



# Catchment Overview: River Llynfi 2023 update

*A report prepared on behalf of Wye Salmon Association (WSA)*

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## Executive Summary

## Introduction

In March 2022, the Wye Salmon Association (WSA) produced a report on the Llynfi Catchment (Green, 2022a). This was intended as the first exemplar of a ‘bottom up’ approach to exploiting citizen science (CS) data to help inform water quality improvement actions within this sub catchment, and thereby within the wider Wye SAC. Although there are undoubtedly some common issues affecting the whole Wye Catchment, it is apparent that the various sub catchments each have a unique blend of problems which would be better addressed by tailored local solutions.

This report provides an update on the above work, primarily adding a further fifteen months’ water quality (WQ) data from both WSA and NRW. In addition, we consider the implications of some new scientific literature and comment on the latest [Core Management Plan](#) for the River Wye SAC. Finally, we discuss the emerging problem of anaerobic digester (AD) plants, their generic pollution hazards, and their role in helping intensive poultry operations bypass planning restrictions.

Data cut-off for this report is September-21 through to November-22.

## Literature review

*Water quality benefits from an advice-led approach to reducing water pollution from agriculture in England* (Davey et al., 2020)<sup>1</sup>

Although this paper focusses on data from English rivers, the findings are undoubtedly equally applicable to Wales. The authors perform a sophisticated statistical analysis of WQ data from multiple catchments with a view to determining the efficacy of farm scale mitigation measures (specifically Catchment Sensitive Farming - CSF). They conclude that whilst WQ benefits do emerge over time, they are limited in magnitude.

*“In absolute terms, the scale of water quality improvement resulting from CSF is modest in comparison with current water quality policy goals ... for the agriculture sector, more radical changes are likely to be required, including targeted land use change”.*

*Re-focusing Phosphorus use in the Wye Catchment* (Withers et al., 2022)

In our earlier paper we made reference to preliminary work by RePhOKUs, as presented by Shane Rothwell to the Wye Nutrient Management Board in 2021. This paper is the final report from their analysis of the Wye Catchment, using the latest DEFRA statistics. The results are considerably worse than the preliminary presentation suggested, with the soils of the Wye Catchment accumulating 3000 t yr<sup>-1</sup> of phosphorus (17 kg ha<sup>-1</sup> yr<sup>-1</sup>). Whilst poultry manure is the major component of phosphorus input, it is noted that cattle & sheep are also operating in phosphorus surplus (relevant to the Llynfi), mainly as a result of supplementary feeds.

With regard to mitigation,

*“there is currently no emphasis on the wider system level change that may be required to reduce the annual P input pressure”.*

## Core Management Plan

The revised Core Management Plan for the Wye SAC (NRW, 2022) has now been released. This is a large and complex document, and a full review is beyond the scope of this report. Nevertheless, in brief, the River Wye qualifies as an SAC by virtue of 11 features, spanning otters, salmon, shad, bullheads,

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<sup>1</sup> Although this paper is not new, it was un-known to us at the time of writing our Llynfi Catchment report.

crayfish, aquatic vegetation and bogs. All 11 are in unfavourable condition. Of these features, 7 are relevant to the Llynfi water bodies deemed to fall within the SAC (Lower Llynfi, Dulas & Triffrwd). These are: river & brook lampreys, Atlantic salmon, bullheads, otters, white-clawed crayfish and *Ranunculus fluitantis* & *Callitriche-batrachion* (R&CB) vegetation. Salmon, otters and R&CB vegetation are cited as “key” species or habitats, the rest being “sympathetic”. Under “*Status and management*” for R&CB vegetation, we find the Ithon and Llynfi specifically cited as having problems with regard to water quality – in particular high phosphate levels leading to eutrophic conditions favouring epiphytic algae over flowering plants.

In the table of actions, we find all three Llynfi waterbodies “*need action*”, although the specifics of said action are largely unspecified. We do however note the welcome concern relating to pollution arising from the AD plant at Great Porthamel Farm. Likewise, the statement that “[*The lower Llynfi*] has been identified for monitoring as one of particular concern for diffuse pollution impacts” is to be welcomed. On the other hand, we are puzzled by the statement that “*Talgarth STW has been upgraded ...*”. Having checked with DC-WW, this upgrade occurred in 2015 and the further enhancements proposed under AMP-8 are still to be confirmed. Implementation would be on a 2027 timescale.

In summary then, the Core Management Plan provides a description of the status of the Llynfi sub catchment but actually fails to offer a clear plan to improve it.

## NRW WQ data

### Sampling locations

NRW WQ data for the Llynfi sub catchment, spanning five waterbodies (Triffrwd, Dulas, Ennig, Llynfi source to Dulas and Llynfi Dulas to Wye), has been obtained via FOI request. Regular sampling has been carried out at 11 locations within the sub catchment, as shown in Figure 1 below.



Figure 1: NRW WQ sampling locations within the Llynfi sub catchment; Llynfi catchment boundary is shown with respect to Three Cocks, rather than the Wye confluence.

*Any chance of improving the visibility of the location names?*

In the lower catchment, sampling sites are located at the downstream end of each water body. Four of these (Triffrwd, Dulas, Ennig and Llynfi source to Dulas) correspond closely to WSA sites. In the upper catchment around Llangorse, the Llynfi Bridge and Lake Outlet sites are identical to WSA sites. In addition, there is sampling of the lake, plus three tributaries. The two un-named tributaries are presumably selected because of their high nutrient loads (see below).

### Data analysis

Mean values of the key parameters over the period Sep-21 to Nov-22 are shown in Table 1 below. Only three locations are sampled monthly, the rest being predominantly quarterly. The “No. Samples” column refers to RP and pH data; other parameters are recorded less frequently. Nevertheless, some patterns emerge.

Specific conductivity largely tracks alkalinity, which tends to be highest on streams flowing off the old red sandstone hills on the eastern edge of the catchment (Ennig and Llangorse tributaries). Conversely, the Triffrwd and Dulas flowing from the west, have lower alkalinity. Acidity has limited variability (pH 7.9 – 8.4) but, unsurprisingly, the higher values tend to be associated with higher alkalinity.

Location	No. Samples	SC (uS/cm)	Acidity (pH)	Alkalinity (mg CaCO <sub>3</sub> /l)	RP (mgP/l)	TP (mgP/l)
Llangorse village unnamed trib.	5	433	8.4	189	0.058	
Llangorse Lake	15	317	8.2	140	0.079	0.138
Llynfi u/s Llangorse lake	5	361	8.0	158	0.037	
R Ennig c/w Llynfi	9	337	8.4	149	0.046	
R Llynfi, Llangorse Lake Outlet	4	337	7.8	149	0.173	
R. Dulas at c/w R. Llynfi	9	291	8.1	115	0.035	
R. Llynfi @ Llynfi Br. Llangorse	5	335	7.8	132	0.111	
R. Llynfi above Dulas Brook	5	360	8.2	153	0.095	
R. Llynfi at c/w R. Wye	15	370	8.1	138	0.056	
Triffrwd Brook at A438 Bridge	15	260	8.0	103	0.029	
Unnamed trib. into Llangorse lake 2	5	476	8.3	188	0.076	

Location	Nitrate (mgN/l)	Nitrite (mgN/l)	Unionised NH <sub>3</sub> (mgN/l)	NH <sub>3</sub> -N (mgN/l)
Llangorse village unnamed trib.	3.21	0.004	0.0005	0.018
Llangorse Lake	0.41	0.010		
Llynfi u/s Llangorse lake	1.65	0.007	0.0006	0.040
R Ennig c/w Llynfi	1.61	0.002	0.0003	0.009
R Llynfi, Llangorse Lake Outlet	0.26	0.007		0.151
R. Dulas at c/w R. Llynfi	1.84	0.003	0.0003	0.012
R. Llynfi @ Llynfi Br. Llangorse	0.58	0.012		0.144
R. Llynfi above Dulas Brook	1.68	0.015	0.0005	0.031
R. Llynfi at c/w R. Wye	2.25	0.009	0.0004	0.025
Triffrwd Brook at A438 Bridge	1.76	0.004	0.0001	0.023
Unnamed trib. into Llangorse lake 2	5.46	0.008	0.0007	0.016

Table 1: NRW WQ results, showing mean values over period Sep-21 to Nov-22

Upstream of Llangorse, we see the two unnamed tributaries having much higher RP concentrations than the upper Llynfi (orange highlight). The outlet from the lake has the highest RP concentration in the catchment and the Llynfi remains high down to the Dulas confluence (red highlight). By comparison, the Ennig and Dulas carry 50% less RP concentration (green highlight), and the Triffrwd (blue highlight) is slightly lower still.

