Written Evidence from the RePHOKUs Project

Background
The RePhoKUs project (An UKRI project funded under the Global Food Security Programme entitled 'The Role of Phosphorus in the Resilience and Sustainability of the UK Food System', BB/R005842/1) involves a team of multidisciplinary scientists looking at management strategies and pathways for more efficient and sustainable phosphorus (P) use in the UK food system at a range of scales (catchment, regional and national), including some assessment of the adaptive capacity of stakeholders to undertake change. The project addresses two key issues for the UK's long-term food and water security: firstly, the continuing and unacceptable pollution of inland and coastal waters arising from P losses from the food system, and secondly the vulnerability of our food system to future shortages of imported P, a critical and finite resource on which the UK is heavily reliant on. The project started in May 2018 and finishes in December 2021.

The project is led by Paul Withers, a Professor of Catchment Biogeochemistry at Lancaster University, who has led a number of large research projects for government, industry and research councils investigating the cycling, transfer, ecological impacts and control of phosphorus loss to water in rural agricultural catchments. Many of the projects have involved work in the Wye catchment. He is also a member of Defra's expert group developing water targets to underpin the governments Environment Bill.

Summary of Key Points
- The Wye catchment has a high risk of agricultural P loss due to high P input pressure*, poorly-buffered and highly dispersible P-rich soils and moderate to high rainfall.
- Farming generates an annual P surplus (i.e. unused P) of ca. 2000 tonnes (11 kg P/ha) in the Wye catchment, which is accumulating in the catchment soils. This P surplus is nearly 60% greater than the national average, and is driven by the large amounts of livestock manure produced in the catchment.
- The risk of P loss in land runoff due to accumulation of soil P is greater in the Wye catchment than in other UK soils.
- Analysis of long-term river P concentration data for the Wye catchment outlet at Redbrook suggests river P pollution may be gradually rising again.
- While clear evidence of positive links between annual catchment P input pressure (and P surplus) and river P concentrations and fluxes exists at the regional scale across Great Britain, and at sub-catchment scales in Northern Ireland (NI), evidence of this link across the Wye catchment has not yet been found.
- EA/NRW water quality monitoring programmes are not considered adequate to capture river quality impacts of short-term or small area changes in agricultural practice. Similarly, the general provision of census data is not at a sufficiently fine resolution to accurately quantify spatially distributed P input pressure in catchments. These are both generic problems confounding provision of robust evidence of cause and effect.

*Defined as the Net Anthropogenic P Input (NAPI) and calculated as the net P inputs from agriculture and the human population.

- Water quality in the Wye catchment, and many other livestock-dominated catchments, will not greatly improve without reducing the agricultural P surplus and drawing-down P-rich soils to at least the agronomic optimum. This will take many years.
- A combination of reducing the number of livestock and processing of livestock manures to recover renewable fertilisers that can substitute for imported P products is needed to effectively reduce the P surplus.
- Catchment stakeholders have a nascent capacity to change practice but require a firmer evidence base and on-the-ground support to implement both incremental and transformative change in practices to improve river water quality. Experience in Northern Ireland suggests support schemes have a measurable impact on behavioural change.

Key Insights from the RePhoKUs Project

The Wye Catchment Case study

The Wye catchment is one of three study catchments within the RePhoKUs project examining how P use can become more sustainable. Previous research (1994-2008) has shown the reddish silty soils that dominate the catchment are P-rich, have low P buffering capacity and disperse easily during rainfall events leading to high rates of P loss. This is a very challenging environment in which to farm without impacting on river water quality. RePhoKUs has built on this previous work by (a) providing a detailed assessment of the P input pressure being exerted on the catchment using a well-established Substance Flow Analysis (SFA) methodology[1], (b) investigating the links between P input pressure and river P concentrations and fluxes (not yet finished), (c) testing whether the P fertility of representative soils can be drawn-down without affecting crop yield and for how long, and (d) assessing stakeholder adaptive capacity* to change practices.

