Pen y Glol Discharge

H1 Annex J Groundwater Risk Assessment

Client:

Pen y Glol Ltd

Report Reference (Project/Document/Issue)

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Report Status:

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Prepared by:

RUKHYDRO Limited

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Report for

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Scope of Work

This report has been prepared to meet the proposed scope of work set out in Rukhydro Limited's proposal letter (Ref 00095/Cp030i1) dated 09 February 2021. The report contents reflect the scope, information provision by the client and third parties, time and costs and other assumptions agreed in that proposal or documented in writing as amendments to that proposal.

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Summary

Purpose of this Document

This report provides a quantitative groundwater risk assessment for a discharge to ground of treated sewage effluent at the Pen y Glol Caravan Park, ~6 km NW of Holywell, Flintshire (post code CH8 8RQ; see Figure 1.1). The report provides a basis for discussing discharge quality and flow constraints with Natural Resources Wales (NRW; Cyfoeth Naturiol Cymru). From this the feasibility of putting in place appropriate treatment and discharge infrastructure can be assessed by others.

This report has been prepared for Pen y Glol Ltd against a scope of work and assumed time inputs set out in Rukhydro's proposal (Ref 00095Cp018i1) dated 09 February 2021.

Layout of this Report

Section 2 of this report provides details of the discharge and general site setting. Section 3 provides groundwater risk scoping calculations and Section 4 provides recommendations for discharge flow and quality constraints. References are in Section 5.

Sections 2 and 3 have a summary section and these are reproduced in this front of report summary section together with an overview of Section 4.

General Setting

Location, Catchment and Geology

The Pen y Glol (static) caravan park sits within the upper reaches and outer edges of the topographic catchment of the Afon Glanffyddion about 6 km NW of Holywell, Flintshire. It also sits on the outer edge of the currently delineated source protection zone (SPZ1 = SPZ3) for the Ffynnon Asaph spring near Dyserth. Welsh Water take some of the spring's discharge for public water supply via their Trecastell water treatment works (WTW).

Both catchments, which have significant overlap, are underlain predominantly by the Carboniferous age Clwyd Limestone Group. Nine sink holes have been mapped by NRW in the southwestern and western part of the SPZ; but there are none mapped in the vicinity of Pen y Glol. Much of the catchment has a thin covering of glacial till (boulder clay), but previous studies have judged that this does not significantly affect recharge and there is very little runoff in the catchment. There is no glacial till covering at Pen y Glol.

Unlikely to be in the Ffynnon Asaph SPZ

Based on good correlations between measured mean daily flows in the River Wheeler at Bodfari (Afon Chwiler) and then spot flows in Ffynnon Asaph spring and again with the Afon Glanffyddion at Trelawynd and at Dyserth, annual average flows have been calculated for the spring and the two river locations. This work suggests that the spring's discharge dominates flows in the Afon Glanffyddion at Dyserth. Using the same effective rainfall as for the adjacent River Wheeler (Afon Chwiler) catchment also suggests that the currently delineated SPZ for the Ffynnon Asaph is conservatively too large by about 30%.

Pre-existing information on groundwater levels and flows in the Clwyd Limestone is limited. There are no NRW monitoring boreholes in the area. A new groundwater level dataset has been collated based on water levels reported in the BGS borehole database and locations (and derived elevations) of springs and "issues" shown on Ordnance Survey maps. Although there are uncertainties such as seasonal water level variation and hydraulic connection between

strata, this dataset and associated contours suggest there is a groundwater divide about 800 m to the south of the Pen y Glol site with groundwater moving NE – NNE towards the Dee Estuary to the north of that divide or moving south-westwards to discharge mainly in the Ffynnon Asaph spring. Assuming that groundwater divide is correct, it removes circa 3.33 km^2 (~15%) from the currently delineated 22.1 km^2 Ffynnon Asaph SPZ and is plausible given the SPZ appears about 30% too large based on a water balance.

Groundwater and Abstractions

A recharge and area based estimate of groundwater flow in the vicinity of Pen y Glol is 2320 to 2720 m^3/year per 10 m cross flow width.

There are no hydraulic property data for the limestone in this area. A transmissivity of 43 to 50 m^2/day has been back calculated using the recharge and groundwater catchment based groundwater flows and the hydraulic gradient derived from contoured groundwater levels. These transmissivities are moderate to moderately high when compared to data for the limestone from other parts of England and Wales. Similarly, a derived average hydraulic conductivity of 0.14 to 0.25 m/day is consistent with limited published data for the limestone.

There are no licensed abstractions to the NE - NNE, downgradient, of Pen y Glol although there are licensed abstractions 3.28 km NNNE (process water) and 4.6 km ENE (spray irrigation). There is however a registered private water supply well 2.4 km NNE used for drinking water and food production. This abstracts from the Gwespyr Sandstone Formation which is separated from the underlying limestone by the lower permeability Bowland Shale, Pentre Chert and Teila Formations.

Existing Sewage Treatment and Discharge System

PYG Ltd.'s 'domestic' foul drainage is collected via site sewers and taken to one of five septic (22 m^3) tanks. The treated foul drainage is then pumped, together with grey water from the site laundry and foul drainage from the site office and three other units, to receive final treatment at a sixth septic tank (No.1).

Discharge from this sixth septic tank is then discharged to ground in an area of ash woodland via three drainage runs comprising 4 inch (~102 mm) perforated pipes set in 20 mm size limestone pebble gravel filled infiltration trenches. PYG Ltd note that the total length of the drainage trenches is circa 200 m (50 m + 3 x 50 m) and are ~1 m deep and 0.8-0.9 m wide (so covering an area of up to 180 m^2).

PYG Ltd indicate a maximum flow rate of 13 m^3/day, but 15 m^3/day is assumed for the purpose of this risk assessment. The system has been designed to deal with the variable occupancy of the site; i.e., biological treatment is less effective if incoming flows are lower than their treatment capacity. The site has been a static caravan site since 1971 and has been effectively its current size since at least 2008. The discharge of the foul drainage to ground has been occurring since 1971.

Other Treated Sewage Disposals in the Area

There are no nearby sewage treatment works or sewers; the nearest sewage pumping station is circa 1.8 km NNW. The catchment to the Afon Glanffyddion has a sewage treatment works discharge (permitted dry weather flow of 207 m^3/day) to the river at Trelawynd, but there are no other consented discharges to surface water in that catchment. There are however 29 consented discharges to ground of treated sewage (including two also with trade effluent) with a total consented discharge of 61.6 m^3/day. There are five discharges within 1 km of the Pen y Glol site; the largest of which is circa 800 m NNE, downgradient, and consented for 5 m^3/day.

Water Quality Monitoring in the Area

There are very few local water quality monitoring points. The Tre Eden mine adit discharge circa 2850 m east could plausibly collect groundwater from the limestone if the mine network reaches that area. Two streams are also monitored; one ~2.5 km EENE and a second ~3.5 km NNNE.

A review of data provided by NRW and by Welsh Water (for Ffynnon Asaph) has been undertaken. There is no clear evidence of impact on surface water or groundwater from the current Pen y Glol discharge, although the higher electrical conductivity and nitrate in the Tre Eden mine adit groundwater could plausibly be linked to nitrate from several septic tank discharges in the area as well as from agriculture.

Low ammoniacal nitrogen, orthophosphate and total phosphate in the Tre Eden mine adit discharge indicates that if septic tank discharges are a cause of higher nitrate, then there is attenuation of ammoniacal nitrogen and phosphate.

Risk Assessment

Risk Screening

In terms of risk screening, the current up to 13 m^3/day Pen y Glol discharge is therefore a discharge of <15 m^3/day of domestic sewage effluent via two stages of septic tank treatment and a constructed infiltration system (albeit not British Standard) to ground in an area of ash woodland. There is a very thick unsaturated zone, although flow through it is likely to be via fractures. It appears unlikely that the site is within a source protection zone and the nearest and most sensitive receptor is circa 2.4 km away, protected by lower permeability and non-karst flow strata and reporting good water quality despite Pen y Glol discharging since 1971.

As the discharge is not via a British Standard (BS6297:2007(+A1:2008) drainage field or mound and there is potential for some rapid flow in the saturated limestone aquifer, the risk cannot be judged low. But being unlikely within a SPZ and distant from sensitive, but protected receptors, then equally the risk cannot be judged very high. Further quantitative risk assessment is therefore provided.

Quantitative Risk Assessment

Infiltration rates are calculated to be higher than guidance requirements allow and the drainage field floor area is about 42 to 48% of the minimum required area for a new British Standard drainage field.

With a likely >40 m thick unsaturated zone thickness, albeit with travel times of 4 to 5 days, nitrate loading is likely to be the main concern. Assuming published data for septic tank effluent quality, nitrate loading is calculated as 444 kg N/year. This equates to 1.3% of the Ffynnon Asaph spring discharge's nitrate load and 3.8% of the nitrate load discharged from the Tre Eden adit. Although it is unclear on the effectiveness of the two-stage septic tank system, a package treatment plant may be able to reduce this loading to 85% of that assumed.

Dilution of the nitrate load with the current drainage field is calculated to increase nitrate concentrations in downgradient groundwater by 23.5 to 25.9 mg/l N compared to a drinking water standard of 11.3 mg/l N. So, there is a potential deleterious impact downgradient unless the discharge quality is lower than assumed or there is nitrate uptake in the ash woodland.

Increasing the cross-flow width (NW-SE) of the drainage field to the full extent of the site (circa 200 m wide) would potentially reduce the increase in nitrate in downgradient groundwater to 7.3 to 8.9 mg/l N. There is a potential to decrease this to between an increase of 6.2 to 7.6 mg/l N if a package treatment plant could be installed and used effectively.

Although attenuation of many contaminants in the >40 m thick unsaturated limestone is plausible / likely, attenuation in the saturated zone where flow will be via fractures and possibly by karst features, is less likely. The downgradient lower permeability Bowland Shale, Pentre Chert and Teila Formations and the non-karstic flow Dwespyr Sandstone will provide more attenuation than the limestone, but this has not been enumerated.

Risk Assessment Conclusion

Overall, whilst the risks to groundwater are not high due to the current two stage septic tank and drainage field discharge, thick unsaturated zone and distance to receptors, measures should be taken to reduce risks to groundwater downgradient in the limestone.

System Improvement Recommendations

Recommendations have been detailed in Section 4 for sampling of effluent quality from the current two-stage septic tank system, for an options appraisal to improve effluent quality and for options to make the drainage field British Standard compliant and extend width-(NW-SE)-wise to maximise dilution.

With those evaluations undertaken it is then recommended that the best practicable option is reviewed for water quality improvement versus energy use, cost and ease of operation and maintenance in discussion with NRW.

Through this process, it should be possible to agree a treatment and disposal design with NRW for permitting and construction.

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1. Introduction

1.1 Purpose of this Report

This report provides a quantitative groundwater risk assessment for a discharge to ground of treated sewage effluent at the Pen y Glol Caravan Park, ~6 km NW of Holywell, Flintshire (post code CH8 8RQ; see Figure 1.1). The report provides a basis for discussing discharge quality and flow constraints with Natural Resources Wales (NRW; Cyfoeth Naturiol Cymru). From this the feasibility of putting in place appropriate treatment and discharge infrastructure can be assessed by others.

1.2 Scope of Work

This report has been prepared for Pen y Glol Ltd against a scope of work and assumed time inputs set out in Rukhydro's proposal (Ref 00095Cp018i1) dated 09 February 2021.

1.3 Guidance and Approach

1.3.1 Guidance

In correspondence with Pen y Glol Ltd ('PYG Ltd'), NRW have requested that the groundwater risk assessment is prepared with reference to guidance published on the Defra website[1] entitled "*Infiltration systems: groundwater risk assessments*".

In an email of 19 January 2021 to PYG Ltd, NRW have further clarified that given the discharge's location within a delineated inner source protection zone (SPZ1), they expect a detailed quantitative assessment backed up with site investigation data to be undertaken. In a further clarification of 04 February 2021, NRW note that site investigation does not necessarily mean installation of groundwater monitoring boreholes, but if none are installed uncertainties in the properties of the unsaturated zone and dilution in groundwater would need to be mitigated by a higher level of treatment.

1.3.2 Approach

As will be detailed in subsequent sections of this report, the discharge is to the 'Carboniferous Limestone' which commonly exhibits rapid water movement via karstic and fracture systems (Robins and Davies, 2015). Construction of groundwater monitoring boreholes (a minimum of three) into the Carboniferous Limestone would likely have required drilling to depths significantly more than 50 m and even then, with possible karstic flow, would not be guaranteed to monitor any impacts of the discharge. They would also likely conclude that fissure flow through the unsaturated zone was likely. Such boreholes were therefore deemed likely to provide little value for a high cost and so have not been installed.

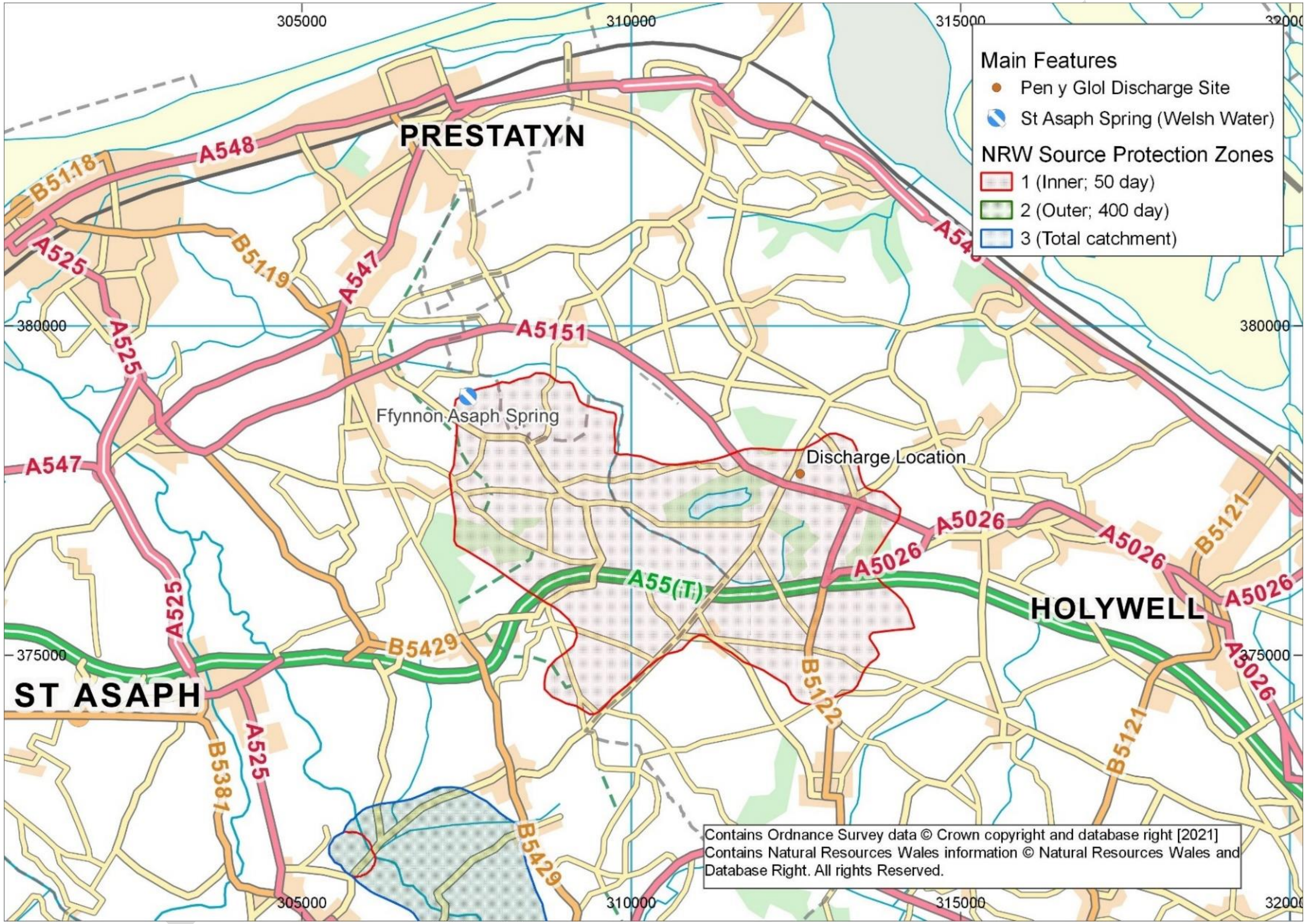
The risk assessment therefore constrains the site setting as much as possible with desk-based information supplemented by non-borehole site specific information. And the discharge flow and quality constraints are then developed using conservative assumptions.

1.4 Layout of this Report

Section 2 of this report provides details of the discharge and general site setting. Section 3 provides groundwater risk scoping calculations and Section 4 provides recommendations for discharge flow and quality constraints. A summary is provided in previous pages.

[1] https://www.gov.uk/guidance/infiltration-systems-groundwater-risk-assessments

Figure 1.1 – Location of the Proposed Pen y Glol Discharge



Note: The proposed discharge is in the outer parts of the currently delineated Source Protection Zone (SPZ) for the Welsh Water Ffynnon Asaph (St Asaph) public water supply. The inner (SPZ1) zone is delineated with the same extent as the outer zone (SPZ3) as saturated zone travel times of less than 50 days from anywhere in the SPZ haven't been ruled out.

2. General Setting

2.1 Purpose of this Section

This section of the report provides background information on the general setting of the site; providing details of aspects including site topography and drainage, site history, geology, groundwater aspects and background water quality. The report sections are intended to meet those in the guidance[2] used by NRW.

2.2 Site Details

2.2.1 Location and Site Area

The Pen y Glol Caravan Park is located ~6 km NW of Holywell, Flintshire (post code CH8 8RQ; site centre at NGR: 312535, 377825; see Figure 1.1). The location of the site in its more immediate surroundings is shown on an approximately 1:10 000 scale map on Figure 2.1. The area within the site boundary (as shown on Figure 2.1) is approximately 27,650 m^2.

2.2.2 Details of Dwellings

The site contains 78 owner occupied static caravans, a laundry and the site office. Figure 2.2 reproduces a detailed site plan showing the layout of properties. A planning application for ten more caravans has been submitted to Flintshire County Council but is not yet determined.

Pen y Glo Ltd (PYG Ltd) note that, since they took on operation of the site in 2008, the caravan park has not been more than 50% utilised. Most caravans are only occupied by two people.

2.2.3 Topography

Figure 2.1 shows that the Pen y Glol site has an elevation of circa 210-220 m AOD; sloping approximately north to south. There is higher ground ~600 m to the NW at Glol (232 m AOD) and ~950 m to the NE at Coed y Garreg (248 m AOD) and the connecting ridge between these passes through the higher ground of Pen y Glol. The Ffynnon Asaph source protection zone (SPZ1=SPZ3) boundary lies along that ridge and so just includes the Pen y Glol site.

Ground levels fall away to the southwest, south and southeast towards the A5151 road.

2.2.4 Existing Foul Drainage Scheme

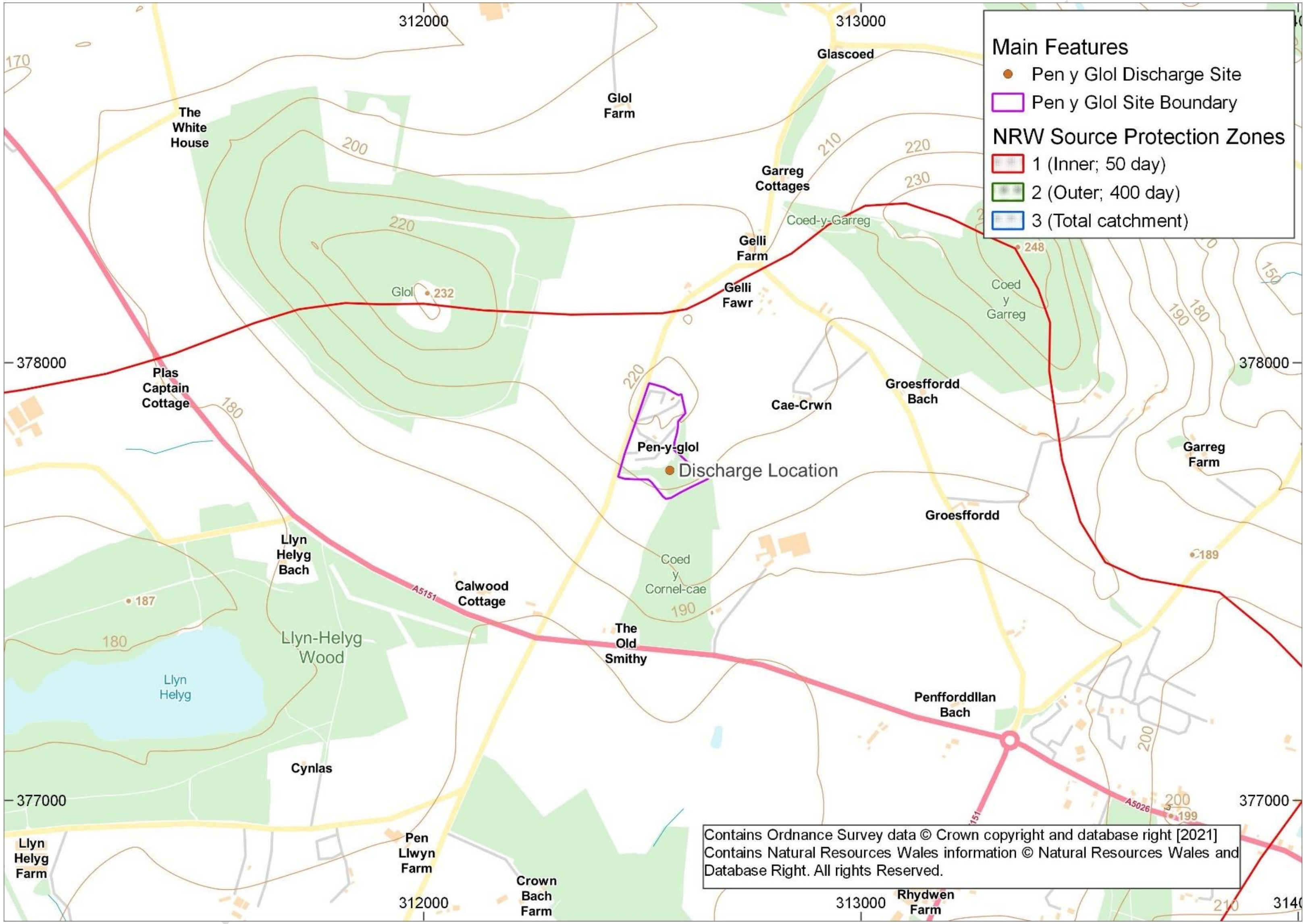
Figure 2.2. shows PYG Ltd.'s foul drainage plan; illustrating how 'domestic' foul drainage is collected via site sewers and taken to one of five septic tanks (No. 2 to 6). Each septic tank has a 22 m^3 holding capacity and is de-sludged annually.