The two un-named tributaries to Llangorse are also notable for having high nitrate concentrations (purple highlight). These values are low by comparison to the Garren (~10-12mgN/l) but are higher than the rest of the Llynfi catchment. In our Garren study, we found nitrate concentrations correlating with areas of arable agriculture, so it is unsurprising to find the nitrate signal increasing again in the lower Llynfi (teal highlight).

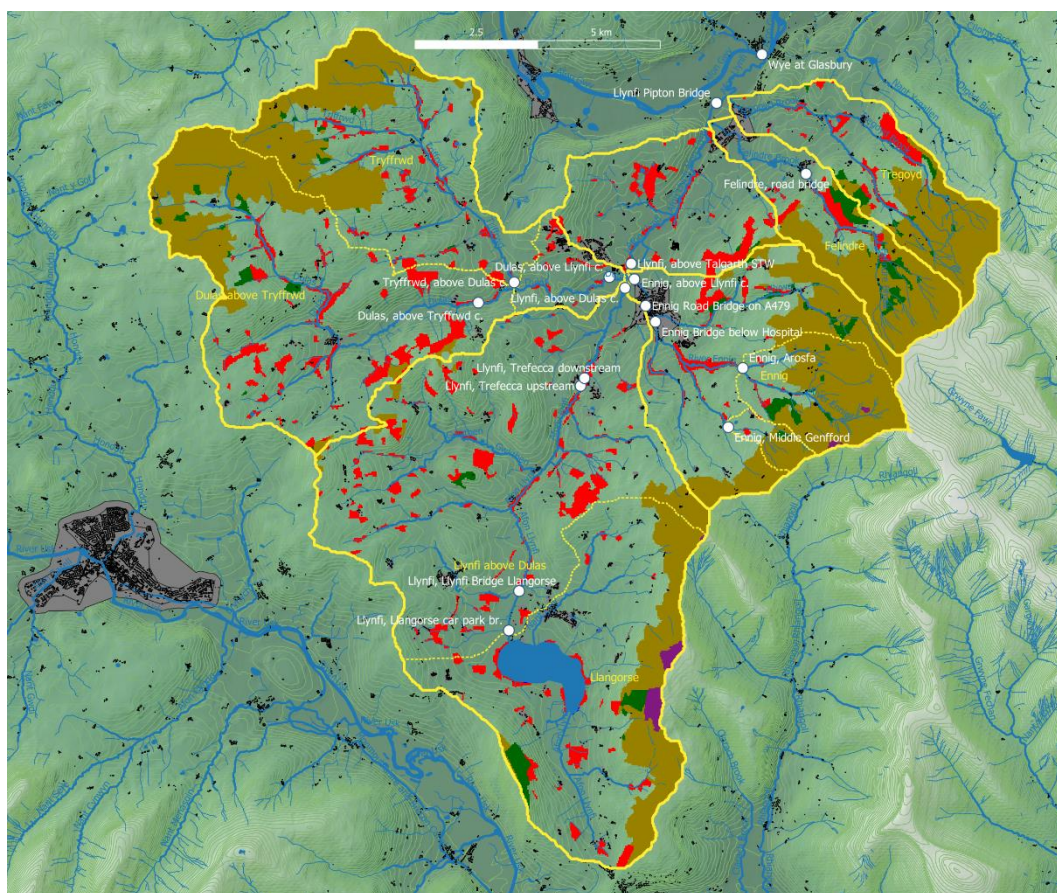
Nitrite is primarily a breakdown product of nitrate (*the other way round. Nitrite oxidises to nitrate. The precursor to nitrite, again by oxidation - the Nitrogen cycle - is ammonia*) and there is no obvious information to be taken from this signal. Unionised ammonia is very low everywhere, however note that these are all single measurements. Ammoniacal nitrogen is highest at the Llangorse Outlet (olive highlight), being substantially lower elsewhere.

Finally, returning to nitrate, note the substantial increase (x2) between the Llangorse Outlet and Llynfi Bridge, 800m downstream (red highlight). However, the number of samples differs at these locations (4 and 5, respectively). If we take the four matched pairs of samples (taken within 30 minutes of each other), we find that nitrate increased from a mean of 0.26 mgN/l at the Lake outlet to 0.48 mgN/l at Llynfi Bridge. Applying the single-sided Student t-test tells us that this increase is significant at the 85% confidence level. It is evident that this signal is driven by just two of the four samples; on the other two days, nitrate concentration was identical at the two locations. This is perhaps suggestive of a time-variant, anthropogenic source.

## WSA citizen Science data

### Sampling locations

WSA CS data from 2020-21, as used in the V1 *Llynfi Catchment Overview* report (Green, 2022b), comprised 116 samples and was largely restricted to PO<sub>4</sub> data from Pipton Bridge, Llynfi Bridge Llangorse and Felindre Brook. A key recommendation of the V1 *Llynfi Catchment Overview* report was therefore for WSA to attempt to expand the geographical spread of CS sampling sites in order to get a better understanding of the full catchment. Figure 2 below shows the 17 locations currently being sampled in and around the Llynfi sub catchment. Also shown (yellow) are the catchment boundaries for the principal tributaries (corresponding to NRW waterbodies), plus catchment areas for some key sampling sites (shown dashed).



**Figure 2:** WSA sampling locations (white), relevant sub catchments (yellow) and unimproved land types (brown is acid grassland; red is broadleaved woodland & dark green is coniferous woodland). Dotted boundaries show sub catchments above our sampling points, where relevant. Solid boundaries relate to the principal tributaries; Ennig, Dulas and Llynfi above Dulas and correspond to NRW waterbodies.

**Again, any chance of improving the visibility of the white words?** Several sampling locations correspond to NRW sites. The two sites below Llangorse are the same, as are sites at the bottom of the Triffwrdd, Dulas, Ennig and Llynfi above the Dulas. Additionally, WSA have two sites in the headwaters of the Ennig, plus two in Talgarth spanning the Ellywe confluence. There is an additional site on the Dulas above the Triffwrdd confluence and two sites on the Llynfi at Trefecca. In the lower river, sites are located immediately upstream of Talgarth STW and at Pipton Bridge below the Felindre confluence (but upstream of NRW's Wye Confluence site). The Felindre is also monitored.

The catchment topography is worthy of comment before proceeding. The watershed along the Black Mountains to the east, peaks at around 710m above sea level. However, the Llynfi itself nestles in the valley bottom and from source to Wye confluence, has a fall of only 95m – 30m of which occurs in the short stretch above Llangorse Lake.

The tributaries from the east are a different matter. The Tregoyd falls 360m from source to confluence; the Felindre falls 320m; and the Ennig falls 415m. To the west, both the Triffrwd and Dulas fall about 170m down to their confluence. Thus, the Tregoyd, Felindre, Ennig, Triffrwd and upper Dulas (above Felinfach) are all headwater streams with high gradients.