(a) Catchment P SFA

An SFA maps all significant food system materials and their P content entering, leaving or circulating within the catchment and is a useful tool for identifying significant P inefficiencies, losses and accumulations[1]. The SFA for the Wye catchment shows that the largest P import is in livestock feed (~3000 tonnes P) and the largest internal flow of P is in livestock manure (~5000 tonnes P), signifying that the livestock sector dominates P use in the catchment. The percentage contribution of livestock type (2016 data) to the manure loading in the catchment is: Cattle (33%), poultry (30%), sheep (34%), pigs (2%), other (2%). An imbalance between agricultural P input (fertiliser, manure and biosolids) and harvested P offtake (grass and crops) leaves ca. 2000 tonnes of P that are accumulating in agricultural soils in the Wye catchment every year. This is equivalent to a rate of 11 kg P/ha/yr, which is considerably higher than the UK national average of 7 kg/ha/yr[2].

* Adaptive Capacity: The preconditions that allow systems to adjust to potential damage, take advantage of opportunities or to respond to shocks and stresses.

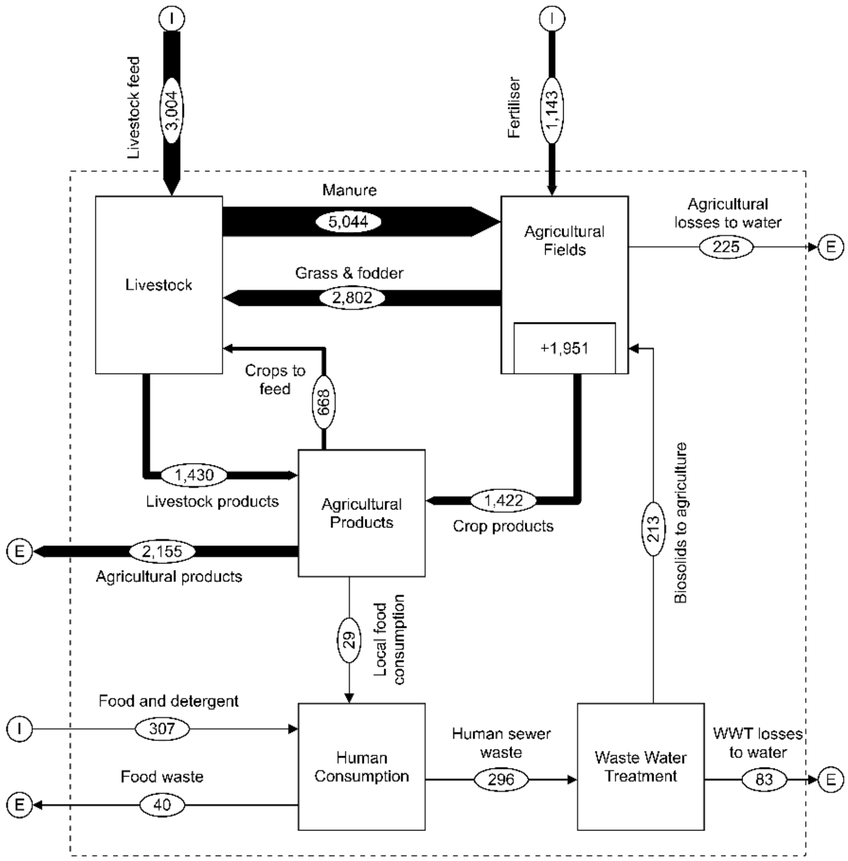

Figure 1: Phosphorus substance flow diagram for the Wye catchment developed using STAN software. All data are mass of elemental P in tonnes per annum, the dashed line represents the catchment boundary, and the flow line thickness is proportional to the magnitude of the flow.