Treated foul drainage is then pumped to the "collecting manhole" and together with grey water from the site laundry and foul drainage from the site office, and units 00 and 38-40 then receives final treatment at a sixth septic tank (No.1). Discharge from this sixth septic tank is then discharged to ground in an area of ash woodland from grid reference 312565, 377755.

PYG Ltd note that the discharge takes place via three drainage runs comprising 4 inch (~102 mm) perforated pipes set in 20 mm size limestone pebble gravel filled infiltration trenches. Figure 2.3 shows the intended design of the existing infiltration to ground system, but PYG Ltd note that when the drainage system came to be constructed, to make sure the system worked within the constraints of the woodland, the herringbone design was converted into three separate drainage runs.

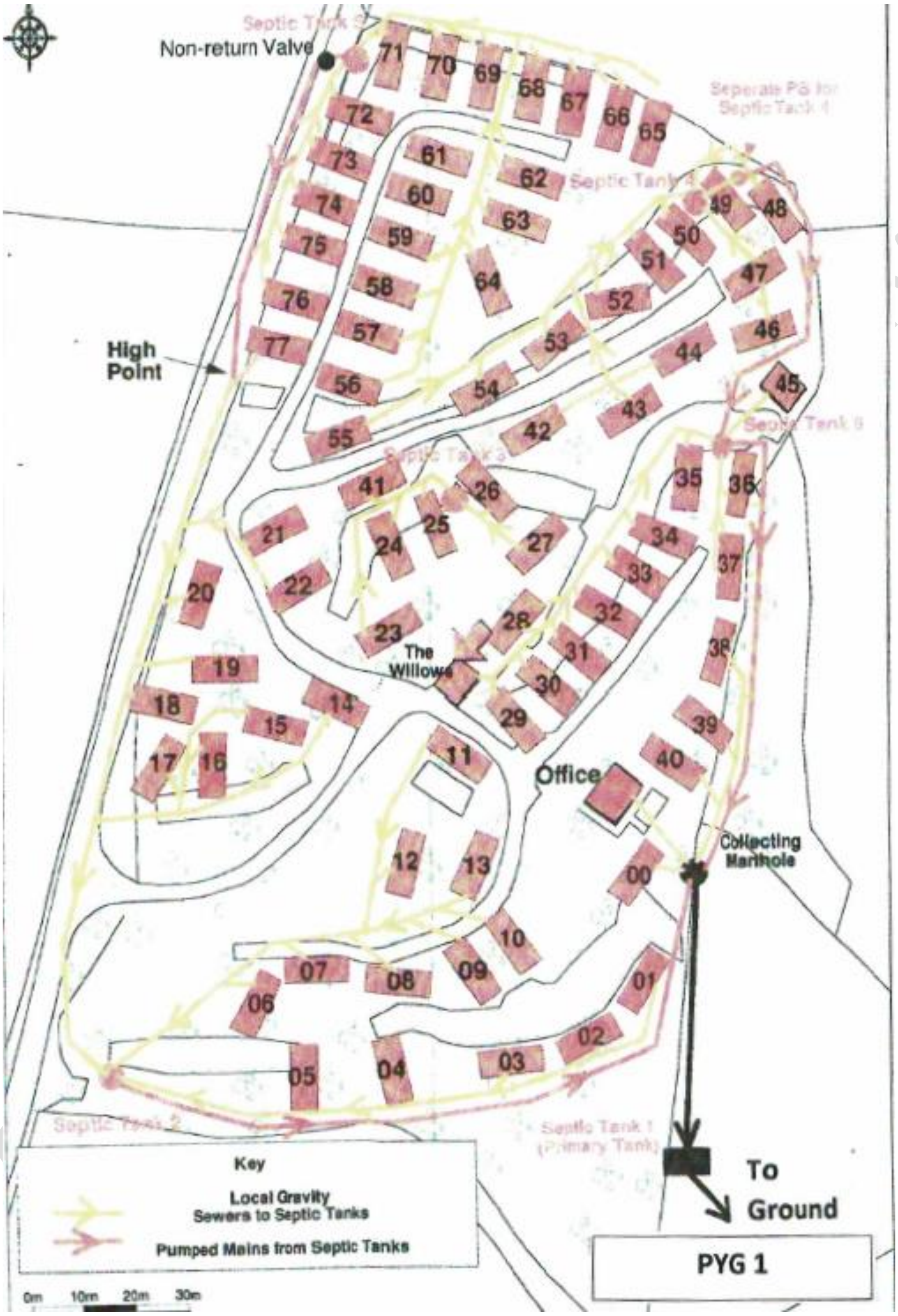
[2] https://www.gov.uk/guidance/infiltration-systems-groundwater-risk-assessments

Figure 2.1 – Pen y Glol Site Boundary and Existing Discharge Location



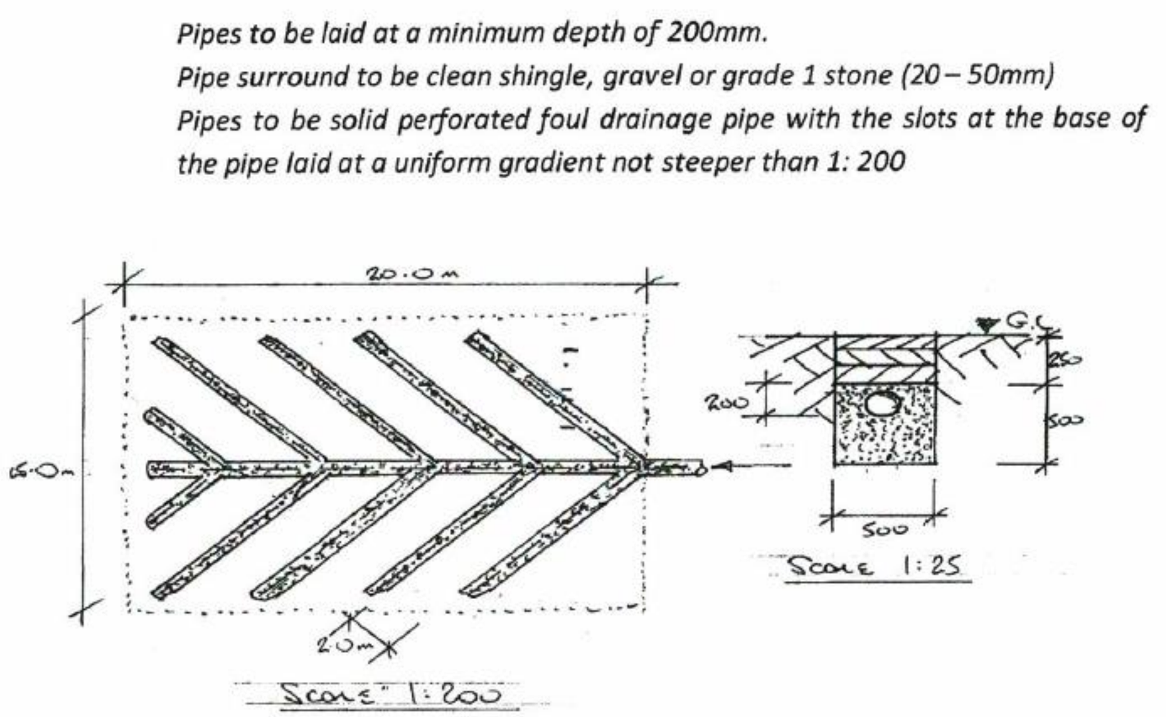
Note: The Pen y Glol caravan park site is just within the Source Protection Zone for the Welsh Water Ffynnon Asaph (St Asaph) public water supply.

Figure 2.2 – Caravan Park Layout including Existing Foul Drainage



Note: Image reproduced from Pen y Glo Ltd (pdf) drawing ref PYG 1B dated 23 November 2020.

Figure 2.3 – Existing Drainage Field Layout Design*



Note: Image reproduced from Pen y Glo Ltd (pdf) drawing ref PYG 2F dated 23 November 2020. The as-built design was modified from this with a 50 m long first trench feeding into three 50 m long end trenches fanning from circa 145° to 215°. Each trench was ~0.8-0.9 m wide and 1 m deep backfilled to pipe level with gravel.

PYG Ltd note that the drainage runs comprise a feeder 50 m long trench orientated southwards from the final septic tank connecting into three 50 m long end-trenches spanning an orientation between 145° to 215° (~35° either side of south). Also, that the trenches were ~1.0 m deep and circa 0.8-0.9 m wide. PYG Ltd indicate a maximum flow rate of 13 m^3/day, but 15 m^3/day is assumed for the purpose of this risk assessment.

Based on Ordnance Survey Terrain 50 gridded data, ground elevations in the vicinity of the discharge to ground (i.e., NGR: 312565, 377755) are circa 213.5±2.0 m AOD.

2.2.5 Other Site Drainage

Roof runoff and direct rainfall percolates direct to ground and there is no surface water drainage from site and no stream passing through the site.

2.2.6 Site History

PYG Ltd note that the site started as a caravan site in 1971 and they took over its operation in 2008. Figure 2.2's layout of numbered static caravans shows the development of the site. PYG Ltd note that since 2008 only two static caravan units have been added and the discharge system has been as described at least since then.

Publicly available old maps suggest the area now occupied by the static caravans and site office was developed as a quarry between 1878 and 1899 with "*Quarries*" in that area labelled until 1964 but not in 1969. Development of the site as a caravan park in 1971 is consistent with that cessation of quarrying from the mid-1960s.

The area of the discharge to ground is not shown as quarried and has been mapped as woodland since at least 1872.

2.3 Rainfall and Surface Water Setting

2.3.1 Rainfall and Effective Rainfall

For the nearby[3] 62.9 km^2 catchment of the River Wheeler (Afon Chwiler), the CEH UK national river flow archive website[4] reports average annual rainfall of 863 mm/year for the period 1961 to 1990. The River Wheeler's catchment is reported to be natural (i.e., no significant abstractions, discharges or impoundments) and so its flow is likely to reflect effective rainfall on its catchment area. The mean flow of 0.741 m^3/s over its catchment area of 62.9 km^2 equates to an average annual effective rainfall of 372 mm/year.

A report (Low & Gunn, 2013) on the delineation of the Ffynnon Asaph (St Asaph's spring) source protection zone uses an effective rainfall for that area of 234 mm/year based on Met Office 40 km x 40 km MORECS square 104 data. MORECS square 104 covers this part of North Wales but also the Wirral and Liverpool; both lower lying warmer and likely drier areas. It is likely that 234 mm/year is an under-estimate of the effective rainfall at Pen y Glol and the 372 mm/year from the River Wheeler catchment is likely more representative.

2.3.2 River Catchments

The Pen y Glol site lies just within the topographic catchment of the Afon Glanffyddion (Glanffyddion Cut WFD river water body) which drains in a general east to west direction towards the town of Dyserth (see Figure 2.4).

The higher ground of Coed y Garreg, circa 850 m NE of the Pen y Glol discharge forms a catchment divide with land to the north draining generally northwards into the Afon y Garth and land to the east draining generally north-eastwards into the Nant Sir Roger (Un-named Dee Estuary South WFD river water body). Both catchments drain into the Dee estuary.

2.3.3 Surface Water Features (including Sinkholes)

Ordnance Survey data (see Figure 2.4) show the following nearest water features (with distances and direction from the current Pen y Glol discharge location):

- a ~50 m long pond feature circa 590 m to the SSE;
- the nearest headwater of the Afon Glanffyddion circa 780 m to the S;
- the nearest shore of Llyn Helyg circa 1050 m to the SW;
- a 70 m long pond to the NE of Bryn Coch Farm circa 1390 m to the NE;
- the nearest headwater of the Nant Sir Roger circa 1420 m to the ENE;
- the nearest springs are at Nant-Evan circa 1870 m NE and at circa 2450 m to the east in the headwaters of the Nant Sir Roger (SW of Whitford).

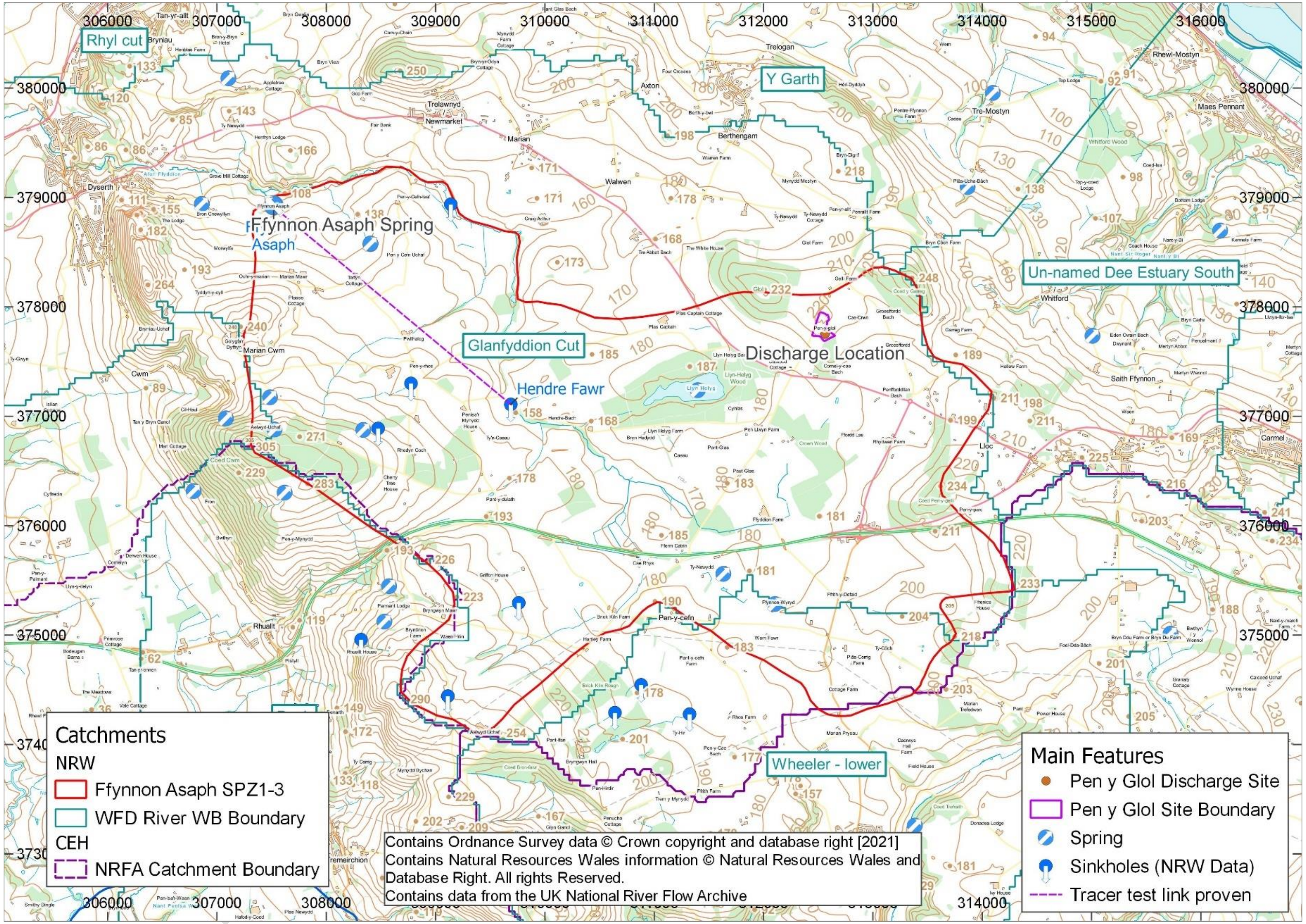
In addition, based on information (NRW dataset) in a report on the Ffynnon Asaph spring catchment (Low and Gunn, 2013), the nearest sinkholes[5] (see Figure 2.4; with distances and direction from the current Pen y Glol discharge location) are:

- The Hendre Mawr sinkhole on the main course of the Afon Glanffyddion 2950 m WSW;
- A sinkhole on the main course of the Afon Glanffyddion 3630 m to the WNW.

NRW map nine sinkholes in the Ffynnon Asaph spring's catchment.

[3] Centre of catchment located ~7 km SSE of the Pen y Glol site.
[4] https://nrfa.ceh.ac.uk/data/station/info/66004 (*Data from the UK National River Flow Archive*)
[5] A place on a stream or river where the surface water drains into the ground leading to either reduced flow or no flow in the water course downstream of there. These are common features in karstic limestone.

Figure 2.4 – Surface Water Catchments, Sink Holes and Springs



Note: The Pen y Glol caravan park site is just within the Source Protection Zone for the Welsh Water Ffynnon Asaph (St Asaph) public water supply. Springs listed in Appendix A.

2.3.4 Licensed (Surface Water and Groundwater) Abstractions

There are no NRW licensed abstractions from surface water or groundwater within the Ffynnon Asaph source protection zone or within the catchment of the Afon Glanffyddion upstream of its confluence with the Ffynnon Asaph spring. The Ffynnon Asaph spring is a licensed public water supply to Dwr Cymru (Welsh Water) for 4.55 Ml/day (Low and Gunn, 2103).

2.3.5 River Flows

River flow data have been provided by NRW as:

- daily mean flows for the River Wheeler at Bodfari (Afon Chwiler; NRFA Station 66004; NGR: 310504,371333) from 1970 to March 2021;
- spot flow measurements and gauging location grid references for 23 locations with six or more gaugings within a radius of 10 km of the Pen y Glol site;

Figure 2.5 shows the locations of the gauging points and Table 2.1 provides their grid references, number of spot-flow measurements since 1970 and the period of record for gauging locations considered as more relevant to Pen y Glol; in terms of adjacent catchments.

Table 2.1 Details of Spot Flow Gauging Sites

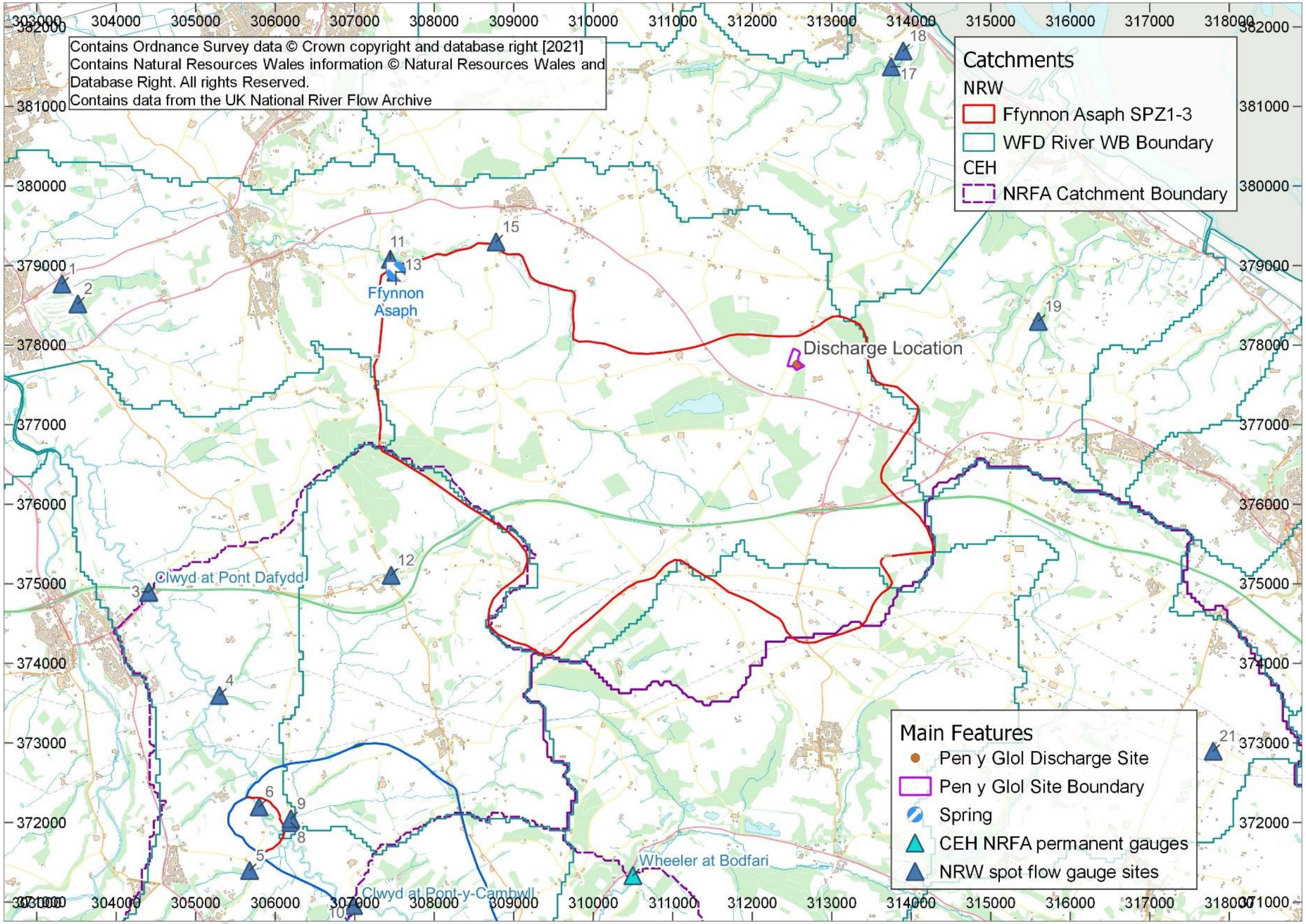
Map ID (on Fig 2.5)	Location[1,2]	Easting[1]	Northing[1]	Readings	Data From	Data To
1	Dicks Gorse	303320	378770	6		
2	Rhuddlan Golf Club	303520	378520	24		
3	Pont Dafydd	304412	374902	386	29/09/1971	10/03/2020
4	Afon Bach	305300	373600	7		
5	Padrig Rd. Br.	305680	371400	45		
6	Llannerch Pk	305800	372200	19		
7	Bastion, Prestatyn	306180	383210	7		
8	Bach, U/S	306200	372000	71		
9	Llannerch Park	306200	372050	11		
10	Pont Y Cambwll	306985	370963	499	14/01/1970	14/12/2020
11	Dyserth	307450	379080	110	11/01/1990	02/09/2013
12	Rhuallt	307460	375110	8	24/05/1989	03/10/1989
13	Ffynnon Asaph*	307520	378920	30	21/09/1995	10/09/1998
14	Bodfari	308500	370400	176	24/07/1990	14/12/2020
15	Trelawnyd S.W	308780	379300	13	20/02/1978	06/12/1990
16	Point Of Ayr	312300	383400	8		
17	Garth Mill	313750	381500	15	20/02/1978	13/08/1998
18	Garth Sluices	313900	381700	7	29/01/1982	15/08/2006
19	Forest Hill Fish Farm	315600	378300	6	17/06/1994	12/10/1994
20	Nannerch S.W	316700	369900	9	07/07/1987	14/10/1989
21	Lixwm S.W	317800	372900	23	01/05/1987	18/07/1986
22	Bagillt Tunnel*	321950	375450	47		
23	Nant Mill	328850	350110	6		

Notes:
1. Data provided under an Open Government Licence. Contains Natural Resources Wales information © Natural Resources Wales and/or database right.