The height of the hills to the east and west also leads to a land use impact. Much of this land is too rough and steep to get a tractor on. So, we find a large coverage of acid grassland (brown areas in figure 2), as opposed to the improved grassland lower down the valleys. It is clear that all of our ‘headwater streams’ have catchments incorporating large areas of unimproved land. Note the catchments for Felindre, Ennig Arosfa, Ennig Middle Genfford, Triffrwd and upper Dulas. This is important because unimproved land types have very low export coefficients for phosphorus. The main phosphorus load on the Llynfi will undoubtedly be coming from the managed land downstream and not so much from these headwaters. *How much free-ranging sheep on unmanaged grassland?*

The boundaries determined from each of the sub catchments shown in Figure 2 have been used to extract annual rainfall statistics from CEH data, thereby allowing an estimate of mean river discharge at each WSA sampling site. This allows us to take average phosphorus concentration and convert it to a mass flowrate for each sampling site.

The V2 dataset (Sept-21 to Nov-22), comprises 416 samples over many more locations and adds TDS to the parameters measured. pH is also monitored at a subset of locations. The following table shows a summary of samples at each location.

Location	Number of samples		
	PO <sub>4</sub>	EC-TDS	pH
<b>Dulas</b>			
Dulas, above Llynfi confluence	19	18	2
Dulas, above Tryffrwd confluence	28	28	
<b>Ennig</b>			
Ennig, above Llynfi confluence	12	10	1
Ennig, bridge below hospital	4	4	
Ennig, Arosfa	29	29	
Ennig, Middle Genfford	27	27	
Ennig, road bridge A479	4	4	
<b>Felindre Brook</b>			
Road Bridge Felindre	42	42	5
<b>Llynfi</b>			
Llynfi, Above Dulas confluence	16	16	
Llynfi, Llangorse car park bridge	27	11	
Llynfi, Llynfi Bridge Llangorse	28	11	
Llynfi, Pipton Bridge	42	40	38
Llynfi, above Talgarth STW	32	31	31
Llynfi, Trefecca downstream	12	11	11
Llynfi, Trefecca upstream	16	16	16
<b>Tryffrwd</b>			
Tryffrwd, above Dulas confluence	31	31	1
<b>Wye</b>			
Wye, Glasbury	39	38	37

Table 2: samples recorded at each location by WSA over the period Sep-21 to Nov-22

This dataset has been merged with NRW volumetric flow data from the Three Cocks gauging station to facilitate the load apportionment modelling to follow.

## Data analysis

### Acidity

Regular measurement of pH has been undertaken at just five sites, being recorded by 2 of our Llynfi volunteers using *HM Digital pH-80* instruments. Mean and maximum pH values at these sites are as follows.

Location	Samples	Mean pH	Max pH
Llynfi, Trefecca upstream	16	8.5	9.2
Llynfi, Trefecca downstream	11	8.3	8.8
Llynfi, above Talgarth STW	31	8.7	9.9
Llynfi, Pipton Bridge	38	8.7	10.0
Wye, Glasbury	37	8.5	10.3

Table 3: WSA pH results for the period Sep-21 to Nov-22

However, a problem is evident with the data from Talgarth STW, Pipton Bridge and Glasbury, as indicated by the suspiciously high maxima. A calibration check was performed on this instrument on 14-Aug-22, which found a +0.4 error. Thus, all data recorded prior to this data for these locations needs to be discarded. A similar calibration drift was found on the Trefecca instrument, invalidating data recorded during November. Filtering out the affected data results in the following adjusted summary:

Location	Samples	Mean pH	Max pH
Llynfi, Trefecca upstream	10	8.3	8.6
Llynfi, Trefecca downstream	8	8.1	8.4
Llynfi, above Talgarth STW	8	7.9	8.0
Llynfi, Pipton Bridge	8	7.9	8.1
Wye, Glasbury	7	7.8	8.0

Table 4: WSA pH results for the period Sep-21 to Nov-22 after removal of erroneous data

The results above are now similar to the NRW results (Table 1) for proximate locations.

This experience emphasises the need for more frequent calibration of pH-80 instruments and WSA procedure has now been changed to calibrate monthly.

### Electrical conductivity

Data in Epicollect is recorded as TDS, for the most part being measured using *HM Digital TDS-3* meters, which uses a NaCl calibration factor of 0.5. These data have been converted back to electrical conductivity at 25°C (otherwise known as specific conductance, SC) by dividing by the calibration factor. Some users have *HM Digital EC-3* meters which report as EC. We report these results unmodified.

In our Garren project, we discovered that EC is usually a well-behaved function of river discharge (volumetric flow). Thus, we shall employ the same methodology here. Figure 3 shows the relationship above Talgarth STW. There are two key features to this graph. Firstly, we see a linear reduction in SC with discharge. This arises because during heavy rainfall, additional surface drainage pathways turn on which reduce the ability of drainage water to pick up dissolved minerals (notably CaCO<sub>3</sub>). The gradient of this relationship and the zero-flow intercept are characteristics of the river and its drainage pathways. Groundwater dominated catchments typically have low gradient, while surface water dominated catchments tend to have higher gradients.

Additionally, at this location, we see a small upswing at low flowrates. The upswing follows a dilution curve and results from the addition of a fixed mass flow of material – in this case probably from upstream sewage discharges. The solid line represents the best fit to the following equation:

$$SC = \frac{A}{Q} + B(1 - C \cdot Q)$$

Where  $Q$  is the volumetric flowrate and  $A$ ,  $B$  &  $C$  are adjustable parameters.  $A$  is the fixed mass flow;  $B$  is the zero-flow intercept and  $C$  is the gradient.



Figure 3: discharge dependency of electrical conductivity in the Llynfi above Talgarth STW

Rather than present 15 graphs, we shall summarise this as  $A$ ,  $B$  &  $C$  parameters in Table 5 below.

Location	Mean SC	A	B	C
Felindre, road bridge	382	0.00	387	0.01
Llynfi, Pipton Bridge	408	4.65	403	0.03
Llynfi, above Talgarth STW	387	2.00	396	0.04
Llynfi, above Dulas confluence	448	1.30	412	0.04
Llynfi, Trefecca downstream	468	1.13	462	0.07
Llynfi, Trefecca upstream	440	1.27	450	0.07
Llynfi, Llynfi Bridge Llangorse	339	0.00	345	0.01
Llynfi, Llangorse car park	334	0.00	340	0.01
Dulas, above Llynfi confluence	384	1.14	356	0.06
Dulas, above Triffrwd confluence	316	0.47	350	0.07
Triffrwd, above Dulas confluence	307	0.58	307	0.07
Ennig, above Llynfi confluence	380	0.39	367	0.08
Ennig, Arosfa	361	0.02	358	0.00
Ennig, Middle Genfford	357	0.00	357	0.00

Table 5: EC mean values and load apportionment parameters

### A parameter

Looking first at anthropogenic, fixed-flow load (parameter  $A$ ), we find ten locations (highlighted red) where there is a measurable signal. This parameter has the dimensions of a mass flowrate, and so should be additive. It is no surprise that we see such a signal at Pipton Bridge, where the river is carrying the effluent from both Talgarth and Felindre STWs. However, a significant part of this signal is already present upstream of Talgarth STW. Moreover, this is clearly coming from all three tributaries. In fact the sum of the  $A$  parameters for the Ennig, Dulas and Llynfi above the Dulas is 2.8, which is reasonably close to the value of 2.0 found above Talgarth STW. In similar fashion, note that the Triffrwd plus the Dulas above the Triffrwd is approximately equal to The Dulas above the Llynfi.

The Dulas carries the effluent from STWs at Bronllys Hospital, Llanfilo and (via the Tryffrwd) from Llandefalle. But the middle reaches of the Llynfi have no licensed direct emissions. Thus, we must

conclude that the signal on the Llynfi above the Dulas confluence comes from unpermitted direct discharges – septic tanks and/or agricultural leakage.

