Cilyrychen Quarry – Further information review in support of abstraction licence application

Final Report

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Purpose

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Executive summary

Overview

This report presents the findings of additional hydrogeological assessment to support that undertaken previously in relation to the abstraction licence application, to authorise a resumption of the previously exempt dewatering abstraction from Cilyrychen Quarry.

All the evidence when combined together serves to demonstrate a lack of any effect on the integrity of the turlough as a result of authorising this application to resume dewatering from Cilyrychen Quarry. A comprehensive review of all the available evidence has consistently shown that no reasonable scientific doubt remains as to a continued absence of any such effects on the turlough.

The proposal involves no new quarry extension or deepening. The proposal requires dewatering to provide a larger working area to process previously won limestone stockpiled within the quarry. The proposal is therefore a reversion to a historic dewatering condition at the quarry. Concerns however exist that this dewatering could affect eco-hydrological conditions with the nearby Pant-y-Llyn Turlough which is a feature of the Cernydd Carmel SAC.

A review has been completed of the available technical investigation reports describing the nature and hydrogeology of the Pant-y-Llyn Turlough including work previously undertaken by CCW. The findings provide multiple lines of evidence that all combine to demonstrate no reasonable scientific doubt remains as to the absence or lack of effects, from both the previous historic abstraction and the proposed resumption of quarry dewatering, on the integrity of the Turlough.

CCW reports identified that the catchment of the Turlough should conservatively be assumed to comprise the extent of "Gwenlais impounded karst" which outcrops to the west of Cilyrychen Quarry. However, Cilyrychen Quarry does not lie within this aquifer block as the Bettws Fault acts to form the eastern boundary of the "Gwenlais impounded karst" and serves as a low permeability barrier to groundwater flow between the Turlough and Cilyrychen Quarry.

Evidence presented in the CCW report, has been utilised to inform the current conceptual understanding of the Pant-y-Llyn turlough. This understanding has led to the conclusion that the groundwater catchment area to the turlough is likely to be smaller than the entire impounded karst extent, as evidenced by:

- Tracer tests suggesting the groundwater input comes from the immediate vicinity of Pant-y-Llyn turlough (Farr et al., 2012).
- Water quality data revealing that the Pany-y-Llyn water is less mineralised with a lower conductivity than waters from the Gorswen borehole to the west. This infers the groundwater discharging to Pant-y-Llyn has a short residence time with shallow groundwater flow pathways in the immediate vicinity of the turlough (Farr et al., 2012).
- Hydrographs from various groundwater monitoring boreholes and Pant-y-Llyn demonstrate that precipitation (i.e. rainfall) causes rapid recharge to the turlough. This reflects the importance of the surface water catchment

and suggests a short residence time when groundwater levels are elevated and cause the turlough to fill up (Farr et al., 2012).

Despite the groundwater catchment to the turlough likely to being smaller than the wider area of impounded karst, impact linkages might be possible from effects on the groundwater system within the wider block. For example, a dewatering activity across wider areas could move the position of groundwater boundaries or increase the rate of vertical groundwater movement from the shallow karst system to the deeper karst system. Evidence was therefore needed to confirm that the Bettws Fault acts as an effective barrier and that the Quarry does is isolated from the Gwenlais impounded karst area.

CCW (2012) concluded that "Further work is required to prove a link between Pant-y-Llyn and the currently inactive Cilyrychen Quarry (LRG, 2007).". Since this report additional information has been made available including:

- Monitoring of levels in the Turlough and quarry during a dewatering event,
- Water quality analysis,
- Hydraulic analysis of groundwater flow across the Bettws Fault.

These lines of evidence have been used to assess the potential for impact linkages between the proposed dewatering operation and the Turlough and to conclude that they can not exist based on a test of reasonable scientific doubt.

Cilyrychen Quarry is not within the defined aquifer block which supports the Turlough. This is due to the presence of the Bettws fault between the turlough and the quarry, which has thrust the lower permeability Brownstones Formation against the limestone, thereby forming a barrier to groundwater flow and defining the eastern boundary of the groundwater catchment. There are several lines of evidence to support this:

- The Turlough lies on the west of the mapped line of the Bettws Fault and the Brownstone formation.
- Water levels in the Turlough and surrounding aquifer differ significantly from the water level within the Quarry and some 80m higher than the water level in the Quarry. If there was movement of groundwater across the fault, the hydraulic gradient has been calculated using a simple analytical equation to represent groundwater movement to have an average of 16%. This is very steep and could only be sustained if the permeability of the unit between the two was very low.
- No seepage faces were observed on the edge of the dewatered quarry, and the quarry took a long time to recover after dewatering showing that there was little groundwater input. If there was hydraulic connection across the fault then seepage faces indicative of groundwater movement and discharge above the quarry would be reasonably anticipated.
- The conductivity of the quarry lake water is relatively low. If there was a connection between the quarry and the groundwater system beneath the turlough across the fault, it would be expected to be through a deep longer residence time groundwater path, and the conductivity level of the quarry would be higher. The relatively low conductivity of the quarry lake provides no evidence of this path.
- None of the Historic tracer tests reported by CCW show evidence of water crossing the Bettws Fault.

- Water levels in the turlough were not affected in a period of pumping of the Quarry during 2021. This is despite regional groundwater levels being on the low side of Normal to Notably low during this period.

Overall, the Turlough would not exist if there was a hydraulic link to the quarry. As such it is reasonably concluded that there is no hydraulic impact linkage between the proposal to resume dewatering operations at the quarry and the Turlough.

This report presents the evidence and explanation for why there has been an absence of any such reports or effects on the Turlough in the past and in support of authorising an abstraction licence, time-limited until 30th March 2030, for a resumption of quarry dewatering, illustrating how no reasonable doubt remains of any resultant impacts on the integrity of the Turlough. A resumption of water level monitoring of the Turlough is also proposed to provide the observation data during the period of authorised abstraction.

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1 Introduction

This report summarises the available evidence for the current understanding of the hydraulic functioning of the Pant-y-Llyn Turlough and the relationship between the catchment of the turlough and the Cilyrychen Quarry to the east.

CCW Staff Science Report No. 12/8/1 (Farr et al., 2012) identified that strata forming what has been termed the Gwenlais impounded karst formed a wider aquifer block that supported the groundwater conditions at the Turlough and within this the likely extent of the groundwater catchment that directly fed it. This report draws evidence from that report plus additional information to show that the Cilyrychen Quarry does not lie within the same groundwater catchment, nor the wider aquifer block of the turlough. As such it is reasonably concluded that no impact linkage is possible between the proposed dewatering works at the quarry and the eco-hydrological controls supporting the conditions at the Turlough.

Evidence to support this statement is provided within this report and a discussion is presented, which demonstrates that 'no scientific doubt remains' (Habitats Regulation Requirements) as to the absence of potential effects on the turlough due to the proposed resumption of abstraction within Cilyrychen Quarry.

1.1 Data Sources

The Pant-y-Llyn turlough is a predominantly groundwater fed water feature situated within the Gwenlais impounded karst limestone. The hydrological and hydrogeological characteristics of the turlough are described in Sections 2.2 to 2.5, with information drawn from a report the Countryside Council for Wales (CCW), written by Farr et al., (2012). Sections 2.8 and 2.9 discuss the information and evidence presented after the NRW report was published in 2012.

The NRW/CCW report by Farr et al., (2012) compiled the findings from several other studies by the Countryside Council for Wales (CCW), Limestone Research Group (LRG) and academic authors. The studies include:

- Campbell at al., (1992). Pant-y-Llyn - the first Welsh Turlough. Earth Science Conservation 31: 3-7.
- Hardwick and Gunn (1992). The hydrology and hydrogeology of Pant-y-llyn and environs. CCW Earth Science Report 92/1. Bangor, Countryside Council for Wales.
- Limestone Research Group (LRG) (1998). Hydrogeological studies at Pant-y-Llyn, Carmarthenshire. CCW Contract Science Report 219. Bangor, Countryside Council for Wales.
- Limestone Research Group (LRG) (1998). Unfinished Draft. Hydrogeological Investigation works at Cernydd Carmel, Pant-y-Llyn and Environs for CCW.
- Countryside Council for Wales (CCW) (2008). Core Management Plan including conservation objectives for Cernydd Carmel SAC.
- Farr et al., (2012). Hydrology, Water Quality and Condition of Pant-y-Llyn, Wales' only Turlough. CCW Staff Science Report No. 12/8/1. Collaborative project between hydrogeologists from the Environment Agency Wales (EAW) and ecologists from the Countryside Council for Wales (CCW).

Since this main study additional information has become available including:

- LIDAR surveys.
- Sediment sampling within the Turlough.
- Water level monitoring in the Turlough during times of groundwater abstraction from the quarry.

These sources of information are discussed in individual sections below.

2 Current understanding of the Pant-y-Llyn Turlough

The following sections outline additional information used to update the conceptualisation of the Turlough that is presented in Section 3.

2.1 Tracer tests

Tracer tests were carried out within the limestones surrounding the Turlough by Hardwick and Gunn (1992), which provided information on groundwater flow direction. In summary, groundwater flow was traced from the turlough to the base of the disused Glangwenlais Quarry to the west and also reported to 'mostly discharge at the Nant Gwenlais Spring'(CCW, 2012). Box 1 contains extracts from the report which provide details on the tracer tests results. Locations of the test inputs and discharge locations are presented in Figure 3-1 and Map 2, 3 and 4.

Box 1 - Section 1.2, page 11,12 (CCW, 2012)
Previous tracer data suggests that the groundwater supply comes from a fault-bounded karstic limestone block catchment within the immediate vicinity of Pant-y-Llyn rather than the main karst system. However groundwater hydrographs within the Glangwenlais karst area are very similar to water levels at Pant-y-Llyn. (from Exec summary, page viii) Tracer Tests suggest the turlough is not simply fed by discrete, well-defined conduits or along the strike of the limestone (Hardwick & Gunn, 1992). Instead, Pant-y-Llyn seems to gain and lose its water locally as the piezometric head rises and falls (page 11). Tracer tests also carried out by LRG show that most groundwater in the catchment discharges at the Nant Gwenlais Spring. One tracer test from Pant-y-Llyn was traced to the base of Glangwenlais quarry (page 12).

2.2 Boreholes and hydrographs and water quality

Data from groundwater monitoring boreholes, locations shown in Map 2, were used to construct hydrographs showing the local catchment's response to rainfall. The CCW (2012) outlines water samples from the boreholes were also taken for chemical analysis. Results are discussed in the direct extracts shown in Box 2.

Box 2 - Section 1.2, page 13 (CCW, 2012)

Hydrographs from boreholes and Pant-y-Llyn show that precipitation can cause rapid recharge, reflecting the effect of the surface water catchment providing rapid recharge to Pant-y-Llyn (page 13).