The use of some regional level data (e.g. for fertiliser P use) for the SFA does introduce some uncertainty. Current local information also suggests that the chicken population in the catchment may now actually be nearer double that reported in the 2016 census used in the SFA. If that were correct, then feed P imports would likely be ~2200 tonnes greater and both the manure flow and annual surplus would increase by ~1300 tonnes P which would mean an annual surplus P accumulation rate of 18 kg/ha. Similarly, movements of poultry manure into and out of the catchment are difficult to quantify and are currently assumed to cancel each other out.

Significant agricultural soil P surplus is not only wasteful, but poses an increased risk of diffuse pollution to watercourses[3,4]. Bringing the catchment into a net-zero P balance will require (using 2016 livestock numbers) significant change in P use practice roughly equivalent to not applying any P fertiliser and half of the poultry manure P. However, historic overapplication has resulted in large legacy P reserves in the Wye soils which also poses a P loss risk. Reducing these legacy P reserves would require the catchment to be in a negative P balance, requiring further major changes to current practice.

(b) Links between P input pressure and river P pollution

To investigate the link between P input pressure and river P pollution, NAPI values for the NUTS 1 level regions of Great Britain using regional agricultural and population census data for 2016 was compared with average annual river P concentrations and fluxes measured at sites withing the national Harmonised Monitoring Scheme (HMS).

A clear relationship between regional NAPI and HMS measured P flux to rivers was found for both human and agricultural components (Figure 2, panels a, b, c). Regions with the highest agricultural P input pressure were those with high livestock populations and manure P production. The South-East region was an outlier in the human P pressure/P flux relationship owing to a particularly high population density (includes London) but a high P removal efficiency at wastewater treatment works in the region. There is also a relationship between the monitored P flux and the flow weighted mean P concentration (Figure 2, panel d), except for the outlier North-West region which has a very high P flux, but also high rainfall diluting the river P concentration.