### *B parameter*

The *B* parameter is a measure of the natural electrical conductivity of a river. It is analogous to the mean value, but with the benefit of having any fixed-flow load removed. Stated accuracy of the *TDS-3* instrument is  $\pm 2\%$  of reading, which (rounding up) roughly equates to  $\pm 10 \mu\text{S}/\text{cm}$ .

In the Llynfi immediately below Llangorse, we see *B* values around  $340 \mu\text{S}/\text{cm}$  and the mean value here correspond well to the NRW mean value. In line with the earlier discussion of alkalinity, we find slightly higher values on the Ennig headwater sites and on the Felindre all of which drain the Black Mountains. The Triffrwd, draining the western catchment, is notably lower.

Levels progressively increase moving through the lower catchment. Whether this is a genuine geological effect, or due to diffuse anthropogenic input is not known. The mean value at Pipton ( $408 \mu\text{S}/\text{cm}$ ) is a little higher than NRW's mean of  $370 \mu\text{S}/\text{cm}$  at the Wye confluence. However, these points are 2km apart and span the Tregoyd confluence and so could be genuinely different.

### *C parameter*

The *C* parameter tells us about catchment drainage pathways – which in principle helps us interpret phosphorus LAM analysis.

The *C* parameter is the gradient of the straight-line section of Figure 3. Low gradients indicate groundwater dominated drainage pathways. Higher values are indicative of surface pathways turning on during rainfall (including agricultural under-drainage and ditches). All areas of the catchment are seen to have broadly similar slopes, with the exception of 5 sites (highlighted orange).

The two Llangorse sites are unsurprising. One would not expect to see a significant EC flow dependency coming out of a lake. The water has been in there for weeks absorbing the local mineralogy.

More of a surprise are three of the headwater sites on the Ennig and Felindre. They are in marked contrast to the Triffrwd, which has a larger *C* parameter – more typical of a flashy stream. The explanation relates to the wide, round tops on the Black Mountains. The land up there is flattish and can be boggy here and there. The result is that the sources of these streams are groundwater dominated, draining the wet soil of the tops, before tumbling down the steep sides to the valley.

### *Phosphorus*

Phosphorus is measured using the Hanna low range phosphate checker, which reports ppm (mg/l) as  $\text{PO}_4$ . The Epicollect data has been divided by 3.06 to convert to mg/l as P – which is compatible with NRW data and WFD/SAC WQ targets. So, everything to follow is stated as RP in mgP/l.

### *Targets*

Llynfi WQ targets are complicated by being only partially within the River Wye SAC.

A key point is that SACs do not correspond to WFD waterbodies and so do not automatically include tributaries. This is how the Garren and Monnow systems, for example, get excluded from the Wye SAC. In the context of the Llynfi, we have five WFD waterbodies:

<i>Waterbody ID</i>	<i>Waterbody name</i>
55036950	Afon Llynfi - conf Dulas Bk to conf R Wye
55036920	Dulas Bk - source to conf Afon Llynfi
55036970	Triffrwd - source to Dulas
55036910	Ennig - source to conf Afon Llynfi
55036900	Afon Llynfi - source to conf Dulas Bk

Table 6: WFD water bodies within the Llynfi sub catchment

The Wye SAC extends up the Llynfi as far as the Dulas confluence. It then proceeds up the Dulas, incorporating the Triffrwd along the way, but stops at Felinfaich. It does not extend up to the source of the Dulas. Llangorse Lake is an entirely separate SAC. Therefore, the whole of the Llynfi between Llangorse and the Dulas confluence is not SAC. Nor is the Ennig. But here lies the silliness. The Ennig and Llynfi above the Dulas make up two thirds of the lower Llynfi flow. So how the Lower Llynfi can be expected to comply with the more stringent SAC targets, unless the Ennig and middle Llynfi also do so, is a mystery. The one note of pragmatic sanity here is that NRW report SAC compliance to waterbody granularity. Here, then, are the current RP targets (mgP/l) implied by the above logic:

<i>Waterbody ID</i>	<i>Waterbody name</i>	<i>SAC RP target</i>	<i>WFD good RP target</i>
55036950	Afon Llynfi - conf Dulas Bk to conf R Wye	0.025	
55036920	Dulas Bk - source to conf Afon Llynfi	0.025	
55036970	Triffrwd - source to Dulas	0.015	
55036910	Ennig - source to conf Afon Llynfi		0.057
55036900	Afon Llynfi - source to conf Dulas Bk		0.057
	Felindre, road bridge		0.048
	Ennig, Arosfa		0.038
	Ennig, Middle Genfford		0.034

Table 7: RP targets for Llynfi WFD water bodies, plus targets applicable to three WSA monitoring sites

### Mean values

Mean RP values from WSA measurements are shown in the following table.

<i>Site</i>	<i>Number of samples</i>	<i>Mean RP (mgP/l)</i>	<i>SAC status</i>	<i>WFD status</i>	<i>V1 RP (mgP/l)</i>	<i>NRW RP (mgP/l)</i>
Felindre, road bridge	43	0.031		Good	0.023	
Llynfi, Pipton Bridge	49	0.051	Fail		0.049	
Llynfi, above Talgarth STW	32	0.052	Fail			
Llynfi, above Dulas confluence	16	0.086		Moderate	0.081	0.095
Llynfi, Trefecca downstream	12	0.074		Moderate		
Llynfi, Trefecca upstream	16	0.076		Moderate		
Llynfi, Llynfi Bridge Llangorse	28	0.106		Moderate		0.111
Llynfi, Llangorse car park	27	0.091		Moderate	0.077	
Dulas, above Llynfi confluence	19	0.043	Fail			0.035
Dulas, above Triffrwd confluence	28	0.060	Fail			
Triffrwd, above Dulas confluence	31	0.021	Fail			0.029
Ennig, above Llynfi confluence	12	0.049		Moderate	0.060	0.046
Ennig, Arosfa	29	0.027		Good		
Ennig, Middle Genfford	27	0.020		Good		

Table 8: mean RP values for WSA measurements over the period Sep-21 to Nov-22. The column V1 RP is the corresponding WSA data from last year and NRW RP is for the current period, being reproduced from Table 1.

This is more readily understood by the graphically presentation of Figure 4.