Corresponding recessions are found in the groundwater hydrograph from the Gorswen borehole. However, as mentioned in section 2.2.3, the onset of recession in Gorswen lags behind Pant-y-Llyn by approximately 6 days (Section 2.2.4, page 22)

Peak water levels at Gorswen EA borehole lag slightly behind those seen at Pant-y- Llyn, with the borehole water level continuing to rise after water levels in the turlough had begun to recede. The peaks are approximately coincident at lower stages but a lag exists at higher water levels of up to 9 days. This is no surprise as depth to water table at Gorswen can be c.45m below ground level, and any recharge would need more time to reach this depth (Section 2.2.3, page 21)

Groundwater levels recorded in Gorswen borehole (Figure 9) show most similarity to levels in Pant-y-Llyn. Although the hydrographs are similar in general shape, the amplitude of change in Pant-y-Llyn is just 3m, whereas at Gorswen it is over 10m

Glangwenlais Quarry borehole has artesian over flowing conditions during times of high groundwater levels and as a result has been very difficult to monitor. (Section 2.3, page 24)

Figure 2-1: Gorswen borehole groundwater level hydrograph and rainfall (from Farr et al., 2012 (Figure 9)).

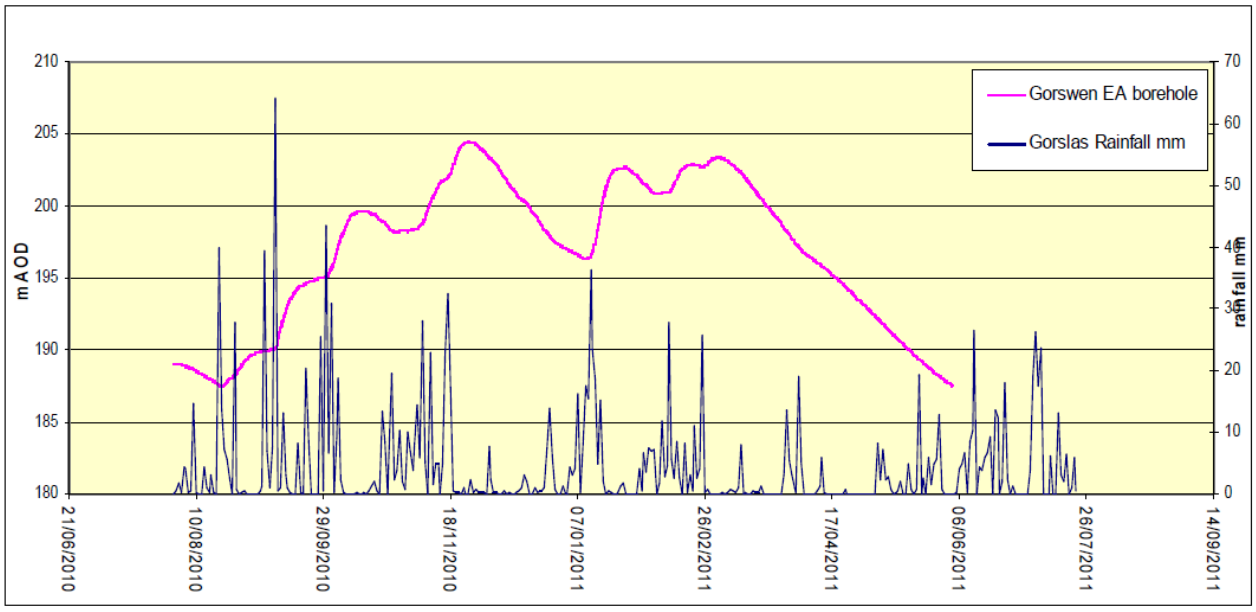
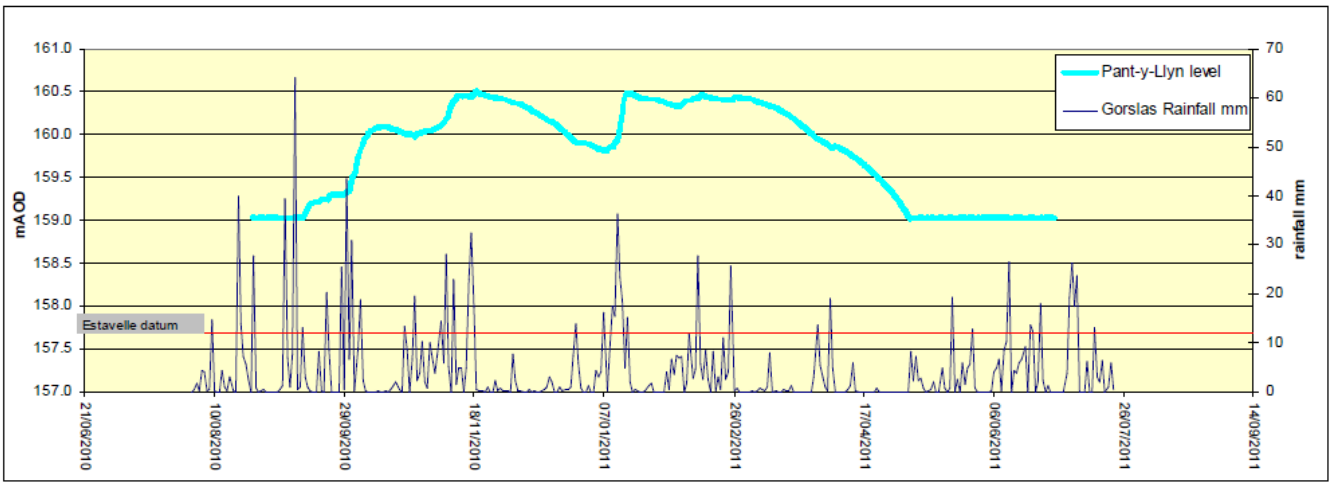


Figure 2-2: Pant-y-Llyn Hydrograph and rainfall



2.3 Water Quality

Sampling and testing of the water from the turlough and nearby boreholes was conducted by CCW, with the main conclusions presented in Box 3.

Box 3 (CCW, 2012)

We consider the Turlough feature at Cernydd Carmel to be in Favourable condition. This is because the hydrology at the site was favourable, there was no evidence of significant scrub invasion, and water quality was generally good.

This assessment should be considered as low confidence and is subject to the following caveats and concerns: inadequate biological data was available; there are intermittent chlorophyll and nutrient spikes which require further investigation (Section 6.2, page 57)

Water quality data also confirms that water in Pant-y-Llyn is less mineralised with a lower conductivity, suggesting a shorter residence time than, for example, waters from Gorswen borehole. This is further suggestion that some shorter flow paths, perhaps within the surface water catchment are important (page 13).

2.3.1 Quarry Water Quality

Four water quality samples were gathered from water contained within the quarry void in August 2022 (see Appendix A). Figure 2-3 presents a piper diagram of the samples and compares them against water quality samples taken from the Turlough in CCW (2012). The diagram shows that both water bodies have similar water quality. This reflects that both cross the same geological units, although either side of the Bettws Fault (see Map 1).

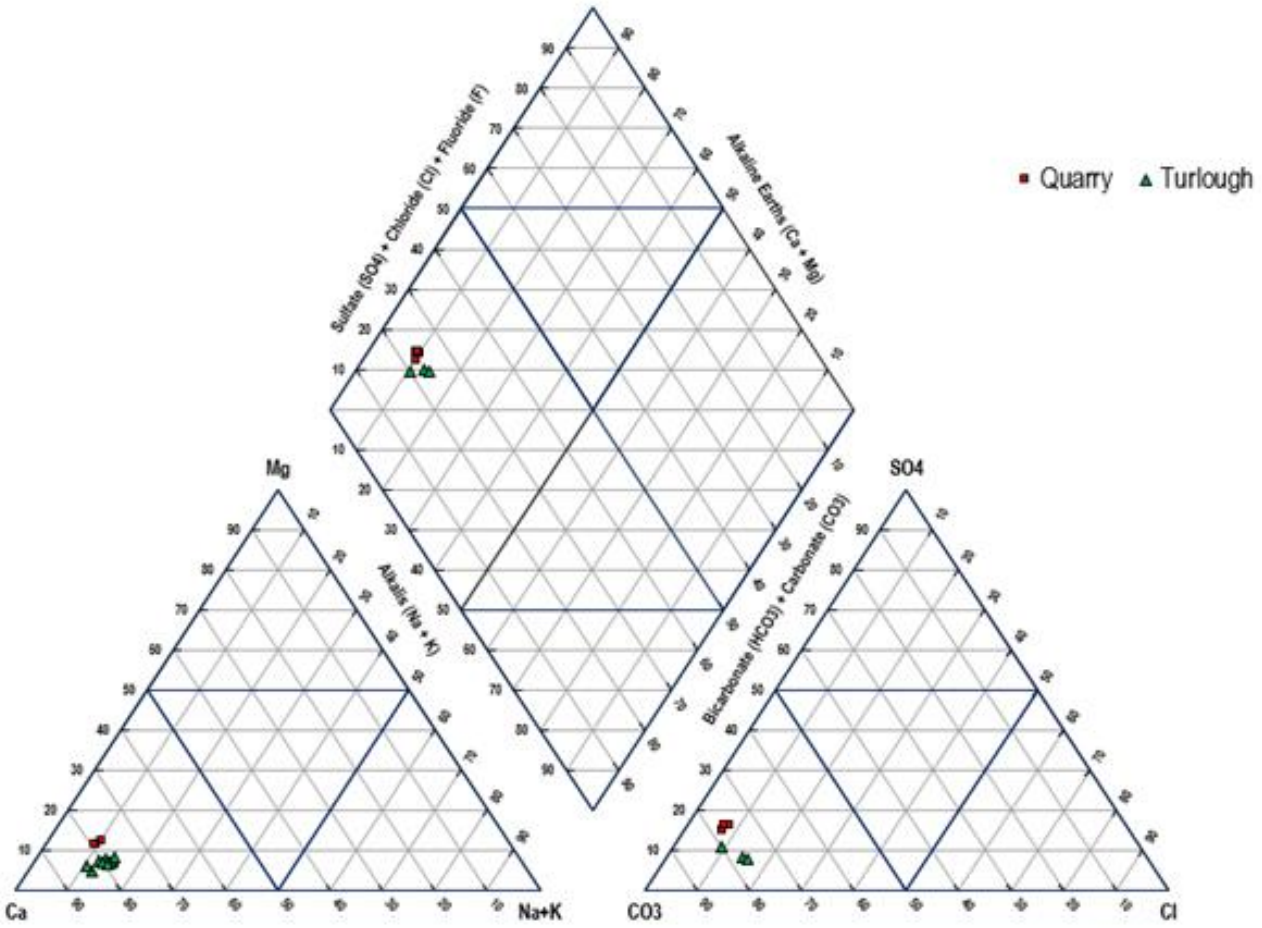
Conductivity of the samples can be used as a proxy for residence time of the water beneath ground. CCW (2012) notes:

> *"Conductivity measured at 20oC averages 232 µs/cm and 440 µs/cm in Pant-y-Llyn and groundwater respectively. Lower conductivities in Pant-y-Llyn may reflect shorter*

residence times from recharge and also the effect of some direct rainfall recharge. It is usual for there to be higher conductivities in groundwater than surface water bodies"

An average conductivity of 265µS/cm was recorded in water samples collected from the quarry in August 2022, which is similar to the conductivity of samples taken from the Turlough (232µS/cm) in CCW (2012). If there was a connection between the quarry and the groundwater system beneath the turlough across the fault and the intervening Brownstones Formation, it would be expected to be through a deep and longer residence time groundwater path, and the conductivity level of the quarry water would be higher.