Figure 2.6 shows the long-term variability of the river flows on the River Wheeler at Bodfari; a largely natural flow regime catchment (see Section 2.3.1) immediately south of the Ffynnon Asaph catchment. CEH NRFA flow statistics[6] (e.g., mean flow, 95th percentile flow) for the period 1970 to 2020 are also shown. The 95th (low) and 5th (high) flows are 0.243 m^3/s and 1.68 m^3/s and the mean is 0.743 m^3/s. Figures 2.7 to 2.9 compare spot flows at the more relevant (closest) spot gauging locations with daily mean flow on the River Wheeler at Bodfari.

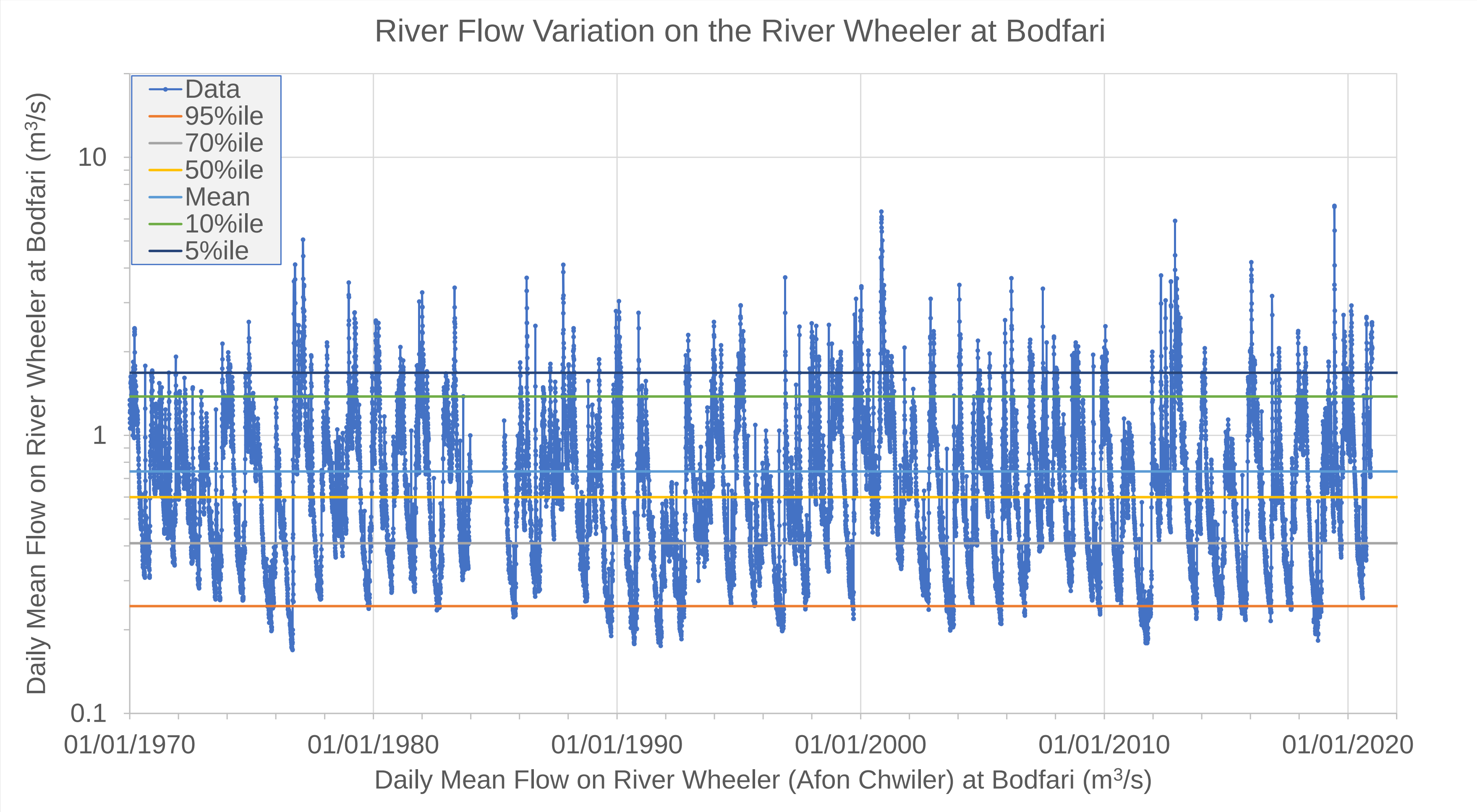
[6] Data from the UK National River Flow Archive (https://nrfa.ceh.ac.uk/data/station/meanflow/66004)

Figure 2.5 – River Flow Gauging Locations



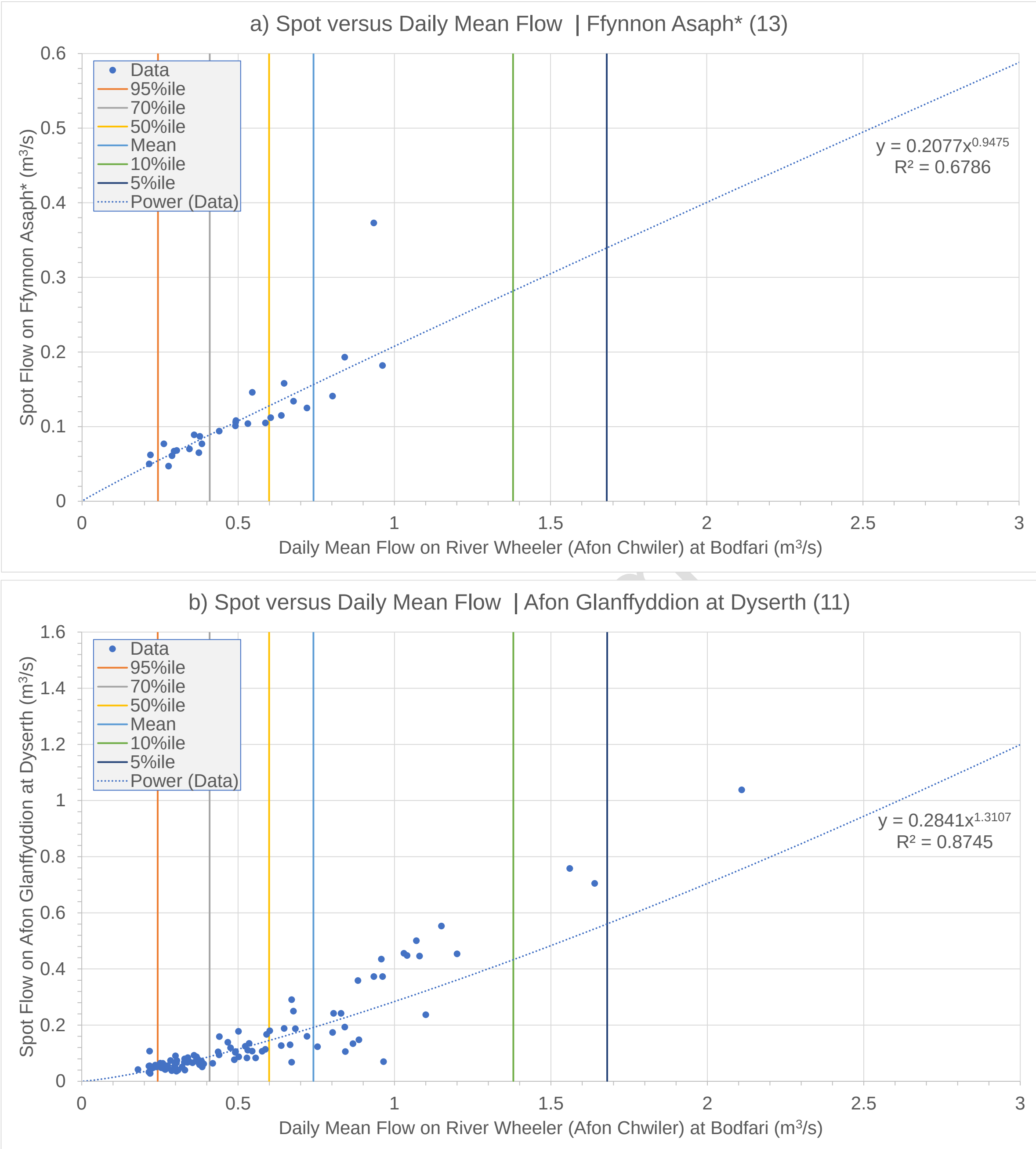
Note: The Pen y Glol caravan park site is just within the Source Protection Zone for the Welsh Water Ffynnon Asaph (St Asaph) public water supply.

Figure 2.6 – Daily Mean Flow for the River Wheeler at Bodfari



Note: Data provided under an Open Government Licence. Contains Natural Resources Wales information © Natural Resources Wales and/or database right. Flow statistics (e.g.,95%ile = 95th percentile) from the UK National River Flow Archive. Note Log_{10} scale for flow.

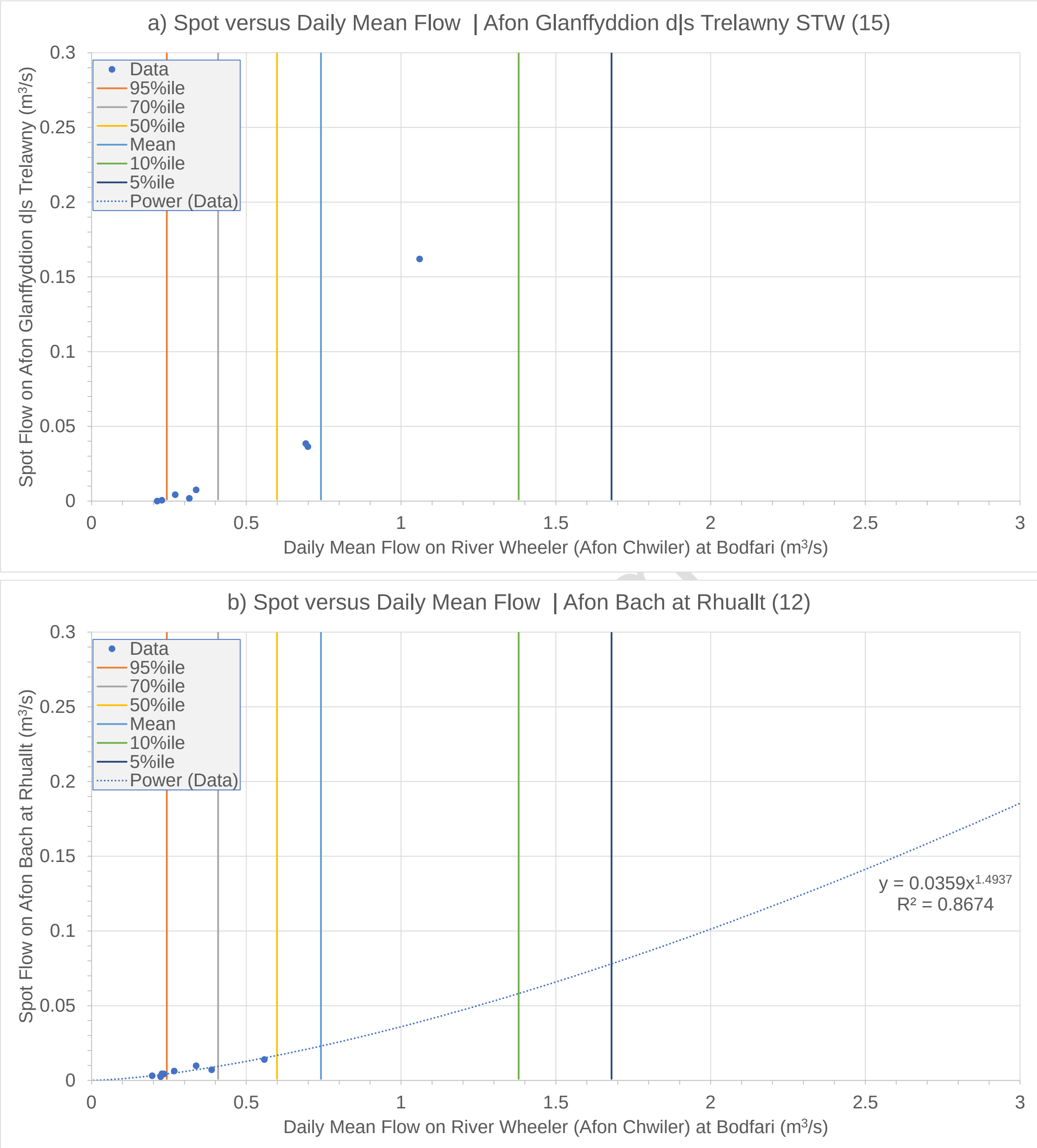
Figure 2.7 – Spot Flows at Ffynnon Asaph and Dyserth versus River Wheeler at Bodfari



Note: Data provided under an Open Government Licence. Contains Natural Resources Wales information © Natural Resources Wales and/or database right. Flow statistics from the UK National River Flow Archive.

There is a strong relationship between flows on the River Wheeler at Bodfari and flows in Ffynnon Asaph and in the Afon Glanffyddion at Dyserth; especially so for low to mean flows.

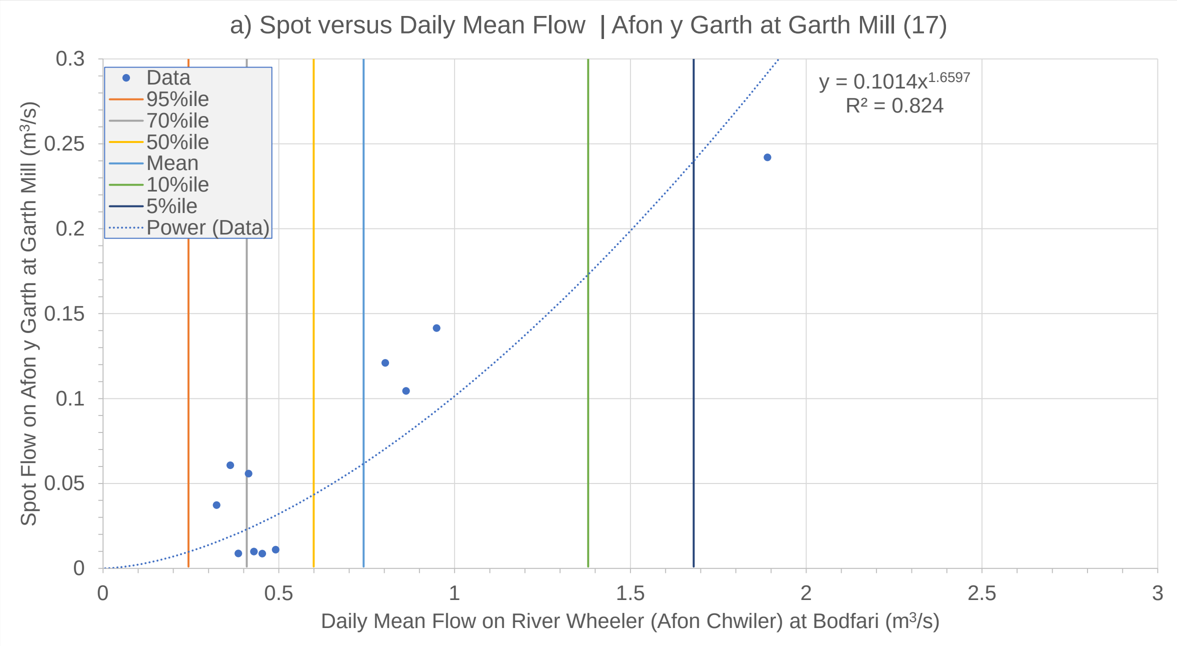
Figure 2.8 – Spot Flows at Trelawny and Rhuallt versus River Wheeler at Bodfari

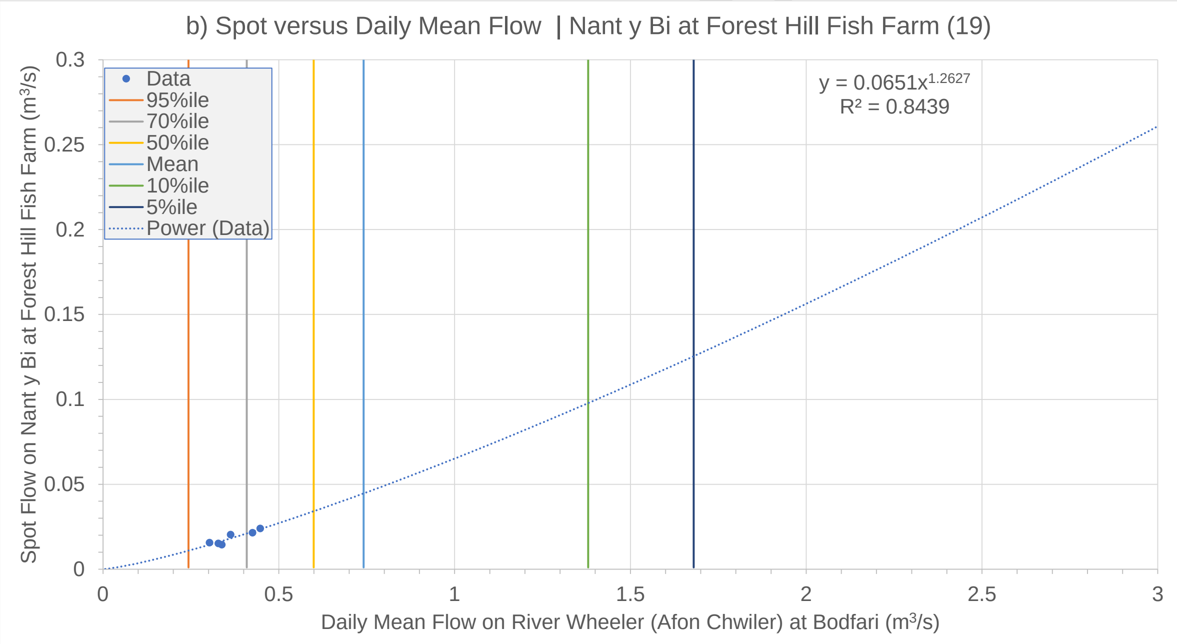


Note: Data provided under an Open Government Licence. Contains Natural Resources Wales information © Natural Resources Wales and/or database right. Flow statistics from the UK National River Flow Archive.

There is a good relationship between flows on the River Wheeler at Bodfari and flows on the Afon Glanffyddion downstream of the Trelawny sewage treatment works and on the Afon Bault near Rhuallt, but data are largely limited to low to mean flows.

Figure 2.9 – Spot Flows at Garth Mill and Forest Hill Fish Farm versus River Wheeler at Bodfari





Note: Data provided under an Open Government Licence. Contains Natural Resources Wales information © Natural Resources Wales and/or database right. Flow statistics from the UK National River Flow Archive.

There is a moderately strong relationship between flows on the River Wheeler at Bodfari and flows in Afon y Garth at a wide range of flows (though more variability at low flows). On the Nant y Bi, there is a strong relationship with flows on the River Wheeler, but data are limited to low to moderately low flows.

The presented data indicate that the variation in flows on the River Wheeler at Bodfari provide a good surrogate for the variation in flows at several other spot flow gauging locations in the area; particularly so at low to average flows.

It is assumed that the spot flows on the Ffynnon Asaph discharge are upstream of the Welsh Water (Dwr Cymru) abstraction. That abstraction is licensed up to a maximum daily rate of 4.55 Ml/day (Low and Gunn, 2103), equivalent to 0.052 m^3/s, but is also limited to 50% of the flow of the Afon Glanffyddion immediately upstream of Dyserth, suggesting at low flows abstraction is less than 0.052 m^3/s. Overall, this means that the spot gauged flows on the Ffynnon Asaph are likely close to natural flows.

Table 2.2 collates flow statistics for the River Wheeler and the sites for which spot flow data are shown on Figure 2.7 to 2.9 using the Excel chart trend function derived formula shown on those charts.

Table 2.2 Measured and Calculated Flow Statistics

		Flow (m^3/s) Statistic					
Map ID[1]	**Location**	**95%ile**	**70%ile**	**50%ile**	**Mean**	**10%ile**	**5%ile**
	R. Wheeler at Bodfari	0.243	0.409	0.599	0.741	1.38	1.68
11	Afon Glanffyddion at Dyserth	0.044	0.088	0.145	0.192	0.433	0.561
13	Ffynnon Asaph	0.054	0.089	0.128	0.156	0.282	0.340
15[3]	Afon Glanffyddion d|s Trelawny STW	0.002	0.01	0.025	0.045		
12	Afon Bach at Rhuallt	0.004	0.009	0.017	0.023	0.058	0.078
17	Afon y Garth at Garth Mill	0.010	0.023	0.043	0.062	0.173	0.240
19	Nant y Bi at Forest Hill Fish Farm	0.011	0.021	0.034	0.045	0.098	0.125

Notes:
1. Map id as used on Figure 2.5;
2. Raw data provided under an Open Government Licence. Contains Natural Resources Wales information © Natural Resources Wales and/or database right. Flow statistics for the River Wheeler at Bodfari from the National River Flow Archive.
3. Statistics for this site estimated by nearest spot flow measurement as a recorded zero flow prevents a power function being fitted to the remaining data.