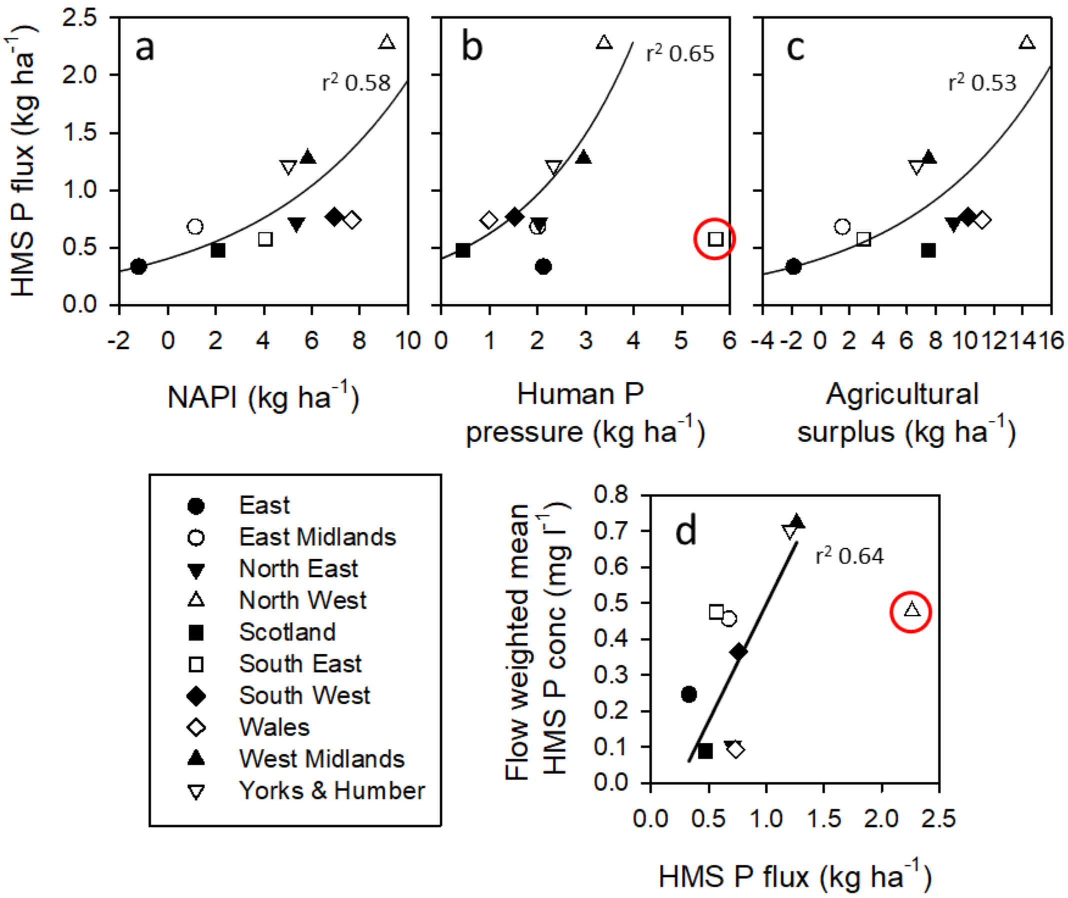

Figure 2: The relationship between Net Anthropogenic Phosphorus Input (NAPI) and annual riverine P flux estimated from the Harmonised Monitoring Scheme (HMS) (panel a); human P pressure and P flux (panel b); agricultural surplus and P flux (panel c); and P flux and flow weighted mean riverine P concentration (panel d) for each of the NUTS level 1 regions in GB. Outlier data points circled in red were omitted from the curve fit.

Similarly, within Northern Ireland (NI), where major river water quality failures are due to high P fluxes in a livestock dominated region, there is a strong relationship between livestock density, the P surplus and the distribution of P-rich soils (> 26 mg/L Olsen-P) in various sub-catchments and their draining river P concentrations[4] (e.g. Figure 3a,b).

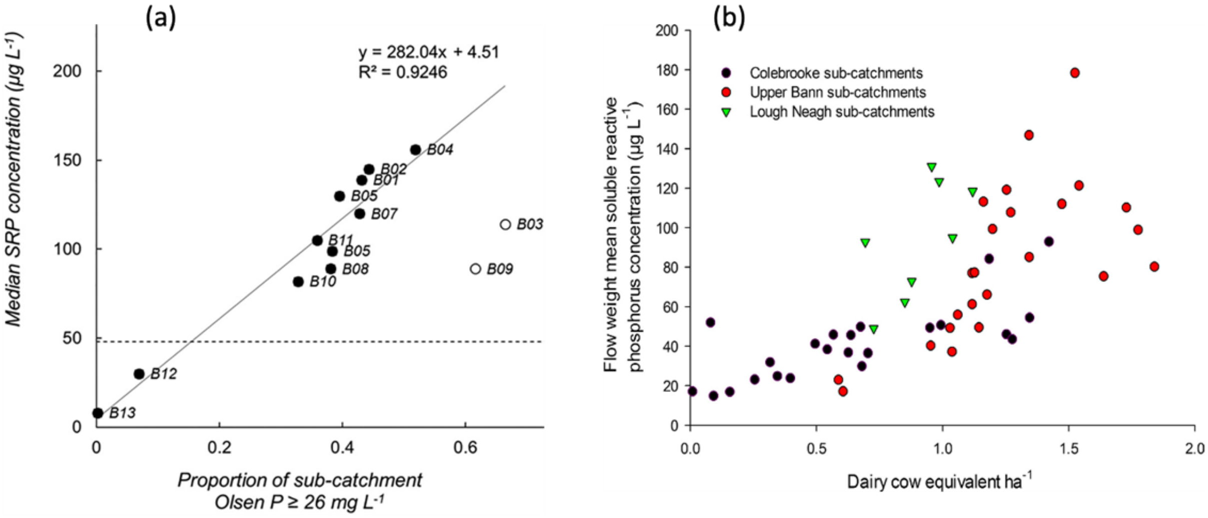

Figure 3: Positive relationships between (a) the distribution of P-rich soils in Upper Bann sub-catchments and (b) livestock intensity in Colebrooke, Upper Bann and Lough Neagh sub-catchments in NI, and the average or flow-weighted concentrations of soluble reactive P (SRP) in draining rivers. The dotted line in panel a represents the WFD target river SRP concentration for good ecological status.