Figure 2-3: Piper Diagram of Quarry and Turlough Water Quality



2.4 Surface water catchment

The surface water catchment is defined in the CCW report (CCW, 2012) is shown in Maps 1 - 4 and discussed in direct quotes in Box 3.

Box 4 - Section 1.2, page 13 (CCW, 2012)
The surface catchment of Pant-y-Llyn is likely to be principally influenced by the steep sided topography within the immediate area. LRG (1998) proposed a surface water catchment (Figure 2), with which we are in agreement. Recharge falling in this area will reach Pant-y-Llyn rapidly. This will be instant in the case of direct rainfall, and may take only days via through flow in soils and shallow groundwater pathways after heavy rainfall events. Short time lags between rainfall events and increasing levels in Pant-y-Llyn highlights a fairly rapid response and suggests there may well be an element of more rapid conduit flow.

2.5 Groundwater flow and catchment area

While the groundwater catchment of the turlough is difficult to define, the CCW report (CCW, 2012) is confident that the Bettws fault acts as the eastern boundary, bringing the less permeable Brownstones Formation into contact with the limestone resulting in a barrier to groundwater flow - as discussed in Box 5. The information in the Box shows that there is confidence in defining the aquifer block that supports the Turlough. The CCW report identifies this as Gwenlais impounded karst. Interpretation of the report indicated that the Gwenlais impounded karst consists of outcrop of the Dowlais Limestone Formation, Honeycombed Sandstone Member, Penderyn Oolite Member and Oxwich Head Limestone Formation west of the Bettws Fault. This comprises the main recharge area and incorporates the main discharges to the south. This is shown as the "Aquifer Block" in Map 2-4. Within this aquifer block the extent of the groundwater catchment is less well constrained and will vary in extent with varying groundwater levels. There is some evidence from water quality sampling to show that the groundwater that enters the Turlough is from a shallower karst system, however this does not mean that the groundwater levels within the Turlough are not supported by groundwater conditions in the wider aquifer block.

Box 5 - (CCW, 2012)

At present the area of the Gwenlais impounded karst is considered to be the potential groundwater catchment. This position was adopted on the recommendation of LRG as a precautionary approach and reflects uncertainty regarding the real extent of the groundwater catchment (Section 8.1.2, page 57).

LRGs tracer tests show the main discharge point is the spring that feeds the Nant Gwenlais brook (Section 8.1.2, page 57).

In general, groundwater could be assumed to flow downdip and from the west (Section 1.2, page 11)

Surface water enters the main karstic system through five main sink holes, from west to east a Dyllgoed Isaf, Pwll Edrychiad, Garn Farm, Sinc Llinos and Bwlchau Sink. These discharge predominantly at the Nant Gwenlais spring southwest of Glangwenlais Quarry (Section 8.1.2, page 57)/

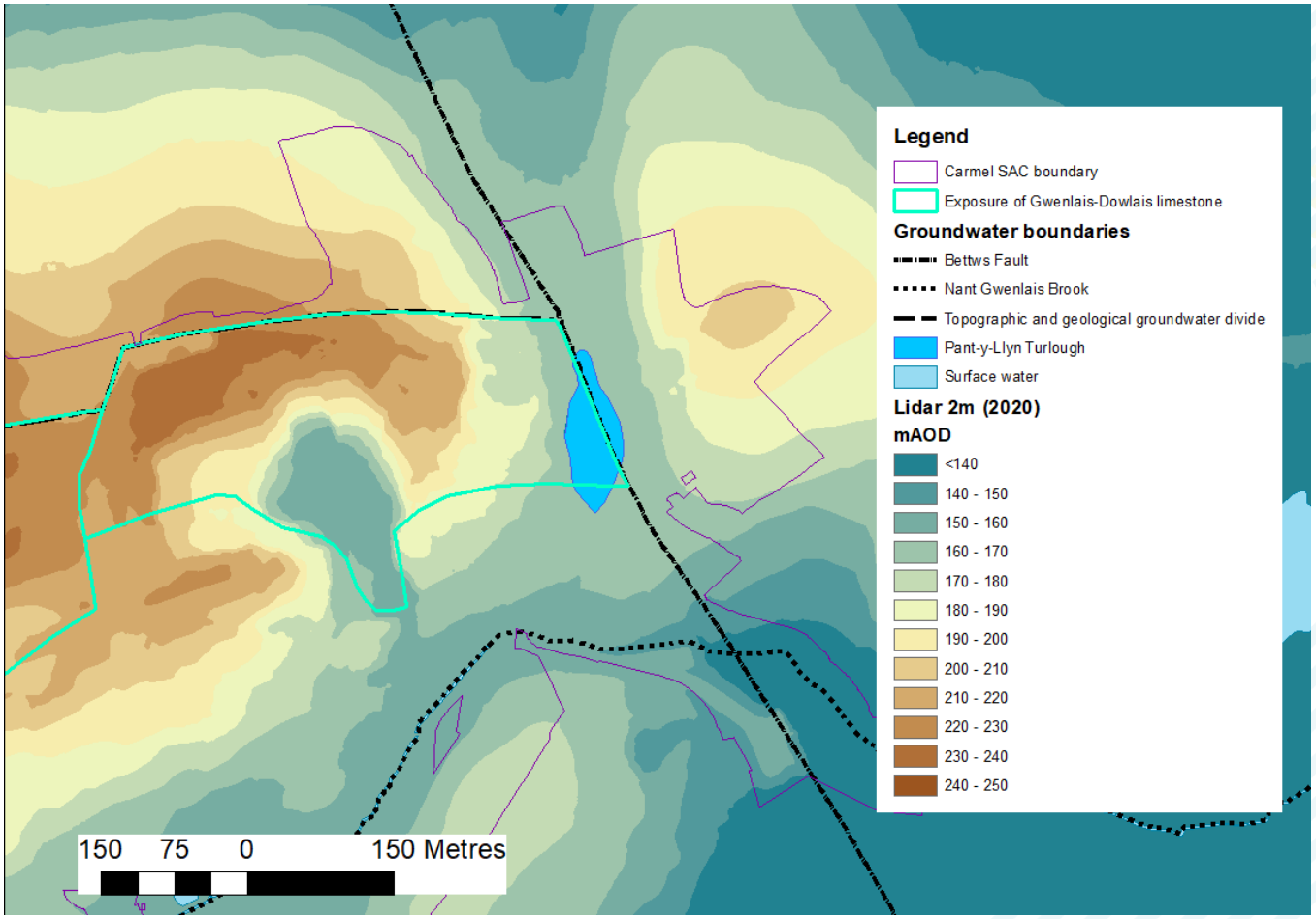
Based on the tracer data, there is no clear evidence that Pant-y-Llyn is predominantly fed by the main karst system. While groundwater hydrographs within the Gwenlais karst area do show very similar hydrographs and responses to water levels at Pant-y-Llyn, this is not necessarily indicative of a direct connection. Instead, as all karst systems in the area receive the same precipitation this may just be similar karst systems responding to the same input. Water level and water quality data(which indicate shallow, rapid flow paths within the local vicinity of Pant-y-Llyn) may provide further consideration for a smaller, possibly fault-bounded karstic limestone catchment within the immediate vicinity of Pant-y-Llyn. (Section 8.1.2, page 57).

The eastern boundary (of the groundwater catchment) may be marked by the Bettws fault (Figure 1), which brings the Devonian strata into contact with the Carboniferous Limestone, and seems to act as a barrier to groundwater. LRG (1998) suggest that there may be a possibility of flow along or near to the Bettws fault, south to the Nant Gwenlais brook. This is certainly possible, but the fault brings Devonian strata into juxtaposition with the Carboniferous Limestone and this effect is likely to act as a barrier to groundwater flow, due to the contrasting hydraulic properties of the two stratigraphic units (Section 1.2, page 14).

2.6 The Role of Glangwenlais Quarry in the Shallow Groundwater System

The Glangwenlais Quarry forms a valley that cuts north-south across the limestone outcrop. The base of the valley is around 5m lower (circa 156mAOD) than the turlough to the west. This will limit the contribution of groundwater to the turlough from the west. This again provides additional evidence that the Turlough is supported by a shallow karst system (see Figure 2-2).

Figure 2-4: Topography and Groundwater Divides around the Turlough and Glangwenlais Quarry



2.7 Bed Sediments

Jones et al (2017)1 presents analysis of the bed sediments of the Turlough. It shows that there is over 5m of peats, silts and clays within the base of the Turlough. Water level monitoring shows that these thick low permeability deposits do not act to allow the water in the Turlough to remain perched, when groundwater levels in the underlying aquifer drop. This suggests that despite these deposits, there is a good hydraulic linkage through karst features to the wider limestone aquifer.