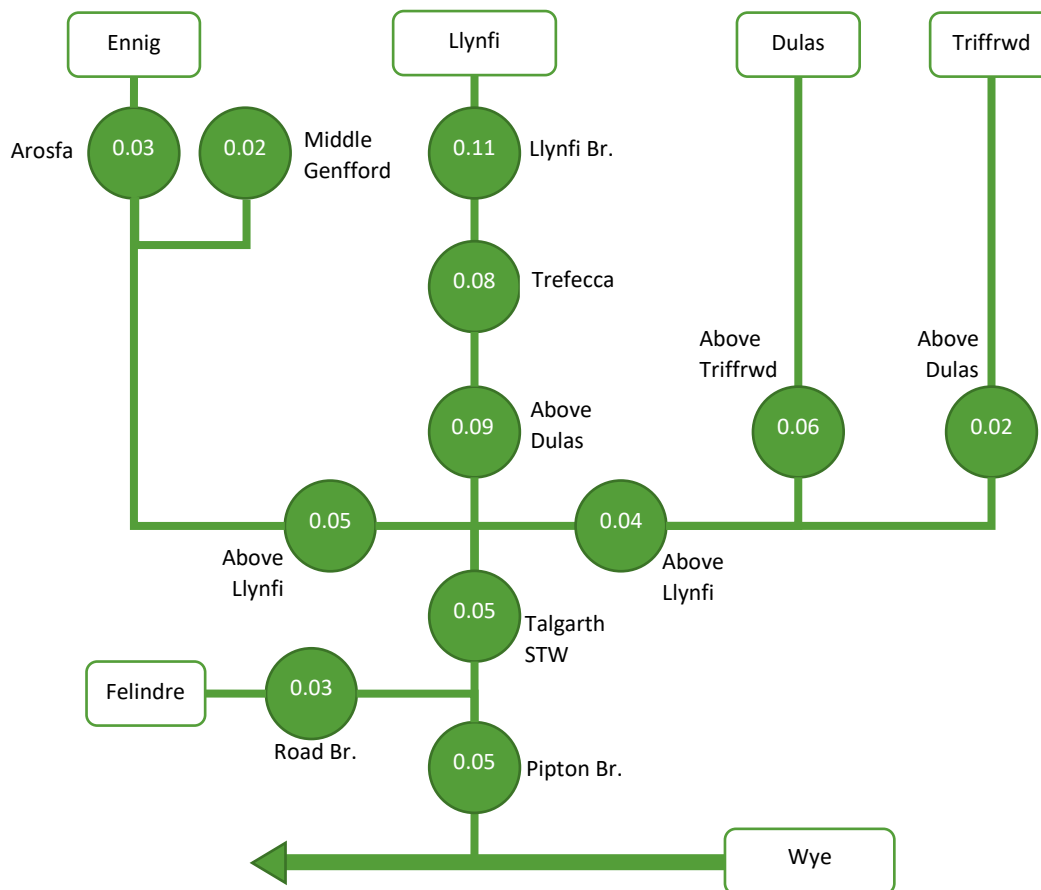


Figure 4: catchment schematic showing RP concentrations (mgP/l)

Looking at the headwater sites first, we find the *Ennig* at Arosfa and Middle Genfford achieving *good* WFD status – which is consistent with our expectations based on the amount of unimproved land. But after flowing through several km of improved grassland in the lower valley, the numbers above the Llynfi confluence at Talgarth are typical of the wider catchment. The *Triffrwd* likewise, would achieve WFD good status, but fails the more stringent SAC test. On the *Felindre*, we have a similar situation, achieving good WFD status but failing SAC targets, should this stream be considered part of the Wye SAC.

*Llangorse Lake* is a disaster zone, as always. The RP concentrations in the Llangorse outflow are massively above the WFD *good* status target and are significantly higher than the typical levels found lower down the catchment.

The *Dulas* fails miserably against its SAC target but note that at the Llynfi confluence it would scrape a WFD good classification. The higher value above the Triffrwd confluence suggests that the lower value downstream is the result of mixing with the cleaner Triffrwd water.

The *Middle Llynfi* (Llangorse to Dulas confluence) starts in a very bad place and appears to improve by dilution, moving downstream. It fails to achieve WFD good status. The *Lower Llynfi* is a little lower, presumably benefitting from the cleaner Dulas and Ennig water.

A rough overview would be as follows. Headwaters are in the region 0.02 – 0.03 mgP/l. The intensive farming in the lower valleys increases this to 0.05 – 0.06 mgP/l. Llangorse is around 0.10 mgP/l and this high value impacts the whole of the middle Llynfi.

Overall, Table 8 shows a good match to corresponding NRW data (Table 1), and to corresponding WSA data from the previous year.

### RP mass flowrates

It is helpful to consider the phosphorus measurements as a mass flowrate through the catchment. Figure 5 below is another schematic map of the catchment, this time showing RP mass flowrate (kgP/day) at each sampling location. This is simply calculated as our average RP concentration multiplied by estimated annual mean flowrate at each location.

What this illustrates is how the RP mass flow builds up moving down the catchment. Summing the 3 flows joining at Talgarth, for example, gives 12.0 kgP/day – which is not too different to the 10.4 kgP/day we measure at Talgarth STW, which suggests that the model is reasonable. Now the sobering point is that, if the lower Llynfi is to achieve SAC compliance for RP (<0.025 mgP/l), then the mass flowrate in this section of river needs to be below 5.0 kgP/day. But we see that we already have 4.0 kgP/day coming out of Llangorse, so it's difficult to see how the Lower Llynfi SAC targets could ever be achieved without a massive improvement at Llangorse Lake.

WFD *good* status (<0.057 mgP/l) requires us to keep the lower river below 11.3 kgP/day – which is just about achieved based on WSA data at Pipton and Talgarth STW. But SAC targets appear out of reach.

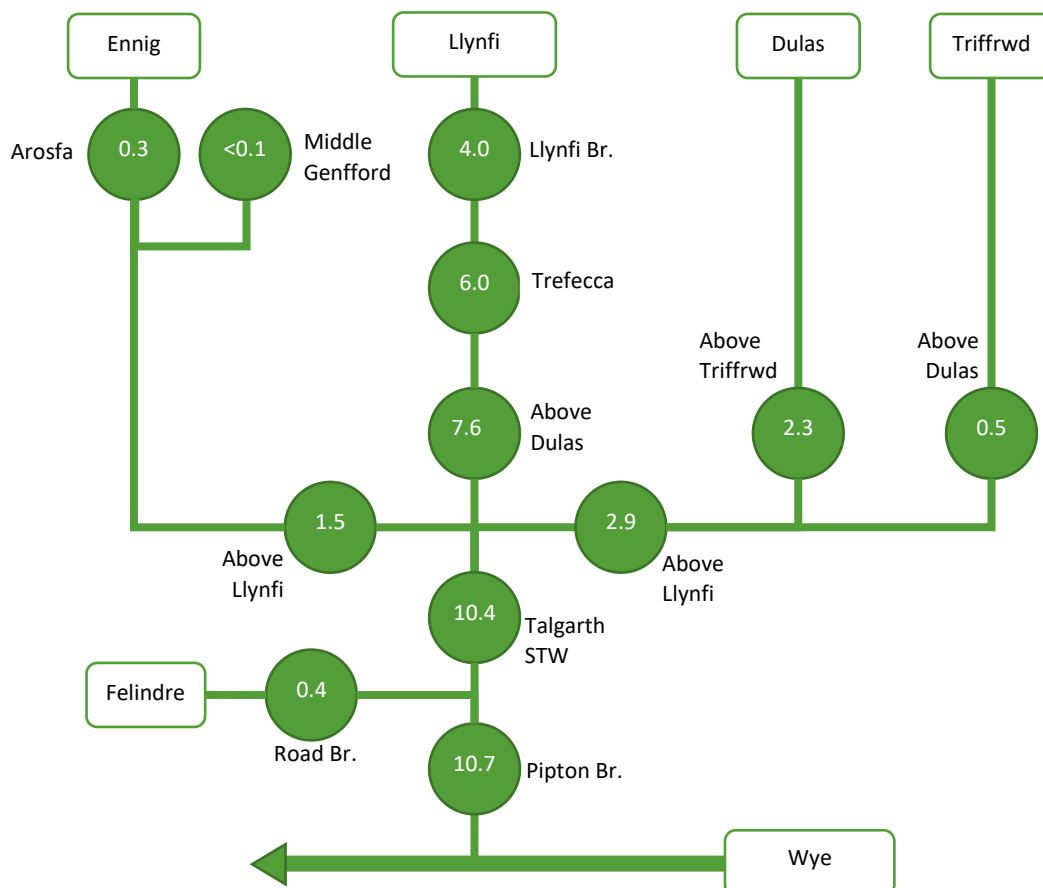


Figure 5: catchment schematic showing RP mass flowrate as kgP/day.

## Point sources

WSA have monitored three locations where specific local sources of pollution are suspected. At these locations, we have matched sets of measurements taken upstream and downstream of suspected sources.

### Ennig/Ellywe confluence

Two recently introduced sites on the Ennig at Talgarth are proving interesting. The sites are located upstream and downstream of the Ellywe confluence, although it is currently not confirmed that the Ellywe is the actual source of the problem. Table 9 below shows matched RP and EC data obtained so far.