The flow statistics in Table 2.2 show that:

- Flows at Ffynnon Asaph dominate flows in the Afon Glanffyddion at Dyserth at low flows (9^{th} and 70^{th} percentile) and are circa 82% and 61% of flows at mean and 5^{th} percentile (high) flow conditions.
- Flows on the Afon Glanffyddion upstream of the Ffynnon Asaph spring discharge are relatively small, so most of the Afon Glanffyddion's catchment drains to the Ffynnon Asaph spring except during periods of very high rainfall / runoff;
- Flows in the Afon Bach, Afon y Garth and Nant y Bi are also low when compared to those in the Ffynnon Asaph spring.

2.3.6 Ffynnon Asaph (St Asaph's) Spring Catchment

Findings from the Low and Gunn (2013) Report

Low & Gunn (2013) used existing hydrological data and results of tracer tests to try and define a catchment for the Ffynnon Asaph spring. Their report concludes:

- "*The catchment of Ffynnon Asaph remains of uncertain extent and considerably more research is necessary before the catchment, and hence the SPZ can be defined with confidence*."

- "*There is a notable paucity of data on flow from the spring both in terms of total volume and distribution over time. This study has estimated annual average flow as 170 l/s and on that basis* [and assuming the MORECS effective rainfall of 234 mm/yr] *has suggested a catchment area of 22.9 km^2*."
- Based on a review of water quality and rainfall data conclude that most flow from the spring is from direct recharge to ground, to the limestone, but occasional sharp falls in electrical conductivity (EC) and temperature suggest some runoff-recharge.
- And regarding run-off recharge, their tracer testing supported previous research that there is a connection between the Afon Glanffyddion and the spring, most notably by the Hendre Mawr swallet (NGR: 309700 377120; see Figure 2.4). They report that at times all the Afon Glanffyddion's flow sinks to ground at Hendre Mawr. Also, that the line of connection between that swallet and the spring is directly in line with a geological fault in the limestone; implying the connection may be related to an unmapped extension of that fault.
- Based on tracer tests, under high flow conditions there is discharge from the limestone and runoff to the Afon Glanffyddion below the Hendre Fawr swallet, but at low flows much of the river upstream of the Hendre Fawr swallet is likely to sink and migrate via the limestone to the Ffynnion Asaph spring. This is consistent with Section 2.3.4's findings from examining spot flow measurements.
- There are no grounds to suggest that travel times from any point within the SPZ will be greater than 50 days, so SPZs 1, 2 and 3 are coincident

Low and Gunn (2013) determined a flow derived catchment area of 22.9 km^2 as an upper estimate, noting significant uncertainty. They also delineated a recommended new source protection zone (SPZ) 30% greater than this of ~30 km^2 which took in all the surface water catchment to the Afon Glanffyddion at the confluence with the Ffynnon Asaph discharge.

The SPZ boundary shown on Figures 2.4 and 2.5 covers an area of 22.1 km^2; the same land area as Low and Gunn (2013) show on maps to be the existing SPZ at that time. So, the SPZ was not updated following the Low and Gunn (2013) work. That existing, and still current SPZ appears to be the surface water catchment to the Hendre Fawr swallet plus areas downstream of there and which are also to the south of the Afon Glanffyddion.

Review of Catchment Size based on River Flow Analysis

Based on the comparison of spot flow data with daily mean flows on the River Wheeler at Bodfari in Section 2.3.4 (see also Table 2.2), the mean flow from Ffynnon Asaph is estimated as 156 l/s and the mean flow downstream at Dyserth on the Afon Glanffyddion is 192 l/s . Low and Gunn's estimate of 170 l/s for Ffynnon Asaph and so is closely compatible (i.e., 163±7 l/s).

As noted in Section 2.3.1, the average annual effective rainfall (374 mm/year) for the River Wheeler catchment is more likely to be representative of conditions over the Ffynnon Asaph / Afon Glanffyddion catchment than the 234 mm/year based on MORECS square 104 used by Low and Gunn (2013).

Assuming an effective rainfall of 325 to 375 mm/year, the following catchment areas are calculated[7] from the mean flows:

- Ffynnon Asaph with mean flow of 163±7 l/s = 13.13 to 16.51 km^2;
- Afon Glanffyddion at Dyserth with mean flow of 192 l/s = 16.15 to 18.64 km^2.

[7] Flow as l/s x (3600 x 24 x 365.25/1000) to give flow as m^3/year then divided by 0.325 to 0.375 m/year effective rainfall.

These areas are smaller than the 22.9 km^2 catchment area estimated by Low and Gunn (2013) for the catchment to Ffynnon Asaph and smaller than the pre-existing and still current SPZ of 22.1 km^2 for Ffynnon Asaph. This suggests the current SPZ for Ffynnon Asaph is conservatively large; by at least 34%[8].

2.3.7 Risk of Flooding

NRW's website based flood risk assessment map website indicates that the Pen y Glol site is not at risk of flooding.

2.3.8 Consented Discharges

Details of consented discharges in Wales have been downloaded from NRWs website[9] and locations of those in the general area are shown on Figure 2.10. Most of the consented discharges in the catchment are for discharges from septic tanks or small package treatment from private properties and to ground via infiltration systems. There is one Welsh Water treated effluent discharge from the sewage treatment works (STW) at Trelawnyd to the Afon Glanffyddion (map location 15).

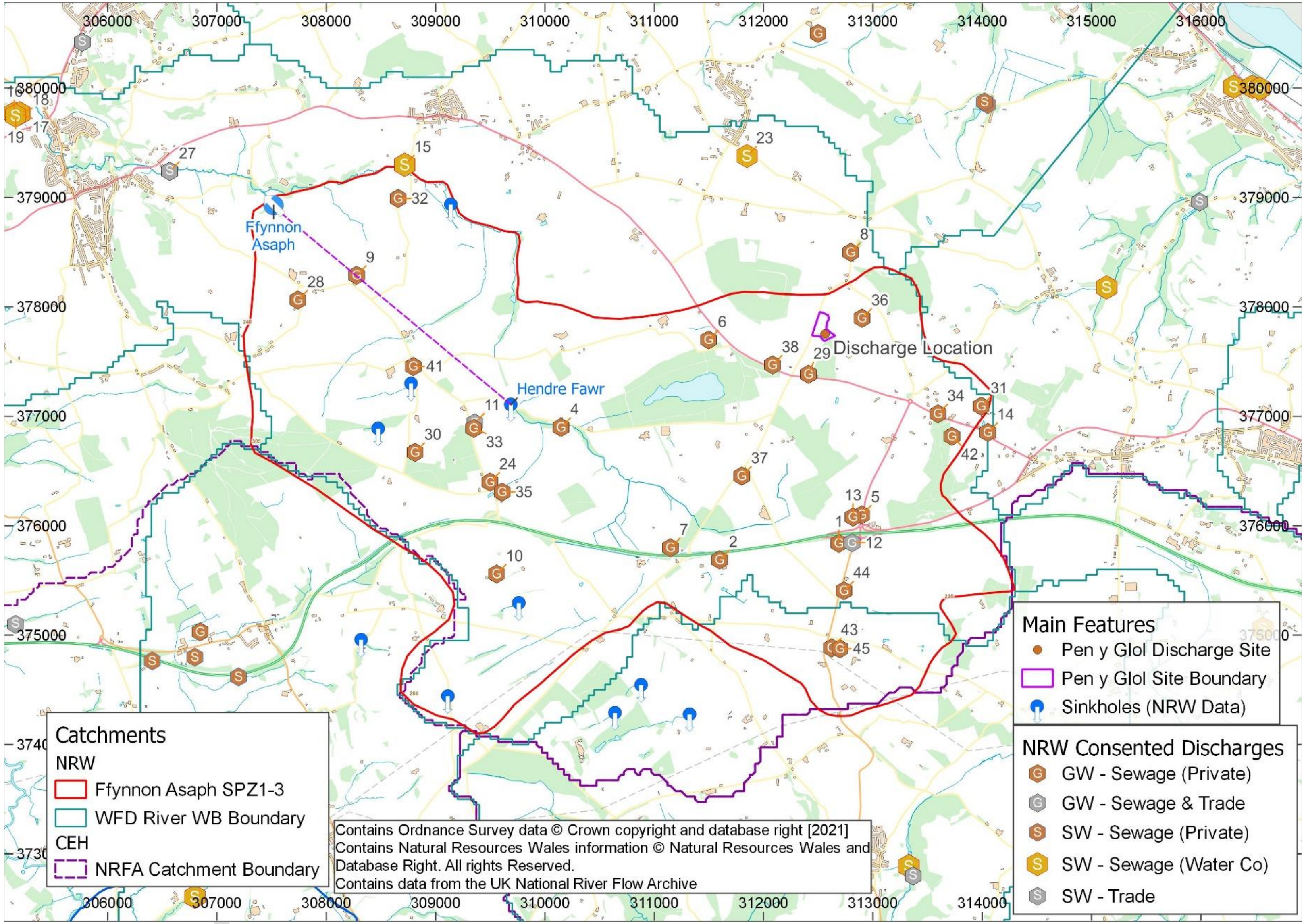
Table 2.3 provides details of the largest treated sewage effluent discharges and summary statistics of all discharges within the Afon Glanffyddion catchment to the confluence with the Ffynnon Asaph spring discharge (i.e., upstream of the spring discharge). Table 2.3 shows:

- The largest discharge (up to a dry weather flow of 207 m^3/day) in the catchment is from the Trelawnyd sewage treatment works (Map ID 15) and this is to the Afon Glanffyddion;
- There are no other discharges to surface water in the catchment except an emergency discharge from the Glan llyn Berthengam pumping station (Map ID 23);
- The largest permitted discharge to ground / groundwater is for 8.4 m^3/day for the Penisar Myndd caravan park (Map ID 11); 360 m SW of the Hendre Fawr sinkhole / swallet;
- There is a 5 m^3/day permitted (septic tank) discharge circa 780 m NNE of the current Pen y Glol discharge;
- The total permitted discharge from septic tanks / package treatment plants to ground / groundwater is 61.6 m^3/day of which 13.4 m^3/day includes some "Trade" discharge from a caravan park and from a café.

These treated sewage discharges compare to the estimated 95th percentile (dry weather flow) for the Ffynnon Asaph spring discharge of (see Table 2.2) of 4666 m^3/day (0.054 m^3/s). The total permitted discharges to ground therefore represent (61.6/4666 =) 1.3% of the 95th percentile flow.

[8] 22.1 km^2 for existing SPZ divided by 16.51 km^2 the higher water balance estimate based on flows.
[9] http://lle.gov.wales/catalogue/item/ConsentedDischargesToControlledWatersWithConditions/?lang=en

Figure 2.10 – Consented Discharges to Controlled Waters



Note: Data provided under a NRW Conditional Licence. Contains Natural Resources Wales information © Natural Resources Wales and/or database right. Only discharges within the Afon Glanffyddion water body / catchment are numbered. The Water Company consented discharge No.2 is a pumping station emergency overflow and not a discharge under normal operation.

Table 2.3 Summary of Consented Discharges within the Afon Glanffyddion Catchment[1]

Map ID	Category of Discharge[2]	Type of Discharge[3]	Discharge to	Dry Weather Flow[4] (m^3/day)	Total Flow (m^3/day)
Discharges ≥3 m^3/day total flow					
15	SW -Sewage - Water Undertaker	Sewage treatment works	Afon Glanffyddion	207.0	1242.0
23	SW -Sewage - Water Undertaker	Sewage Pumping station emergency discharge	Not named	5.6	
11	GW - Sewage & Trade	Septic Tank (Caravan Park)	Groundwater		8.4
13	GW - Sewage - non Water Undertaker	Septic tank and filter (Multiple Domestic Properties)	"		6.3
12	GW - Sewage & Trade	Septic Tank (Cafe)	"		5.0
8	GW - Sewage - non Water Undertaker	Septic Tank (Single Property)	"		5.0
10	"	"	"		5.0
14	"	"	"		5.0
35		Septic tank and filter (Multiple Domestic Properties)	"		3.0
No[5]	**Category of Discharge[2]**	**Type of Discharge[3]**	**Discharge to**	**Dry Weather Flow (m^3/day)**	**Total Flow (m^3/day)**
Summary of all discharges					
3	SW - Sewage - Water Undertaker			212.6	1242.0
27	GW - Sewage - non Water Undertaker				48.2
2	GW - Sewage & Trade				13.4

Notes:

1. For discharges in the catchment to the confluence of the Afon Glanfyddian and Ffynnon Asaph spring discharge. Also includes discharges 43-45 which are not designated as being within the Glanfyddian Cut water body but are within the Ffynnon Asaph SPZ. Data provided under an Open Government Licence. Contains Natural Resources Wales information © Natural Resources Wales and/or database right.
2. This is a summary category devised by Rukhydro and as used to categorise discharges on Figure 2.10. GW = Groundwater and SW = surface water.
3. This is based on the NRW consented dataset category "Discharge site type code & description".
4. Dry weather flow (DWF) is the treated sewage discharged excluding rainfall and significant groundwater inputs, whereas total flow can contain rainfall, runoff and groundwater inputs. Most septic tanks total flow should be similar to the DWF.
5. This is the number of discharges of this category and not the map reference.

2.4 Soils and Geology

2.4.1 Soils

Photographs of site soils from the woodland provided by PYG Ltd show an organic-rich soil with frequent sand to cobble sized limestone fragments. The UKSO soil observatory website[10] notes for the site and discharge area:

- Free draining slightly acidic but base-rich soils (Soilscapes layer);
- Medium (silty) to light (silty) to heavy (soil texture simple layer);
- Clayey loam to silty loam (soil texture layer);
- Shallow (soil and subsoil can be dug to no more than 0.5 m; soil depth layer);
- Layered subsoil of clay, silt and sand (subsoil grain size layer).

10 http://mapapps2.bgs.ac.uk/ukso/home.html

2.4.2 Artificial Ground and Superficial Deposits Mapping

Figure 2.11 show the distribution of artificial ground and superficial deposits ('drift') as mapped by the British Geological Survey (BGS) in the general area of the Afon Glanffyddion catchment and Ffynnon Asaph spring SPZ.

The nearest mapped artificial ground is circa 980 m NNW of the Pen y Glol discharge site.

Figure 2.11 shows that the Pen y Glol site is in an area mapped as being free of superficial deposits. Otherwise perhaps circa 80% of the Ffynnon Asaph SPZ is covered in superficial deposits – primarily 'Devensian Till' – a sandy, gravelly, cobbly clay ('Boulder Clay').

2.4.3 Bedrock (Solid) Geology

Figure 2.12 shows the distribution of bedrock strata and mapped faults and Table 2.4 summarises the stratigraphy (bedrock succession).

Table 2.4 Bedrock Succession in the Ffynnon Asaph SPZ

Period	Parent Group	Formation Name	Age (Myrs)	Dominant Lithology
Carboniferous	Millstone Grit	Gwespyr Sandstone	318 to 320	Sandstone and [subequal/subordinate] argillaceous rocks, interbedded
	Craven	Bowland Shale	319 to 337	Mudstone
		Pentre Chert	328 to 329	Chert
		Teilia	329 to 331	Limestone and mudstone, interbedded
	Clwyd Limestone	Cefn Mawr Limestone	329 to 337	Limestone and [subequal/subordinate] argillaceous rocks, interbedded
		Loggerheads Limestone	331 to 337	Limestone with areas of knoll-reef limestone
		Llanarmon Limestone	331 to 343	Limestone
		Ffernant	343 to 347	Mudstone, siltstone and sandstone.
		Foel	345 to 347	Limestone and [subequal/subordinate] argillaceous rocks, interbedded
Silurian		Nantglyn Flags	424 to 433	Mudstone and siltstone

Notes:

1. All information as provided on BGS Geology of Britain Viewer and links to BGS Lexicon of Named Rock Units. Contains British Geological Survey Materials © UKRI 2021.

The Pen y Glol site and its current discharge location is in an area mapped as the Loggerheads Limestone Formation of the Clwyd Limestone Group (formerly 'Carboniferous Limestone'). The higher ground occupied by Coed y Garreg circa 900 m NE is mapped as being an area of knoll-limestone within that Loggerheads Limestone Formation. The nearest mapped geological fault is 370 m to the west.

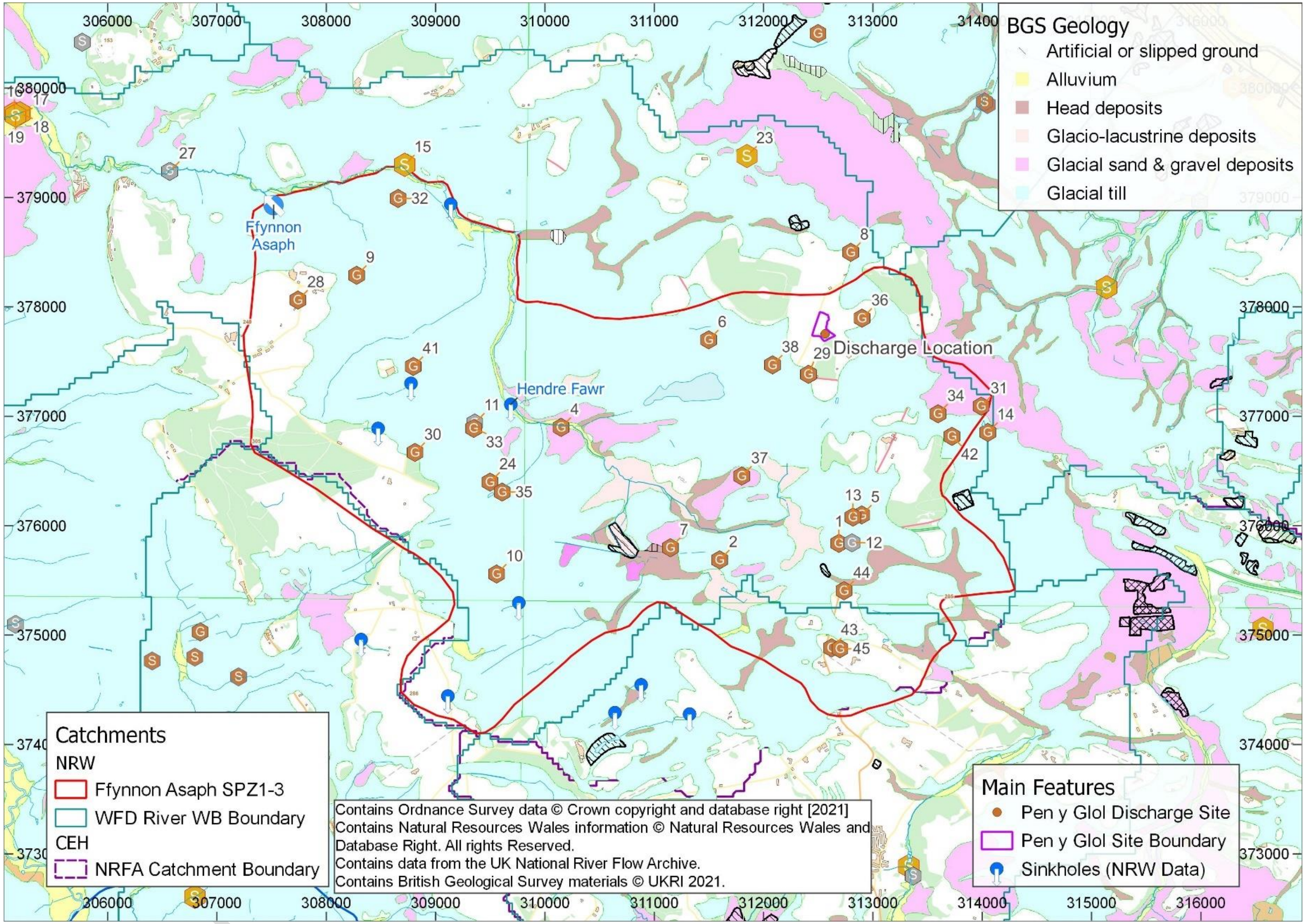
The BGS Lexicon describes the lithology of the Loggerheads Limestone Formation as: "*Thickly bedded, massive, pale grey shelly limestones (packstones and grainstones), locally mottled and pseudobrecciated, arranged in shoaling upwards cycles capped by calcretes, hummocky palaeokarstic surfaces and associated thin bentonitic clay seams (palaeosols) and rare coals. Locally dolomitised and with scattered chert nodules.*"

Most of the Ffynnon Asaph SPZ / catchment is underlain by the Clwyd Group limestones, although mudstones and siltstones of the Nantglyn Flags are present on the southwestern side.

