British Egg Industry Council

SOIL AND WATER QUALITY DIRECTLY ASSOCIATED WITH FREE RANGE EGG PRODUCTION UNITS WITHIN THE WYE AND USK CATCHMENT AREAS

A report prepared by RSK ADAS Ltd

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ADAS GENERAL NOTES

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EXECUTIVE SUMMARY

There is a general concern over water quality in the UK and in recent years, a particular focus on pollution issues in the catchment areas of the rivers Wye and Usk in England and Wales. Despite the protected status of these rivers, there have been reports of algal blooms, eutrophication and ecological decline. These are indicative of an over-abundance of nutrients such as nitrogen and phosphorus in the water.

Water quality in the Wye and Usk is affected by a multitude of factors, including current and a legacy of residential development, industry, agriculture and climate change. The poultry sector has been implicated as a possible contributor. This may be because the apparent decline in water quality in these rivers has coincided with substantial growth in poultry numbers in the locality. This has involved expansion of both egg and chicken production.

The scope of this report covers the egg sector only. There has been a major UK move to free range egg production systems in recent years in response to changing consumer and retailer requirements. Free range egg production is mainly in the hands of family-run farming businesses that have diversified into poultry either alongside or instead of other enterprises. Free range houses allow birds outdoor access during the daytime. A specific concern raised is that run-off from these land areas and from hardstanding around the houses can lead to water contamination of local rivers.

The aim of this study was to assess nutrient levels in soils from land that is used for free range egg production and in watercourses that collect water draining from this land. The British Egg Industry Council (BEIC), working with egg packers identified 'high risk' free range egg production farms in the Wye and Usk catchment area. The risk assessment was based on the location, topography and history of the operation. The age of the units was not recorded, in terms of the number of years of continuous production but they were considered well-established and likely to have been in production for at least five years. A total of 17 sampling visits were made by ADAS to 14 different farms.

Soil sampling on the range followed conventional sampling protocols. Soil samples were collected from one end of the range to the other in a 'W' shape pattern. A minimum of eight soil samples (approximate depth 7.5cm) were collected on each occasion and these were aggregated into a single composite sample for testing. A 'control' soil sample was also collected from a nearby area of grassland that was, as far as possible, not grazed by livestock or in receipt of manure or fertiliser applications. These areas could include verges or waste land. Following a 'W' shape pattern was not always possible for control samples. In total, soil data are available from 17 range and 17 control samples.

Suitable locations for water sampling were identified by ADAS, the aim being to collect an upstream and a downstream sample from a watercourse as close as possible to the point(s) of entry of water from the range land. The timing of water sample collection was particularly important, since water had to be flowing through ditches and streams adjoining the farm. Periods of drought had to be avoided, as did times when poultry housing orders were in place in response to avian influenza. For these reasons, the sampling period was extended and covered a period of almost two years, from July 2021 to June 2023. On some occasions, it was not possible to collect water samples during visits and so three farms were re-visited when conditions were considered more suitable. In total, water data are available from 11 upstream and 11 downstream samples.

Soil and water samples collected by ADAS were analysed by NRM Laboratories. For soil, a standard suite of analyses was undertaken, comprising pH, phosphorus, potassium and magnesium. For water, analyses were for total phosphorus, dissolved phosphorus, total potassium, nitrate nitrogen and ammonium nitrogen. Biochemical oxygen demand (BOD) and faecal indicator organisms (FIO) were

also assessed to provide a guide to organic pollution. Sample results were returned to ADAS for aggregation. No meaningful comparison of the microbiological results was possible because of the sensitivity of the microbiological analysis and since the limits of detection reported by the laboratory were changed part way through the project.

The purpose of the soil analysis was to allow comparison between range and control land (and with levels found elsewhere in the country) to determine nutrient levels which might be associated with the use of the land by free range laying hens. Water sampling and analysis was intended to show any changes between upstream and downstream samples which might be attributable to run-off from the range.

Variation in relative levels of dissolved and total P, nitrate and ammonium N and BOD may also provide a possible indication of the source of the P. High total P with low soluble P, high nitrate and low ammonium N, and low BOD suggests the P may be associated with soil input to the water course. High soluble P, ammonium N and BOD implies that the P may be more likely to originate from organic manures, particularly if associated with high or increased levels of coliform bacteria. Mean soil sample results are set out in Table 1 below:

Table 1 Summary of soil sample results (mean of all samples)

	Control	Range area
Soil pH	5.95	6.05
Phosphorus (P) Index (value mg/l)	2 (22.0)	3 (27.5)
Potassium (K) Index (value mg/l)	2+ (188.8)	3 (253.4)
Magnesium (Mg) Index	3	3

Table 1 shows slightly increased P and K in soils on range areas, compared to control. It is important to understand that 'managed agricultural soils' of any kind (including range areas) are generally likely to have higher indices than 'unmanaged agricultural soil' which represented the control samples.

The increase in nutrient levels on the range land is relatively modest. The results are within the range that might be expected of managed agricultural soils across England and Wales, as shown by comparison with the PAAG soil analysis data survey.

Mean water sample results are set out in Table 2 below.

Table 2 Summary of water sample results (mean of all samples)

	Upstream	Downstream
Total P (mg per litre)	0.11	0.07
Dissolved P (mg per litre)	0.13	0.23
Total K (mg per litre)	1.96	2.44
Nitrate nitrogen (mg per litre)	1.43	2.19
BOD (mg per litre)	2.09	1.70
Ammonium nitrogen (mg per litre)	0.07	0.06
Presumptive *E. coli* (cfu/100ml)	425	446
Presumptive coliforms (cfu/100ml)	468	547

The water sample results were more difficult to interpret and some anomalies were apparent in the findings. In particular, the results from one site (sample 12) were both atypical and inconsistent and may reflect analytical error, sampling variability or a combination of both. Specific local issues could also have contributed to the findings and further investigation and re-sampling would be required to clarify this.

Based on all analyses, the mean total phosphorus (P) level in water was lower downstream than upstream but the findings were heavily influenced by sample 12 results. If this sample were removed from the analysis, there would be little difference in total P in the mean upstream and downstream samples. Importantly, the findings do not indicate any noticeable increase in total P in water downstream, compared to upstream.

In total, the results show that the range land of the majority of the units studied does not appear to have any significant direct impact on the quality of the watercourse sampled.

Mean nitrate levels from downstream samples were higher than upstream samples and although the range of nitrate levels was considerable (from 0.1mg/l to 4.4mg/litre), levels were low in comparison with Water Framework Directive limits.

Average BOD was lower in the samples collected downstream of the units but levels and the change in BOD were comparatively low in most of the water samples.

It was not possible to draw any conclusions on the possible origin of P in individual site results from consideration of the relative levels of nitrate N, ammonium N, coliform bacteria and the ratio of soluble: total P.

CONTENTS

1 INTRODUCTION

1.1 Background

This report has been prepared by RSK ADAS Limited ('ADAS') for the British Egg Industry Council (BEIC). It is one of a series of poultry sector initiatives commissioned by BEIC in response to public concerns over environmental pollution and water quality. It is likely that the report will be used by the BEIC in discussions with other parties and so relevant background information has been included.

Public concerns cover a range of issues and locations, but there has been a particular focus on pollution in the catchment areas of the rivers Wye and Usk in England and Wales. Water quality is affected by a multitude of factors, including current and a legacy of residential developments, industry, agriculture and climate change. The poultry sector has been implicated as a possible contributor. This may be because the apparent decline in water quality in these rivers appears to have coincided with substantial growth in poultry numbers in the locality. This has involved expansion of both egg and chicken production.

In the **egg sector**, there has been a major UK move towards free range production systems in recent years. In these systems, laying hens normally have continuous access to a grassed range area during daylight hours. However, they are free to remain in the house where feed and water is provided and perches, litter and nests are available.

Increased numbers of free range egg production units are the result of consumer preference for this egg type, and the decision of many major multiple retailers and others to sell only free range, barn and organic eggs from 2025. Increased *per capita* egg consumption, UK human population growth and very high levels of customer commitment to UK-produced eggs have also been important. The enterprises are largely in the hands of family-run businesses that have diversified into egg production, either alongside or instead of other enterprises. This has typically helped supplement declining income from beef and sheep production or to replace dairy cattle. Eggs from these farms are generally contracted to larger egg packing companies that supply retail and other customers.

In **chicken meat sector,** there has also been expansion resulting from increased demand, linked to the same issues of consumption trends and population growth noted above. Again, there is a strong customer commitment for UK-produced chicken, although in comparison with eggs, imported meat accounts for a larger percentage of UK consumption. The systems used for producing meat chickens are generally indoor-only, with the birds being raised on concrete floors lined with a bedding of wood shavings or chopped straw. Free range systems are far less common for chicken meat production than they are for eggs.

1.2 Scope of report

The scope of this report covers the egg sector only and specifically assesses the direct effects of birds ranging on free range egg production units in the Wye and Usk catchment area. ADAS was commissioned by BEIC to collect samples of soil from the range areas of free range egg production farms and from nearby areas of un-managed land for analysis. Water samples were collected upstream and downstream from a local watercourse. The work was carried out between July 2021 and June 2023.

