Dee and its tributaries are considered None. There is a Low residual risk to the DCWW abstraction, which is not considered to amount to a derogation.

6 CONCLUSIONS

The analyses presented in this report align with the discussions held with NRW and the level of risk associated with the proposed increase in abstraction, based on the results of the test pumping undertaken.

The analyses provide sufficient information to allow determination of the abstraction licence variation to be concluded.

The analyses show that:

- On a practical level there is no material interaction with the non-tidal River Dee and its tributaries;
- Numerical assessment shows that the vast majority of groundwater flux that the Kinnerton boreholes intercept would otherwise flow to the wider groundwater system and out to the tidal reaches of the River Dee and the sea;
- The numerical assessment has developed a water balance including recharge, that takes account of the proposed increase in abstraction and has allowed impacts to be assessed;
- Groundwater level changes have been evaluated using an analytical approach which has been calibrated against the test pumping data;
- A qualitative impact assessment in a standard format (e.g. Greenleaves III or similar) is presented; and
- The results of the impact assessment show that the residual risks, with the mitigation in place, pose an impact ranging from Low to None. Risks to the non-tidal River Dee and its tributaries are considered None. There is a Low residual risk to the DCWW abstraction, which (taking account of mitigation) is not considered to amount to a derogation.

The following mitigation is proposed:

- Reduce annual abstraction applied for to 616,000m^3/year (equivalent hourly rate 70m^3/hour);
- Reduce hourly maximum rate applied for to 120m^3/hour (effectively halving the pumping hours available per year, compared to a 24/7/365 abstraction);
- Control water level in Kinnerton boreholes to 1m higher than top of the aquifer via a hands off level condition. This will protect the confined state, while taking account of borehole hydraulics and inefficiency;
- Monitor water levels electronically at NRW observation boreholes; and
- Provide data analysis and new impact assessment to support abstraction licence renewal.

Additional academic test pumping and monitoring would not provide useful output, as the duration of testing required to induce useful change at the NRW observation boreholes would be too long. Rather, monitoring of operational abstraction under the varied licence is recommended, and the data presented and evaluated as part of licence renewal or review. A hands-off level condition would prevent excessive drawdown at the Kinnerton boreholes and will limit the drawdown within the zone of influence.

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APPENDICES

Appendix A HIA Methodology

HIA METHODOLOGY – TIER 2

1 INTRODUCTION

DEFRA's GL III [Ref. 1] contains generic guidelines for the assessment and management of environmental risks. GL III outlines a staged approach to risk assessment and the document is intended to guide regulatory staff in Government and its agencies, as well as those carrying out assessments, to reach a decision on managing environmental risk.

The hydrogeological risk assessment has been carried out using a Source-Pathway-Receptor (S-P-R) approach following the principles described in GL III [Ref. 1] and the methodology in the Environment Agency's approach to groundwater protection [Ref. 2] and associated technical guidance [Ref. 3]. Where S-P-R linkages have been identified, the sensitivity of the receptor, magnitude of impact and significance of effect has been considered in order to assess potential risks.

Ref. 2 describes a tiered approach to risk assessment, starting at Tier 1 and progressing to Tier 3. Tier 1 is essentially a qualitative approach and Tier 3 is a highly quantitative approach. The choice of approach should be based on how complicated the hydrogeological system is, how sensitive the receptors are, and how easily and fully the risks can be mitigated. As such the selection process is iterative, and in complex systems there may be a mixture of approaches where simple, low risk sub-systems are assessed with a Tier 1 approach and more complex aspects with risks that cannot be fully mitigated may need a complex quantitative approach. The methodology described in this Appendix is for a Tier 2 assessment.

2 RECEPTOR SENSITIVITY

The sensitivity of water dependent receptors is based on their status and in the case of aquifers, their resource value, as described in Table 1.

Table 1 Receptor Sensitivity

Receptor Sensitivity	Description	Examples
Very High	Water resource or receptor with an importance and rarity at an international level with limited potential for substitution.	A water resource making up a vital component of an SAC or SPA. A water body achieving a status of 'High status or potential' under the WFD. Principal aquifer providing potable water to a large population. EC designated Salmonid fishery.
High	Water resource or receptor with ahigh quality and rarity at a national or regional level and limited potential for substitution.	A water resource designated or directly linked to a SSSI. A water dependent NNR or County Wildlife Site. Principal aquifer providing potable water to a small population. A river designated as being of Good status or with a target of Good status or potential under the WFD. EC designated Cyprinid fishery.

Receptor Sensitivity	Description	Examples
Medium	Water resource with ahigh quality and rarity at a local scale; or water resource with a medium quality and rarity at a regional or national scale.	Secondary A aquifer providing potable water to a small population. An aquifer providing abstraction water for agricultural or industrial use. A local, undesignated water dependent nature conservation area.
Low	Water resource with a low quality and rarity at a local scale.	An ordinary water course or other water body without significant ecological habitat. A Secondary B or poorly permeable aquifer.

3 MAGNITUDE OF IMPACT

The magnitude of a potential impact on a receptor depends on the nature and extent of the proposed development, and is independent of the sensitivity of the water resource, as described in Table 2.