Box 6: Figure from Jones et al (2017)

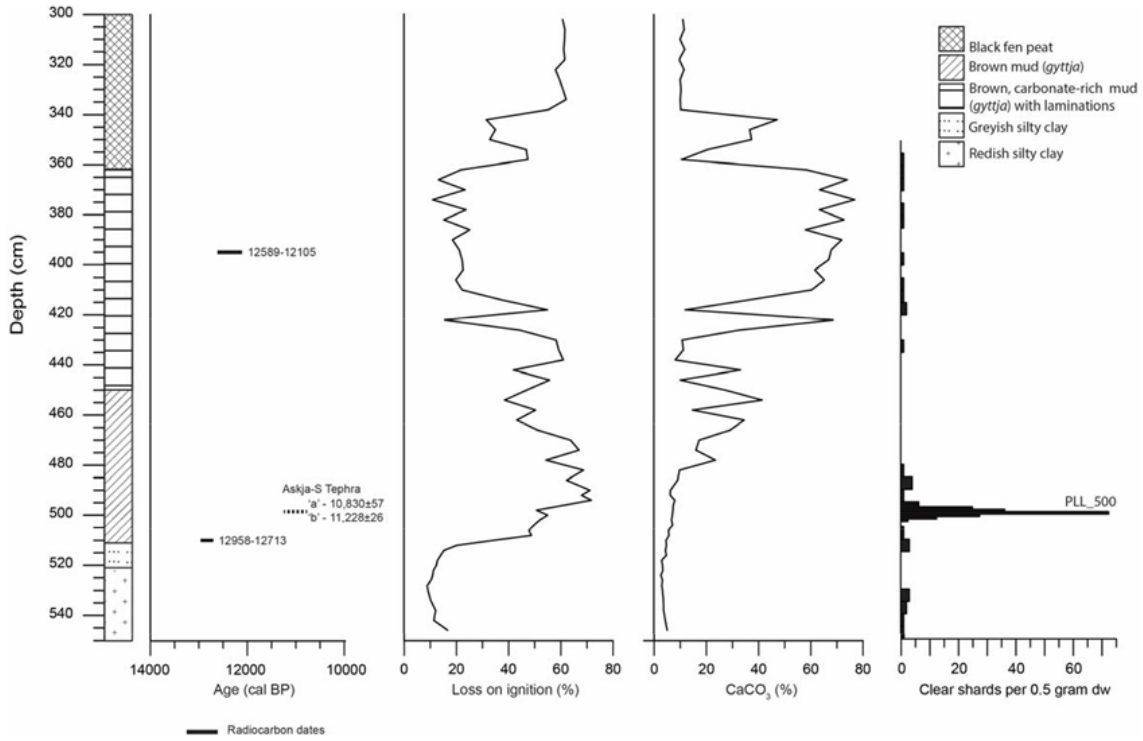


Figure 3. Lithostratigraphy, radiocarbon dates, loss on ignition, $CaCO_3$ content and total shard concentrations for the Pant-y-Llyn core (BGS Borehole reference SN61NW12). Radiocarbon dates are derived from bulk sediment samples. Calibrated age ranges are shown here and outlined in table 1. Askja-S Tephra age estimates are from Bronk Ramsey et al., 2015 (a) and Ott et al., 2016 (b).

1 G Jones, S Davies, G Farr, and J Bevan, Identification of the Askja-S Tephra in a rare turlough record from Pant-y-Llyn, south Wales Proceedings of the Geologists' Association Vol 128, Issue 4, August 2017, Pages 523-530

2.8 Test pumping - dewatering - recovery

Within Cilyrychen quarry, water was pumped from 6/4/21 to 9/7/21, prior to this application process commencing. Pumping took place 24 hours a day with around ten days of no pumping within this period for maintenance of the pump infrastructure. It was pumped using the pump proposed for this abstraction application. The pumping rate was therefore in the region of the pump capacity, of 735 m3/h. By the time of the cessation of pumping, the water level in the void had fallen an estimated 10 m (as illustrated by the 'tide line' in Figure 3-5. By late November 2021, the water level had only risen back ~1 m, and water level within the quarry has not yet recovered to the level prior to pumping. This demonstrates an extremely slow response to recharge, runoff and/or infiltration. This is fundamentally different from the rapidly responding karst system that supports the Pant-y-Llyn Turlough as evidenced through literature review.

2.9 Pant-y-Llyn water level monitoring

Data provided by Natural Resource Wales (NRW) includes observations of the turlough levels for the period from May 2010 to August 2022, which is shown in Figure 2-5. The data shows that following the dewatering operations in Cilyrychen (6/4/21 to 9/7/21) and through the slow recovery to November 2021 (shown by the orange bar), the turlough progressed through an entire cycle of emptying and filling, which indicates that there was no significant change in ecohydrological conditions within the turlough during this period of the abstractions. During Summer-Autumn 2021 the minimum level within the Turlough was 0.5magl, this is despite the CEH water resources portal showing that regional groundwater levels in South Wales were towards the bottom of Normal and dipped into Notably Low during September. This means that during a dry period, and a period of suppressed water levels in the Quarry following pumping, the Turlough still maintained water within it. If pumping from the Quarry had affected water levels in the Turlough then the recorded rise shown in the figure during the latter stages of the dewatering would not have been possible.

Figure 2-5:Pant-y-Llyn water level monitoring

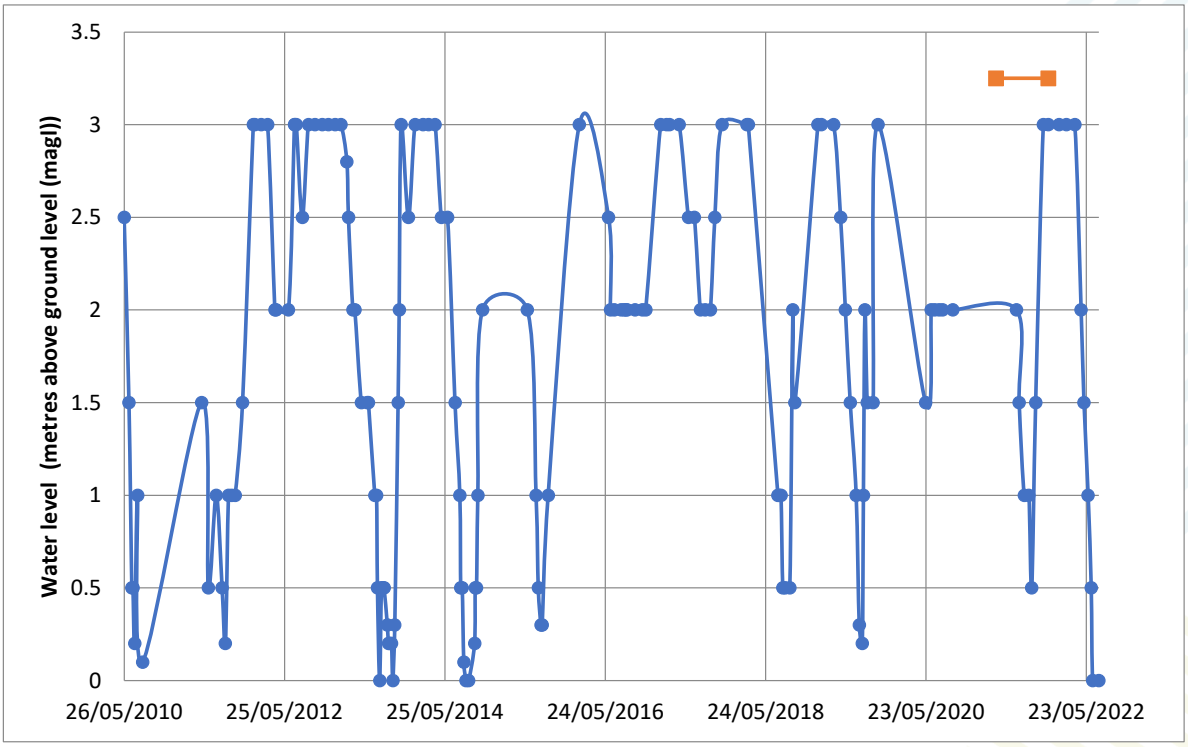
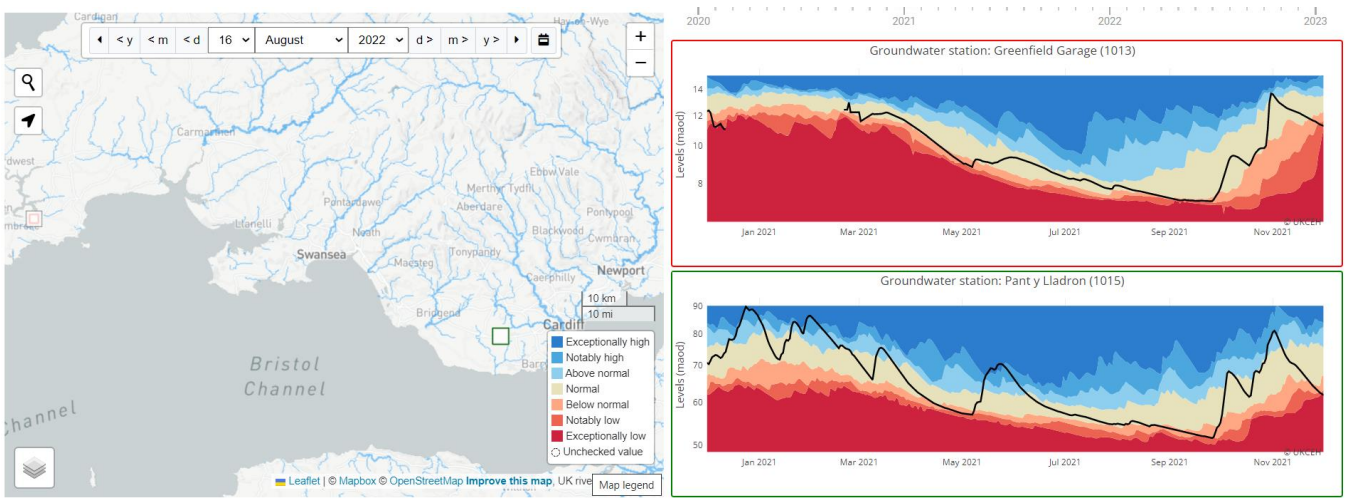


Figure 2-6: South Wales Groundwater Levels During 2021



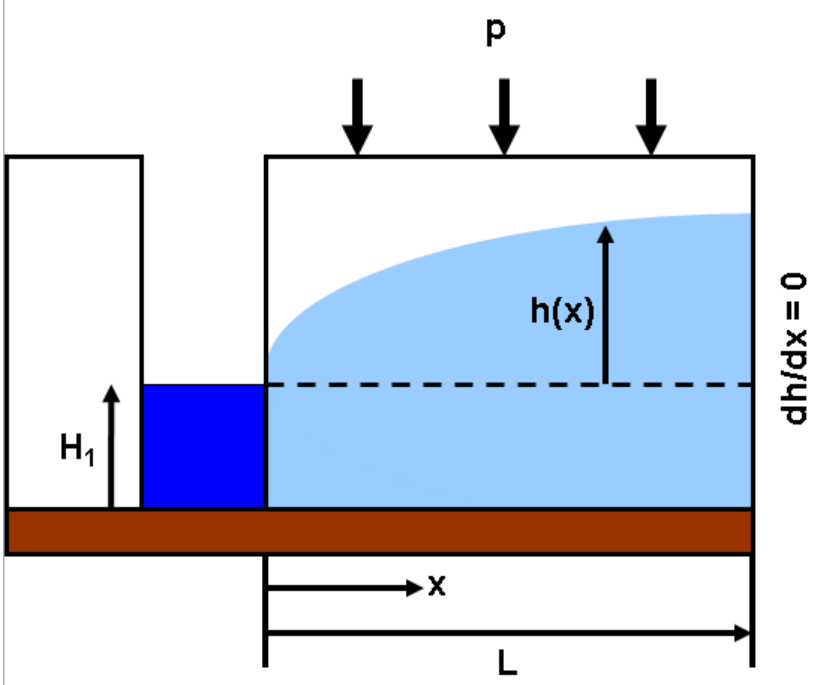
2.10 Maintaining Head Difference without the Bettws Fault

The turlough lies at an elevation of circa 156mAOD (CCW 2012) to 160mAOD (LIDAR survey). The LIDAR level of the Cilyrychen quarry sump lake is circa 80m below the Turlough and around 550m away. Box 7 presents a well-known 1-D analytical groundwater model using two permeabilities: 100m/d as a low permeability figure for a karst system (see Box 8) and 10m/d equivalent for a clean sandstone. In order to maintain the head difference between the two water bodies, if an aquifer lay between them daily recharge would need to be between 0.6 and 6m per day. This is clearly unrealistic and clearly shows that the permeability of the unit between the two has to be much lower to maintain a head difference. Using an annual recharge of 1,500mm (which would be a high estimate and equivalent to 0.004m/d), the analytical equation suggests a bulk permeability of 0.06m/d. This is equivalent to the reasonably anticipated permeability of a mudstone which aligns most closely with the description of the Brownstone Formation.