The soil and water samples were analysed for nutrient content by NRM laboratories. The approach and the results are provided in this report, together with the broader context and conclusions on the findings. The report is structured as follows:

- The third part of this Introduction (section 1.3) summarises recent issues in relation to the Wye and Usk catchment areas and findings from other studies that relate to the poultry sector.
- Section 2 reviews the key nutrients from agricultural sources that are likely to affect water quality and their main characteristics.
- Section 3 sets out the relevant regulatory context for agriculture in England and Wales, in relation to environmental protection and other voluntary controls that are applied through assurance schemes.
- Section 4 summarises the main agricultural land uses in the catchment area, providing perspective on the scale of different farming sectors.
- Section 5 explains the methodology for the sampling work undertaken by ADAS, covering both soils and water on and around free range egg production sites.
- Section 6 presents the results in terms of soil and water quality.
- Sections 7 and 8 present a discussion of the results and conclusions from the study.
- The Appendices set out the sampling dates and approach (Appendix 1) and detailed results for soil and water samples (Appendices 2 and 3) which are summarised in the main body of the report.

1.3 Recent issues

The river Wye is one of the longest and largest flowing rivers in England and Wales, with a main channel that is 250 kilometres long and draining a catchment area of 4,136 square kilometres[1]. The river Usk in Wales has a main channel over 120 kilometres long and drains a catchment area of 1,358 square kilometres[2]. Both the Wye and Usk have areas that are designated Sites of Special Scientific Interest (SSSI) and Special Areas of Conservation (SAC), with both rivers supporting species that are protected by Council Directive 92/43/EEC[3], which covers the conservation of natural habitats and wild fauna and flora.

Good water quality is vital to ensure the ecological health of rivers, supporting the wildlife species that live there and maintaining the ecosystem services they provide, such as potable drinking water and places for recreational activities. However, eutrophication is becoming an increasingly common phenomenon in bodies of water across the UK[4]. This is described as a severe ecological condition, brought about by an over-abundance of nutrients in water, causing excessive algal and plant growth.

In recent years, there have been reports of algal blooms and ecological decline both in the Wye and the Usk, despite their protected status. Recent NRW figures reported by Monmouthshire County Council (2023) have shown that 88% of the river Usk's water bodies failed to meet the required target for phosphate levels, with 67% of the river Wye's water bodies failing, whilst water column nitrogen concentrations were also found to be excessive[5]. Excessive nitrogen in potable water can be a risk to human health although the levels found are understood to be well below legal limits and therefore implications are likely to be ecological rather than human health related. Both nitrogen and phosphorus contribute to algal blooms and eutrophication[6].

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[1]https://naturalresources.wales/media/663017/SSSI_1342_Citation_EN00132f4.pdf
[2]https://naturalresources.wales/media/663716/SSSI_1425_Citation_EN0016492.pdf
[3]https://www.legislation.gov.uk/eudr/1992/43/data.pdf
[4] https://www.gov.uk/government/publications/eutrophication-risk-in-english-rivers-under-climate-change
[5]https://www.monmouthshire.gov.uk/planning/water-quality/
[6] https://www.sciencedirect.com/science/article/pii/S0048969700003739

Water quality in the Wye and Usk is affected by a multitude of factors. According to comprehensive sampling undertaken by the Environment Agency in 2021, 329 analyses of samples taken from rivers that feed into the Wye failed to achieve a 'good' rating in measured parameters, such as phosphate or dissolved oxygen levels. Of these poorer traits, 63 were attributed to arable farming activities, 43 to livestock farming activities (all species) and 14 from wastewater treatment activities, with a certainty of 'confirmed' or 'probable'. This was from a total of 152 such samples where the failure could be attributed to a source with the same level of confidence[7].

A report by the Environment Agency (2022) stated that a positive but very weak correlation (R^2=0.04) exists between the number of poultry units in a river catchment and corresponding river orthophosphate levels. However, it stated that current data are too incomplete to support or refute any statistically significant relationship between them[8]. The report noted that further investigation is needed to better understand any potential relationship between the poultry units and river nutrient levels in the Wye.

Previous studies have also noted the effects of manure application on agricultural land leading to nutrient run-off and subsequent water quality issues[9]. In comparison with other organic manures, poultry manure has a relatively high nutrient content[10]. In England, pollution from agriculture and rural land management is considered the biggest contributor to poor water quality in the river Wye[11] but this may simply reflect that this is a rural catchment with comparatively few non-agricultural sources.

Public awareness of, and concern for, river pollution has increased in recent years. This has included efforts to raise awareness of what are seen as the impacts of poultry units and to tackle them. In February 2021, River Action UK launched a campaign in relation to the poultry industry, which aimed to increase public awareness of what they saw as the link between agriculture and river pollution. They have since put forward an action plan that includes a ban on the construction of new livestock production units in the catchment, a nutrient runoff mitigation plan for free range egg producers and the closure of any non-compliant agricultural facilities[12].

The River Action UK campaign in 2021 was aimed at what were referred to as the 'intensive poultry industry'. The term 'intensive poultry unit' has been used to describe developments that are seen as the cause of pollution problems but there is no single, precise definition. In UK environmental permitting legislation, it may be a unit with over 40,000 bird places (broilers or laying hens). Above this threshold, units must hold a permit to operate from the Environment Agency (in England) or from Natural Resources Wales.

Many current free range egg production units operate below the threshold number of 40,000 places for permitting. Assurance scheme requirements limit the house capacity to 16,000 laying hens for free range production. A unit of two houses (32,000 birds) is commonplace although larger units with three houses (48,000 birds) or more do exist.

In terms of planning for new developments, the threshold for preparing an environmental impact assessment is 60,000 for laying hens (85,000 birds for broilers). In some cases, additional planning stipulations may need to be met for units below these thresholds. Within the Wye and Usk Special Areas of Conservation (SAC), water quality concerns due to pollution mean that any new development (including any poultry unit) requiring planning consent must demonstrate under Council Directive

[7] https://environment.data.gov.uk/catchment-planning/ManagementCatchment/3117/rnags
[8] https://consult.environment-agency.gov.uk/west-midlands/river-wye-water-quality/supporting_documents/Wye_Report_Q1_2022_23.pdf
[9] https://iwaponline.com/wst/article-abstract/48/10/217/10344/Impact-of-agricultural-practices-and-river
[10] https://www.cropfertilityservices.com/chicken-manure-vs-cow-manure/
[11] https://environment.data.gov.uk/catchment-planning/OperationalCatchment/3014/print
[12] https://riveractionuk.com/Campaigns/a-plan-to-save-the-wye/

92/43/EEC (see above) that, overall, it achieves 'nutrient neutrality' and has no further adverse effect on the protected site area. This will be possible if the farm can show that the overall net export of pollutant produced (phosphate in the Wye and Lugg, phosphate and nitrate in the Clun, ammonia universally) does not increase from its existing condition.

Where proposals do not necessarily achieve a direct net decrease, the approach of nutrient neutrality allows the developer to employ mitigation measures to ensure an overall net decrease. For example, this may be achieved if manure is exported from the catchment.

The Brecon and Radnor Branch of CPRW (Campaign for the Preservation of Rural Wales)[13] has launched a petition to control the intensive poultry industry in Wales (September 2022). It states that poultry manure is a potent pollution risk if inappropriately stored, spread or transported and this would be confirmed by other information sources and technical experts. It notes too that *'water contamination may also arise as a result of run off from outdoor ranges and hardstanding, shed washing, soil erosion and contaminated waters from shed roofs'*. It further states that growth in the poultry industry has coincided with a rise in phosphate levels in several of the county's rivers, including the Wye, the Lugg and the Ithon.

A number of news reports have also implicated diffuse agricultural pollution as responsible for water quality issues in the river Wye, including the expansion of free range egg production[14]. In an article in the Observer newspaper (14 January 2024), the Wye and Usk Foundation attribute current poultry sector challenges to *'historic poor planning decisions, such as when the planners have insisted the units be located too close to watercourses'*.

A recent report by Onward UK (a non-profit think tank) cited a correlation between the increasing number of poultry units in the area and increasing phosphates in the river Wye. The report recommended that government should introduce poultry manure management grants to tackle the issue[15]. Furthermore, companies such as Tesco and Avara Foods (a leading meat chicken producer in the UK) have announced plans to reduce the impact of their supply chains on water quality in the river Wye[16,17].Noble Foods (the largest UK egg packer) has also announced initiatives in the area[18]. In the Observer article referred to above, the Environment Agency states that *'we are already offering a wide range of support to farmers to speed up their transition to more sustainable practices.'*

In October 2023, River Action UK was granted permission for a judicial review[19] against the Environment Agency, claiming that it has acted unlawfully by not enforcing the Farming Rules for Water[20]. They claimed that had this legislation been fully enforced, the substantial increase in levels of phosphorus in the soil across the catchment could have been substantially mitigated. This, they stated was a major cause of the river's algal blooms. In a recently published judgement[21] on 24 May 2024, it was concluded that *'the grounds of the claimant's application for judicial review do not succeed'.*

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13 https://www.brecon-and-radnor-cprw.wales/?page_id=2211
14 https://www.brecon-and-radnor-cprw.wales/wp-content/uploads/2020/06/200621_Sunday-Times_Wye-crisis.pdf
15 https://www.ukonward.com/wp-content/uploads/2023/12/Onward-Greener-Pastures-16.12.23-2.pdf
16 https://www.poultrynews.co.uk/health-welfare/avara-foods-makes-progress-on-plan-to-protect-river-wye.html
17 https://www.thegrocer.co.uk/tesco/tesco-winds-up-partnership-with-wwf-as-it-launches-new-nature-plan/685780.article
18 https://www.noblefoods.co.uk/nature-based-solutions-for-farmers-in-the-wye-usk/
19 https://riveractionuk.com/river-action-wins-landmark-court-ruling/
20 https://www.gov.uk/government/publications/farming-rules-for-water-in-england
21 https://www.judiciary.uk/wp-content/uploads/2024/05/River-Action-v-Environment-Agency.pdf

2 REVIEW OF KEY NUTRIENTS FROM AGRICULTURAL SOURCES

In rivers, lakes and marine waters, nutrients such as nitrogen and particularly phosphorus stimulate the growth of algae. At moderate levels, algae serve as food for aquatic organisms, including fish. However, high nutrient concentration in water systems causes algae to grow excessively and can make water unsafe for drinking. It also affects the natural ecosystem and can lead to depletion of the oxygen in the water, the process known as eutrophication. This has negative consequences for biodiversity, fisheries and recreational activities.