Table 2 Magnitude of Impact

Magnitude of Impact	Description	Examples
High	Results in a major change to attributes.	Loss of EU designated Salmonid fishery. Change in WFD classification of a water body. Compromise employment source. Pollution of potable source of abstraction. Prevents abstraction. Impact on SAC or SPA qualifying criteria.
Medium	Results in impact on integrity of attribute orloss of part of attribute.	Loss / gain in productivity of a fishery. Contribution / reduction of a significant proportion of the effluent in a receiving river, but insufficient to change its WFD classification Impacts on but doesn't prevent abstraction.
Low	Results in minor impact to attributes.	Measurable changes in attribute, but of limited size and/or Proportion.
Very Low	Results in an impact on attribute but of insignificant magnitude to affect use and/or integrity.	Physical impact to a water resource, but no significant reduction/ increase in quality, productivity or biodiversity. No significant impact on the economic value of the feature.

4 POTENTIAL SIGNIFICANCE OF EFFECT

The significance of the potential effect is derived by combining the assessments of both the sensitivity of the water resource and the magnitude of the impact in a simple matrix, as presented in Table 3.

Table 3 Significance of Effect

Receptor Sensitivity	Magnitude of Impact			
	High	Medium	Low	Very Low
Very High	Major	Major	Moderate	Moderate
High	Major	Moderate	Moderate	Minor
Medium	Moderate	Moderate	Minor	Negligible
Low	Moderate	Minor	Negligible	Negligible

5 LIKELIHOOD OF OCCURANCE

The overall risk analysis is dependent on the likelihood that an event will occur. In the case of a Tier 2 assessment the likelihood is assessed qualitatively, but is based on a quantitative assessment. Table 4 describes the categories and provides examples.

Table 4 Qualitative Likelihood of Occurrence

Qualitative Likelihood of Occurrence	Description	Examples
Highly Likely	High probability of occurrence	Spillage at a poorly maintained and operated facility. Uncontrolled activity in or on an aquifer, close to surface water. Uncontrolled known discharge. Predicted or predictable dewatering impact.
Likely	On balance could occur	Controlled but un-mitigated activity. Complex process where failure of a part is likely to lead to release. Large area where 100% sealing cannot reasonably be expected. Predicted dewatering within reasonable confidence limits.
Moderate	Equally likely/unlikely	Unmitigated, low risk controllable activity. Partially contained site.
Unlikely	On balance wouldn't occur	Mitigated higher risk simple, controllable activity. Underlain by poorly permeable strata. Existing contained site. Receptor outside predicted zone of influence of dewatering.

Qualitative Likelihood of Occurrence	Description	Examples
Very Unlikely	Very low probability of occurrence	Essentially no risk due to geological setting. Extreme set of circumstances required to generate low probability. Fully mitigated low or medium risk.

6 QUALITATIVE RISK ANALYSIS

The residual qualitative risk is derived by combining the likelihood of occurrence and the potential significance of effect in a simple matrix, as presented in Table 5. Risks which are assessed to be very high, high or medium are considered to be significant, whilst those that are low, very low or none are not significant.

Table 5 Qualitative Risk Analysis

Qualitative Likelihood of Occurrence	Significance of Effect			
	Major	Moderate	Minor	Negligible
Highly Likely	Very High	High	Medium	Low
Likely	High	Medium	Low	Very Low
Moderate	Medium	Low	Very Low	None
Unlikely	Low	Very Low	None	None
Very Unlikely	Very Low	None	None	None

7 REFERENCES

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Ref. 3: Groundwater risk assessment for your environmental permit. Environment Agency, Updated April 2018. https://www.gov.uk/guidance/groundwater-risk-assessment-for-your-environmental-permit.

Appendix B HIA Results

Appendix B

Table 6 - Hydrogeological Risk Assessment Output

Hazard	Source (S)	Pathway (P)	Receptors (R)	S-P-R Linkage	Receptor Sensitivity	Magnitude of Impact		Potential Significance of Effect	Likelihood of Occurrence with embedded mitigation		Risk Analysis (with mitigation)
						Value	Justification		Value	Justification	
Reduction in Groundwater Flux	Padeswood abstraction	Groundwater	Sherwood Sandstone aquifer	Y	High	Medium	Overall reduction in flux in proporation to increased abstraction	Moderate	Unlikely	CAMS ledger shows resource is available	**Very Low**
Reduction in surface water flows in tributaries	Padeswood abstraction	Infiltration	Tributaries to River Dee	Y	High	Very Low	Numerical assessment shows very low interaction	Minor	Unlikely	Numerical analysis is a steady state assessment and thefeore worst case. Unlikely to be achieved within licence timeframe	**None**
Reduction in water level in DCWW borehole	Padeswood abstraction	Groundwater	Shordley Farm	Y	High	Low	Abstraction up gradient and from different (lower) aquifer	Moderate	Unlikely	Abstraction up gradient and from different (lower) aquifer	**Very Low**
Reduction in water level in DCWW borehole	Padeswood abstraction	Groundwater	DCWW borehole	Y	Very High	High	Test pumping showed no impact; numerical analysis worst case indicates 18m drawdown	Major	Unlikely	Mitigation proposed see report text	**Low**
Reduction in flows in River Dee (U/S of Chester)	Padeswood abstraction	Infiltration	River Dee baseflow	Y	Very High	Very Low	Numerical assessment shows very low interaction	Moderate	Very Unlikely	Numerical analysis is a steady state assessment and thefeore worst case. Unlikely to be achieved within licence timeframe	**None**
Local reduction in groundwater levels	Padeswood abstraction	Groundwater	Sherwood Sandstone aquifer	Y	High	Low	local drawdown keep aquifer confined as proven by test pumping	Moderate	Very Unlikely	Protection of confined conditions can be controlled by licence condition	**None**