Overall, this analysis shows that for the Turlough to exist at the height and distance from the quarry as it does today, there must be very limited flow to the east. This is an illustrative analysis why the Turlough's conditions can be maintained so close to the existing quarry void.

Box 7: Analytical Groundwater equation

1-D ANALYTICAL MODEL OF GROUNDWATER FLOW TO A WATER BODY (variable saturated thickness)



Dupuit-Forchheimer Equation:

$$\frac{d}{dx}\left(\frac{dh^2}{dx}\right) = -\frac{2p}{K}$$

K = hydraulic conductivity (m/d)
h = hydraulic head (m)
p = recharge (m/d)
x = horizontal distance (m)

Left-hand boundary: CONSTANT HEAD
$h = H_1$ at $x = 0$

Right-hand boundary: NO-FLOW
dh/dx=0 at x = L

Solution:

$$h = \sqrt{H_1^2 + \frac{p}{K}\left(2Lx - x^2\right)}$$

The head, h_L, at the no-flow boundary is

$$h_L = \sqrt{H_1^2 + \frac{pL^2}{K}}$$

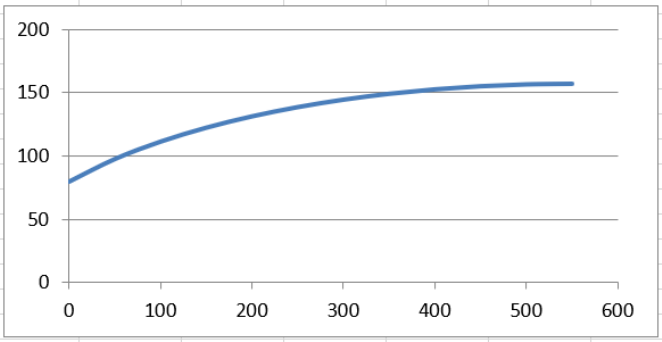
MODEL PARAMETERS

Parameter	Symbol	Value	Units
Hydraulic conductivity	K	100	m/d
Recharge	p	6	m/d
Model length	L	550	m
Constant head on left-hand-side	H1	80	m

RESULTS

Distance, x (m)	Head, h (m)	
0	80	Copy down formula
50	97.724101	
100	111.35529	
150	122.27019	
200	131.14877	
250	138.38353	
300	144.22205	
350	148.82876	
400	152.31546	
450	154.75788	
500	156.20499	
550	156.6844	

Head at no-flow boundary	
156.6844	m



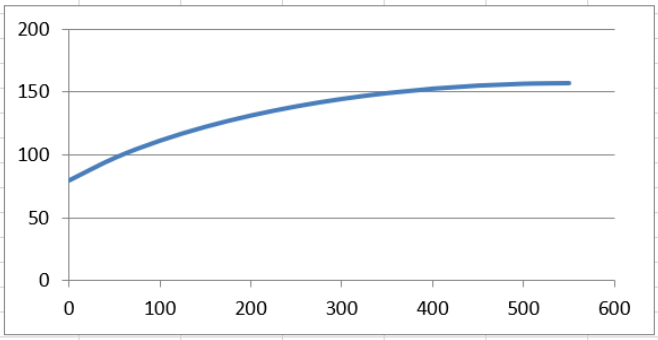
MODEL PARAMETERS

Parameter	Symbol	Value	Units
Hydraulic conductivity	K	10	m/d
Recharge	p	0.6	m/d
Model length	L	550	m
Constant head on left-hand-side	H1	80	m

RESULTS

Distance, x (m)	Head, h (m)	
0	80	Copy down formula
50	97.724101	
100	111.35529	
150	122.27019	
200	131.14877	
250	138.38353	
300	144.22205	
350	148.82876	
400	152.31546	
450	154.75788	
500	156.20499	
550	156.6844	

Head at no-flow boundary	
156.6844	m



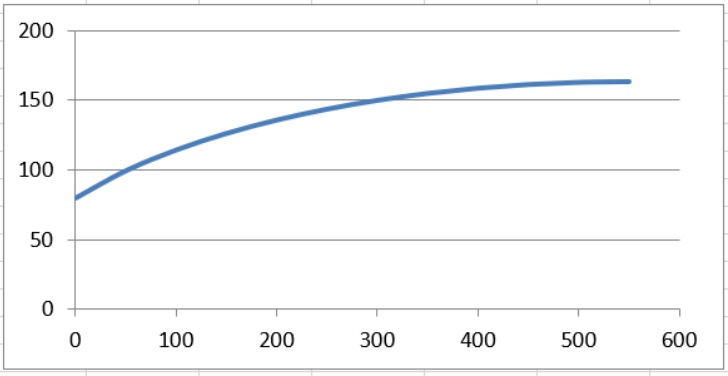
MODEL PARAMETERS

Parameter	Symbol	Value	Units
Hydraulic conductivity	K	0.06	m/d
Recharge	p	0.004	m/d
Model length	L	550	m
Constant head on left-hand-side	H1	80	m

RESULTS

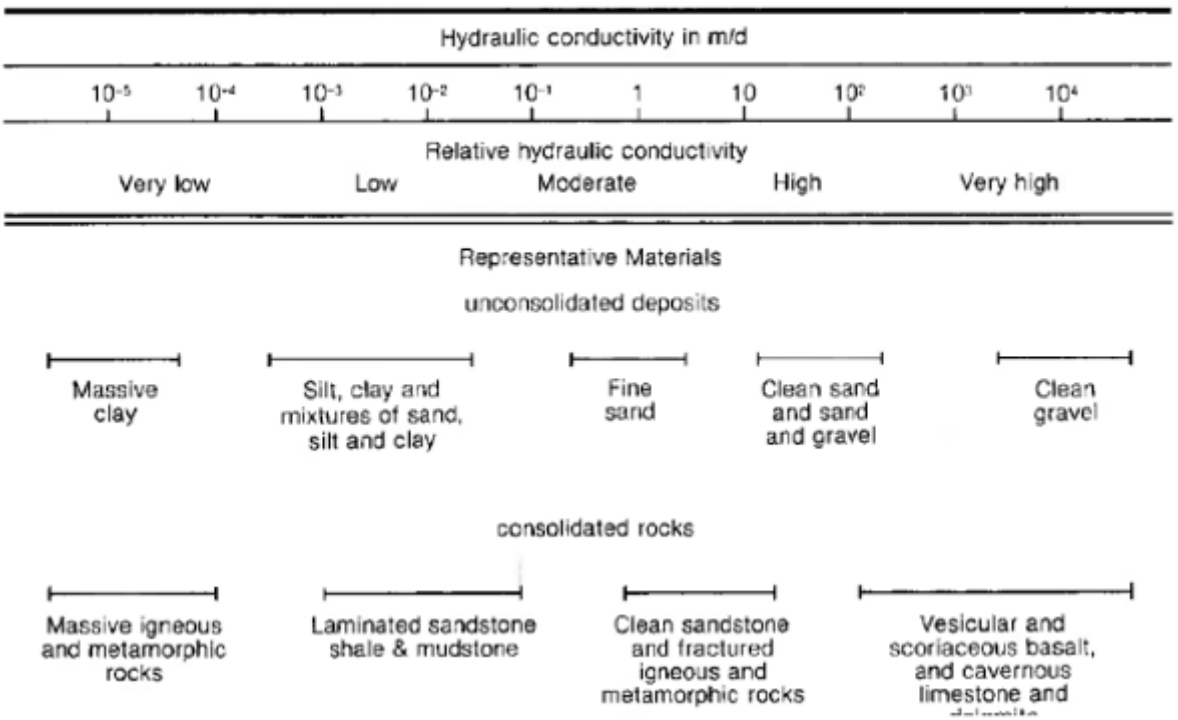
Distance, x (m)	Head, h (m)	
0	80	Copy down formula
50	99.498744	
100	114.30952	
150	126.0952	
200	135.6466	
250	143.41083	
300	149.6663	
350	154.59625	
400	158.32456	
450	160.93477	
500	162.48077	
550	162.99284	

Head at no-flow boundary	
162.99284	m



Brassington (2006) - Field Hydrogeology Hydraulic Conductivity ranges

Table 5.4 List of indicative porosities and hydraulic conductivities for unconsolidated sediments and rocks



3 Revised Conceptual Model - Pant-y-Llyn Turlough

3.1 Conceptual model

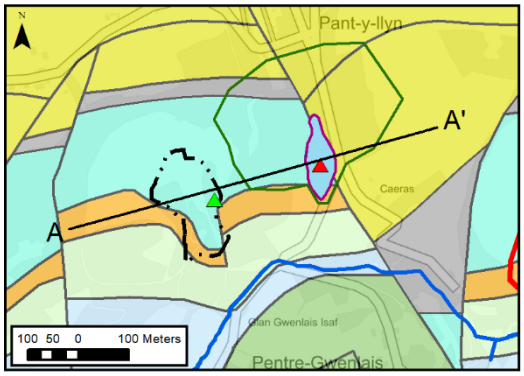
A conceptual model of the Pant-y-Llyn Turlough is displayed in Figure 3-1, incorporating evidence in this report and focuses on explaining the relationship between the Turlough, groundwater and the bedrock geology. Figure 3-2 shows the updated conceptualisation from the initial report by JBA showing the relationship between the quarry and the turlough. The models comprises the following features:

- Geology:
  - Gwenlais impounded karst limestone (Dowlais Limestone Formation - west of Bettws fault): Tabular, thick-bedded, medium to dark grey, fetid, bituminous, fossiliferous, peloidal grainstone, packstone and wackestone limestones with dark grey shale interbeds (BGS Online Lexicon);
  - Brownstones Formation (east of Bettws fault): Red, brown and purple fluvial sandstones with red mudstone interbeds;
  - superficial till deposits underly the turlough and comprise at least 5.5m of peat, silts and clays.
- Hydrogeology:
  - Dowlais/Gwenlais limestone - designated a Principal Aquifer;
  - Brownstones Formation - designated a Secondary A Aquifer;
  - Superficial till deposits - low permeability peats, clays and silts.
- Surface water catchment, hydrology and recharge:
  - Surface water catchment principally influenced by the steep sided topography within the immediate area of the turlough;
  - majority of the recharge comes from the west;
  - water level peaks lagged by between 1 and 8 days behind heavy rainfall events;
  - recharge is more rapid during wetter months where the water table is higher (e.g winter) and slower when the water table is depressed (e.g late summer).
- Cycle of the turlough emptying and filling:
  - Turlough has undergone seven full cycles of filling and emptying within the last 11 years (0.63 times a year);
  - Maximum recorded dry period of two months (though intermittent);
- Three conditions of groundwater levels within local karst limestone:
  - 1) Turlough gaining - high local groundwater levels due to rapid response to rainfall;
  - 2) Turlough emptying - tracer test results confirm groundwater flow paths between turlough and Glangwenlais;
  - 3) Low groundwater levels in dry periods - elevation of Nant Gwenlais Brook. Fluctuating groundwater levels evidenced by cycle of filling and emptying of turlough. During extended dry periods, the level drops below the base of the turlough.
- Groundwater catchment, boundaries and flow:
  - Groundwater catchment considered, conservatively, to be the exposed area of the Gwenlais impounded karst - west of the Bettws fault;

- Bettws fault - acts as a barrier to groundwater, due to the contrasting hydraulic properties;
- Groundwater flow is predominantly to the south-west where it discharges at Nant Gwenlais spring.