Analysis of the relationship between NAPI and river P concentrations/flux for the previously researched catchments in the Wye catchment, and more widely across the UK, is not yet complete, and unlike NI, is confounded by (a) a water quality monitoring programme of poor coverage and resolution, and (b) a lack of high-resolution crop and fertiliser census data to accurately calculate NAPI for a given catchment boundary. A temporal analysis of river P concentrations at the catchment outlet (Figure 4) suggests P losses in the Wye catchment may be gradually rising again after a period of improvement following the introduction of P removal at large wastewater treatment centres[5].

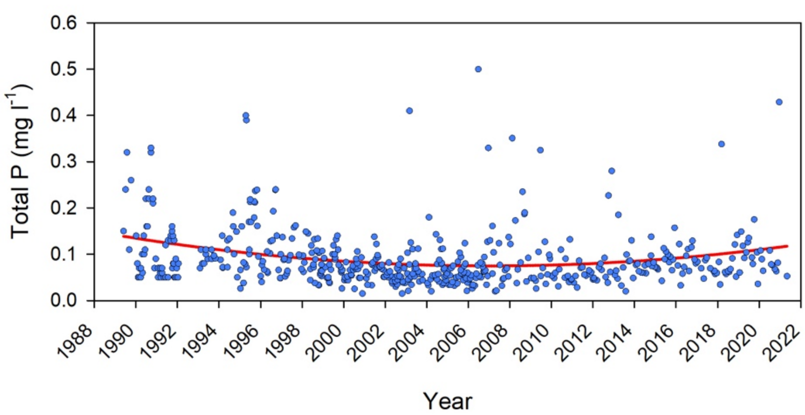

Figure 4: The concentration of total phosphorus (P) at the outlet of the Wye (Redbrook) from 1989 to 2021 (data provided by Natural Resources Wales).

(c) Drawing down Legacy Soil P Reserves

A pot trial was conducted at Lancaster University under controlled conditions to assess the potential agronomic availability of legacy P stores in representative soils from the projects three study catchments. Soils in the Wye catchment exhibit much greater concentrations of soluble reactive P (SRP)* in the soil pore water when soil P (measured as plant-available Olsen P) was above ca. 11 mg/kg, compared to the other catchment soils (Figure 5, panel b). Data on the current distribution of soil Olsen-P across the catchment is still being gathered, but the trial results confirms previous work showing that the Wye soils are still P leaky at the agronomic optimum[3,6].

Trial results also indicate that drawing down soil P levels to at least the recommended agronomic optimum Olsen-P level (equivalent to 18 to 29 mg/kg in this trial) by omitting P inputs would confer no yield penalty, and that legacy P stores provide a source of P to crops for a number of years (e.g. a soil with a mid-Index 3 Olsen P could supply 6-7 years typical crop harvest offtake before P deficiency is likely).