An overview of the characteristics of the main nutrients of interest is set out below.

2.1 Nitrogen

Nitrogen (N) is a vital component of all plants as it is a major component of chlorophyll, the compound by which sunlight energy is used to produce sugars from water and carbon dioxide (photosynthesis). It is also important as a major component of amino acids (the building blocks of proteins), of energy-transfer compounds and as a significant component of nucleic acids such as DNA which allows cells to grow and reproduce[22].

Nitrogen in the soil is therefore needed for plant growth and it generally exists in three forms, namely i) organic nitrogen compounds; ii) ammonium (NH_4^+) ions and iii) nitrate (NO_3^-) ions. However, if excess nitrogen is applied to fields from manures or synthetic fertilisers, water pollution may occur. Nitrates or organic nitrogen compounds enter groundwater through leaching and reach surface waters via runoff from agricultural fields. A high level of nitrate makes water unsuitable for drinking and elevated levels pose a risk to human health. The UK's legal drinking water standard for nitrate is based on the WHO's guideline which is 50mg per litre.

Nitrogen can go through many transformations in the soil, these processes being collectively referred to as 'the nitrogen cycle.' At any one time, 90-95% of the potentially available nitrogen in the soil is in organic form. This may not be directly available for plants, but it can be broken down by micro-organisms to the crop-available forms of ammonium and nitrate nitrogen.

The nitrate form of nitrogen is highly soluble. This means that it leaches easily when excess water percolates through the soil. This is because nitrate ions do not bind to the soil solids, as they carry negative charges and they therefore remain dissolved in the soil water. The readily available nitrogen content of livestock manures varies with species, diet and bedding material (when provided). Poultry manures (along with cattle and pig slurries and anaerobic digestate) have relatively high available nitrogen contents (over 30%) in comparison with farmyard manure.

Several factors determine whether and to what extent nitrate leaches into the groundwater from manures deposited directly onto the range land from free range laying hens. In general, ensuring that the nitrogen input (from manures or fertilisers) matches crop need is key and the presence of an actively growing vegetative cover of grass or other crops on range land is preferable. Soil type also has a significant impact on nitrate leaching. In free draining sandy soils, nitrates can leach much more easily than on silty and clay soils.

[22] https://www.cropnutrition.com/nutrient-management/nitrogen/

2.2 Phosphorus

Phosphorus (P) is an essential nutrient for plants, as it is a part of several key plant structure compounds and a catalyst for numerous biochemical reactions, notably photosynthesis. Phosphorus is a vital component of the nucleic acids DNA and RNA which carry genetic material; the structures of both are linked together by phosphorus bonds. Adenosine triphosphate (ATP) which is formed during photosynthesis and is known as the 'energy unit' of plants both for storage and use, contains phosphorus in its structure.

The phosphorus content of soils is variable and many different factors can influence it. These include the material from which the soil is derived, the degree of weathering and erosion, climatic conditions, crop removal and fertiliser application. Phosphorus exists in organic and inorganic forms. Organic phosphorus is found in plant residues, microbial tissues and manures, whereas inorganic forms consist of apatite (the original source of all phosphorus), complexes of iron and aluminium phosphates, and as phosphorus absorbed onto clay particles. Phosphorus uptake by plants is as orthophosphate (H_xPO_4) which is negatively charged. Its availability is severely affected by low or high soil pH, therefore maintaining agricultural soils at pH 6.0-7.0 is essential to ensure maximum crop uptake.

Arable farming is believed to significantly contribute to orthophosphate (the simplest and most common soluble phosphate ion) concentrations within these rivers, due to drainage water and 'clear' surface run-off. Any soil erosion is likely to carry sediment and can contribute to insoluble phosphate.

Unlike nitrogen, phosphorus moves very little in mineral soils, staying close to its place of origin. As a result, little phosphate is lost by leaching. The most significant pathways to water sources are through soil erosion and surface run-off[23].

According to a report by the Environment Agency[24], over the last 70 years there has been a surplus of phosphorus inputs applied to agricultural land through fertilisers and manures. This has created a large 'legacy' reserve of phosphorus in soils, which increases the risk of pollution. In recent decades, there have been significant reductions in the use of phosphate fertilisers, due to increasing prices and improved efficiency of manure use. It is also understood that there may have been a reduction in the phosphorus content of poultry manure over the years due to the use of feed enzymes and changes in nutrition and feed efficiency.

The underlying problem may still be the total amount of phosphorus imported into certain locations in the form of livestock feeds. If the resulting livestock manures contain more phosphorus than is needed locally for crop production, they must be exported for land spreading out of the area or utilised in alternative ways. Otherwise, there is likely to be an accumulation in soils and losses to the aquatic environment. According to a report by Lancaster Environment Centre, in 2021[25], approximately 6,500 tonnes of phosphate was imported to the Wye valley, mostly as livestock feed (5,300 tonnes). Around 3,500 tonnes of this (48%) were exported as agricultural products (e.g. meat, milk, eggs, wool etc.), suggesting that the soil phosphorus efficiency for the catchment is around 52%.

Agricultural soils used for grassland or arable have a target phosphate index of 2 (16-25 mg per litre) for optimum economic crop yield and production. Index 3 (26-45 mg per litre) may be appropriate for certain vegetables. The land manager's task is generally to maintain soils at index 2, through maintenance applications of phosphate or replacing the phosphate off-take when crops are removed and harvested. When phosphate indices rise above index 2, there is generally no additional economic benefit to the crop, and the risk of phosphate losses rises. Due to the immobility of P in the soil,

[23]https://www.cropnutrition.com/nutrient-management/phosphorus/
[24]https://consult.environment-agency.gov.uk/++preview++/environment-and-business/challenges-and-choices/user_uploads/phosphorus-pressure-rbmp-2021.pdf
[25] https://councillors.herefordshire.gov.uk/documents/s50101856/RePhoKUs_Wye_Report_310522.pdf

placement of P fertiliser close to seeds of some crops (notably maize), can give an economic benefit even where P indices are above target.

2.3 Potassium

Potassium (K) is the third major nutrient required by all crops. It is present in large quantities in plants in the form of the cation K^+. It is an essential nutrient for ensuring maximum economic yield, it ensures a balanced approach to crop nutrition and influences crop quality. Its role is fundamental to many metabolic processes because it activates numerous enzymes required for chemical reactions, including the synthesis of proteins and sugars required for plant growth. Other roles include helping plants resist lodging (by influencing osmosis and turgor pressure) and helping to maintain a rigid, upright structure (by cell wall construction). Potassium is also important in regulating the opening and closing of stomata. These are tiny apertures on the underside of leaves that allow the movement of carbon dioxide into the plant and the release of oxygen and water vapour. In short, a deficiency of potassium in crops results in lower nitrogen use efficiency, greater drought susceptibility, increased lodging, reduction in photosynthesis and restricted movement of water, nutrients and sugars around plants[26].

Potassium behaves similarly to nitrogen within the soil and is much more mobile than phosphorus. Potassium is lost through the soil by leaching, although amounts are generally very small. The concentration of potassium in UK rivers rarely approaches 10mg per litre with the EC Drinking Water Directive setting a maximum admissible limit of 12mg per litre. Unlike nitrogen and phosphorus, losses of potassium to water are generally not an environmental concern in the UK[27].

2.4 Magnesium

Magnesium (Mg) is classed as a secondary nutrient for plants, whereas nitrogen, phosphorus and potassium are primary nutrients. Standard soil or manure analyses generally include magnesium though because a deficiency can affect both crop quality and yield. Its main roles within plants are forming chlorophyll and enzyme activators. Photosynthesis, protein formation and energy transfer all depend partly on an adequate supply of magnesium. Magnesium is mobile once it is inside the plant and is taken up as the ion Mg^{2+}, meaning it can move from older to younger tissues[28]. Like potassium, magnesium is of no major environmental concern. No guidelines exist for its content in drinking water as no negative human or animal health effects are expected[29].

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[26] https://www.pda.org.uk/the-role-of-potash-in-plants/
[27] https://www.pda.org.uk/pda_leaflets/29-potash-and-the-environment/
[28] https://www.pda.org.uk/magnesium-nutrient-crops-grass/
[29] Magnesium (Mg) and water (lenntech.com)

3 LEGISLATION AND CODES OF PRACTICE

This section summarises the current legislation and industry codes of practice that are relevant to the scope of this report. Different rules apply in England and Wales, and since the catchment area in question extends to both countries, these differences are discussed in this section with a particular focus on poultry manure.

3.1 Control of Agricultural Pollution Regulations (CoAPR) - Wales

The Welsh Government introduced regulatory measures to address agricultural pollution which have applied to all farms in Wales from April 2021. Transitional periods for some measures were put in place, with the final measures to be complied with by August 2024. Prior to the introduction of these rules, only 2.4% of Wales's area was designated as Nitrate Vulnerable Zones (NVZ) where farms were subject to closed periods for spreading fertilisers and manures. The NVZ rules were replaced by the CoAPR and holdings previously in NVZs were expected to be fully compliant with the new regulations from April 2021 and were not subject to the transition periods.