- The Cilyrchen Quarry lies outside the aquifer block that supported turlough
  - The Bettws fault and the Brownstone formation forms a groundwater barrier between the quarry and turlough.

Figure 3-1: Pant-y-Llyn conceptual model



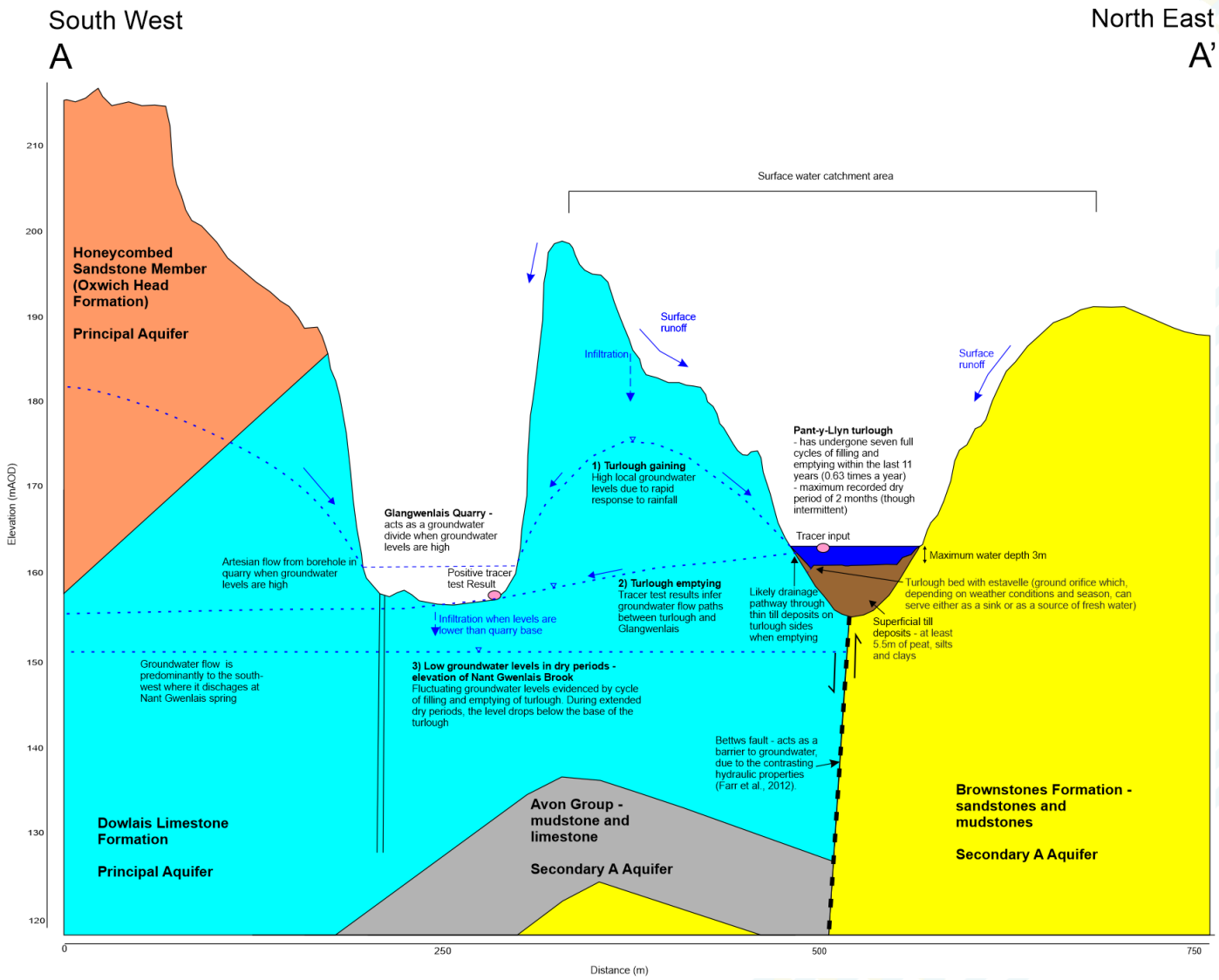
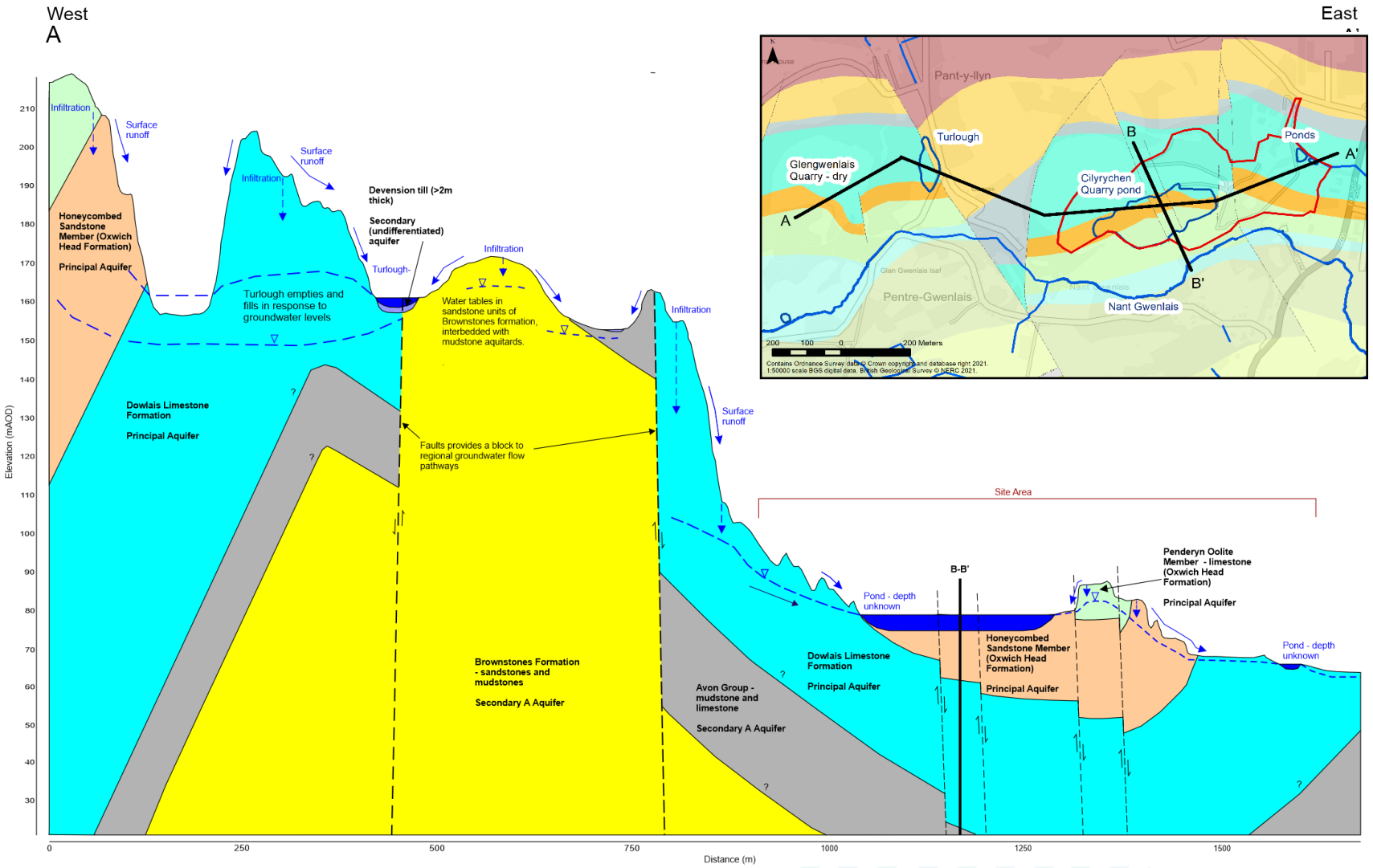


Figure 3-2 - Updated Quarry and Turlough Conceptual Model



4 Conclusions

4.1 Extent of the Pant-y-Llyn groundwater catchment

Farr et al., (2012) proposed, conservatively, that the turlough's groundwater catchment area comprises the extent of Gwenlais impounded karst to the west. (Maps 1 and 2). This has been interpreted as the Aquifer Block shown in Maps 2 - 4.

Evidence presented in the CCW report, has been used to inform the current conceptual understanding of the Pant-y-Llyn turlough (as shown in Sections 0 and 3). This understanding has led to the suggestion that the groundwater catchment area to the turlough is likely to be smaller than the entire area of impounded karst, as evidenced by:

- Tracer tests suggesting the groundwater input comes from the immediate vicinity of Pant-y-Llyn turlough (Farr et al., 2012).
- Water quality data revealing that the Pany-y-Llyn is less mineralised with a lower conductivity than waters from the Gorswen borehole to the west. This infers the groundwater discharging to Pant-y-Llyn has a short residence time with shallow groundwater flow pathways in the immediate vicinity of the turlough (Farr et al., 2012).
- Hydrographs from various boreholes and Pant-y-Llyn demonstrate that precipitation causes rapid recharge, which shows the effect of the surface water catchment and suggests a short residence time when groundwater levels are elevated and cause the turlough to fill up (Farr et al., 2012).

Despite the groundwater catchment likely to being smaller than the wider Aquifer Block (see Maps 2 – 4), impact linkages might be possible from effects on the groundwater system within the wider block. For example, a dewatering operation could move the position of groundwater boundaries or increase the rate of vertical groundwater movement from the shallow karst system to the deeper karst system. Evidence was therefore needed to confirm that the Bettws Fault acts as an effective barrier and that the Quarry does not lie within the Gwenlais impounded karst area.