In their evaluation of the catchment to Ffynnon Asaph, Low and Gunn (2013) noted that:

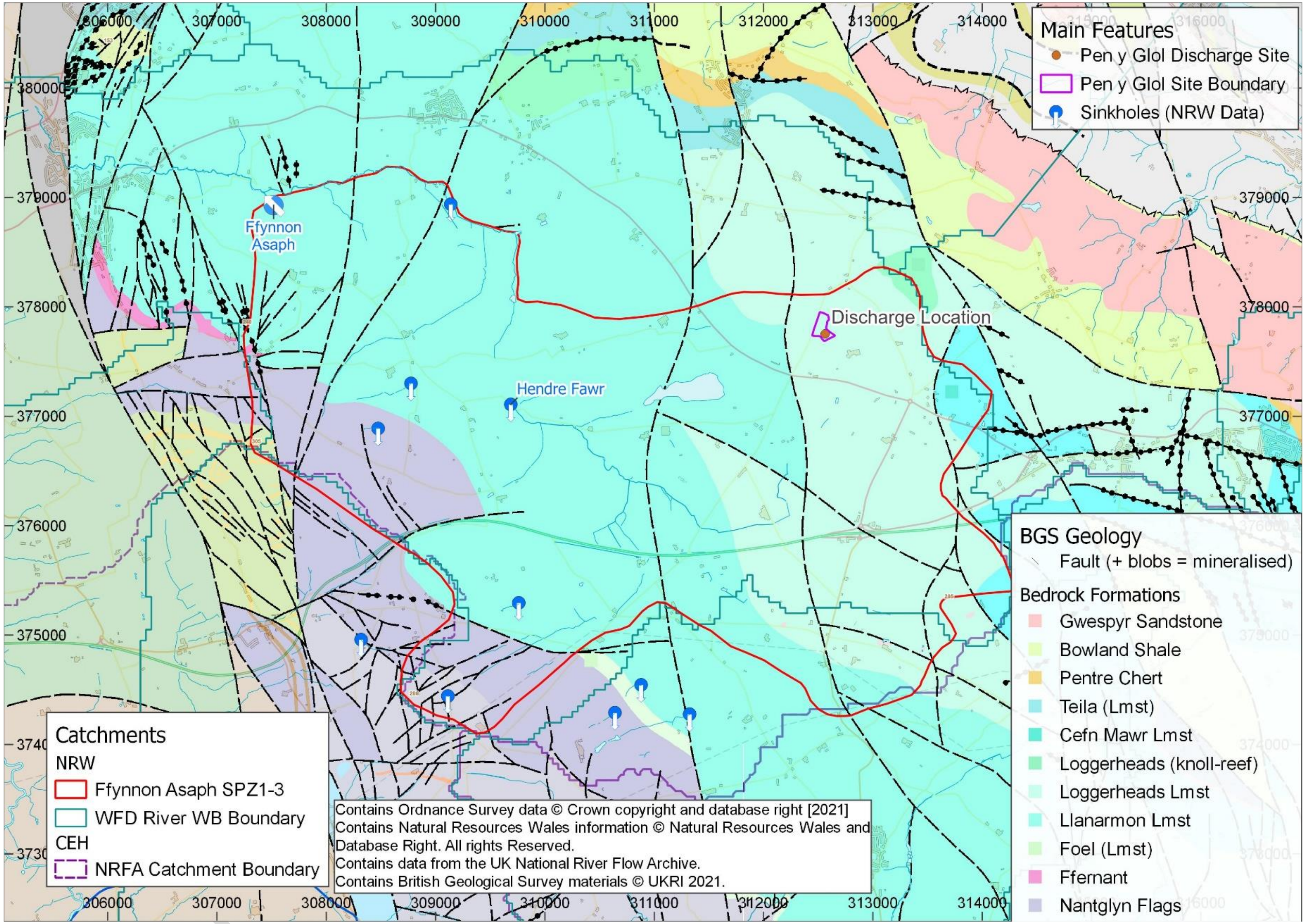
- The Clwyd Limestone Group consists of limestones, with bands of carbonaceous mudstone and occasional dolomitic limestone and chert. It is underlain by the Nantglyn Flags (mudstones, sandstones and siltstones) and overlain by the Bowland Shale (mainly blocky mudstone) and Teilia Formation (calcareous mudstones).

Figure 2.11 – BGS Mapped Artificial Ground and Superficial Deposits



Note: See Figure 2.10 for legend for consented discharges (hexagonals). Data provided under a NRW Conditional Licence. Contains Natural Resources Wales information © Natural Resources Wales and/or database right. Superficial deposits are not mapped in the vicinity of the Pen y Glol discharge. Geology is BGS WMS Mapping.

Figure 2.12 – BGS Mapped Bedrock (Solid) Geology



Note: See Figure 2.10 for legend for consented discharges (hexagonals). Data provided under a NRW Conditional Licence. Contains Natural Resources Wales information © Natural Resources Wales and/or database right. The Pen y Glol discharge is in an area mapped as the Loggerheads Limestone. Geology is BGS WMS Mapping. Woodland areas not shown.

- The sequence dips generally to the north-east and is strongly faulted by two almost orthogonal fault-sets which fault the limestone down in steps towards the northeast.
- The combination of dip and faulting causes the thickness of the remaining limestone to increase rapidly to the northeast, from zero to around 300 m where it passes under the Teilia and Bowland Shale Formations.

The 1:50,000 scale BGS (2006) map shows a dip arrow immediately west of the Pen y Glol site (but east of the fault – downthrown to the east) and records a gentle dip of 4° to the north.

2.4.4 Local Boreholes

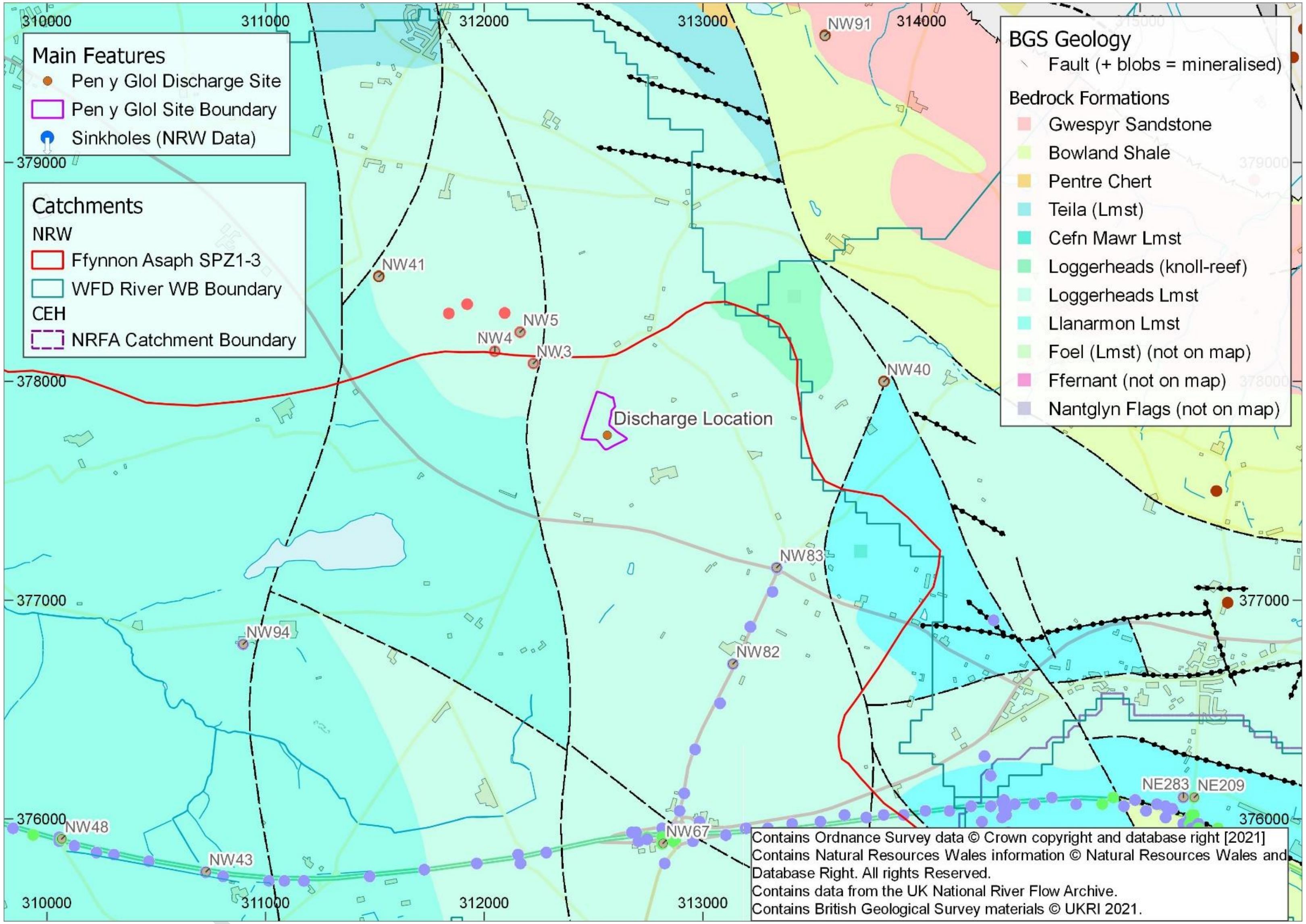
Figure 2.13 shows the location of BGS records boreholes in the vicinity of the Pen y Glol site. Table 2.5 provides the details for two nearby boreholes; both in areas mapped as the Loggerheads Limestone as is the Pen y Glol site.

Table 2.5 Detailed Geology in Nearest Boreholes

Soil / strata	Thick -ness (m)	Depth to base (m bgl)
SJ17NW3 - Glot No 1 bore; ~480 m to NW; 1966 (Ground level ~216 m AOD).		
Soil	0.91	0.91
Brown boulder clay and gravel	1.22	2.13
Limestone, pale grey to buff, very variable in grain size – very fine to very coarse, 'brecciated'; numerous irregular and impersistent stylolites.[2]	2.01	4.14
Limestone, pale grey and buff, very fine to coarse-grained; ½" grey green mudstone @16feet; highly inclined stylolites 23 to 25 feet, slightly ferruginous mineralisation on joint 19 to 20 feet.	4.22	8.53
Limestone, pale grey brown to brown, variable grain size but mainly fairly coarse; numerous stylolites; colonial coral; slight ferruginous mineralisation on joints, and a few galena crystals on joint at 60feet.	15.75	24.38
Limestone, pale grey to pale grey brown, variable grain size – fine to fairly coarse; stylolites in bottom foot.	9.14	33.53
Mudstone, brownish grey, soft, blocky	0.20	33.73
Limestone, greyish brown, fairly coarse grained.	1.11	34.85
Limestone, mainly pale grey and ale greyish brown, fine to coarse-grained; scattered stylolites.	6.58	41.48
Limestone, greyish brown, fairly coarse-grained.	0.61	42.09
Limestone, pale grey brown, fine to coarse-grained; thin ferruginous spar veins.	1.52	43.61
Mudstone, greenish grey, soft, blocky.	0.30	43.91
Limestone, brown, earthy, 'brecciated'.	0.07	43.98
Limestone, mainly pale grey brown and pale grey, fine to fairly coarse-grained, slight ferruginous mineralisation on joints; stylolites at 163 and 164 feet.	16.97	60.96
SJ17NW83 – A55 Holywell Bypass 216; ~980 m to SE; 30/11/1979; Ground level 185.99 m AOD		
Topsoil	0.40	0.40
Made Ground (Soft to firm, brown mottled, silty sandy CLAY with some assorted gravel and occasional inclusions of peat and clinker fragments).	1.60	2.00
Glacial deposits (Grey fine to coarse GRAVEL, cobbles and occasional boulders in a matrix of brown, silty, slightly sandy clay. Gravel mainly limestone.)	1.50	3.50
Limestone (Moderately to slightly weathered, becoming faintly weathered to fresh at about 6.00m grey moderately strong, crystalline LIMESTONE. Joint sets (generally rough ~planar): 1. 70° - subvertical; 2. 50 – 60° 3. 30 – 40°	2.01	4.14

1. All information as provided on BGS Geology of Britain Viewer and links to BGS Lexicon of Named Rock Units. Contains British Geological Survey Materials © UKRI 2021.
2. Stylolites "*are serrated surfaces within a rock mass at which mineral material has been removed by pressure dissolution, in a deformation process that decreases the total volume of rock. Minerals which are insoluble in water, such as clays, pyrite and oxides, as well as insoluble organic matter, remain within the stylolites and make them visible.*" (https://en.wikipedia.org/wiki/Stylolite).

Figure 2.13 – Locations of BGS Borehole Records and BGS Bedrock Geology



Note: Geology is BGS WMS Mapping. BGS WMS boreholes shown as blue (<10 m deep), green (10 to 30 m deep), red (>30 m deep) or brown (no depth information) dots. Only selected boreholes labelled by Rukhydro. Boreholes are prefixed with e.g., SJ17 (as per their OS area) on the BGS borehole database.

In the nearest borehole (SJ17NW3), thin glacial till (boulder clay) is logged, but not mapped as such by BGS (see Figure 2.11). Beneath that thin glacial till layer, the sequence is dominated by limestone, although two thin (≤0.3 m thick) mudstones (probably palaeosols) are recorded below 33 m depth. The limestone varies in colour and grain size, and commonly show pressure solution effects ('stylolites') from past deformation. Joints with ferruginous discolouration are noted in the upper 25 m; implying water movement via fractures.

Other boreholes near SJ17NW3 provide less detailed descriptions, but it is of note they record the limestone is in some places "rubbly" and in other places "jointed".

The next nearest borehole is SJ17NW83 (see Figure 2.13 and Table 2.5). Again, beneath relatively thin glacial deposits (with some localised man-made disturbance), limestone is logged. Of note are the three different orientation joint sets.

These logs for relatively local boreholes indicate that any superficial deposit thickness is small and the Loggerheads Limestone Formation is likely a fractured variable colour and grain size limestone which is weathered or shows evidence of flow in fractures its upper parts near ground level.

2.4.5 Site Investigations

No borehole or trial pit logs have been made available from site. PYG Ltd note that trenches excavated to 1.8 m prior to Waterco (2019) infiltration rate tests in 2019 hit solid limestone rock at a depth of just over 1 m bgl.

2.5 General Hydrogeology

2.5.1 Aquifer Designation

The BGS Geoindex Onshore map viewer[11] notes that the Carboniferous Limestone (Clwyd Limestone) at the Pen y Glol site and dominating the Ffynnon Asaph SPZ is designated as a Principal aquifer. The glacial till, where present, is designated as Secondary undifferentiated.

2.5.2 Groundwater Vulnerability

The BGS Geoindex Onshore map viewer shows the area of the Pen y Glol site as being of High vulnerability, Principal aquifer". This also applies to other parts of the Clwyd Limestone where there is no superficial deposits cover. Where there is cover the vulnerability in the Ffynnon Asaph SPZ is shown as being of medium or low vulnerability.

2.5.3 Source Protection Zones

As noted in Section 2.2.3, the Pen y Glol site lies just within the source protection zone (SPZ) of the Ffynnon Asaph spring discharge from which Welsh Water abstract water for public supply. Section 2.3.6 has provided information on the delineation of the SPZ and noted that as delineated the SPZ is conservatively large; likely about 34%. So, the Pen y Glol site may fall outside the true SPZ.

The inner and outer SPZ and total catchment for Ffynnon Asaph cover the same area because when delineated there was considered insufficient evidence for anything other than rapid (50 day) travel times from any point of the catchment.

[11] http://mapapps2.bgs.ac.uk/geoindex/home.html?_ga=2.144860925.81897523.1627305627-826579747.1618325712

2.5.4 Regional Groundwater Flow in the Carboniferous Limestone

The BGS Earthwise online publication *Hydrogeology of Wales: Carboniferous aquifers - the Carboniferous Limestone aquifer*[12] notes regarding the Clwyd Limestone Group:

> "*Groundwater flows through the limestone in the Clwyd catchment via fractures and available karst features in a north-easterly direction to discharge to the sea. Swallow holes are common in the main Clwyd Limestone Group outcrop to the east of the Vale of Clwyd. Ffynnon Asaph [SJ 0752 7893] which flows at 4.3 Ml d^{-1} traditionally supplied the town of Prestatyn. Local metal mining in the limestone has exposed a number of cave and conduit systems, some of which have had a direct effect on mine dewatering.*"

Notes on the BGS (1989) *Hydrogeological Map of Clwyd and the Cheshire Basin*[13] regarding the Carboniferous Limestone state:

- "*The limestones have very low porosities and intergranular permeabilities, yields from the matrix being minimal;*
- *Groundwater is contained and moves within enlarged fissures;*
- *Fissures are often fault controlled, and flows tend to become concentrated along a number of horizons more permeable than one above and below;*
- *Although the fissures are relatively sparse, they tend to be large and groundwater flows can therefore be rapid; velocities of several metres per second have been recorded;*
- *Flows from these systems issue at a limited number of large springs, and groundwater catchments can bear little resemblance to surface topography.*
- *Tunnels and adits through the limestone, associated with old mineral workings, cross the fissure systems and have a significant effect on the hydrogeology of the area. Two of these, the Bagillt Tunnel and Halkyn High Level, are now used for water supply.*
- *In the vicinity of the Vale of Clwyd, the limestone is locally either present at surface or covered only by permeable drift, and here most of the effective precipitation is recharged and little run-off occurs.*
- *Drilling in the limestone is highly speculative since the water is restricted to discrete, irregularly spaced fissures that are not extensively interconnected. Boreholes failing to intersect fissures are generally dry and few have been attempted in this area*."

Flows in the Carboniferous Limestone are therefore restricted to often poorly connected fractures and karst features, but in which transport of water and pollutants is rapid. Drilling of e.g., monitoring boreholes has a low chance of success in encountering significant groundwater.

[12] http://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Wales:_Carboniferous_aquifers_-_the_Carboniferous_Limestone_aquifer
[13] http://www.largeimages.bgs.ac.uk/iip/hydromaps.html?id=clwyd-cheshire.jp2 (Contains British Geological Survey materials © UKRI [2021])

2.6 Groundwater Levels, Gradient and Flow

2.6.1 Available Groundwater Level Data

BGS Hydrogeology Map

The BGS (1989) *Hydrogeological Map of Clwyd and the Cheshire Basin* does not show groundwater level contours for the Carboniferous Limestone. It also notes that few monitoring boreholes have been constructed due to the unreliability of encountering significant (connected) groundwater.

Report on the Ffynnon Asaph Catchment

Low and Gunn (2013) note: "*There has been little work on, or monitoring of, the hydrogeology of the area; there are no EAW* [what is now NRW] *observation boreholes in the area, there are no aquifer properties data listed in the* [Major][14] *Aquifer Properties Manual (Allen et al, 1997), and there have been no reported formal tracer tests.*"

NRW Observation Borehole Data

Details of groundwater observation boreholes within 10 km of the site were requested from and provided by NRW. But the closest monitoring boreholes are >7 km SW of the Pen y Glol site and do not monitor the Clwyd Limestone. One borehole (SJ07_025; Dinorben Arms; NGR: 309250,370080) is located within a small fault bounded and isolated block of Clwyd Limestone circa 8.4 km SSW from the Pen y Glol discharge site. Data are for the period July 1973 to July 1976 and vary seasonally and steadily between 5.62 and 7.88 m depth. With this location so distant from the Pen y Glol site and being in an isolated block of limestone, its relevance to groundwater levels near Pen y Glol is very low.

BGS and Local Authority Records and Mapped Springs

The BGS borehole database has been reviewed for information on groundwater levels for boreholes and trial pits in the general area of Pen y Glol and the Ffynnon Asaph SPZ. 24 records contained information on groundwater level or in four cases a depth of groundwater that could be inferred from a 20 ft (6.1 m) deep borehole / well and a note that it was used for groundwater abstraction. A depth to water level of 4 m (~12 feet) was assumed.

Flintshire and Denbighshire local authorities were also contacted for details of private water supplies and from this information the location and elevation of eleven likely reliable and currently flowing springs was also obtained.

The location and elevation of the following features was obtained from Ordnance Survey 1:25,000 scale maps, a 1968-1669 1:10,560 scale map or a 1964 1:2500 scale map:

- 17 springs;
- one spring which became a well and two wells with streams flowing from them;
- 17 "issues[15]";
- the Ffynnon Asaph spring (~116 m AOD);
- one river stage measurement of the tributary of the Afon Glanffyddion[16].

[14] There is a discussion on the Carboniferous Limestone of North Wales in the Minor Aquifer Properties Manual (Jones et al., 2000), but this says: *"The aquifer properties of the Carboniferous Limestones of north Wales are unknown*" and "*The limestones have minimal primary porosity or permeability with groundwater storage and movement restricted to solution enlarged fractures*."

[15] "Issues" are usually located at the heads of streams and are assumed to be the start of groundwater discharge.

[16] This was added because without it generated groundwater level contours in that area were inconsistent with the elevation of local streams.

CCW Report on Spring-fed Llyn Helyg

A report (Shilland and Monteith, 2001) for the Countryside Council of Wales, now part of NRW, notes that Llyn Helyg, circa 1050 m WSW of the Pen y Glol discharge location, is spring-fed and has a water level of 177 m AOD (and maximum water depth of circa 1 m). This water level elevation has also been used to constrain groundwater levels in the area.

2.6.2 Mapped Groundwater Levels

Figure 2.14 shows the groundwater levels collated from the BGS, local authority and mapped springs as discussed in the above subsection. The collated data are provided in Appendix A.

Groundwater level contours have been added using the simple contouring application in QGIS (v3.10.10). Constraint of these groundwater contours is poorer towards the northwest and southeast of the mapped area due to fewer data being collated for those areas. The contouring also assumes hydraulic continuity between groundwater in the limestone and in adjacent strata. No allowance is made for possible seasonal variations in groundwater levels.

Despite the above uncertainties and limitations, the groundwater level contours suggest:

- Groundwater in the vicinity of Pen y Glol is at an elevation of circa 165-170 m AOD and appears likely to flow north-eastwards[17] to discharge into the springs of the Afon Y Garth catchment;
- There is a likely groundwater divide circa 800 m SW of Pen y Glol; south of which groundwater flows south-westwards to discharge either into the Afon Glanffyddion or at the Ffynnon Asaph spring;
- The southwestern, southern and eastern boundaries of the Ffynnon Asaph SPZ appear broadly consistent with the groundwater level contours and the perturbation of groundwater contours near Ffynnon Asaph are consistent with that spring’s discharge.

2.6.3 Groundwater Gradient

The groundwater level contours in the vicinity of Pen y Glol suggest a hydraulic gradient of (10 m in 675 m=) 0.0148 towards the NE-NNE (~30°).