Date	RP (mgP/l)		EC (µS/cm)	
	Upstream	Downstream	Upstream	Downstream
30/08/2022	0.046	0.111	412	418
06/09/2022	0.049	0.095	368	390
21/09/2022	0.043	0.092	354	402
05/10/2022	0.033	0.102	330	388
Mean	0.043	0.100	366	400
Delta		+135%		+9%

Table 9: RP and EC data from two locations on the Ennig. "Upstream" is the bridge below the hospital; "Downstream" is the A479 bridge.

It is clear that there is a very significant increase in RP between these two locations. Moreover, this is part of a general increase in EC and by implication, total dissolved solids. Because the bulk of the EC signal is due to natural dissolved minerals (predominantly CaCO<sub>3</sub>), the 9% increase potentially represents a massive increase in non-mineral load. It is reasonable to assume that RP is just one small component of this pollution. Applying a single sided Student T-test tells us that both increases are statistically significant at the 99% confidence level.

### Llynfi at Trefecca

The WSA volunteer covering this area is aware of a particularly smelly discharge entering the river at Trefecca. He has therefore been sampling above and below this point source. The source is currently assumed to be a "misconnected" domestic drain from a location within the village and is under investigation by NRW.

Using the same methodology as above, we have 11 matching pairs of data. Rather than listing all of this, we report the key statistics in Table 10 below.

	RP (mgP/l)		EC (µS/cm)		pH	
	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
Mean	0.070	0.080	465	468	8.54	8.28
Delta		14%		1%		-3%

Table 10: RP, EC & pH data from two locations on the Llynfi at Trefecca.

The increase in RP is much less than seen on the Ennig due to the relatively higher dilution here. Nevertheless, applying a single-sided Student T-test tells us that this result is significant at a 95% confidence level. The reduction in pH is similarly significant. The change in EC is more subtle but is still significant with 80% confidence. Thus, we can say with some certainty that the river chemistry changes at Trefecca.

### Llynfi at Llangorse

In our earlier Llynfi Catchment Overview report (Green, 2022b), using load apportionment modelling (LAM), we found a significant fixed flow signal at Llynfi Bridge, Llangorse, which we suggested would most likely be caused by direct discharging private sewage systems, possibly associated with the adjacent caravan park. We had limited data from the upstream site at the Car Park Bridge but noted that this was often lower than at Llynfi Bridge. This year we have 27 paired samples for RP and 10 for EC.

Firstly, we compare mean values, just like at Trefecca:

	RP (mgP/l)		EC (µS/cm)	
	Upstream	Downstream	Upstream	Downstream
Mean	0.091	0.107	312	319
Delta		18%		2%

Table 11: RP and EC data from two locations on the Llangorse Lake outflow. Upstream refers to the Car Park Bridge immediately below the lake; Downstream refers to Llynfi Bridge, 800m downstream.

Both increases are statistically significant. EC with 95% confidence, and RP with 80% confidence. Despite the larger sample size, RP confidence is reduced at Llangorse by the larger variance of RP concentration found in the outflow.

Secondly, we can perform a LAM analysis, as we did in the earlier report. Figure 5 below shows the LAM plot for the downstream location.

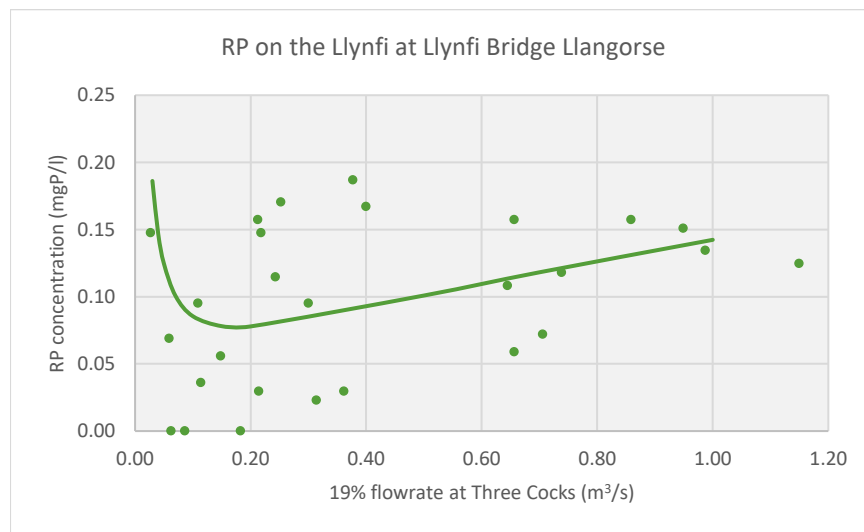


Figure 5: discharge dependency and LAM model for RP on the Llynfi at Llynfi Bridge Llangorse

The solid curve represents the LAM model for the data and analysis of variance indicates statistical significant at the 90% confidence level. Once again, we see a marked upswing at low flows, which is indicative of a fixed flow source. Moreover, the A parameter (0.0051) is almost identical to last year's value (0.0053). Thus, everything we said about the fixed flow volume in our first report remains true.

Looking upstream at the Car Park Bridge, we obtain the following LAM plot.

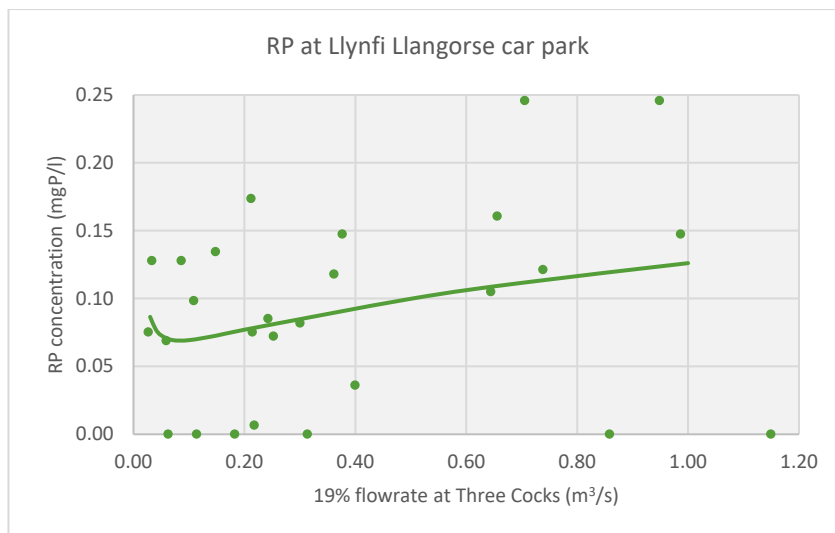


Figure 6: discharge dependency and LAM model for RP on the Llynfi at Llangorse Car Park Bridge

This rather suggests that there may be a little fixed flow signal already present at the car park bridge (the A parameter is 0.0018). However, the statistical confidence is much lower in this model. What we can say with confidence is that we do not have anything like the magnitude of fixed flow load we find at Llynfi Bridge.

## Anaerobic digestion

The rapid spread of farm-based anaerobic digestion (AD) units within Wye Catchment is an emerging area of great concern. The catchment currently suffers the environmental consequences of an excessive concentration of intensive poultry units. This occurred despite the National Rivers Authority recognising the inherent unsustainability of the industry's practice of "spreading as a means of disposal" and calling for stricter planning enforcement as early as the 1990s (NRA, 1995). Because this didn't happen, regulators are now faced with retrospectively addressing the environmental disaster resulting from excess phosphorus. The concern now is that regulators are once again sleepwalking into another long-term environmental disaster by not adequately regulating rural AD plants.