4.2 Connection between Cilyrychen Quarry and Pant-y-Llyn

CCW (2012) reported concluded that "Further work is required to prove a link between Pant-y-Llyn and the currently inactive Cilyrychen Quarry (LRG, 2007).". Since this report additional information has been made available including:

- Monitoring of levels in the Turlough and quarry during a dewatering event,
- Water quality analysis,
- A simple groundwater flow analysis.

Overall, this has been used to confirm that there are no potential impact linkages between the quarry and Turlough.

Cilyrychen Quarry is not within the Aquifer Block supporting the Turlough. This is due to the Bettws fault, which has thrust the lower permeability Brownstones Formation against the limestone, which will serve to act as a barrier to groundwater flow and therefore marks the eastern boundary of the groundwater catchment within which the Turlough is located. There are several lines of evidence to support this:

- The Turlough lies on the western edge of the Bettws Fault and the Brownstone formation.
- The Turlough lies at an elevation of circa 80m above the typical water level in the Quarry. If there was flow of groundwater across the intervening Bettws Fault, the hydraulic gradient would have an average of 16%, which is very steep

and could only be sustained if the permeability of the unit between the two was very low.

- No seepage faces indicative of groundwater flow across the Bettws Fault have been observed on the western edge of the Cilyrychen quarry, and the quarry took an exceptionally long time to recover after dewatering initial dewatering in 2021 which does not suggest rapid ingress of groundwater.
- The conductivity of the quarry lake is relatively low. If there was a connection between the quarry and the groundwater system beneath the turlough across the fault, it would be expected to be through a deep long residence time groundwater path, and the conductivity level of the quarry would be higher. The relatively low conductivity of the quarry lake measured in August 2022 provides no evidence of this.
- None of the historic tracer tests show evidence of water crossing the Bettws Fault.
- Monitoring data indicates that the Turlough was maintained during the period of dewatering of the Quarry during 2021. This was also during a period when regional groundwater levels were on the low side of Normal to Notably low during this period as evidenced by NRW groundwater level information.

Overall, it is posited that the Turlough would not exist if there was a hydraulic link to the quarry. The evidence in this report has been used to assess the potential for impact linkages between the proposed dewatering operation and the Turlough and to conclude that they can not exist based on a test of reasonable scientific doubt.

Appendices

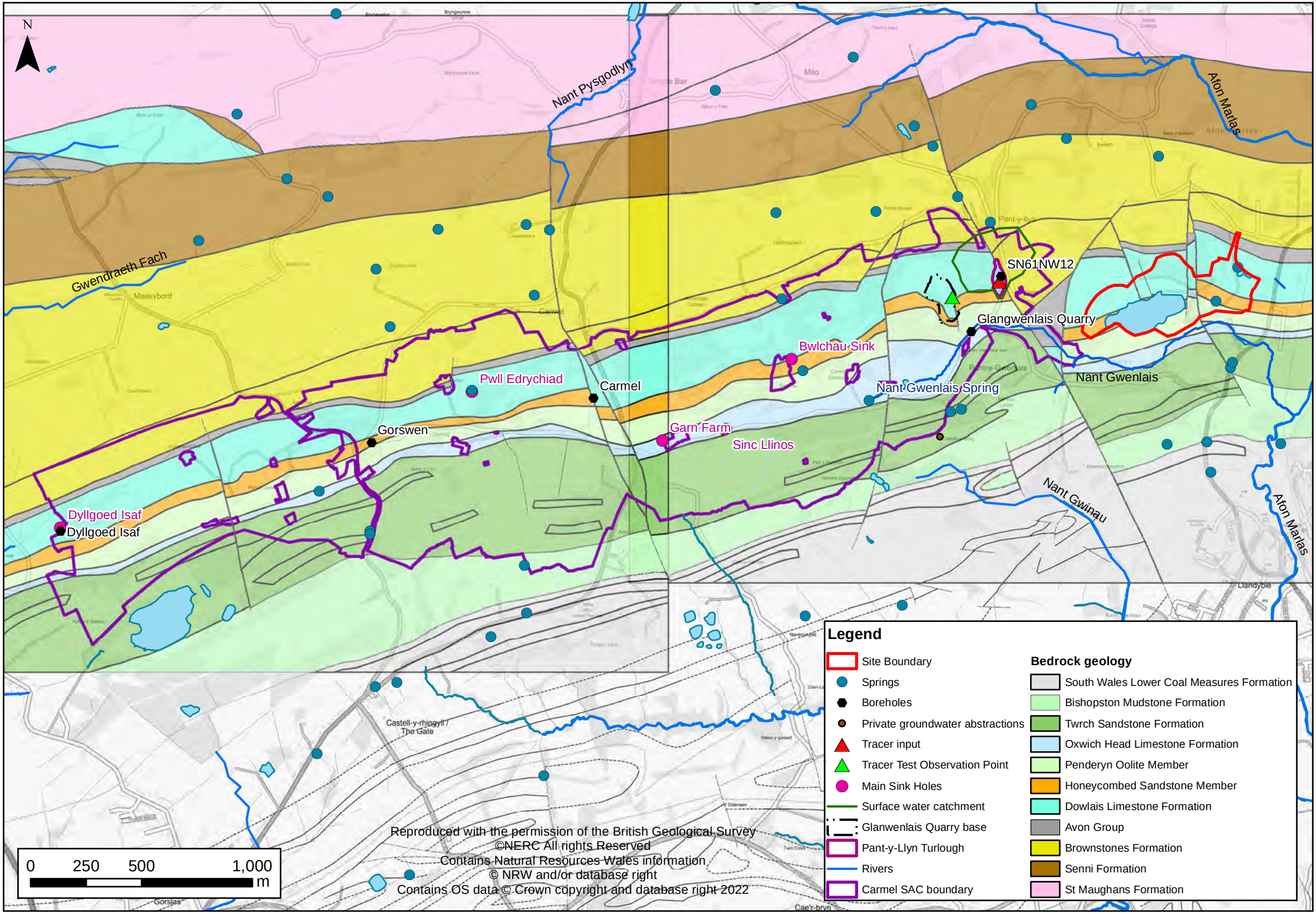
A Map

Map 1 - Bedrock, boreholes, springs and sinks

Map 2 - Topography, groundwater catchment, boundaries and flow direction

Map 3 - Bedrock, groundwater catchment, boundaries and flow direction

Map 4 - Zoomed Pant-y-Llyn turlough Topography, groundwater catchment, boundaries and flow direction


N
Nant Pysgodlyn
Afon Marlas
Gwendraeth Fach
Maesybont
Carmel
Pant-y-llyn
SN61NW12
Glangwenlais Quarry
Bwlchau Sink
Pwll Edrychiad
Carmel
Nant Gwenlais Spring
Nant Gwenlais
Gorswen
Garn Farm
Sinc Llinos
Dyllgoed Isaf
Dyllgoed Isaf
Nant Gwinau
Afon Marlas
Llandyfaelog
Castell-y-rhingyll / The Gate
Gorslas
Cae'r-bryn
0 250 500 1,000 m
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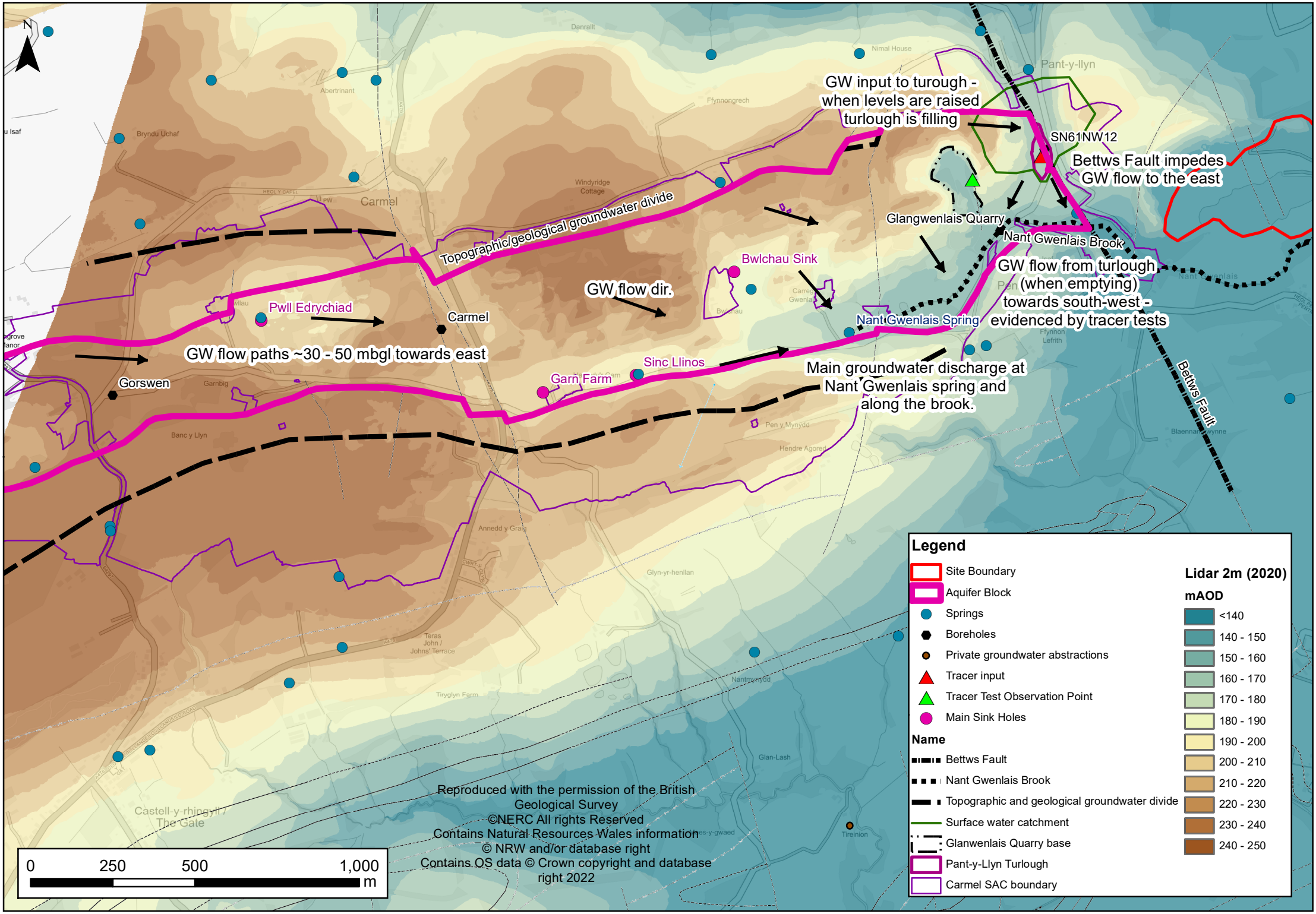
Legend
Site Boundary
Springs
Boreholes
Private groundwater abstractions
Tracer input
Tracer Test Observation Point
Main Sink Holes
Surface water catchment
Glanwenlais Quarry base
Pant-y-Llyn Turlough
Rivers
Carmel SAC boundary
Bedrock geology
South Wales Lower Coal Measures Formation
Bishopston Mudstone Formation
Twrch Sandstone Formation
Oxwich Head Limestone Formation
Penderyn Oolite Member
Honeycombed Sandstone Member
Dowlais Limestone Formation
Avon Group
Brownstones Formation
Senni Formation
St Maughans Formation