The requirements from April 2021 briefly included:

- Notifying NRW of the construction of new or substantially enlarged or reconstructed silage or slurry storage system.
- Controls on the spreading of nitrogen fertiliser at high-risk times and in high-risk areas.
- Rapid incorporation (within 24 hours of spreading) of some high readily available nitrogen organic manures. Slurry and poultry manure must be incorporated into the soil if applied onto bare soil or stubble.

Closed periods for spreading manufactured nitrogen fertiliser are shown in Table 3.

Table 3 Closed periods for spreading manufactured nitrogen fertiliser in Wales

Land use	Closed period
Grassland	15 September to 15 January
Tillage land	1 September to 15 January

The requirements from 1 January 2023 briefly included:

- All farms spreading organic manure to produce risk maps of the holding, showing areas where organic manures should not normally be spread (i.e. within 10m of water courses or 50m of water sources) and indicating the spreading risk classification of each field.
- All organic manures including poultry manure (other than slurry) to be stored in a vessel, in a covered building, on an impermeable surface, or in a temporary field site. Any liquid arising from the manure is classed as slurry and must be contained. If poultry manure containing no bedding is to be stored in field heaps, it must be covered by an impermeable sheet material.
- A limit of 250kg of total nitrogen per individual hectare from organic manure applied in any rolling 12-month period.
- Records to be kept of all manures applied to, exported or imported from the holding e.g. the quantity and the nitrogen content, which could be obtained from standard figures.
- All holdings to have a Nitrogen Management Plan (NMP).

The requirements from 1 January 2024 are that across the whole holding area, a production limit of 170kg per hectare of nitrogen from all livestock manure must not be exceeded for the 12-month period. Businesses may operate under a licence in excess of 170kg per hectare loading during 2024 if they notify NRW by 31 March 2024 and work in accordance with an Enhanced Nutrient Management Plan and certain other conditions.

The final requirements to be imposed from August 2024 are briefly:

- Closed periods for spreading manures with over 30% readily available nitrogen such as poultry manure and slurries. The closed period dates are shown in Table 4.

Table 4 Closed period dates for grassland and tillage land in Wales

Soil Type	Grassland	Tillage Land
Sandy or shallow	1 September to 31 December	1 August to 31 December
All other soils	15 October to 15 January	1 October to 31 January

- Sufficient storage must be provided for poultry manure produced between 1 October and 1 April on the holding (6 months). This might be in the form of suitably located field heaps.
- Calculations must be available to demonstrate there is sufficient capacity for storage of all manures produced on the holding within the storage period.[30]. Note that planning consent may be needed for manure storage buildings.

3.2 Nitrate Vulnerable Zones (NVZs) - England

Around 55% of land in England is designated as NVZs which are areas draining to waterbodies where the nitrate level in drainage water exceeds the statutory limit of 50mg per litre, or where levels are rising and likely to exceed the limit. A large proportion of the Wye catchment area is within an NVZ. Enforcement is by the Environment Agency and was part of cross compliance requirements until the end of December 2023. The CoAPR in Wales and NVZ regulations in England are very similar with only minor differences in relation to restrictions on manure use in respect of end dates for closed seasons.

As the name suggests, this legislation only refers to nitrogen with no consideration of phosphates. The regulations for phosphate in Wales and England are not aligned.

3.3 Farming Rules for Water - England

Every farming business in England must comply with the Reduction and Prevention of Agricultural Diffuse Pollution (England) Regulations 2018 also known as the Farming Rules for Water, 2018. These rules are intended to reduce the risk of water pollution by ensuring farmers carefully plan manure and fertiliser applications to avoid exceeding the crop or soil need. These rules are enforced by the Environment Agency but their interpretation and enforcement has been subject to a degree of controversy and revised guidance, such that enforcement action is currently unlikely due to a direction by the Secretary of State to the Agency.

Some of the criteria considered under current guidance when inspections are carried out include:

[30] https://www.gov.wales/sites/default/files/publications/2023-10/water-resources-control-agricultural-pollution-wales-regulations-2021-guidance-farmers-and-land.pdf

- Land managers should be able to demonstrate organic and inorganic fertiliser applications were planned, for example by having a nutrient management plan.
- Land managers should show evidence of planning manure and fertiliser applications so that they do not exceed the need of the soil or crop. This is to avoid over-applying manures so that the soil indices are not raised above target levels which would increase the risk of diffuse agricultural pollution.
- Application rates of organic manures with high readily available nitrogen should be limited during certain time periods, as set out in Table 5 below. Unlike in the CoAPR and NVZ regulations, there are no statutory closed periods for spreading these manures, though demonstrating that there is crop need during these periods could be difficult.

Table 5 Time periods when application rate limits apply for high RAN organic manure in England

Soil Type	Grassland	Tillage Land
Sandy or shallow	1 September to the end of February	1 August to the end of February
All other soils	15 October to the end of February	1 October to the end of February

- Land managers should have taken appropriate precautions to prevent agricultural diffuse pollution such as incorporating manures to bare soil or establishing green cover or cover crops prior to the winter[31]

3.4 Poultry sector assurance scheme requirements

Over 90% of all UK eggs are reported to be produced on farms that are part of the BEIC Lion Code of Practice[32]. In addition to requiring farmers to comply with relevant legislative requirements, all farms must develop an environmental policy which includes manure disposal in compliance with legislative requirements. Systems must also be in place to control odour, noise and traffic and to minimise and ensure appropriate storage and disposal of wastes. A plan to maintain and protect biosecurity as well as protect and manage the range for outdoor systems must be implemented. In particular, the Code specifies that poultry manure must not be spread on land to which birds have access. This is for bird health reasons. All sites must also have an up-to-date site plan which shows drainage routes and other features and includes a risk assessment for potential spillage.

Whilst these requirements are generally also included within Environmental Permitting legislation, their presence within the Lion Code of Practice means that they must also be adopted on farms that are below the 40,000 bird place threshold for Integrated Pollution Control permitting.

[31] https://www.gov.uk/government/publications/applying-the-farming-rules-for-water/applying-the-farming-rules-for-water
[32] https://www.egginfo.co.uk/british-lion-eggs

4 LIVESTOCK NUMBER AND LAND USE IN THE WYE AND USK CATCHMENTS

4.1 The Wye and Usk Catchment Area

The catchment area in question is defined in Figure 1 below, showing that the Wye catchment is much larger and extends across England and Wales. The Usk catchment is smaller and within Wales only.

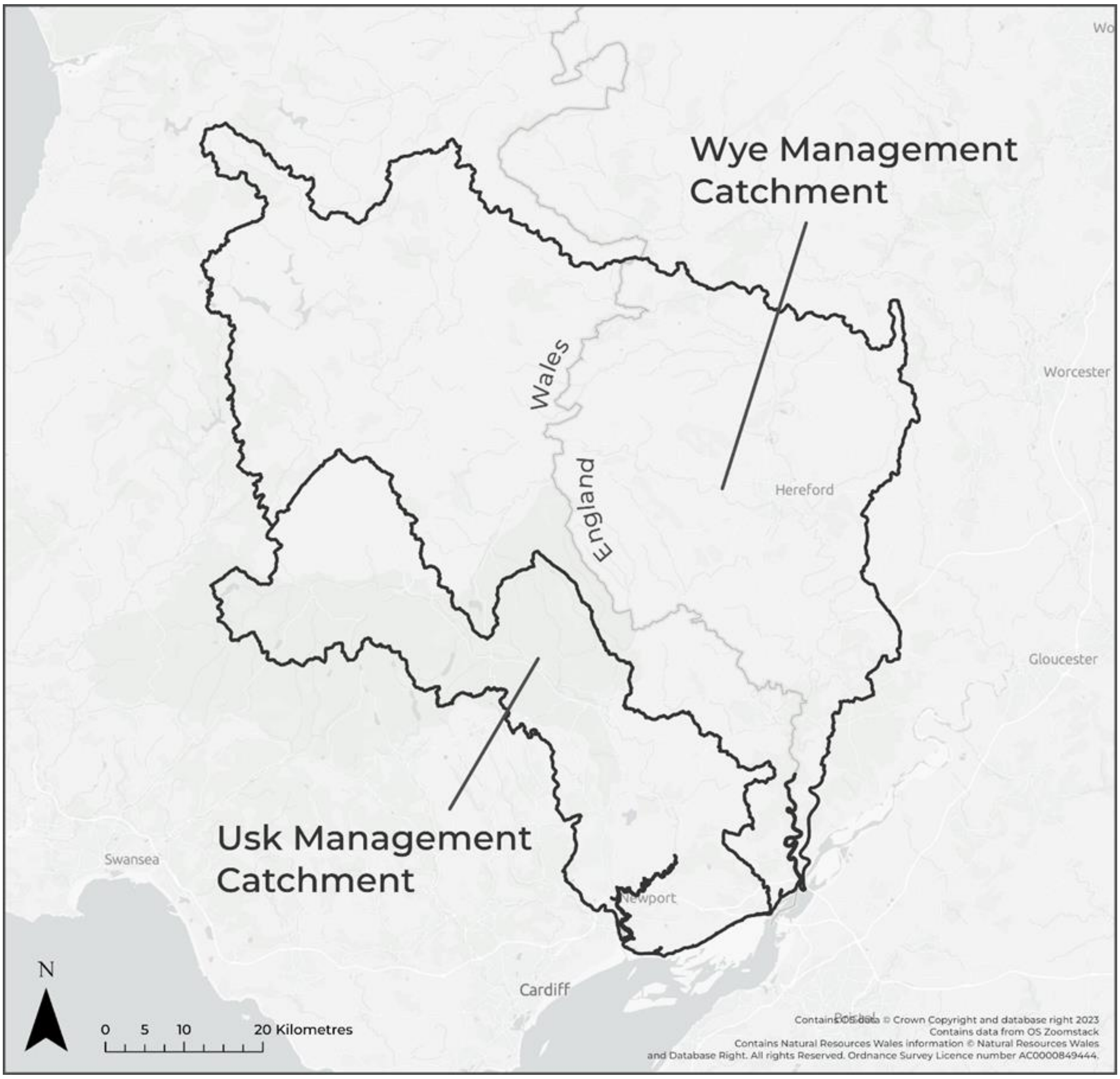


Figure 1 The Wye and Usk Catchment Areas in England and Wales

4.2 Livestock numbers

Changes in livestock numbers in the Wye and Usk catchment over a 15 year period between 2005 and 2020 are summarised in Figure 2. This timescale includes the period over which there has been poultry sector expansion. The numbers are taken from June census data for England[33] and Agricultural Small Area Statistics for Wales[34]. The numbers for all poultry (including laying hens) are also set out in more detail in Table 6. From these sources it is not possible to differentiate between the number of laying hens and 'other poultry' within the Wye and Usk catchment.