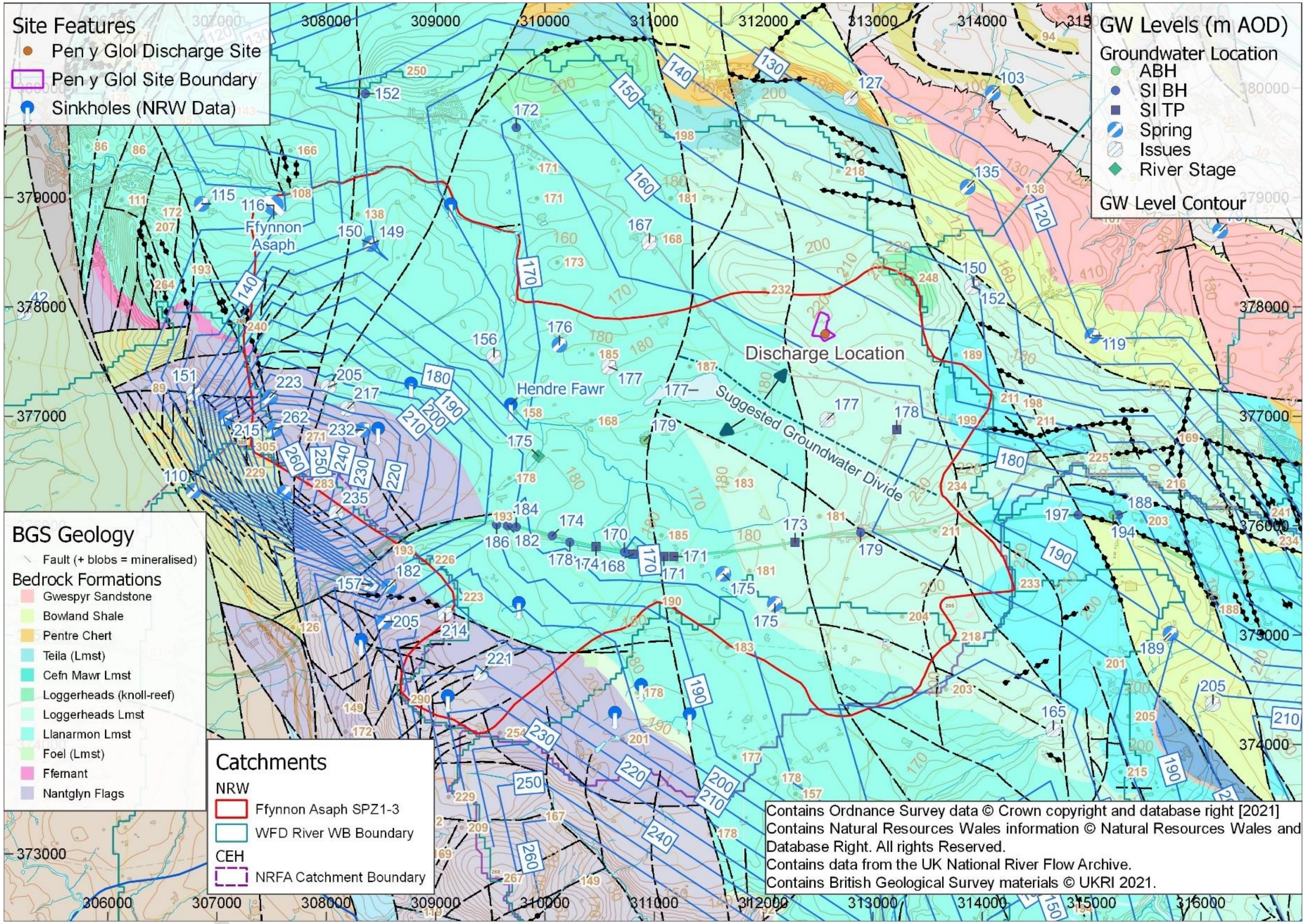
2.6.4 Hydraulic Properties

As noted by BGS (1989) in Section 2.5.4, “*The limestones have very low porosities and intergranular permeabilities”* and *“Groundwater is contained and moves within enlarged fissures”*.

Low and Gunn (2013) note that there are no aquifer properties data listed in the major aquifer properties manual (Allen et al, 1997). There are also none in the minor aquifer properties manual for North Wales (Jones et al., 2000).

[17] This is consistent with the BGS Earthwise online publication *Hydrogeology of Wales: Carboniferous aquifers - the Carboniferous Limestone aquifer* which notes regarding the Clwyd Limestone Group that “Groundwater flows through the limestone in the Clwyd catchment via fractures and available karst features in a north-easterly direction to discharge to the sea”. (see Section 2.5.4).

Figure 2.14 – Area Groundwater Levels based on Borehole Water Levels, Springs and "Issues"



Note: Geology is BGS WMS Mapping. Groundwater levels data sources are tabulated in Appendix A. Only selected boreholes labelled by Rukhydro.

Table 2.6 collates information on hydraulic properties for the Carboniferous Limestone from other area of England and Wales as provided in the major and minor aquifer property manuals.

Table 2.6 Published Hydraulic Properties for the Carboniferous Limestone

Region	Hydraulic Property	Units	Derived From	No	Min	25th %-ile	Med-ian	75th %ile	Next Max	Max	AM	GM
England & Wales[1]	Transmissivity [3]	m^2/day	Pumping Tests	6	0.1				60	770		10
The Pennines[2]	Transmissivity	"	Pumping Tests	19	0.1	1.6	18	43		1015	153	13
"	Storage coefficient	%	Pumping Tests	1							0.03	
"	Porosity	%	Core data (outcrop)	3							1.30	
"	Porosity	%	Core data (boreholes)	4							1.00	
	Hydraulic conductivity	m/day	Core data	?							0.14	

1. Data from the major aquifer properties manual (Allen et al., 1997);
2. Data from the minor aquifer properties manual (Jones et al., 2000);
3. Transmissivity (m^2/day) is the product of hydraulic conductivity (m/d; ≈'permeability') and effective saturated aquifer thickness (m).
4. Samples collected from a 23 m section of a single borehole near Burnley.

2.6.5 Flows and Hydraulic Properties near Pen y Glol

To provide some indication of hydraulic properties of the Loggerheads Limestone in the vicinity of Pen y Glol it has been assumed;

- Recharge from areas to the northeast of the groundwater divide shown on Figure 2.14 flows north-eastwards via the area of Pen y Glol;
- A recharge rate (R) of 290 to 340 mm/year (equating to about 90% of the assumed effective rainfall of 325 to 375 mm/year);
- The distance (L) from the groundwater divide to the Pen y Glol discharge site is circa 800 m (see Section 2.6.2);

Groundwater flow (Q_{10m}) for each 10 m cross-flow width (W) is then calculated (Q_{10m} = R x L x W=) as 2320 to 2720 m^3/year.

With a hydraulic gradient (i) of 0.0148 then this flow would require a transmissivity (T) of the limestone of (T = [Q_{10m}/10]/0.0148=) 15676 to 18378 m^2/year or 43 to 50 m^2/day. These transmissivities are average to moderately high compared to the range of transmissivities of the Carboniferous Limestone measured elsewhere in England and Wales (see Table 2.6).

Low and Gunn (2013) note that the limestone may be up to 300 m thick where it passes under the Teilia and Bowland Shale Formations (see Section 2.4.3), as occurs to 1 to 2 km NE of the Pen y Glol site. Assuming a thickness of 200 to 300 m, then the calculated transmissivity range of 43 to 50 m^2/day equates to a hydraulic conductivity of 0.14 to 0.25 m/day. This compares to the average of 0.14 m/day for the very limited data in the minor aquifer properties manual see Table 2.6). This is the average hydraulic conductivity of the limestone sequence and noting that flow will be concentrated in fissures.

Overall, the recharge and area based estimate of groundwater flow in the vicinity of Pen y Glol of 2320 to 2720 m^3/year per 10 m cross flow width yields transmissivities and hydraulic conductivity values consistent with those limited data published elsewhere. The flow estimates are therefore judged reasonable for use in subsequent risk scoping calculations for the Pen y Glol discharge.

2.7 Groundwater Abstractions

2.7.1 Licensed Abstractions

As noted in Section 2.3.4, there are no NRW licensed abstractions from surface water or groundwater within the Ffynnon Asaph source protection zone or within the catchment of the Afon Glanffyddion upstream of its confluence with the Ffynnon Asaph spring. The Ffynnon Asaph spring is a licensed public water supply to Dwr Cymru (Welsh Water) for 4.55 Ml/day (Low and Gunn, 2103).

Table 2.7 provides details of two licensed abstractions outside these areas and to the northeast (i.e., downgradient) of Pen y Glol. The abstractions are from surface water and are shown on Figure 2.15.

Table 2.7 Abstractions downgradient of Pen y Glol

Map Id[1]	Easting[2]	Northing [2]	Type[3,4]	Licence No.	From	Use	Annual Limit (m^3/year)	Distance and direction from Pen y Glol discharge (m)
1	313000	381000	Licensed	24/67/10/0104	Surface water (Garth Mill Race and Reservoir)	Process water	1,106,746	3280 NNNE
2	317000	379000	Licensed	24/67/10/0118	Surface water (Afon Rhydwen)	Spray irrigation	2,160	4610 ENE
9	313906	379742	Private	Not applicable	Groundwater (Well)	Drinking and food production		2400 NNE

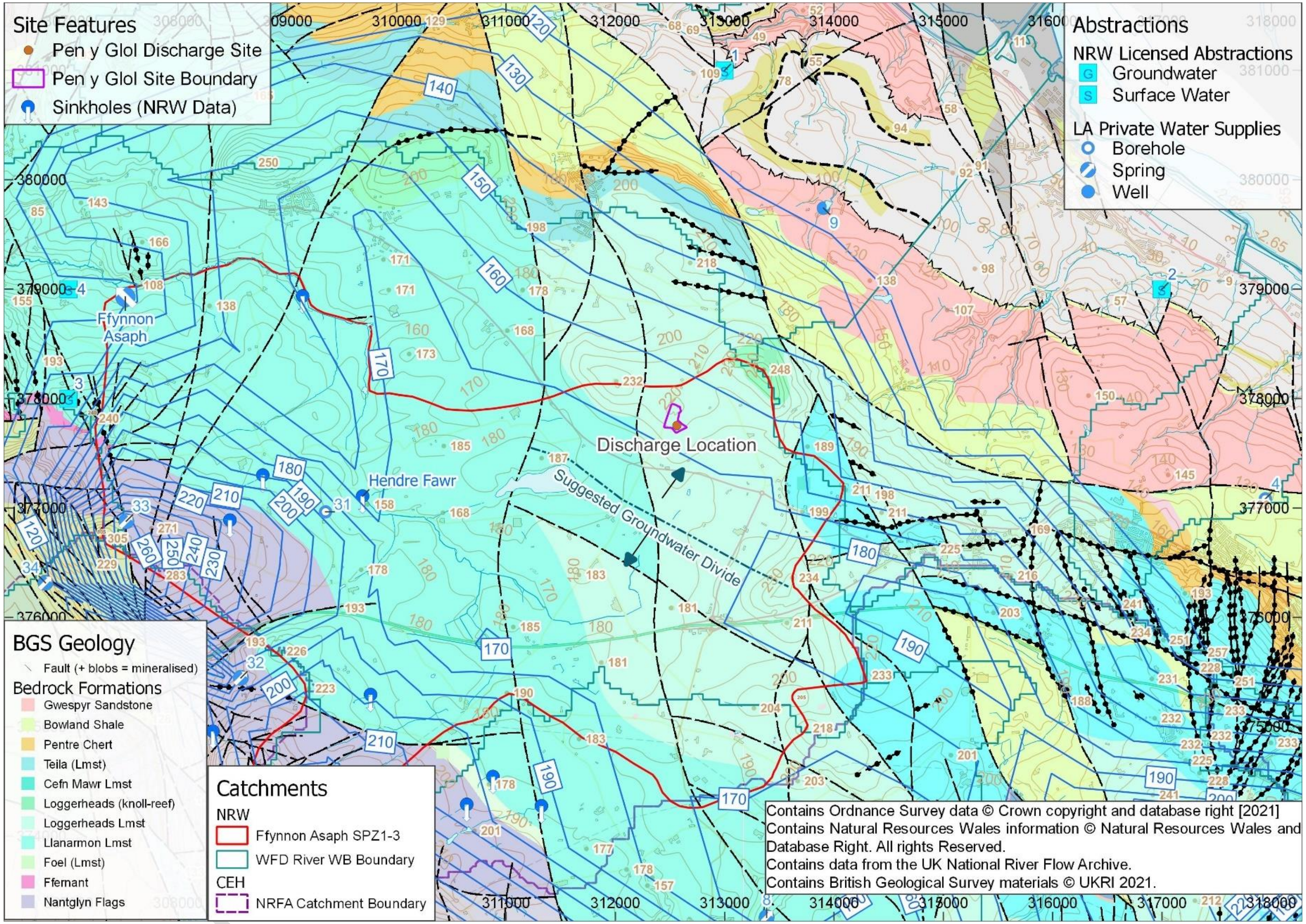
1. As shown on Figure 2.15;
2. Eastings and northings of licensed abstractions are to the nearest 1000 m as provided by NRW.
3. Data for licensed abstractions provided by NRW under NRW Conditional Licence. *Contains Natural Resources Wales information © Natural Resources Wales and database right.*
4. Data for private abstractions provided by Flintshire County Council. A similar dataset was also provided by Denbighshire County Council.

2.7.2 Private Water Supplies

Flintshire and Denbighshire County Councils (CCs) provided details of private water supplies in the general area of Pen y Glol and where nearby are shown on Figure 2.15.

A single registered private water supply is located circa 2400 m NE of the Pen y Glol discharge location. It abstracts from a well located on the BGS mapped Gwespyr Sandstone Formation and is reported by Flintshire CC to be used for drinking and food production, to have good water quality but uses pre-filers and UV to protect the drinking water quality. The Gwespyr Sandstone is separated from the underlying limestone by the Bowland Shale Formation, the Pentre Chert Formation and the Teila Formation interbedded limestones and mudstones (see Section 2.4.3).

Figure 2.15 – Locations of Licensed and Private Abstractions



Note: Geology is BGS WMS Mapping. Locations of Private Water Supplies provided by Flintshire and Denbighshire County Councils.

2.8 Water Quality

2.8.1 Available Data

Surface Water Quality (NRW Data)

NRW provided locations and data for surface water quality monitoring points in the Pen y Glol general area. Locations are shown on Figure 2.16 together with a repeat of the locations of consented discharges from Figure 2.10. Considering the likely northeast direction of groundwater flow then the two most relevant freshwater quality monitoring points are:

- S1166 from a tributary of the Nant Sir Roger upstream of the Whitworth STWs; located circa 2475 m ENE (NGR: 314990, 378200);
- S3833 from at Saunders Dingle, a tributary of the Afon Y Garth; located circa 3530 NNNE (NGR: 313020, 381250).

Summary statistics for selected water quality parameters (mainly nutrients) for these sites are provided in Table 2.8. Data for also provided for two other sites downstream on the Afon Y Garth, two on the Nant Sir Roger downstream of Whitworth, and for the Afon Glanffyddion upstream of Dyserth and the confluence with the Ffynnon Asaph spring discharge.

Groundwater Quality (NRW Data)

NRW report only one groundwater quality monitoring point within a 10 km radius of the Pen y Glol discharge location. This is for the Tre Mine adit site at NGR: 315407 377588 circa 2850 m east. Summary statistics for the same selected parameters are shown in Table 2.8.

Ffynnon Asaph Water Quality (Welsh Water data)

Welsh Water provided water quality data for the raw water at Trecastell water treatment works (WTW), which is the off-take water from the Ffynnon Asaph spring discharge. Summary statistics for the same selected parameters are shown in Table 2.8.

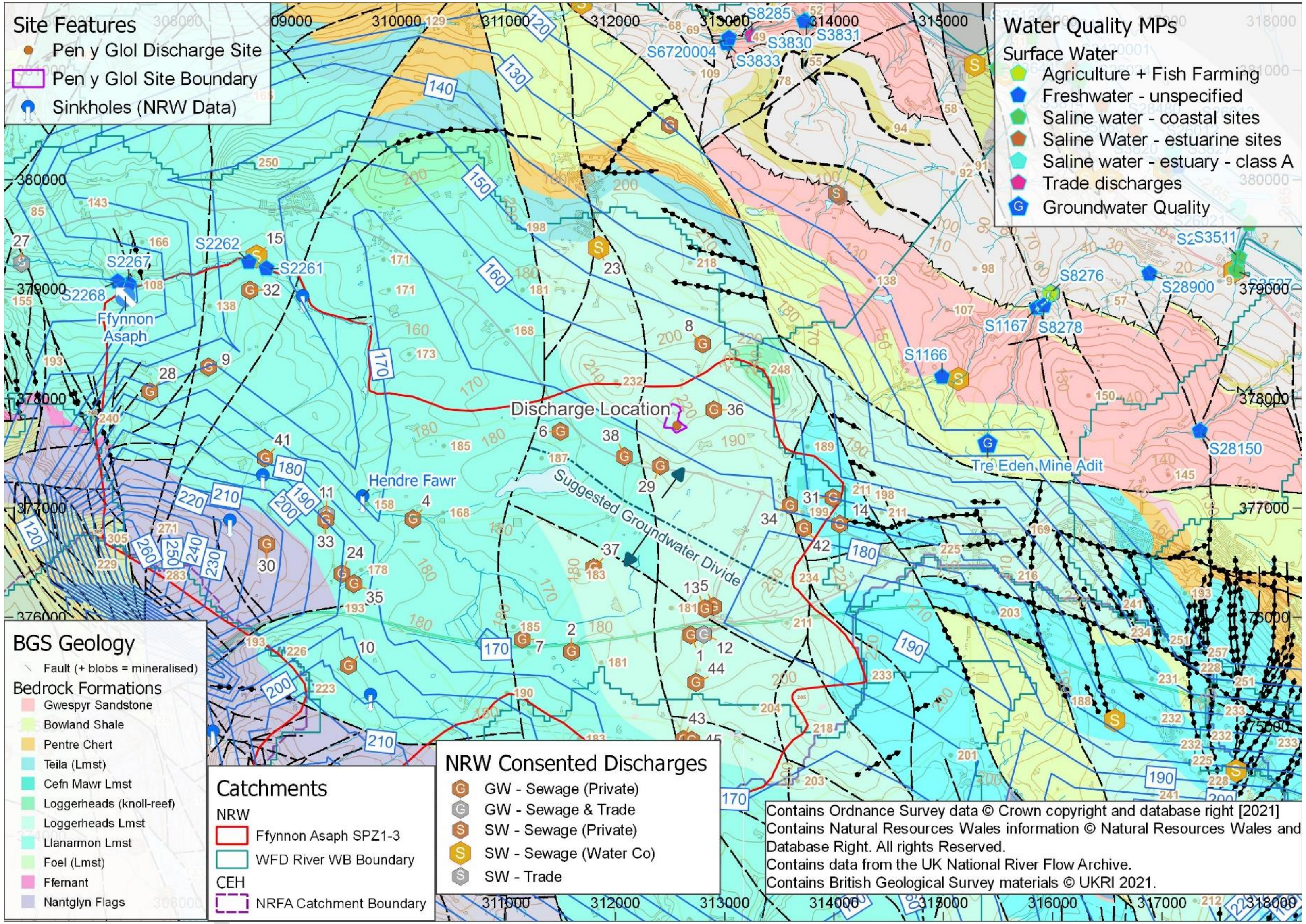
2.8.2 Overview of Selected Water Quality

Table 2.8 shows that:

- Surface waters and groundwater from the Tre Eden mine adit and the Ffynnon Asaph spring all have similar average electrical conductivity 537 to 785 µS/cm range, with the Tre Eden mine the highest and the Afon Glanffyddion upstream of the Trelawnyd sewage treatment works the lowest.
- Average ammoniacal nitrogen is lowest in the Ffynnon Asaph spring (0.02 mg/l N), the Tre Eden mine adit (0.031 mg/l N) and the water course upstream of Whitworth (0.047 mg/l N). Excluding downstream of sewage treatment works, the highest average ammoniacal nitrogen is in Saunders Dingle (the tributary of the Afon Y Garth; 0.14 mg/l N);
- Average nitrate is lowest in the stream upstream of Whitworth (4.37 mg/l N) and the Afon Glanffyddion (4.49 mg/l N) and highest in the Tre Eden mine adit (8.18 mg/l N);
- Average orthophosphate is lowest in the Tre Eden mine adit (0.042 mg/l P) and the stream upstream of Whitworth (0.069 mg/l P) and excluding downstream of sewage treatment works, is highest in the Afon Glanffyddion at Trelawnyd.

There is no clear evidence of impact on surface water or groundwater from the current Pen y Glol discharge, although the higher electrical conductivity and nitrate in the Tre Eden mine adit groundwater could plausibly be linked to nitrate from several septic tank discharges in the area (see Figure 2.16) as well as from agriculture. Low ammoniacal nitrogen, orthophosphate and total phosphate in the Tre Eden mine adit discharge indicates that if septic tank discharges are a cause of higher nitrate, then there is attenuation of ammoniacal nitrogen and phosphate.

Figure 2.16 – Locations of Water Quality Monitoring Points



Note: Geology is BGS WMS Mapping. Monitoring and consented discharges locations provided by NRW. Contains Natural Resources Wales information © Crown copyright and database right [2021]. Consented discharges as presented on Figure 2.10 and discussed in Section 2.3.8.