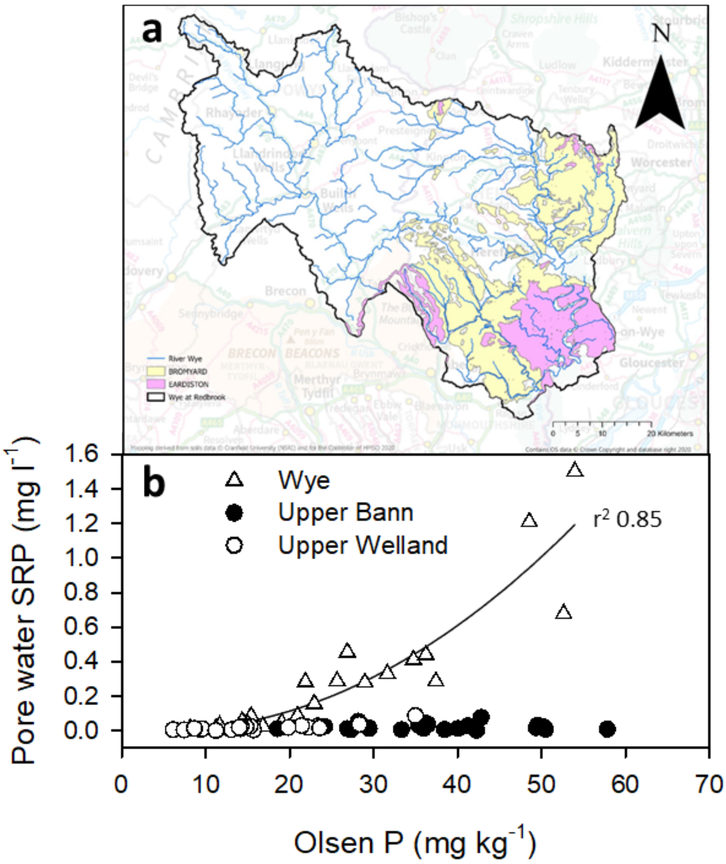

Figure 5: Catchment map showing extent of soil area covered by the legacy P trial in the Wye catchment (panel a) and the relationship between soil Olsen P status and soluble reactive P (SRP) in the soil pore water (panel b) for soils sampled from the Wye, Upper Bann, and Upper Welland catchments.

*Soluble reactive P (SRP) is the main form of dissolved and bioavailable P in the water column and analogous to the WFD targets for good ecological status in freshwaters

(d) Stakeholder Adaptive Capacity

A series of workshops and interviews was undertaken with stakeholders within the study catchments to assess the potential for system change[7,8]. This adaptive capacity analysis showed that providing catchment farmers and water companies (i.e. those key stakeholders who directly manage pollutants and impact water quality) with effective regulatory, training, incentive, technical and infrastructure support is key to effective water quality management. Other organisations, such as those involved in the hands-on delivery of Catchment Sensitive Farming and land stewardship schemes which are showing some encouraging signs of success, also play an important role as key enablers of adaptive capacity. Key to these small-scale successes is the trust built by face-to-face activities with demonstrable results. For example, questionnaire replies to an EU-funded soil sampling scheme in NI suggest such activity has resulted in definite behavioural changes in relation to type (86% of respondents) and amount of fertiliser used (68%), lime usage (80%) and slurry management (28%)[8]. However, these enabling activities require a substantial and sustained increase in funds, staff, and other resources to operate at scales that will meaningfully improve general understanding and P management to improve water quality, especially given the long lag-times between changes in practice and measurable improvements in water quality.

Key Recommendations for Action

- Policies to mitigate river P pollution should change emphasis and seek to reduce the P input pressure on catchments *in addition* to the current emphasis on mitigating transport and delivery of P from land to water. Catchments cannot continue to absorb annual P surpluses without risk of long-term endemic P loss.
- Better enforce and support existing regulation (e.g impending Water targets and existing Farming Rules for Water) with policies, tools and governance towards achieving net zero P surplus at catchment and regional scale
- Reduce livestock manure P loading through a reduction in animal numbers and by processing manure to produce renewable fertilisers to replace imported fertiliser, and by exporting manure to other regions.
- Provide incentives to draw-down areas of high-risk P-rich soils to at least the agronomic optimum.
- Provide a stronger evidence base of the link between farming and sector activities, the P surplus and river P pollution by investment in better quality and higher resolution river monitoring programmes and land use and farm census practice data (including fertiliser P application rates) to accurately quantify P stores and flows.
- Substantially scale-up and provide for stable resourcing and long-term funding of local catchment officers, complementary land stewardship schemes and permanent knowledge sharing and coordination platforms to build stakeholder trust and understanding of P issues, and support uptake of both incremental and more transformative structural changes in practice.

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