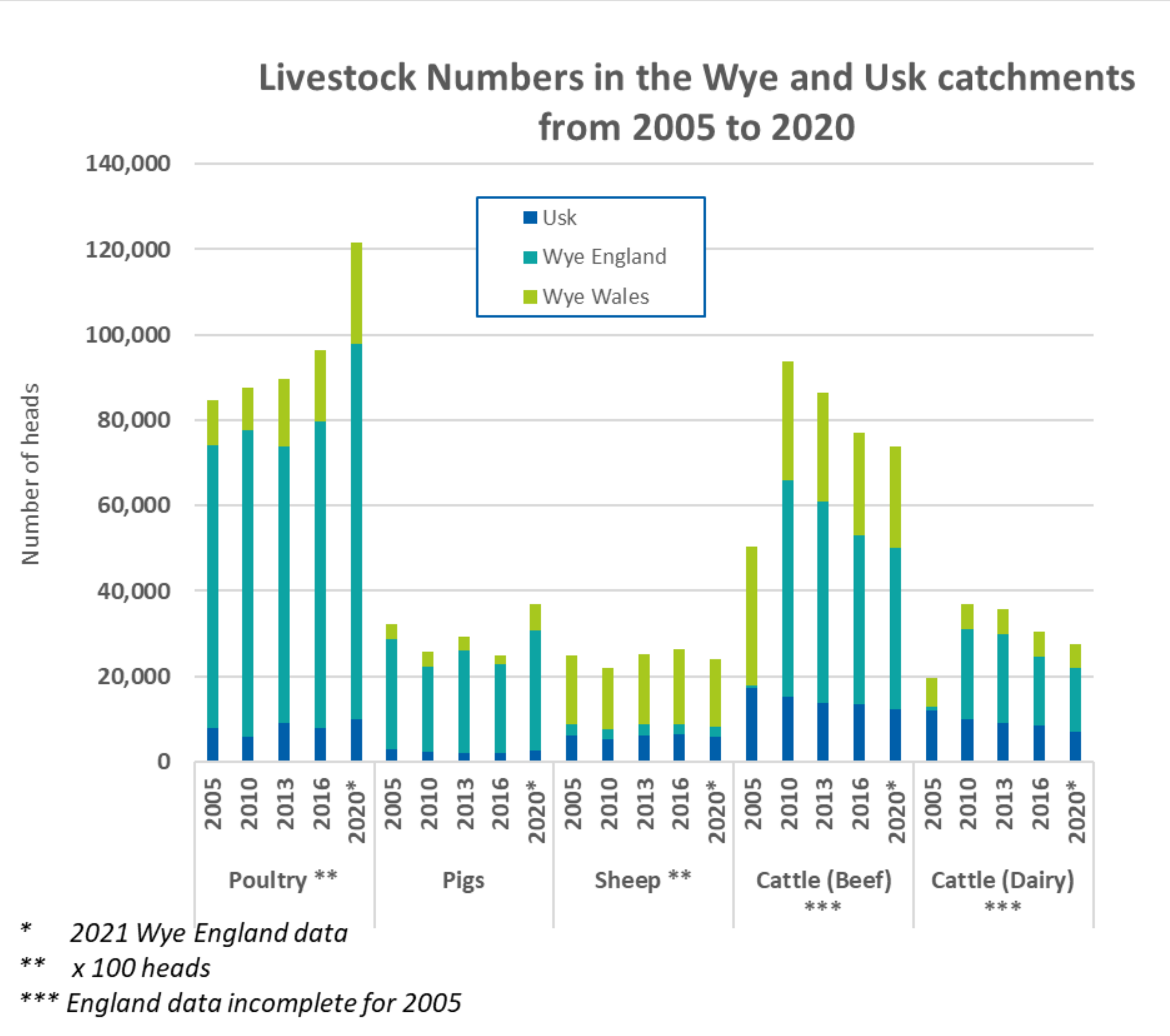


Figure 2 Livestock numbers in the Wye and Usk catchments from 2005 to 2020

33 https://www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june

34 https://www.gov.wales/agricultural-small-area-statistics-2002-2020

Table 6 Summary of total poultry numbers in the Wye and Usk Catchment between 2005 and 2020

	Usk Catchment (Wales)	Wye Catchment England	Wye Catchment Wales	Total
2005	784,723	6,625,220	1,064,620	8,474,563
2010	583,156	7,185,689	985,484	8,754,329
2013	905,852	6,469,501	1,588,568	8,963,921
2016	805,535	7,161,278	1,679,222	9,646,035
2020	998,977	8,789,436	2,379,320	12,167,733

Figure 2 shows that cattle numbers have broadly been in decline since 2010, with reductions in the numbers of both beef and dairy cattle. The number of pigs has remained broadly consistent in England but there has been an increase in Wales. Whilst this increase is equivalent to around 38%, pig numbers in the catchment generally remain low.

The number of sheep has broadly been maintained in numbers from 2005 to 2020 across the Wye catchment in Wales. However, in the Usk catchment, sheep numbers are reported to have dropped by around 14% in 2010 from their 2005 peak, with numbers recovering over subsequent years. Sheep numbers in the Wye catchment in England shrank by around 14% between 2005 and 2021.

Based on the numbers in Table 6, total poultry has increased by around 44% between 2005 and 2020. The data indicate that the largest numbers of poultry are in the Wye catchment in England. The increase in numbers here is around 33%. Whilst numbers in the Wye catchment within Wales are much smaller, they have more than doubled between 2005 and 2020.

From the available data shown in Table 6, it is not possible to identify the number of laying hens within the totals shown for poultry between 2005 and 2020. It is generally accepted that there has been expansion in both the broiler and laying hen sectors over this period. Based on overall UK numbers, there are typically around three to four times more broilers in place than laying hens at any one time. Whilst this may provide some guidance on relative numbers, it should be considered an estimate only since a particular geographical area may not reflect the national situation.

Whilst it may be useful to compare the scale of different livestock sectors in the catchment in terms of ‘livestock units’ the lack of detailed information for poultry prevents an accurate assessment.

Other sources provide different estimates of poultry numbers in the area. For example, the Greener Pastures report by Onward UK (see section 1.3)[35] states that there are now more than 20 million chickens in the Wye catchment. This is said to be up from around 13 million ten years ago. An article in the Times newspaper (23 February 2023) is cited as the source of the figures in this report. Separately, the Brecon and Radnor Branch of CPRW has estimated the likely increase in poultry numbers in Powys (which includes part of the Wye and Usk catchments) based on planning applications since 2016.

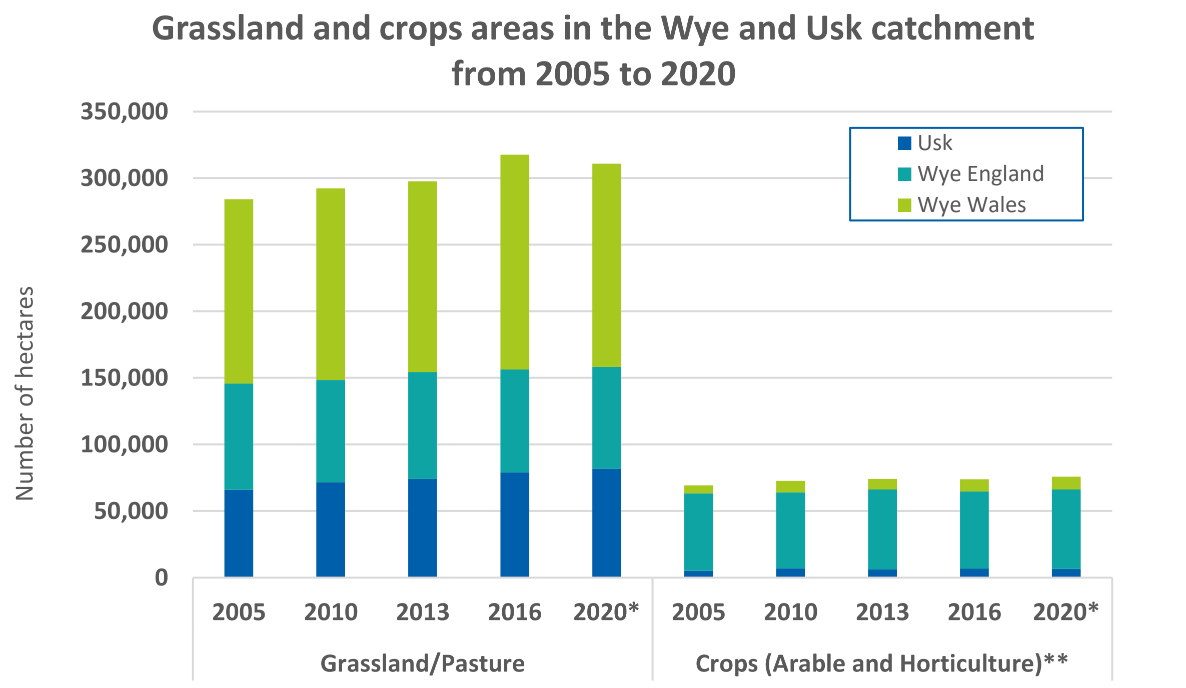
[35] https://www.ukonward.com/wp-content/uploads/2023/12/Onward-Greener-Pastures-16.12.23-2.pdf