Table 2.8 Water Quality Statistics for Selected Water Quality Monitoring Points (Page 1 of 2)

Station Id[1]	Station Name[2]	Easting	Northing	Data from	Data to	Conductivity at 20 C (µS/cm)			Alkalinity to pH 4.5 as $CaCO_3$ (mg/l)			Ammoniacal Nitrogen as N (mg/l)		
						No	Mean	95%ile	No	Mean	95%ile	No	Mean	95%ile
Surface Water (NRW Data)														
S1166	W/C U/S WHITFORD STW	314990	378200	02/03/1988	31/05/1991	38	559	654	0			38	0.047	0.153
S1167	NANT SIR ROGER D/S WHITFORD	315860	378830	02/03/1988	31/05/1991	37	555	601	0			36	0.318	1.593
S28900	STREAM NEAR GWIBNANT FARM	316887	379144	16/01/2013	10/12/2015	0			36	259	287	36	0.060	0.204
S3833	SAUNDERS DINGLE	313020	381250	14/08/1995	19/06/2003	8	683	899	0			8	0.140	0.500
S3830	NANT FELIN BLWM US GARTH POOL	313750	381450	14/08/1995	19/06/2003	7	627	638	0			7	0.108	0.373
S3831	A.GARTH US GARTH POOL	313730	381450	14/08/1995	19/06/2003	7	718	737	0			7	0.091	0.365
S2261	A GLANFFYDDION FELINDRE	308810	379190	14/05/1979	04/03/2020	212	537	615	92	239	296	265	0.090	0.282
S2262	A.G'FYDDION D TR'LYD S	308650	379250	30/04/1980	04/03/2020	159	563	643	57	230	269	187	0.418	1.800
Groundwater (NRW Data)														
27977	Tre Eden Mine Adit	315407	377588	14/06/2004	03/12/2020	25	746	937	31	266	294	31	0.031	0.050
Ffynnon Asaph Spring (Welsh Water Data)														
	Trecastell WTW			05/06/1980	31/12/2020	1552	585	670				1255	0.020	0.041

1. As shown on Figure 2.16;
2. As provided by NRW under NRW Conditional Licence. *Contains Natural Resources Wales information © Natural Resources Wales and database right.*
3. Statistics calculated by Rukhydro from data provided by NRW. 95th percentile calculated Excel's PERCENT.INC function

Table 2.8 Water Quality Statistics for Selected Water Quality Monitoring Points (Page 2 of 2)

Station Id[1]	Station Name[2]	Easting	Northing	Data from	Data to	Nitrate as N (mg/l)			Orthophosphate, reactive (mg/l P)			Phosphate :- {TIP} (mg/l P)		
						No	Mean	95%ile	No	Mean	95%ile	No	Mean	95%ile
Surface Water (NRW Data)														
S1166	W/C U/S WHITFORD STW	314990	378200	02/03/1988	31/05/1991	38	4.37	8.75	38	0.069	0.180	0		
S1167	NANT SIR ROGER D/S WHITFORD	315860	378830	02/03/1988	31/05/1991	36	5.83	10.28	36	0.716	1.133	0		
S28900	STREAM NEAR GWIBNANT FARM	316887	379144	16/01/2013	10/12/2015	72	4.88	6.11	36	0.064	0.201	0		
S3833	SAUNDERS DINGLE	313020	381250	14/08/1995	19/06/2003	0			0			0		
S3830	NANT FELIN BLWM US GARTH POOL	313750	381450	14/08/1995	19/06/2003	0			0			0		
S3831	A.GARTH US GARTH POOL	313730	381450	14/08/1995	19/06/2003	0			0			0		
S2261	A GLANFFYDDION FELINDRE	308810	379190	14/05/1979	04/03/2020	312	4.49	8.08	258	0.142	0.312	32	0.065	0.133
S2262	A.G'FYDDION D TR'LYD S	308650	379250	30/04/1980	04/03/2020	181	7.29	16.67	180	1.312	5.510	7	0.597	2.455
Groundwater (NRW Data)														
27977	Tre Eden Mine Adit	315407	377588	14/06/2004	03/12/2020	54	8.18	9.84	31	0.042	0.075	5	0.035	0.079
Ffynnon Asaph Spring (Welsh Water Data)														
	Trecastell WTW			05/06/1980	31/12/2020	535	6.873	8.084				197	0.054	0.043

1. As shown on Figure 2.16;
2. As provided by NRW under NRW Conditional Licence. *Contains Natural Resources Wales information © Natural Resources Wales and database right.*
3. Statistics calculated by Rukhydro from data provided by NRW. 95th percentile calculated Excel's PERCENT.INC function.

2.9 General Setting Summary

The Pen y Glol (static) caravan park sits within the upper reaches and outer edges of the topographic catchment of the Afon Glanffyddion about 6 km NW of Holywell, Flintshire. It also sits on the outer edge of the currently delineated source protection zone (SPZ1 = SPZ3) for the Ffynnon Asaph spring near Dyserth. Welsh Water take some of the spring's discharge for public water supply via their Trecastell water treatment works (WTW).

Both catchments, which have significant overlap, are underlain predominantly by the Carboniferous age Clwyd Limestone Group. Nine sink holes have been mapped by NRW in the southwestern and western part of the SPZ; but there are none mapped in the vicinity of Pen y Glol. Much of the catchment has a thin covering of glacial till (boulder clay), but previous studies have judged that this does not significantly affect recharge and there is very little runoff in the catchment. There is no glacial till covering at Pen y Glol.

Based on good correlations between measured mean daily flows in the River Wheeler at Bodfari (Afon Chwiler) and then spot flows in Ffynnon Asaph spring and again with the Afon Glanffyddion at Trelawynd and at Dyserth, annual average flows have been calculated for the spring and the two river locations. This work suggests that the spring's discharge dominates flows in the Afon Glanffyddion at Dyserth. Using the same effective rainfall as for the adjacent River Wheeler (Afon Chwiler) catchment also suggests that the currently delineated SPZ for the Ffynnon Asaph is conservatively too large by about 30%.

Pre-existing information on groundwater levels and flows in the Clwyd Limestone is limited. There are no NRW monitoring boreholes in the area. A new groundwater level dataset has been collated based on water levels reported in the BGS borehole database and locations (and derived elevations) of springs and "issues" shown on Ordnance Survey maps. Although there are uncertainties such as seasonal water level variation and hydraulic connection between strata, this dataset and associated contours suggest there is a groundwater divide about 800 m to the south of the Pen y Glol site with groundwater moving NE – NNE towards the Dee Estuary to the north of that divide or moving south-westwards to discharge mainly in the Ffynnon Asaph spring. Assuming that groundwater divide is correct, it removes circa 3.33 km^2 (~15%) from the currently delineated 22.1 km^2 Ffynnon Asaph SPZ and is plausible given the SPZ appears about 30% too large based on a water balance.

A recharge and area based estimate of groundwater flow in the vicinity of Pen y Glol is 2320 to 2720 m^3/year per 10 m cross flow width.

There are no hydraulic property data for the limestone in this area. A transmissivity of 43 to 50 m^2/day has been back calculated using the recharge and groundwater catchment based groundwater flows and the hydraulic gradient derived from contoured groundwater levels. These transmissivities are moderate to moderately high when compared to data for the limestone from other parts of England and Wales. Similarly, a derived average hydraulic conductivity of 0.14 to 0.25 m/day is consistent with limited published data for the limestone.

There are no licensed abstractions to the NE - NNE, downgradient, of Pen y Glol although there are licensed abstractions 3.28 km NNNE (process water) and 4.6 km ENE (spray irrigation). There is however a registered private water supply well 2.4 km NNE used for drinking water and food production. This abstracts from the Gwespyr Sandstone Formation which is separated from the underlying limestone by the lower permeability Bowland Shale, Pentre Chert and Teila Formations.

PYG Ltd.'s 'domestic' foul drainage is collected via site sewers and taken to one of five septic (22 m^3) tanks. The treated foul drainage is then pumped, together with grey water from the site laundry and foul drainage from the site office and three other units, to receive final treatment at a sixth septic tank (No.1). Discharge from this sixth septic tank is then discharged to ground in an area of ash woodland via three drainage runs comprising 4 inch (~102 mm) perforated pipes set in 20 mm size limestone pebble gravel filled infiltration trenches. PYG Ltd note that the total length of the drainage trenches is circa 200 m (50 m + 3 x 50 m) and are ~1 m deep and 0.8-0.9 m wide (so covering an area of up to 180 m^2). PYG Ltd indicate a maximum flow rate of 13 m^3/day, but 15 m^3/day is assumed for the purpose of this risk assessment. The system has been designed to deal with the variable occupancy of the site; i.e., biological treatment is less effective if incoming flows are lower than their treatment capacity. The site has been a static caravan site since 1971 and has been effectively its current size since at least 2008. The discharge of the foul drainage to ground has been occurring since 1971.

There are no nearby sewage treatment works or sewers; the nearest sewage pumping station is circa 1.8 km NNW. The catchment to the Afon Glanffyddion has a sewage treatment works discharge (permitted dry weather flow of 207 m^3/day) to the river at Trelawynd, but there are no other consented discharges to surface water in that catchment. There are however 29 consented discharges to ground of treated sewage (including two also with trade effluent) with a total consented discharge of 61.6 m^3/day. There are five discharges within 1 km of the Pen y Glol site; the largest of which is circa 800 m NNE, downgradient, and consented for 5 m^3/day.

There are very few local water quality monitoring points. The Tre Eden mine adit discharge circa 2850 m east could plausibly collect groundwater from the limestone if the mine network reaches that area. Two streams are also monitored; one ~2.5 km EENE and a second ~3.5 km NNNE. A review of data provided by NRW and by Welsh Water (for Ffynnon Asaph) has been undertaken. There is no clear evidence of impact on surface water or groundwater from the current Pen y Glol discharge, although the higher electrical conductivity and nitrate in the Tre Eden mine adit groundwater could plausibly be linked to nitrate from several septic tank discharges in the area as well as from agriculture. Low ammoniacal nitrogen, orthophosphate and total phosphate in the Tre Eden mine adit discharge indicates that if septic tank discharges are a cause of higher nitrate, then there is attenuation of ammoniacal nitrogen and phosphate.

The above understanding of the site setting now feeds into the risk assessment in Section 3.

3. Risk Assessment

3.1 Purpose of this Section

Having detailed the setting of the site in Section 2, this section evaluates the risks from the discharge to groundwater and water receptors.

3.2 Approach

NRW have requested that the groundwater risk assessment is prepared with reference to guidance published on the Defra website[18] entitled "*Infiltration systems: groundwater risk assessments*".

3.3 Conceptual Model

The conceptual model for the risk assessment is relatively simple:

- The source is the discharge of up to 15 m^3/day of domestic sewage effluent to ground via an infiltration system;
- The pathway is through the drainage field filter materials and underlying fractured limestone unsaturated zone and then towards the NNE in the fractured and potentially karstic limestone. There is an onward pathway via discharge through the lower permeability Teila, Pentre Chert and Bowland Shale Formations and into the Gwespyr Sandstone or via springs into streams, but groundwater in the downgradient limestone does not receive that protection;
- Receptors are downgradient wells, springs or streams.

3.4 Risk Screening

3.4.1 Unlikely to be within SPZ1 (or SPZ3)

Although the Pen y Glol discharge site is just within the currently delineated boundary of the Ffynnon Asaph spring supply SPZ1 (=SPZ3), Section 2 has shown that on a water balance basis that SPZ is circa 30% too large (see Section 2.3.6). A review of groundwater levels in the area has also shown that the Pen y Glol site sits about 800 m north of a groundwater divide, such that water to the north of that divide flows NE-NNE towards the Dee estuary and groundwater to the southwest of it flows towards the Ffynnon Asaph spring. Removal of the land to the north of that groundwater divide would reduce the current SPZ1 by 15% and so is conservatively only half the ~30% suggested by water balance.

3.4.2 Thick (>40 m) Unsaturated Zone

Ground levels in the vicinity of the discharge are circa 213.5±2.0 m AOD (Section 2.2.4) and groundwater level contours in that area are circa 165-170 m AOD (Section 2.6.2). This suggests an unsaturated zone thickness of 41.5 to 50.5 m; comprising gently (4°) northerly dipping limestones of the Carboniferous Loggerhead Limestone Formation (Section 2.4.3). There is no protective layer of superficial deposits.

Migration through the unsaturated zone limestone is likely to be via fractures. There are no mapped sinkholes in this area, and being at a high topographic level, close to a watershed, significant karstic features and flow seem less likely although cannot be ruled out based on available data.

[18] https://www.gov.uk/guidance/infiltration-systems-groundwater-risk-assessments

3.4.3 Distant (>2 km) Receptors

The nearest and likely most sensitive water receptor is a registered private water supply used for drinking water and food production located circa 2400 m NE of the Pen y Glol discharge location. It abstracts from a well located on the BGS mapped Gwespyr Sandstone Formation and is reported by Flintshire CC to be used for drinking and food production, to have good water quality but uses pre-filers and UV to protect the drinking water quality. The Gwespyr Sandstone is separated from the underlying limestone by the lower permeability Bowland Shale, Pentre Chert and Teila Formations.

This receptor is distant, is hydrogeologically protected by a) e.g., the Bowland Shale Formation and then b) non-karstic flow in the Gwespyr Sandstone. It also has reported good quality despite Pen y Glol's discharge being on-going since 1971 and in its current rate and layout since at least 2008. There is also a permitted discharge of 5 m^3/day sewage effluent to ground circa 800 m closer to it than Pen y Glol (Section 2.3.8).

3.4.4 No Clear Evidence of Water Quality Impact

Available groundwater and surface water quality data do not show clear evidence of impact from treated sewage effluent discharges. Groundwater discharging from the Tre Eden mine adit, possibly an outflow for groundwater from Pen y Glol, shows higher nitrate but low ammoniacal nitrogen and phosphates (implying attenuation).

3.4.5 Drainage Field Suitability

For the protection of groundwater, the Defra guidance's most important requirements are that the discharge to a drainage field should not take place on land:

- within 10m of the nearest watercourse;
- within 50m of a well, spring, borehole or other source of water intended for human consumption;
- that's steeply sloping or waterlogged;
- where there's less than 1.2m depth to water table below the invert of the drainage pipes;
- where percolation rates fall outside an upper and lower range of values;

Except for the last one on percolation rates, not yet reviewed, information in Section 2 has confirmed that all other conditions are met.

3.4.6 Risk Screening Outcome

In terms of risk screening, the current up to 13 m^3/day Pen y Glol discharge is therefore a discharge of <15 m^3/day of domestic sewage effluent via two stages of septic tank treatment and a constructed infiltration system (albeit not British Standard) to ground in an area of ash woodland. There is a very thick unsaturated zone, although flow through it is likely to be via fractures. It appears unlikely that the site is within a source protection zone and the nearest and most sensitive receptor is circa 2.4 km to the NE, protected by lower permeability and non-karst flow strata and reporting good water quality despite Pen y Glol discharging since 1971.

As the discharge is not via a British Standard (BS6297:2007(+A1:2008) drainage field or mound and there is potential for some rapid flow in the saturated limestone aquifer, the risk cannot be judged low. But being unlikely within a SPZ and distant from sensitive, but protected receptors, then equally the risk cannot be judged very high.

As a result of this risk screening further quantitative risk assessment is provided.

3.5 Quantitative Risk Assessment

3.5.1 Infiltration Rates

Guidance

The Defra guidance notes septic tank effluent discharges to ground should have:

- percolation rates (Vp) of between 15 and 100 secs/mm;
- a drainage floor area calculated as the product of:
  - the equivalent number of people (p = discharge rate [q] divided by 0.15 m^3/day);
  - the percolation rate (Vp);
  - a factor of 0.25;
  - (and so, equating to [q/0.15] x Vp x 0.25)
- The drainage floor should be spread over a drainage field in trenches between 0.3 m and 0.9 m wide. The guidance gives an example that if the drainage floor area is calculated to be 60 m^2 and the trench width is 0.9 m then the linear trench length is (60/0.9=) 66 m^2.
- The Defra guidance notes the drainage field area can be reduced by 20% for package treatment plants.

Current discharge infiltration rates

With PYG Ltd noting a discharge of 13 m^3/day (assumed ≤15 m^3/day) to drainage trenches totalling 200 m length and 0.8-0.9 m width (a drainage floor area of 160-180 m^2), the current average infiltration rate is (15 m^3/day /[160 to 180 m^2] =) 0.083 to 0.094 m/day.

The current drainage floor area (A) of 160 to 180 m^2 and discharge rate of up to 15 m^3/day (q) back-calculates into a percolation value (Vp = A/[0.25 x q/0.15]=) of 6.4 to 7.2 secs/mm. This is below the minimum required percolation rate value of 15 sec/mm, which would require a minimum floor area of ([15/0.15] x 15 x 0.25 =) 375 m^2 rather than the current 160-180 m^2 (42 to 48% of the minimum required area for a new drainage field).

Site percolation tests

PYG Ltd have provided information on percolation tests carried out since 2012:

- Site soils (2012) - the time to drain 150 mm of water from a 300 mm x 300 mm hole in the site soils at five test sites repeated averaged at 4804.3 secs (~80 mins) equivalent to an average Vp of (4804.3/150 =) **32.03 secs/mm**. The shortest time was circa 120 secs at one of the five sites giving a Vp of **0.8 secs/mm** but otherwise the times were between 2700 and 7140 secs giving Vps of 18 to 47.6 secs/mm – and so within the 15 to 100 secs/mm range;

- Subsoil / strata at 1 m and 1.8 m depth (2019) – a report by Waterco (2019) for PYG Ltd describes results of infiltration tests in line with BRE Digest 365 specification in four trial pits constructed by PYG Ltd; 3 of circa 1 m (0.94 to 1.02 m) depth and a fourth to 1.73 m. The pits were backfilled with a stone fill with 40% voids. The tests were undertaken by Waterco on 22 November 2019. The Waterco report notes that the infiltration tests conclude that the site is well drained. Infiltration rates varied between 1.455 x 10^{-5} m/s (1.26 m/day) and 3.03 x 10^{-4} m/s (26.18 m/day). Percolation values (Vps) are not reported, but have been calculated[19] here to be equivalent to between 3.3 to 68.7 sec/mm;

[19] This uses the infiltration rate to work out how many seconds it would take to drain 150 mm of water. E.g., if infiltration rate is 3.03 x 10^{-4} m/s then time to drain 0.15m (150 mm) is (0.15/3.03 x 10^{-4}=) 495 seconds, so Vp = (495 secs/150 mm=) 3.30.

- Site tracks (2020) – sites on the fire track, RH track and Ash copse track were tested on 20th and 27th April and on 1st May yielding average times of 125.3 secs, 138.23 secs and 155.5 secs respectively – giving Vps of 0.84 to 1.04 secs/mm.

These tests show the variability in percolation rates between site soils and underlying subsoil or track materials. The site track tests suggest that the underlying subsoils and strata have more than sufficient percolation capacity to prevent surface breakout.

3.5.2 Effluent Quality

Defra's guidance classifies domestic sewage effluent as effluent arising from the following activities:

- toilets;
- swimming pool waste;
- personal washing, showering and bathing;
- cooking at home for family and friends;
- household washing of clothes and bedding using domestic soaps and detergents;
- washing dishes and cooking equipment after using them on the premises;
- commercial cooking – for sale directly to consumers who will eat either off or on your premises (like a restaurant, pub, fast food outlet or sandwich bar);
- washing clothes or linen from activities or residents at a commercial site (like a camp site launderette).

The Pen y Glol site's activities of residential static caravans and a site laundry therefore will lead to what is classified as domestic sewage effluent.

The previously published H1-Annex J4 guidance (Environment Agency, 2011) provides indicative / assumed domestic sewage effluent quality as reproduced in Table 3.1.

Table 3.1 Domestic Sewage Effluent Quality (after Environment Agency, 2011)

Contaminant[1]	Units	Sewage	Septic Tank Discharge	Package Treatment Plant
BOD_{5ATU}	mg/l O_2	~380	368	55
COD	mg/l O_2		677	210
Ammoniacal N[2]	mg/l	~39	81	69
Chloride	mg/l		68.6	88.1
Phosphorus	mg/l		15.8	10.5

1. Not all pollutants I the Environment Agency (2011) report reproduced here;
2. In the guidance these are reported as mg/l NH_4^+ but have been converted here into mg/l N by multiplying by 14/18. The guidance also notes ammoniacal nitrogen may be transformed to nitrate nitrogen in the drainage blanket and/or unsaturated zone and the assessment may need to consider the impact of nitrate on groundwater quality. In theory 50 mg/l N of ammoniacal nitrogen could be converted to 50 mg/l N of nitrate if there were no losses of nitrogen.

There is currently no effluent quality data for the site to check on the efficiency of the current two stage septic tank treatment system.

3.5.3 Effluent Loading to Ground

If it is assumed that the combination of the current:

- two stage septic tank treatment system;
- 42 to 48% of required drainage field area for a new drainage field;
- a 40 to 50 m thick limestone unsaturated zone;

successfully leads to oxidation of all ammoniacal nitrogen and attenuation of phosphate (as nutrient uptake to trees or sorption in the limestone) then the main impact on groundwater to check is from nitrate loading.

Assuming a discharge rate of up to 15 m^3/day and a septic tank ammoniacal nitrogen of 81 mg/l N (as per Table 3.1) converted to 81 mg/l N nitrate then the nitrate loading is (15 x 81=) 1.215 kg N/day. If this carried on throughout the year then that equates to 444 kg N/year. These calculations exclude any take up of nitrogen by the ash tree woodland.

For a whole site area of 27,650 m^2 (Section 2.2.1), 444 kg N/year equates to an equivalent loading of 16060 kg N/km^2/year.

The Pen y Glol discharge likely nitrate loading of 444 kg N/year compares to:

- Leached nitrogen loads of 2000-3000 kg/km^2/year from agriculture / farming for this part of North Wales based on a visual estimate from NEAPN maps for 2014 (Defra, 2016);
- Average nitrogen loads exported through the Ffynnon Asaph spring discharge of ~33 836 kg N/year[20]; i.e., the Pen y Glol nitrogen load would be 1.3% of the Ffynnon Asaph discharge load if the Pen y Glol discharge was in the Ffynnon Asaph catchment.
- Average nitrogen loads exported through the Tre Eden mine adit discharge to the Nant y Bi of 11 616 kg N/year[21], i.e., the Pen y Glol nitrogen load would be 3.8% of the Tre Eden mine adit discharge load if the Pen y Glol discharge was in the adit's catchment.

From Table 3.1 reported ammoniacal nitrogen concentrations from package treatment plants are (69/81=) ~85% of those from septic tanks. Although it is unclear of the treatment effectiveness of the two stage septic tank system at Pen y Glol, this comparison suggests it may be possible to reduce nitrogen loads to 85% of those assumed if a package treatment plant could work effectively at the site.

3.5.4 Unsaturated Zone Travel Times

The time (t_{UZ}) to reach the water table beneath the current discharge trenches has been calculated assuming:

- Infiltration rates (I) between the trenches of 0.083 to 0.094 m/day (Section 3.5.1);
- A minimum depth (z) to water table of 40 m (Section 3.4.2);
- A fracture porosity (n) in the limestone of 1% (Section 2.6.4);

The time is calculated as (t_{UZ} = z x n/I =) 4.3 to 4.8 days. Whilst being short this does allow some time for oxidation of any ammoniacal nitrogen not oxidised in the drainage field.

3.5.5 Dilution

Based on a water balance approach, Section 2.6.5 estimates that groundwater flows near Pen y Glol are circa 2320 to 2720 m^3/year per 10 m cross-flow width (approximately E-W).

PYG Ltd report that the 50 m long drainage trenches are orientated 30° either side of south from an initial 50 m drainage trench flowing north to south. Using trigonometry, the southernmost ends of the outer drainage trenches are (50 x sine(30°)=) 25 m either side of the north-south line. So, the three drainage trenches spread east-westwards by 50 m.

[20] Calculated from the mean estimated flow of 0.156 m^3/s (see Table 2.2) and the mean nitrate concentration of 6.873 mg/l N (see Table 2.8) with adjustment for units.