## The hazards

The first point to recognise is that operating an AD plant is not farming; it is chemical engineering. The skill sets are quite different, particularly on the larger installations. Consequently, the first hazard we encounter is one of point **source** pollution. Typical farms do not operate to the standards of industrial hygiene required to reliably contain large volumes of toxic, corrosive substances, and **liquid digestate is highly toxic should it enter a watercourse, as it contains 3-4% organic matter and about 0.35% ammoniacal nitrogen (NH<sub>3</sub>-N). The negative impact of excessive NH<sub>3</sub>-N, and consequent ammonia toxicity and fish mortality, is exacerbated by high pH, typical of the lower Llynfi.**

As an example of this, we would cite the three acute pollution events which have occurred in recent years on the lower Llynfi. **In 1Q 2016, acute pollution affected the river, causing invertebrate damage but not killing fish. This was attributed to the mis-spreading of liquid digestate (LD) and was successfully prosecuted by NRW against GP Biotec. Five months later in 2016, the first of two catastrophic fish kills, killed fish down to the Wye confluence and then, in 2020, all fish were killed again plus major invertebrate damage. The upstream locations of dead fish were only 250 m apart on land belonging to Great Porthamel Farm, and neither was attributed to mis-spreading of digestate. In NRW's Press Release on 29 August 2020, Ann Weedy said that "Our investigations indicate that the pollutant was an**

organic substance. Organic pollutants result in fish dying of suffocation owing to lack of oxygen". There has been no prosecution.

Furthermore, leakage of industrial effluent continues from this site, as demonstrated by monitoring at two specific locations, by Gwent Angling Society (GAS) in 1Q 2022, notably regarding discharge of NH<sub>3</sub>-N concentrations significantly exceeding the permitted discharge compliance threshold of <0.5 ppm (Green, 2022c; Green & Collins, 2022). These reports were sent to NRW in November 2022. All of this arises from questionable technical competence at the facility and inadequate regulation, including the inevitable consequence of the absence of planning consent from BBNPA, for all drainage and digestate storage infrastructure outside the NRW-permitted area immediately around the AD site (discovered by GAS and Fish Legal in April 2022 and reported to NRW in November 2022). Furthermore, research by GAS in 2021, showed that this is not an isolated problem in Wales, with two incidents on the Teifi in 2016 and 2017, one a major fish kill, and another four related to mis-spreading of LD and LD containment problems.

The second hazard relates to diffuse pollution. It is often claimed that liquid digestate is a replacement for expensive chemical fertilisers on arable farms. Superficially, this seems to be a good thing, both economically and in terms of nutrient recycling. However, arable farms using chemical fertilisers are able to separately manage nitrogen and phosphorus. Soil surveys conducted by RePhOKUs (Withers et al., 2022) and by WSA (Green, 2022d) suggest that P concentrations on arable land are high but relatively stable – unlike pasture which is increasing due to overapplication of organic fertilisers (slurry and poultry manure). All organic fertilisers (including LD) contain far too much P relative to N; moreover N dissipates and P does not. Thus, if arable farmers increase the proportion of organic feed (LD) and apply up to the NVZ nitrogen limit (the common practice), this will inevitably lead to an overapplication of phosphorus and rising soil concentrations. All of this is predictable and emphasises the need for rigorous soil monitoring by regulators.

## Spreading

A key aspect of AD, then, is spreading and regulation thereof. Regulators need to know where LD is going and how much is being applied.

*Gordon, I've deliberately not attempted to make any modifications (only comments) on the next part of your paper as I feel sure that you will want to modify it in light the newer GPB information, and body of stats, that I sent to you earlier today including: past and current waste capacity, some very questionable GPB estimates of LD production, what we know about on and off-site LD storage, and on and off-site LD spreading including at specific locations (albeit nearly four years out of date so needs updating by NRW!). Clearly, we now have a feel for what proportion of LD was spread in the Llynfi sub-catchment in 2019, and how that relates to the size of the whole sub-catchment (though not all of that will be getting any added nutrients at all, of course, so my rather superficial, derived proportion of treated land will be too small). What we don't know of course is what goes where, within or outside the Llynfi catchment four years later in 2023!*

Taking GP Biotec as an example, this has a stated **waste** input capacity of 70,000 (75000) t/year and outputs 55,000 t/year of LD (*worth checking my paper for verification of this estimate?*). This would typically contain 105 t of nitrogen and 15 t of phosphorus. Using the Llynfi population estimates for cattle and sheep from our earlier report, we calculate that manure phosphorus within the Llynfi catchment contains 118 t/year of phosphorus. So, GP Biotec potentially represents a 12% increase. But it is worse than this, because what we need to consider is not the phosphorus circulating within the farm boundary, but the balance at the farmgate (or catchment boundary). RePhOKUs (Withers et al., 2022) tell us that within the Wye Catchment, the cattle and sheep sector imports approximately 2

tonnes of phosphorus in feed for every tonne exported within milk and meat. This is the surplus which accumulates in the soil, driving eutrophication of the rivers. Applying these numbers to the Llynfi, we expect the cattle & sheep surplus to be around 20 tonnes of phosphorus per year. Thus, the output of GP Biotec alone could almost double the Llynfi catchment phosphorus imbalance. *See new data.* Thus, the key questions are where does the feedstock come from and where does the digestate go to?

We have seen with the poultry sector how some locations are cynically abused to dispose of manure – with calamitous implications for soil P. There is a real risk of the same thing happening with digestate and the use of terms such as “land bank” in this context is perhaps an indicator of the realities. The proliferation (*we specifically know of three more, as it looks like our informant over-egged it. See my paper!*) of digestate lagoons around Talgarth suggests that much of the GP Biotec digestate does not go far. (*We now know exactly where it went to in 2018 -19, assuming that GPB was honest which, given their track record, I strongly doubt. I sense evasion, obfuscation and lack of transparency in GPB’s 2019 report – interested in your take on that!*). Spreading this at the NVZ nitrogen limit and assuming no other organic input, requires over 600 ha of arable land – approximately 50% of the arable land in the Llynfi sub catchment. Which is another metric indicating the significance of this one facility.

If farmers are allowed to apply digestate up to the NVZ nitrogen limit every year, without controls on soil phosphorus, export to the river will inevitably increase.

### Transfer of poultry litter

The recently approved planning application for a 90,000-bird broiler unit at Wernhalog near Builth Wells is of great concern to the Llynfi. This was approved by Powys CC on the basis that manure (approximately 2000 t/year) is transferred to GP Biotec. Thus, Powys CC have solved a problem by exporting it to another planning authority, **BBNPA**, within the Wye Catchment **in the** Brecon Beacons National Park. The phosphorus in this manure will equate to around 10 tonnes per year representing a huge increase on the Llynfi phosphorus excess. These estimated quantities are summarised in Table 12.

	<i>Tonnes P per year</i>
<i>Llynfi catchment cattle &amp; sheep surplus</i>	20
<i>GB Biotec current output</i>	15
<i>Poultry manure from Wernhalog</i>	10

*Table 12: estimated phosphorus loads from key sources within the Llynfi sub catchment*

## Conclusion

### *New publications*

The two new papers cited both emphasise the point made in our first Llynfi report that reducing phosphorus levels will require systemic changes to agriculture and that farm scale interventions cannot achieve the scale of improvement required.

### *Core management plan*

The 2022 Core Management Plan for the Wye SAC shows all 11 metrics having unfavourable status. Most of these metrics are applicable to the three Llynfi water bodies falling within the SAC. On the R & CB metric, The River Llynfi is specifically cited as an example of eutrophication causing adverse pressure on aquatic flowering plants. All three water bodies are assessed as “needs action”. The lower Llynfi has been identified by NRW for monitoring as a location of particular concern. Beyond this, no specific actions are identified.