4.3 Land use in the catchment

A summary of land use in the Wye and Usk catchments over time is provided in Table 7 and in Figure 3. Grassland / pasture is by far the most common land use and overall, the calculated percentage for 2019/21 (75%) is very similar to the percentage in 2005 (77%). The table also shows how other main activities have changed in the catchment over the same period. The most sustained land utilisation trend across the entire Wye and Usk catchment is the expansion of woodland areas on farms, with wooded area reported to double between 2005 and 2021. Other land utilisation options tended to increase proportionally with the total amount of land considered farmed. According to the statistics, this has increased by around 13% overall between 2005 and 2021 but the definitions and reasons for this are unclear.

Table 7 Land use (hectares) in the Wye and Usk catchment, 2005 to 2019 (Wales) and 2021 (England)

	Grassland / pasture	Wooded	Cereals	Others inc. horticulture and fallow
2005	284,266	14,532	42,723	26,627
2010	292,405	17,822	48,566	24,063
2013	297,757	17,246	42,371	31,825
2016	315,744	25,302	47,832	26,025
2019/ 2021	310,864	29,611	50,115	24,653



* *2021 Wye England data*
** *English data includes fallow, Welsh data excludes*

Figure 3 Land use in the Wye and Usk catchments from 2005 to 2020

5 METHODOLOGY

5.1 Objectives

The aims of the study carried out by ADAS were as follows:

- To assess soil nutrient levels on land that is used for ranging by free range laying hens and to compare these with levels on nearby land that is not accessed by poultry.
- To assess water quality in nearby watercourses that collect run-off from land used by laying hens for ranging. A comparison was made by collecting one water sample upstream of the land and one downstream.
- To assess the soil nutrient results and draw conclusions on the extent to which soils accessed by poultry differed from soils which were not available to poultry.
- To assess the water quality results and draw conclusions on the extent to which nutrient levels differed between the upstream and the downstream samples.

5.2 Selection of sites for sampling

Free range egg production units are generally contracted to a separate egg packing company for sales and marketing purposes. Several different packing companies draw eggs from the Wye and Usk catchment area. The British Egg Industry Council (BEIC) worked with egg packers to identify 'high-risk' free range egg production farms in the Wye and Usk catchment area. The risk assessment was based on the location, topography and history of the egg production operation. Farm and packer details were forwarded to ADAS to arrange sampling. In some cases, visiting arrangements were made between ADAS and the egg packing company; in other cases, ADAS liaised directly with the farm. The location of the farms within the catchment area is kept confidential to ensure that the farms cannot be identified.

5.3 Sample collection planning

All sampling on farm was undertaken by a small team of ADAS consultants. In some cases, a representative of the egg packing company was in attendance, but this was not always the case.

The timing of sampling was important to ensure that the results were representative and relevant. The timing of the water sampling was considered most critical because it needed to be done at times when water was flowing through ditches or streams adjoining the farm. This meant that during times of drought (no water flow), water sampling could not be undertaken. ADAS adopted a flexible approach and arranged summer visits just after periods of heavy rainfall, to ensure that a flow of water was likely.

Sampling also had to be abandoned for extended periods because of the imposition of poultry housing orders in England and Wales in response to outbreaks of avian influenza in the autumn of 2021 and 2022. Sample collection from land and water at times when birds were being kept inside would not have been appropriate. After the housing orders were lifted in the spring of 2022 and 2023, ADAS considered that sampling should not re-commence for at least one month, to allow time for any effects of ranging to re-emerge[36].

5.4 Sample collection

A sampling plan was drawn up by ADAS at the outset so that a consistent approach was adopted throughout the study. Soil sampling was undertaken on the range land associated with one house on the farm. Samples were collected from one end of the range to the other in a 'W' shape pattern. A minimum of eight samples (approximate depth 7.5cm) were taken from these locations and these were aggregated into a single composite sample for testing.

A 'control' soil sample was also collected. This was taken from a nearby area of grassland that was as far as possible not grazed by livestock and not in receipt of manure or fertiliser applications. A suitable area was discussed on-farm and could include verges, waste land or other areas not used for agricultural purposes or not receiving fertiliser or manure applications. Following the 'W' shape sampling pattern was not always possible for the control samples.

A suitable location for water sampling was identified by ADAS, sometimes in conjunction with the farmer. The 'downstream' sampling point needed to be from a watercourse that receives water from the range land. The 'upstream' sampling point was from the same watercourse, as close as possible above the range land. By choosing the two sample points carefully, the aim was to minimise possible external, non-related factors e.g. other farming activities that could influence the results and the comparison between them.

The water sampling methodology was intended to determine the overall impact of the poultry unit upon the quality of water in the local watercourse. Nutrient levels may be higher in water that is sampled from intermediate discharge or drainage points closer to a poultry house i.e. before reaching the watercourse.

Since collection of samples from watercourses was potentially hazardous in some conditions and on certain sites, the aim was to ensure that two people were always present during sampling.

5.5 Sample analysis

After each visit, soil and water samples were forwarded by ADAS to NRM Laboratories[37] to undertake analyses. For soils, a standard suite of analyses was undertaken, comprising pH, phosphorus, potassium, and magnesium. For water, analyses were for total phosphorus, dissolved phosphorus, total potassium, nitrate nitrogen and ammonium nitrogen. Biochemical oxygen demand (BOD) and faecal indicator organisms (FIO) were also assessed to provide a guide to organic pollution of the water environment. For these, samples had to be delivered promptly to the laboratory and this imposed some constraints on sampling days, because of the need to deliver within the same working week.

[36] Housing orders were in place in England and Wales between 29 November 2021 and 2 May 2022. Later in 2022, all birds were housed again from 7 November in England and from 2 December in Wales. Restrictions in both countries were lifted on 18 April 2023.

[37] www.nrm.uk.com

5.6 Reporting

Sample results were returned to ADAS for aggregation. The findings were assessed so that conclusions could be drawn. All results were analysed, and data were summarised into tables and graphs and averages calculated. For all, actual values (mg/l) were used to calculate averages or differences between control and range areas. The values for P, K and Mg were converted to indices using the ranges for each index.

6 RESULTS

Over an extended period between July 2021 and June 2023, results were obtained following 17 visits to free range egg production units within the Wye and Usk catchment area. On six of these visits, it was not possible to collect water samples. This was generally due to there being no available watercourse with water flowing at the time or to the watercourse being inaccessible. It must be noted that the summers of 2021 and 2022 when the majority of samples were taken coincided with dry summers and low water levels. Water temperatures may have been higher after periods of hot weather but this was not recorded.

Three farms were re-visited, to collect water samples following failure to collect a sample on the first visit. Repeat soil sampling was undertaken at the same time to increase the amount of data available for analysis.

Details of the sampling approach are provided in Appendix 1 and a summary of sample collection dates is provided in Figure 4. In total, 14 different farms were visited.

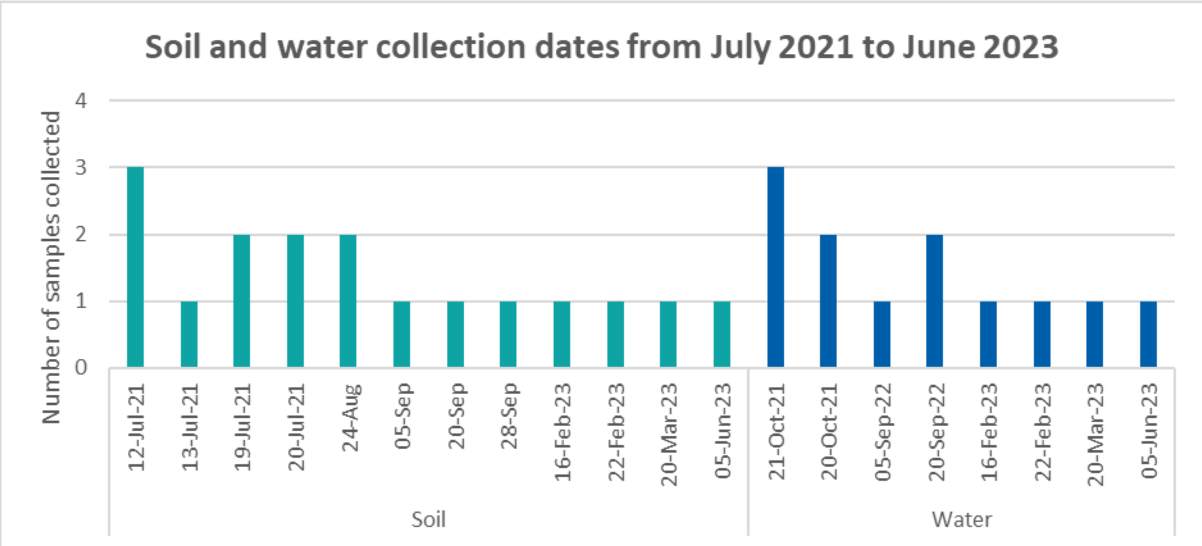


Figure 4 Dates soil and water samples were taken between July 2021 and June 2023

6.1 Soil sample results

Mean soil sample results are provided in Table 8. Individual sample results are shown graphically for pH (Figure 5) and for phosphorus, potassium and magnesium (Figure 6). Individual results for each sample collected are shown in Appendix 2.