[21] Calculated from the mean estimated flow of 0.045 m^3/s for the Nant y Bi (see Table 2.2) and the mean nitrate concentration of 8.18 mg/l N (see Table 2.8) with adjustment for units.

The groundwater flowing beneath the Pen y Glol discharge field is therefore calculated as (50 m x 2320 to 2720 m^3/year per 10 m cross-flow width =) 11600 to 13600 m^3/year.

With a discharge rate of up to 15 m^3/day (5479 m^3/year), then the dilution factor multiple is calculated as (5479 / (5479 + [11600 to 13600] =) 0.29 to 0.32 (unitless).

With this dilution factor range, nitrate concentrations in the discharge of 81 mg/l N (Section 3.5.3) would lead to an increase in nitrate concentration downgradient of the discharge of (81 x [0.29 to 0.32]=) 23.5 to 25.9 mg/l N. This compares to a drinking water standard of 11.3 mg/l N and so there is potential for an impact on downgradient groundwater use without further dilution, dispersion and attenuation.

The maximum cross-flow width of the Pen y Glol site is circa 200 m which could produce diluting flows of 46 400 to 54 400 m^3/year and dilution factor multiples of (5479 / (5479 + [46400 to 54400] =) 0.09 to 0.11 (unitless). This in turn would lead to downgradient nitrate concentration increases of (81 x [0.09 to 0.11]=) 7.3 to 8.9 mg/l N. To remain below the drinking water standard would require background groundwater to have <2.4 mg/l N.

Land between the Pen y Glol discharge and the groundwater divide to the south is shown on Google Earth aerial photo images as managed grassland (possible sheep grazing) and woodland. So, a background groundwater concentration of <2.4 mg/l N is not implausible but is optimistic.

From Section 3.5.3, it may be possible to reduce nitrogen loading to ground / groundwater to 85% of that assumed by installing a package treatment plant. If that was the case, then rather than the increases in downgradient nitrate concentration being calculated as 7.3 to 8.9 mg/l N, at 85% of these, the nitrate concentration increase would be 6.2 to 7.6 mg/l N.

3.5.6 Attenuation

PYG Ltd note that the ash trees in the area of the discharge to ground grow quickly potentially suggesting some uptake of water and nutrients (including nitrogen) from the discharge area.

Attenuation of any contaminants reaching the limestone is likely to include:

- Fixation / sorption of any trace metals due to the high pH and carbonate content of the limestone;
- Sorption of phosphates through calcium phosphate low solubility controls or possibly sorption into more iron-stained fracture surfaces;
- Oxidation of ammoniacal nitrogen and organic carbon[22].

But given the fractured and perhaps in places karst nature of the limestone aquifer, attenuation in the saturated zone such as denitrification has not been considered.

3.5.7 Use of the J5 Infiltration Worksheet

The J5 Infiltration worksheet has not been used to model the impact of the discharge on groundwater given uncertainties in some of the parameters (e.g., hydraulic conductivity) required. Instead, the above quantitative calculations are assumed to be adequate to scope out the potential impact on groundwater from the discharge and from that make recommendations on how risks could be further reduced.

[22] If all the ammoniacal nitrogen is oxidised in the drainage system or shallow unsaturated zone before oxidation of all the organic carbon, then there is potential for denitrification in the unsaturated zone.

3.6 Risk Assessment Summary

Based on the detailed evaluation of the site setting in Section 2, risks to groundwater and water based receptors have been evaluated.

In terms of risk screening, the current up to 13 m^3/day Pen y Glol discharge is therefore a discharge of <15 m^3/day of domestic sewage effluent via two stages of septic tank treatment and a constructed infiltration system (albeit not British Standard) to ground in an area of ash woodland. There is a very thick unsaturated zone, although flow through it is likely to be via fractures. It appears unlikely that the site is within a source protection zone and the nearest and most sensitive receptor is circa 2.4 km away, protected by lower permeability and non-karst flow strata and reporting good water quality despite Pen y Glol discharging since 1971.

As the discharge is not via a British Standard (BS6297:2007(+A1:2008) drainage field or mound and there is potential for some rapid flow in the saturated limestone aquifer, the risk cannot be judged low. But being unlikely within a SPZ and distant from sensitive, but protected receptors, then equally the risk cannot be judged very high. Further quantitative risk assessment is therefore provided.

Infiltration rates are calculated to be higher than guidance requirements allow and the drainage field floor area is about 42 to 48% of the minimum required area for a new British Standard drainage field.

With a likely >40 m thick unsaturated zone thickness, albeit with travel times of 4 to 5 days, nitrate loading is likely to be the main concern. Assuming published data for septic tank effluent quality, nitrate loading is calculated as 444 kg N/year. This equates to 1.3% of the Ffynnon Asaph spring discharge's nitrate load and 3.8% of the nitrate load discharged from the Tre Eden adit. Although it is unclear on the effectiveness of the two-stage septic tank system, a package treatment plant may be able to reduce this loading to 85% of that assumed.

Dilution of the nitrate load with the current drainage field is calculated to increase nitrate concentrations in downgradient groundwater by 23.5 to 25.9 mg/l N compared to a drinking water standard of 11.3 mg/l N. So, there is a potential deleterious impact downgradient unless the discharge quality is lower than assumed or there is nitrate uptake in the ash woodland.

Increasing the cross-flow width of the drainage field to the full extent of the site would potentially reduce the increase in nitrate in downgradient groundwater to 7.3 to 8.9 mg/l N. There is a potential to decrease this to between an increase of 6.2 to 7.6 mg/l N if a package treatment plant could be installed and used effectively.

Although attenuation of many contaminants in the >40 m thick unsaturated limestone is plausible / likely, attenuation in the saturated zone where flow will be via fractures and possibly by karst features, is less likely. The downgradient lower permeability Bowland Shale, Pentre Chert and Teila Formations and the non-karstic flow Dwespyr Sandstone will provide more attenuation than the limestone, but this has not been enumerated.

Overall, whilst the risks to groundwater are not high due to the current two stage septic tank and drainage field discharge, thick unsaturated zone and distance to receptors, measures should be taken to reduce risks to groundwater downgradient in the limestone.

4. System Improvement Recommendations

4.1 Purpose of this Section

Based on the details of the site area in Section 2 and risk assessment in Section 3, this report makes recommendations for investigations on the current treatment efficiency and for improvements in the drainage system.

4.2 Treatment System

4.2.1 Treatment System Quality Assumption

The risk assessment has assumed that the Pen y Glol site's final treated effluent quality is as set out in Table 3.1 for septic tanks. For ease of reference Table 3.1 is repeated below as Table 4.1.

Table 4.1 Domestic Sewage Effluent Quality (after Environment Agency, 2011) (repeat)

Contaminant[1]	Units	Sewage	Septic Tank Discharge	Package Treatment Plant
BOD_{5ATU}	mg/l O_2	~380	368	55
COD	mg/l O_2		677	210
Ammoniacal N[2]	mg/l	~39	81	69
Chloride	mg/l		68.6	88.1
Phosphorus	mg/l		15.8	10.5

1. Not all pollutants I the Environment Agency (2011) report reproduced here;
2. In the guidance these are reported as mg/l NH_4^+ but have been converted here into mg/l N by multiplying by 14/18. The guidance also notes ammoniacal nitrogen may be transformed to nitrate nitrogen in the drainage blanket and/or unsaturated zone and the assessment may need to consider the impact of nitrate on groundwater quality. In theory 50 mg/l N of ammoniacal nitrogen could be converted to 50 mg/l N of nitrate if there were no losses of nitrogen.

It has been assumed that a combination of the current albeit undersized drainage field (see Section 3.5.1) and the likely thick (>40 m) unsaturated zone (see Section 3.4.2) will lead to oxidation of the organic matter (BOD and COD) and ammoniacal nitrogen and attenuation of phosphates through sorption. There is no evidence of these in downgradient NRW groundwater or surface water quality monitoring points.

Oxidation of ammoniacal nitrogen will produced nitrate in the groundwater of the limestone and unless there is some uptake of nitrogen by the ash tree woodland, or denitrification in the unsaturated zone, that nitrate could impact downgradient receptors if it is not sufficiently diluted. The risk assessment has assumed that Table 4.1's septic tank quality of 81 mg/l N ammoniacal nitrogen will become 81 mg/l N nitrate prior to any dilution. The Table 4.1 published information suggests a package treatment plant would reduce the amount of ammoniacal nitrogen, and so nitrate nitrogen, to 85% of that assumed for septic tanks. But it is unclear what effluent quality the current two-stage septic tank system produces.

To minimise the impact on groundwater, requires designing a system to maximise dilution in groundwater and then optimising treatment. Optimising treatment needs to keep in mind energy use for climate change concerns, and so active treatment should not be excessive.

4.2.2 Recommendation - Current Treated Quality Sampling

The treatment efficiency of the current two-stage septic tank system is not known; there are no final effluent quality data. Rather than assuming it is inadequate, it would be prudent to collect samples of the final effluent under a range of site occupancy and seasons as these will affect loading to the system and background temperature (which affects treatment efficiency).

The following minimum final effluent sampling schedule is recommended:

- Four samples during August 2021 during likely peak occupancy and warm temperatures;
- Four samples during October 2021 during likely moderate occupancy and moderate temperatures;
- Four samples between mid-January and mid-February 2022 during likely low occupancy and low temperatures;

The following parameters should be recorded / monitored during each sampling event for the final effluent;

- Occupancy for the week prior to sampling;
- Flow from the final effluent tank;
- Effluent temperature (required during sampling using a field thermometer);
- pH (ideally during sampling using a field pH meter, but also in the laboratory);
- Electrical conductivity (as a general measure of dissolved effluent strength / dilution);
- Total suspended solids (as a general measure of undissolved solids);
- Total organic carbon;
- BOD (5ATU), unfiltered (as a measure of easily degradable organic matter);
- COD, unfiltered (as a measure of total degradable organic matter);
- Ammoniacal nitrogen;
- Total oxidised nitrogen;
- Total nitrogen (inorganic and organic);
- Total phosphorus (unfiltered);
- Photograph of the effluent in a clear sample bottle (as a record of colour and clarity).

Samples should be collected and despatched to an accredited laboratory using instructions from that laboratory on sample bottle type, use of any preservatives and timescales between sampling and analysis.

The above list of determinands should be discussed with the process engineer(s) that are engaged to review the adequacy of the current treatment system (see below) and who may need to design an improved system.

The above sample data as a minimum should be reviewed against the assumed effluent quality in Table 4.1 to see if that quality is better or worse than that assumed in this report for septic tanks. It is likely that effluent quality will vary seasonally.

4.2.3 Recommendation – Process Engineer Engagement

To help optimise sewage treatment on site, a process engineer should be engaged to:

- Review the above sampling schedule to make sure it meets their data requirements to evaluate options for optimising treatment efficiency;
- Evaluate the treatment efficiency of the current two-stage septic tank system and given likely seasonal variability in site occupancy make recommendations and outline designs and costings for options to improve effluent quality. These could include e.g.:
    - Installing a single package treatment plant to replace all existing septic tanks and deal with the full variability of seasonal flows (including options for on-site temporary storage or collection and tankering during periods of peak occupancy);

  - ➢ Installation of more than one smaller package treatment plants to deal with the seasonal variable flows;
  - ➢ Installation of a denitrification step;
  - ➢ Installation of additional effluent polishing (e.g., reedbed system[23]) if land areas and slopes are suitable.
- Provide a summary review on which treatment options are likely to be most feasible and effective together with the likely output effluent quality. That output effluent quality should be compared with the published data for septic tanks and package treatment plants in Table 4.1. The options appraisal should include a simple cost-benefit for changes in BOD, ammoniacal nitrogen and total nitrogen together with comments on energy use and ease of operation and maintenance.

4.3 Drainage System

4.3.1 Existing Drainage System Assumption

Section 3.5.1 has calculated the current drainage floor area (A) is 160 to 180 m^2 and that, with a discharge rate of up to 15 m^3/day, percolation values back calculate to 6.4 to 7.2 secs/mm. This is below the British Standard minimum required percolation rate value of 15 sec/mm, which would require a minimum floor area of ([15/0.15] x 15 x 0.25 =) 375 m^2.

So, to meet the British Standard the drainage floor area needs increasing to a minimum of 375 m^2 if an engineered system can create minimum percolation rates values of 15 sec/mm.

In addition, Section 3.5.5 has noted that the existing drainage system provides a cross-groundwater flow width (NW-SE orientation) of circa 50 m and that this provides insufficient dilution to ensure nitrate concentrations in downgradient groundwater do not exceed the drinking water standard. Section 3.5.5 notes that the maximum cross flow (NW-SE) site width is likely to be circa 200 m meaning dilution could be increased by about four times.

The depth to water table is estimated to be >40 m. Any shallow water encountered is likely to be subsoil temporary perching on top of locally unfractured limestone related to prior prolonged periods of significant rainfall.

4.3.2 Recommendation – Drainage Engineer Engagement

It is recommended that a drainage engineer is engaged to provide final effluent drainage options that will:

- Meet the British Standard and NRW requirements in information requirements (including e.g. logs of trial holes and percolation test results), dimensions (including floor area) and materials for a discharge of up to 15 m^3/day. This would only need to be a drainage mound if an existing subsoil or engineered subsoil drainage field was not feasible;
- Create the maximum practicable cross groundwater flow width (width on an approximate NW-SE orientation) between the furthest apart ends and created to spread effluent evenly across this width in proportion to flow rate (i.e., maximum width when discharging at 15 m^3/day). Options should be considered for a gravity fed system and a pumped system where land gradients are overly restricting.
- Consider the longevity of the system and make recommendations for its maintenance including preventing damage from tree roots.

[23] Consideration could also be given to use of wet-woodland for nutrient uptake. However, tree root depths and damage may make this unworkable within an engineered system and any uptake by trees may therefore need to be seen as unintentional rather than part of a permitted system.

4.4 Combined System Review

The outcomes of the treatment system and drainage system review / options appraisals should be brought together to show combined:

- options for treatment improvement (versus the assumed septic tank quality in Table 4.1); and
- options for dilution of effluent through a British Standard drainage field of available width (NW-SE) compared to a desk-based optimum of 200 m.

These two aspects are inter-linked. For example, if a circa 200 m wide (NW-SE) drainage system is not practicable, then in place of the lost dilution it may be necessary to install a denitrification step into the treatment system. A system with a final effluent of that shown for a package treatment plant in Table 4.1 combined with a circa 200 m (NW-SE) wide drainage system is calculated to increase nitrate concentrations in downgradient groundwater by 6.2 to 7.6 mg/l N (see Section 3.5.5). NRW would need to confirm if that was acceptable.

This combined system review can then be discussed with NRW together with the findings of this risk assessment (and perhaps an addendum note for this report evaluating the revised impact on groundwater) to agree a final design of treatment system and drainage field that would then be permitted (if acceptable to NRW) and constructed.

5. References

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Appendix A
Collated Groundwater Level Data for Contouring

3 Pages

Table A.1 Collated Groundwater Level Data for Contouring (Page 1 of 3)

BGS Ref	Short BGS Ref (as on Fig 2.14)	Name	Easting	Northing	Drilled	Ground Level (m AOD)	Depth (m bgl)	Groundwater Level (m bgl)	Groundwater Level (m AOD)	Type for Fig 2.14 Legend
SJ17NW43	NW43	A55 Travellers Inn Improvement BH02	310730	375760	18/01/1983	169.84	5	-0.05	169.89	SI BH
SJ17NW48	NW48	A55 Travellers Inn Improvement BH17	310070	375910	17/02/1983	175.71	18.5	1.8	173.91	SI BH
SJ17NW94	NW94	Bryn Hedydd	310912	376780		182.5	6.096	4	178.5	ABH
SJ17NE209	NE209	A55 Holywell Bypass 309	315250	376100	01/11/1979	195.91	12.75	8	187.91	SI BH
SJ17NE283	NE283	Gosedd Farm, the Wacco	315200	376100		197	6.096		193.904	ABH
SJ17NW86	NW86	A55 Holywell Bypass TP208	313220	376880	17/10/1979	180.75		2.9	177.85	SI TP
SJ07NE149	NE149	Gop Farm Trelawnyd BH1	308360	379950	12/01/2011	170	105.15	18.288	151.712	SI BH
SJ07NE160	NE160	Fron Deg BH2	309740	379640	18/01/2021	180	65	8	172	SI BH
SJ17NW70	NW70	A55 Holywell Bypass 209	312890	375940	10/12/1979	190.14	24	11.1	179.04	SI BH
SJ17NW89	NW89	A55 Holywell Bypass 301	314880	376100	06/11/1979	204.97	10.7	8	196.97	SI BH
SJ17NW59	NW59	A55 Travellers Inn Improvement TP12	312290	375850	20/01/1983	174.84	2	1.5	173.34	SI TP
SJ17NW54	NW54	A55 Travellers Inn Improvement TP08	311180	375720	20/01/1983	172.54	1.2	1.2	171.34	SI TP
SJ17NW47	NW47	A55 Travellers Inn Improvement TP10	311090	375720	25/01/1983	171.5	2.3	0.9	170.6	SI TP
SJ17NW53	NW53	A55 Travellers Inn Improvement TP07	311020	375720	20/01/1983	170.72	2.1	1	169.72	SI TP
SJ17NW52	NW52	A55 Travellers Inn Improvement TP06	310810	375740	20/01/1983	170.14	2.8	1.7	168.44	SI TP
SJ17NW51	NW51	A55 Travellers Inn Improvement TP05	310470	375810	20/01/1983	175.72	2.1	1.8	173.92	SI TP
SJ17NW46	NW46	A55 Travellers Inn Improvement BH09	310230	375850	20/01/1983	180.71	4	2.8	177.91	SI BH
SJ07NE92	NE92	A55 Travellers Inn Improvement BH14	309740	375990	10/02/1983	186.59	12	3	183.59	SI BH
SJ07NE88	NE88	A55 Travellers Inn Improvement BH08	309660	376000	19/01/1983	188.12	16.25	6.1	182.02	SI BH
SJ07NE86	NE86	A55 Travellers Inn Improvement BH06	309560	376010	19/01/1983	188.99	16.25	2.5	186.49	SI BH
SJ17SE1	SE1	Gledlom Farm	315814	371056	31/12/1925	182.88	76.2	10.668	172.212	SI BH
SJ17SE244	SE244	Gelli Fowler	317700	373400		229	6.096	4	225	SI BH
SJ17SE243	SE243	Easfan nr. Brynford	318000	373800		235	6.096	4	231	SI BH
SJ08SE74	SE74	Kingdom Hall, Prestatyn 1	305635	381659		16	10.2	3.6	12.4	SI BH
SJ07NE135	NE135	Ffynnon Asaph Spring	307520	378930		115.824			115.824	Spring

1. These data form the basis of contours shown on Figure 2.14;
2. Data from BGS borehole database contains British Geological Survey Materials © UKRI 2021.

Table A.1 Collated Groundwater Level Data for Contouring (Page 2 of 3)

BGS Ref	Short BGS Ref (as on Fig 2.14)	Name	Easting	Northing	Drilled	Ground Level (m AOD)	Depth (m bgl)	Groundwater Level (m bgl)	Groundwater Level (m AOD)	Type for Fig 2.14 Legend
		Spring	313869	379097		135			135	Spring
		Spring	308406	378575		149			149	Spring
		Spring	308341	376877		232			232	Spring
		Spring	313386	373261		164			164	Spring
		Spring	315011	377737		119			119	Spring
		Spring	310136	377656		176			176	Spring
		Spring	308407	378581		149.5			149.5	Spring
		Spring	306864	378943		115			115	Spring
		Spring	309361	381038		141			141	Spring
		Spring	307488	377175		223			223	Spring
		Spring	308534	375125		205			205	Spring
		Spring	307621	376304		269			269	Spring
		Spring	315725	375015		189			189	Spring
		Spring	311354	381687		115			115	Spring
		Spring	314099	379957		103			103	Spring
		Spring	316179	378699		79			79	Spring
		Spring which became a well	307107	380091		147			147	Spring
		Well with stream flow from it	311634	375561		175			175	Spring
		Well with stream flow from it	312106	375286		175			175	Spring
		Springs	307084	376982		215			215	Spring
		Llyn Helyg (Spring fed lake)	311400	377240		177			177	Spring
		Issues	313926	378196		150			150	Issues
		Issues	312802	379910		127			127	Issues
		Issues	308199	377073		217			217	Issues
		Issues	308021	377268		205			205	Issues

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Table A.1 Collated Groundwater Level Data for Contouring (Page 3 of 3)

BGS Ref	Short BGS Ref (as on Fig 2.14)	Name	Easting	Northing	Drilled	Ground Level (m AOD)	Depth (m bgl)	Groundwater Level (m bgl)	Groundwater Level (m AOD)	Type for Fig 2.14 Legend
		Issues	309536	377545		156			156	Issues
		Issues	310958	378590		167			167	Issues
		Issues	309417	374649		221			221	Issues
		Issues	309089	375201		214			214	Issues
		Issues	308409	375468		157			157	Issues
		Issues	308094	376117		235			235	Issues
		Issues	306792	377212		151			151	Issues
		Issues	314653	374140		165			165	Issues
		Issues	310589	377454		177			177	Issues
		Issues	316112	374375		205			205	Issues
		Issues	305244	377947		42			42	Issues
		Issues	304426	378889		23			23	Issues
		Issues	313909	378186		152			152	Issues
		Head water of Afon Glanffyddion	312587	376972		177			177	Issues
		Stage on Afon Glanffyddion	309943	376637		175			175	Stage
		Denbighshire LA PrWS No32	308577	375449		182			182	Spring
		Denbighshire LA PrWS No33	307529	376881		262			262	Spring
		Denbighshire LA PrWS No34	306789	376318		110			110	Spring
		Flintshire LA PrWS No2	318505	376261		72			72	Spring
		Flintshire LA PrWS No3	311754	370447		345			345	Spring
		Flintshire LA PrWS No13	313153	370706		215			215	Spring
		Flintshire LA PrWS No14	319878	374649		142			142	Spring
		Flintshire LA PrWS No16	314610	370835		104			104	Spring
		Flintshire LA PrWS No19	319962	376437		57			57	Spring
		Flintshire LA PrWS No20	314522	371784		140			140	Spring
		Flintshire LA PrWS No21	312907	369739		240			240	Spring

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