### *NRW WQ data*

NRW have sampled at 11 sites over the period Sep-21 to Nov-22, but only 3 of these are sampled monthly, with the remainder mostly quarterly. Furthermore, not all determinands are measured on every visit.

The Llangorse Lake outlet shows very high RP (>0.10mgP/l), which impacts the Llynfi down to the Dulas confluence. The Dulas and Ennig have notably lower RP than the Llynfi. The Tryffrwd has the lowest RP of sites sampled.

Nitrate is low everywhere (other than two Llangorse tributaries) but increases in the lower river at the Wye confluence. This is possibly due to the higher concentration of arable farming in the lower catchment.

Acidity varied between pH 7.0 - 8.4 and generally tracks alkalinity at the headwater sites, hence higher to the east of the catchment, running off the sandstone of the Black Mountains.

EC also tracks alkalinity at the headwater sites but appears to increase in the lower valley – possibly the impact of diffuse pollution.

Unionised ammonia is low throughout the catchment. Ammoniacal nitrogen is also low, other than at the lake outlet, where it is notably higher.

Although based on a small sample, it is notable how nitrate increases substantially between the Llangorse outlet and Llynfi Bridge – but not all of the time.

### *WSA WQ data*

WSA have sampled 16 sites within the Llynfi sub catchment over the period Sep-21 to Nov-22. Four of these are headwater sites, 2 on the Ennig, 1 on the Tryffrwd and 1 on the Felindre, all of which have significant areas of unimproved grassland within their catchment. The remainder are in the lower valley, where the rivers pass through intensive agriculture.

pH has been regularly monitored at Trefecca on the middle Llynfi and also on the lower Llynfi. Mean values fall in the range pH 7.9 – 8.3. This is very similar to NRW data.

EC (or TDS) is monitored at all locations, with mean values corresponding well with NRW data, where that is available. The flow dependency of EC has been analysed using a LAM methodology, which provides useful insight into the catchment hydrology.

RP distribution throughout the catchment is consistent with NRW data. The headwater sites (Felindre, Ennig Arosfa, Ennig M. Genfford & Tryffrwd) all have moderate RP levels (0.02-0.03 mgP/l) consistent with the proportion of unimproved land within their catchments. These results are consistent with WFD *good* status, but the Tryffrwd is well above its SAC target). *Delete bracket*. The Dulas and Ennig both degrade in the lower valley to 0.05-0.06 mgP/l. Both fall within WFD *moderate* status, and the Dulas fails its SAC target by a factor of 2. The Llangorse outlet has by far the highest RP concentration in the catchment (>0.09 mgP/l) and this impacts the whole of the Llynfi down to the Dulas confluence. Again, we have a WFD *moderate* status.

We convert the RP concentrations to a mass flowrate by multiplying by estimated discharge at the sampling location. This provides a useful insight regarding SAC compliance. RP mass flowrate through the lower Llynfi (11 kgP/day) is heavily dominated by what is coming out of Llangorse (4 kgP/day). SAC compliance would require a mass flowrate in the lower river below 5 kgP/day. To achieve this would therefore require a dramatic improvement at Llangorse, in addition to any export reductions achieved downstream. This has to be seen as improbable.

### *Point sources*

We have shown increases in both mean RP concentration and mean EC at two locations: on the Ennig around the Ellywe confluence and on the Llynfi at Trefecca. The latter site also shows a reduction in mean pH. At both locations we have very high statistical confidence in the results. The source at Trefecca is apparently already under investigation by NRW as a suspected “misconnection”, however the Ellywe source requires investigation.

We also show a similar increase in mean RP concentration and mean EC on the Llynfi immediately below the Llangorse outlet (between the Car Park Bridge and Llynfi Bridge). This result correlates with an increase in nitrate observed by NRW. Our LAM analysis of the RP signal at Llynfi Bridge shows a strong fixed-flow component. Moreover the fixed flow coefficient agrees very closely with the result from last year presented in our earlier report. Similar LAM analysis of the RP signal at the Car Park Bridge (not possible last year), shows clearly that most or all of the fixed flow RP enters the river between these two sites. This also requires investigation by NRW.

### *AD plants*

We are very concerned about the proliferation of farm-based AD plants throughout the Wye Catchment and *elsewhere in Wales*. According to NRW data, surface water pollution events from such units appears to be an increasing problem. Moreover, regulation appears weak to non-existent (in the case of exempted operations). Hazards arising from AD plants include both acute and chronic point pollution from containment failures, as well as diffuse pollution arising from spreading practices.

We examine the specific case of GP Biotec on the Lower Llynfi, which has a history of acute pollution and, as we have shown in other work, continues to emit chronic pollution from land drains. We show that the quantity of phosphorus being processed on this site is comparable to the estimated livestock phosphorus balance for the whole sub catchment. (Now needs checking given new knowledge, albeit four years out of date, on sub-catchment spreading hectareage. *(What it may be now in 2023 is unknown but NRW should know... shouldn't they??!! If they/ we want to focus some soil testing, then this will be a good place to start and, maybe a map of the 2019 storage and spreading sites, and where we know new ones to be located, would help to visualise these and hold NRW's feet to the fire)* Where the digestate is spread, and in what quantity, really matters to the soil phosphorus levels of the Llynfi sub catchment. As always, the answer is for NRW to initiate regular soil phosphorus monitoring, rather than relying just on river RP data.

The news that significant quantities of poultry litter are to be shipped from an IPU at Builth Wells for processing at GP Biotec (presumably to be spread predominantly within the Llynfi sub catchment) *(unknown but will negatively contribute)* is alarming. We show that this addition is also very significant in terms of sub catchment phosphorus balance.

Finally Gordon, I think it is very important to make mention, at some point under AD, of the significance of how LD is applied, and the potential negative impact that that can have on ultimate potential accumulation in rivers.

When applied to post-harvest stubble, and subsequently cultivated e.g. before sowing in mid-late summer, LD is incorporated, in part to reduce volatile loss of ammonia but also to mitigate run-off.

In many cases however, LD is applied to young standing crops, thus without post-application cultivation. One also wonders how much LD is applied to grassland rather than to arable. In these situations, LD cannot be incorporated post-application, and so has potential to move. Some but not all such movement can be mitigated by compliance with diligent adherence to the use of wide headlands or avoiding spraying next to them. As we know, this is often not complied with, as was filmed by BBC's researchers at Bronllys last year, when spraying a standing crop and involving, guess who, GP Biotec!

I wonder what proportion of LD in the Llynfi sub-catchment goes onto rotational arable land (and thus incorporated to mitigate risk) c.f. what goes onto standing crops or grassland? Maybe the locations of spreading locations will tell a story? You have already shown (and NRW agreed) that arable is a minor player in the Llynfi sub-catchment.

**Gordon,**

**At our meeting with NRW on Tuesday Jeremy Tanner referred to a report on re-naturalising inflows and outflows to Llangorse Lake, with objective of causing sediment to fall out before arriving at lake.. Is this still live and/or part of the current work? Should it be referred to in your report somewhere**

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## List of abbreviations

AD	Anaerobic Digestion
<b>BBNPA</b>	<b>Brecon Beacons National Park Authority</b>
CEH	Centre for Ecology & Hydrology
CSF	Catchment Sensitive Farming
DC-WW	Dwr Cymru – Welsh Water
EC	Electrical Conductivity
FoI	Freedom of Information
GAS	Gwent Angling Society
LAM	Load Apportionment Modelling
NMP	Nutrient Management Plan
NRFA	National River Flow Archive
NRW	Natural Resources Wales
R & CB	Ranunculion fluitantis & Callitriche-Batrachion
RP	Reactive Phosphorus
SAC	Special Area of Conservation
SC	Specific Conductance (conductivity at 25°C)
TP	Total Phosphorus
UKSO	United Kingdom Soil Observatory
WFD	Water Framework Directive