Across all farms, the soil pH was between 5.0 and 7.1 (for control) and between 5.1 and 6.9 (for range) respectively. Overall, the average soil pH for the sampled group was 5.95 for control and 6.05 for range areas, which represents a relatively small difference of 0.1. There was no pronounced trend for the range to be lower or higher than the control. The numerical difference may be within the normal margin of error for sampling and analysis. An overview of the pH differences between control and range on each site is shown in Figure 5.

Table 8 Summary of Soil Sample Results (mean of all samples)

	Control	Range area
Soil pH	5.95	6.05
Phosphorus (P) Index (value mg/l)	2 (22.0)	3 (27.5)
Potassium (K) Index (value mg/l)	2+ (188.8)	3 (253.4)
Magnesium (Mg) Index	3	3

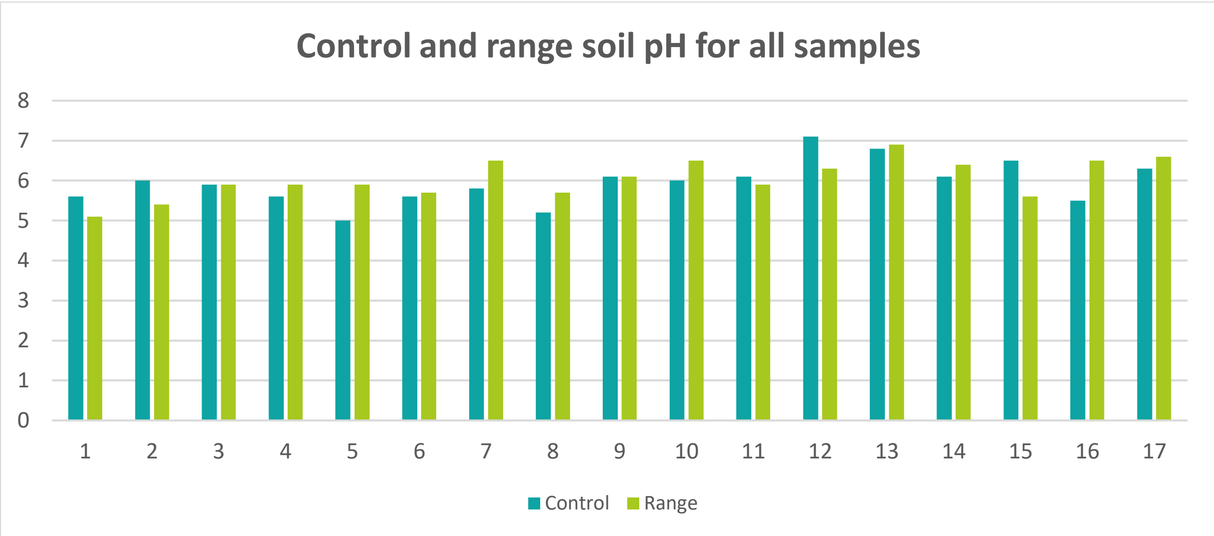


Figure 5 Soil pH control and range for all samples

Table 8 shows that P and K concentrations on average appear to be slightly higher for range areas. As reported by the laboratory, the control samples had an average P index of 2 and the range samples had a P index of 3. However, the average results in mg/l give a more accurate assessment. For P, these values were 22.0 (control) and 27.5 mg per litre (range).

The average K index was slightly higher for range samples (3) than control (2+) and the average value increased from 188.8 to 253.4 mg per litre. For Mg, the index of 3 was the same in both the control and the range samples.

The variation in indices for P, K and Mg in control and range samples is shown in Figure 6.

The overall average P levels for 12 out of 17 samples were higher on the range than the control land. Most of the farms with higher P levels on the range land also had higher concentrations of K. However, this was not the case for sample 4, where K was lower on the range.

Unlike the others, sample 3 had a lower concentration of P and a higher concentration of K on the range. Samples 2 and 13 had a lower concentration of both P and K on the range compared to the control, the opposite finding to that which may have been anticipated.

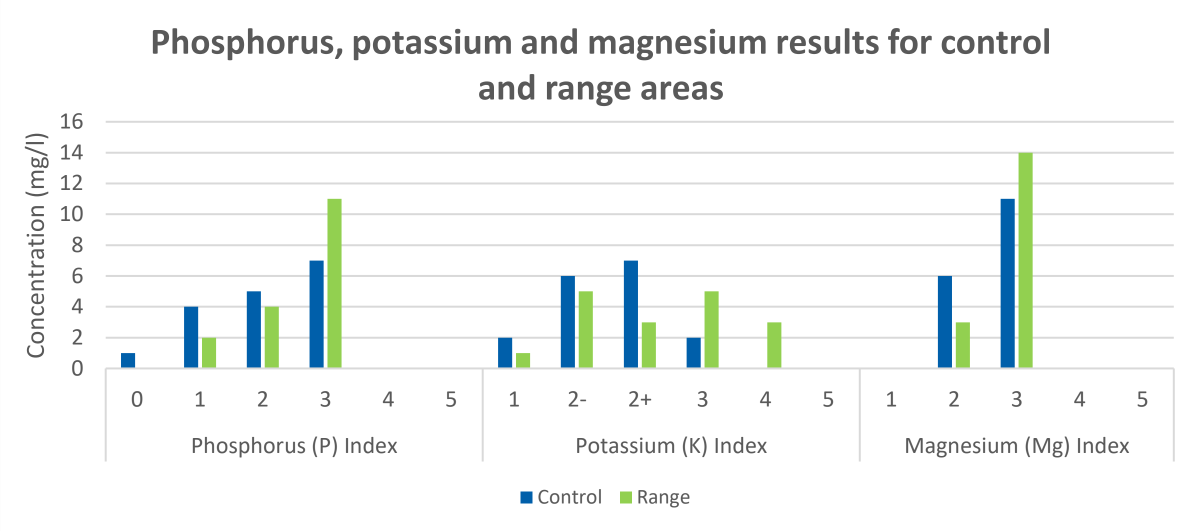


Figure 6 Number of results at each index for phosphorus, potassium and magnesium (control and range areas)

6.2 Water sample results

Mean water sample results are provided in Table 9. Individual sample results are shown graphically for phosphorus (Figure 7 and Figure 8), potassium (Figure 9), nitrate nitrogen (Figure 10) and BOD (Figure 11). Ammonium nitrogen, *E. coli* and coliform results have not been plotted as graphs for the reasons given in the text below. Individual results for each sample collected are shown in Appendix 3.

Table 9 Summary of Water Sample Results (mean of all samples)

	Upstream	Downstream
Total phosphorus (P, mg per litre)	0.11	0.07
Dissolved phosphorus (P, mg per litre)	0.13	0.23
Total potassium (K, mg per litre)	1.96	2.44
Nitrate nitrogen (mg per litre)	1.43	2.19
Biochemical oxygen demand (BOD, mg per litre)	2.09	1.70
Ammonium nitrogen (mg per litre)	0.07	0.06
Presumptive *E. coli* (cfu/100ml)	425	446
Presumptive coliforms (cfu/100ml)	468	547

Table 9 shows that across all samples, the total P concentrations were 0.11mg per litre (mg/l) upstream and 0.07 mg/l downstream. Figure 7 shows individual sample results for total and dissolved P.

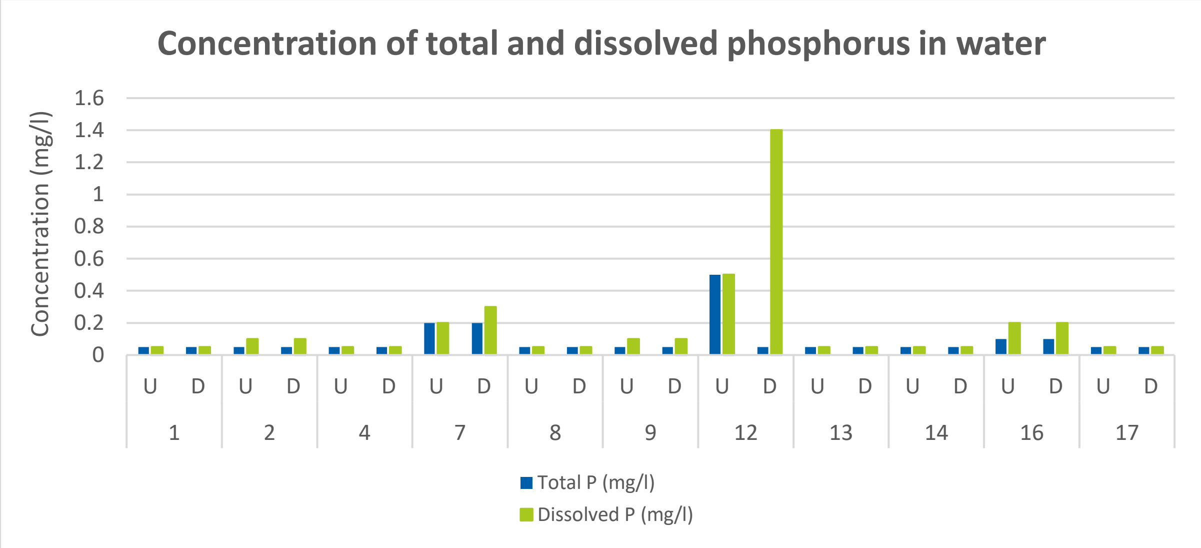


Figure 7 Total and dissolved P concentration (mg/l) for all samples

The mean results are close to the limit of detection and the numerical reduction in the mean downstream sample seems unlikely to be a real difference. However, the results show no evidence of an increase in the total P content of the downstream samples, compared to upstream.