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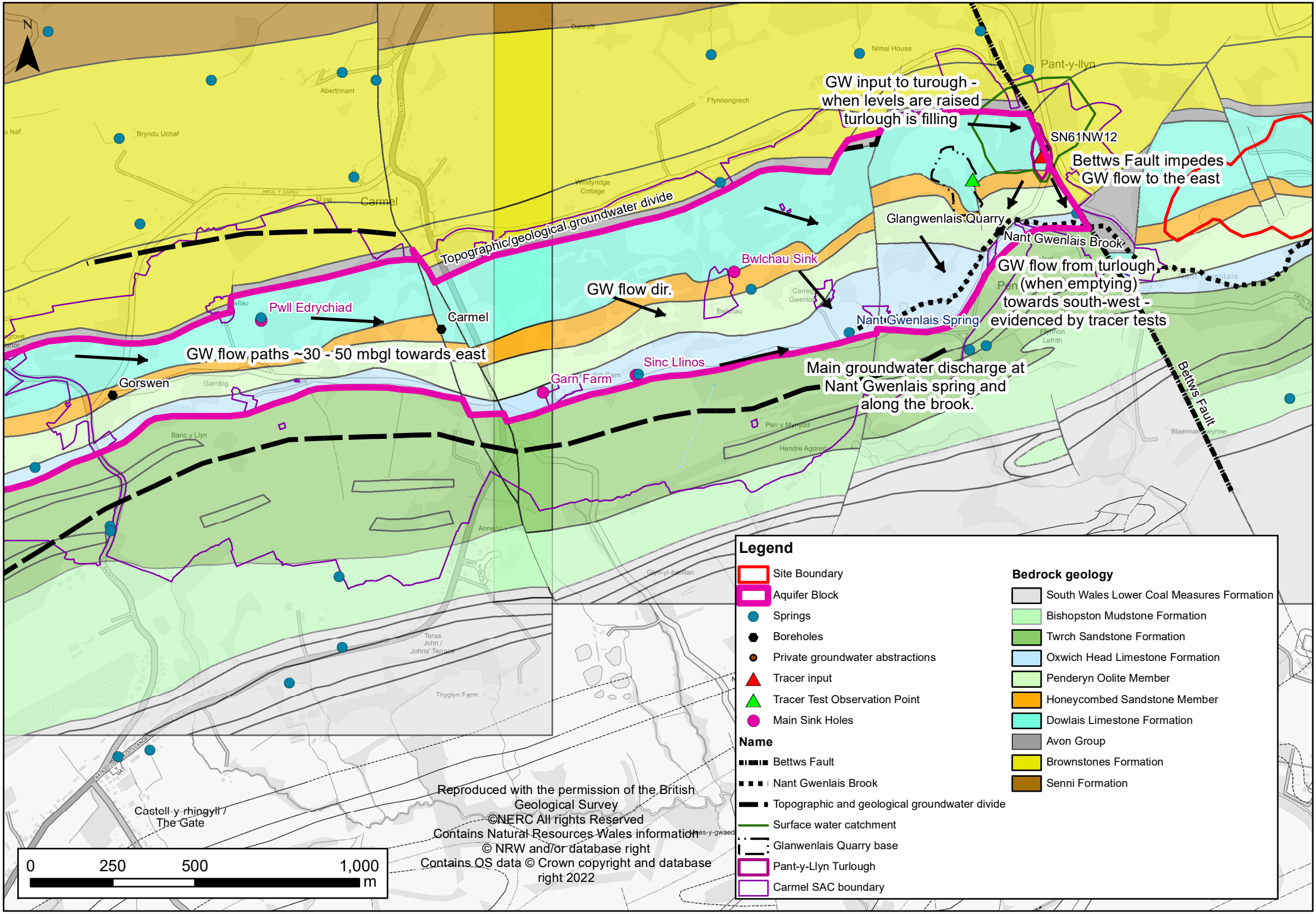
N
GW input to turough - when levels are raised turlough is filling
SN61NW12
Bettws Fault impedes GW flow to the east
Topographic/geological groundwater divide
Glangwenlais Quarry
Nant Gwenlais Brook
Bwlchau Sink
GW flow dir.
GW flow from turlough (when emptying) towards south-west - evidenced by tracer tests
Pwll Edrychiad
Carmel
Nant Gwenlais Spring
GW flow paths ~30 - 50 mbgl towards east
Gorswen
Sinc Llinos
Garn Farm
Main groundwater discharge at Nant Gwenlais spring and along the brook.
Bettws Fault
Castell-y-rhingyll / The Gate
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0
250
500
1,000
m
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Site Boundary
Aquifer Block
Springs
Boreholes
Private groundwater abstractions
Tracer input
Tracer Test Observation Point
Main Sink Holes
Name
Bettws Fault
Nant Gwenlais Brook
Topographic and geological groundwater divide
Surface water catchment
Glanwenlais Quarry base
Pant-y-Llyn Turlough
Carmel SAC boundary
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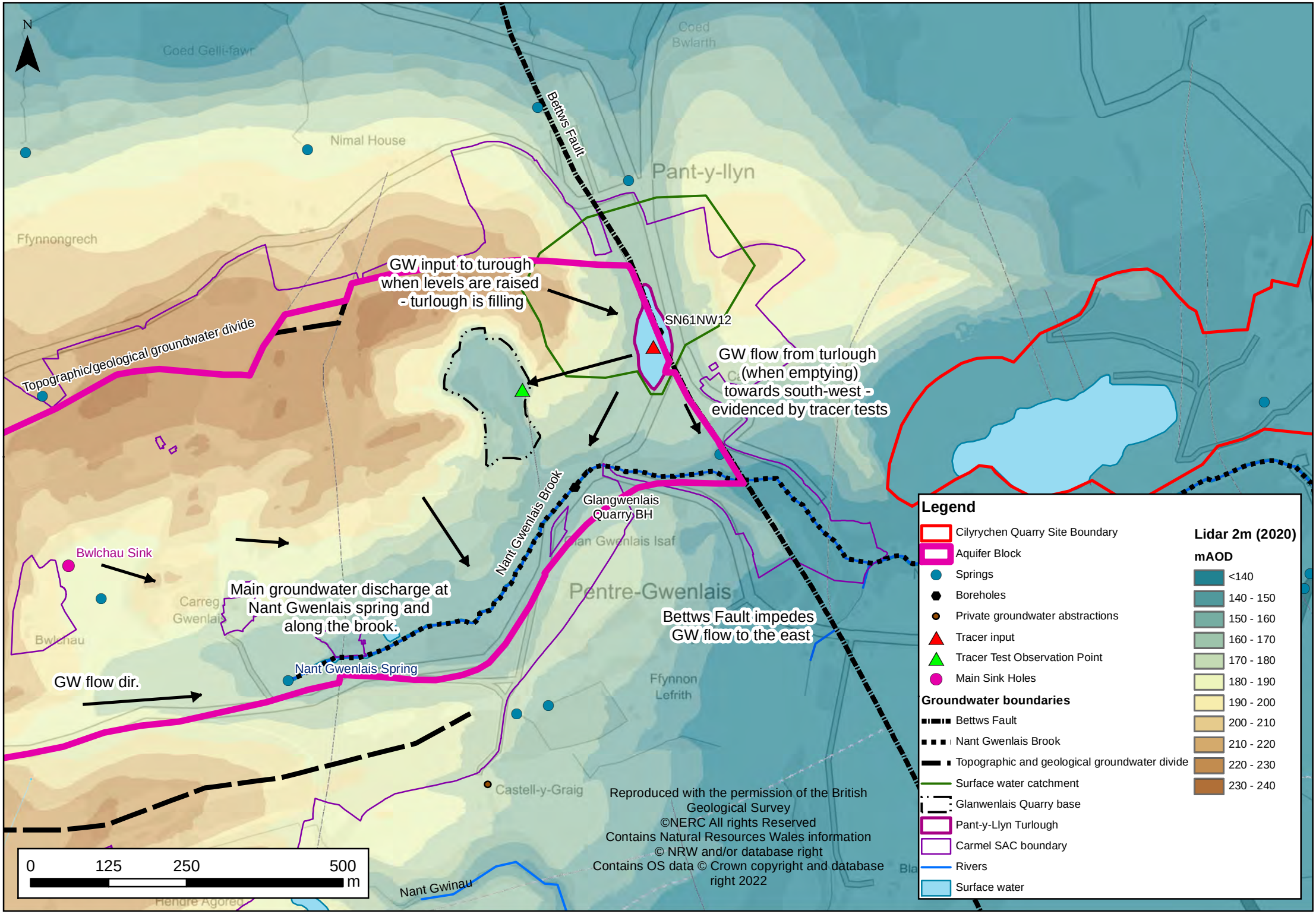
Penderyn Oolite Member
Honeycombed Sandstone Member
Dowlais Limestone Formation
Avon Group
Brownstones Formation
Senni Formation


N
Coed Gelli-fawr
Coed Bwlarth
Nimal House
Bettws Fault
Pant-y-llyn
Ffynnongrech
GW input to turough when levels are raised - turlough is filling
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Bettws Fault impedes GW flow to the east
Carreg Gwenlais
Bwlchau
Nant Gwenlais Spring
GW flow dir.
Ffynnon Lefrith
Castell-y-Graig
Nant Gwinau
Hendre Agored
0 125 250 500 m
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Legend
Cilyrychen Quarry Site Boundary
Aquifer Block
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Boreholes
Private groundwater abstractions
Tracer input
Tracer Test Observation Point
Main Sink Holes
Groundwater boundaries
Bettws Fault
Nant Gwenlais Brook
Topographic and geological groundwater divide
Surface water catchment
Glanwenlais Quarry base
Pant-y-Llyn Turlough
Carmel SAC boundary
Rivers
Surface water
Lidar 2m (2020)
mAOD
<140
140 - 150
150 - 160
160 - 170
170 - 180
180 - 190
190 - 200
200 - 210
210 - 220
220 - 230
230 - 240

B Quarry Water Quality Record

Offices at

Coleshill
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Dublin
Edinburgh
Exeter
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Isle of Man
Limerick
Newcastle upon Tyne
Newport
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Saltaire
Skipton
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