In any single sample, dissolved P should be lower than total P, yet the mean for both upstream and downstream samples showed the reverse. The downstream mean for dissolved P was higher than the upstream mean. The difference between total and dissolved P in the upstream samples is small. The increase in the downstream dissolved P mean (compared to the upstream mean) is largely due to the result from sample 12. Here the upstream sample was comparatively high at 0.5mg/l; the downstream was much higher again, at 1.4mg/l. The latter greatly exceeded the total P for the same sample. This strongly suggests analytical error.

The difference in dissolved P between sample 12 and all others is illustrated in the scatter graph shown in Figure 8. If the results for total and dissolved P for sample 12 were removed, the revised means (mg/l) for the remaining samples would be as follows:

- Upstream total P 0.11
- Downstream total P 0.07
- Upstream dissolved P 0.09
- Downstream dissolved P 0.10

On this basis, dissolved P downstream remains higher than total P downstream. This still indicates an anomaly but these upstream and downstream results are now much closer than previously. Importantly, they do not indicate any noticeable increase in phosphorus downstream, compared to upstream.

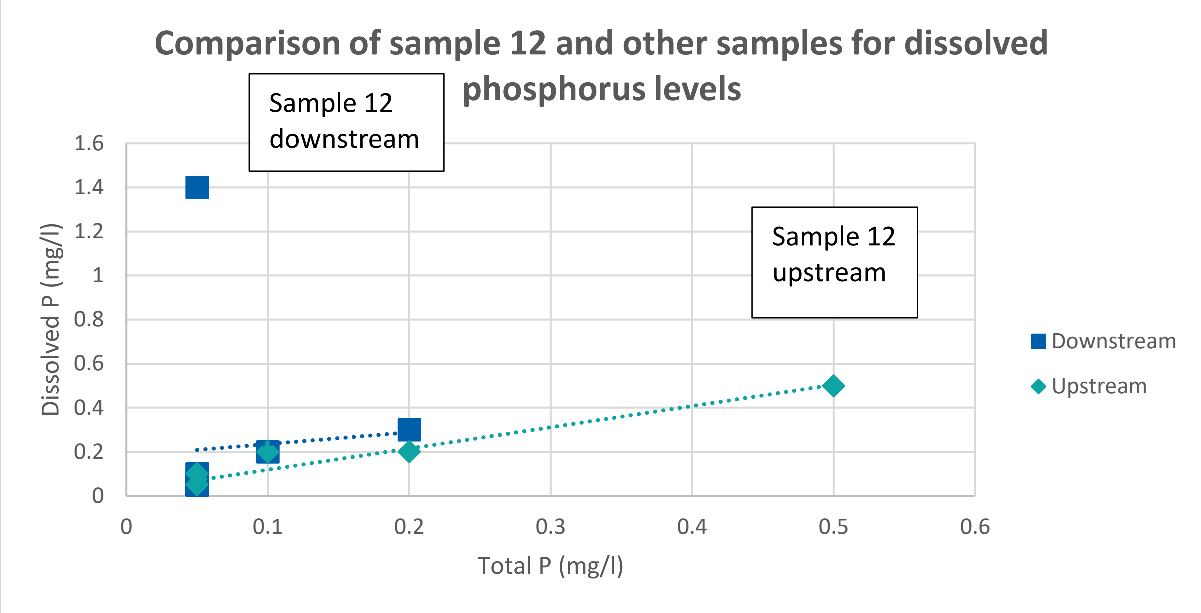


Figure 8 Dissolved P upstream (0.5) and downstream (1.4) results for sample 12 compared to other samples (mg/l)

The mean concentration of potassium (K) was higher downstream (2.44 mg/l) than upstream (1.96 mg/l). Nine of the 11 samples had higher downstream levels and in the remaining two, the levels were the same. No upstream sample was higher in K than the equivalent downstream sample.

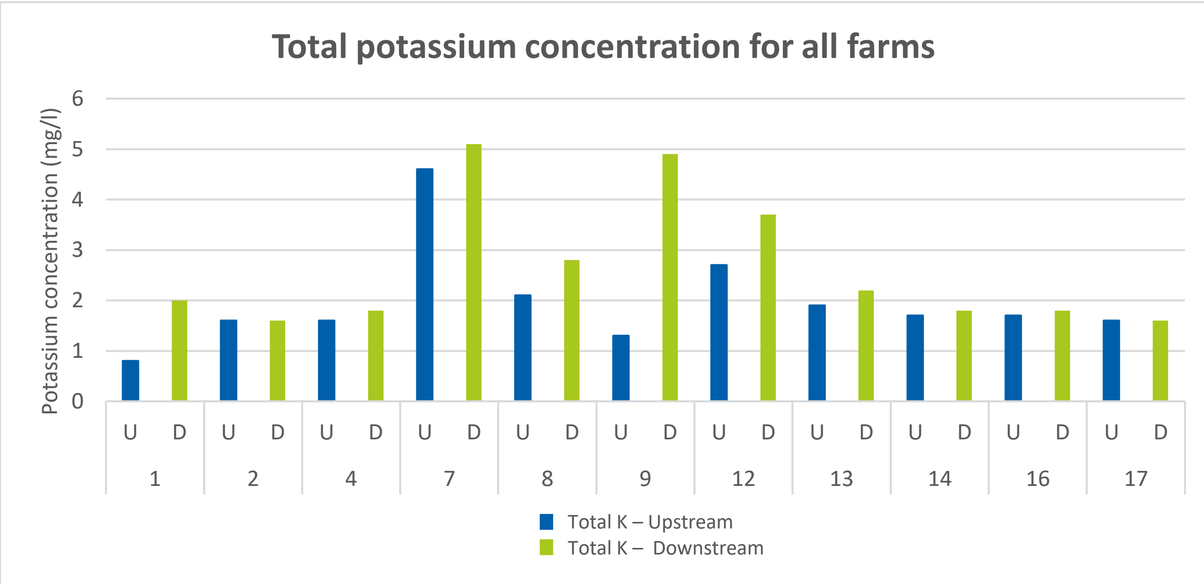


Figure 9 Total K concentration (mg/l) for all samples

Nitrate nitrogen levels were variable across the samples, ranging from less than 0.1 mg/l to 4.4 mg/l. The mean for upstream samples was 1.43mg/l and downstream it was 2.19mg/l. In seven samples, the downstream level was higher, in one sample the trend was reversed. In three samples, levels were the same.

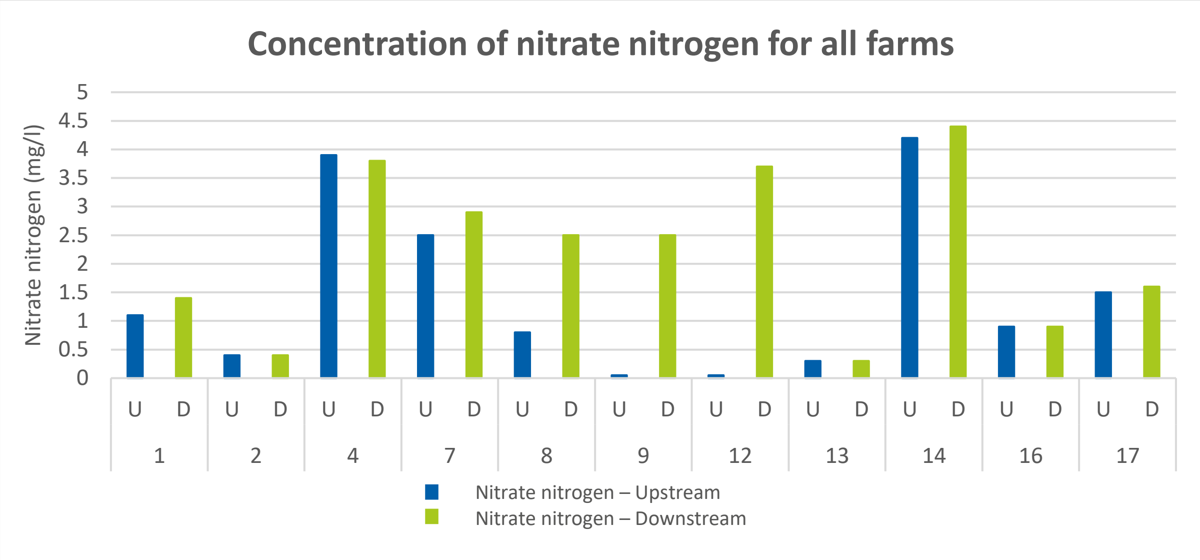


Figure 10 Nitrate nitrogen concentration (mg/l) for all samples

The mean BOD was higher upstream (2.09mg/l) than downstream (1.70). This was largely due to a single high upstream figure in sample 12 (see Figure 11). Most samples had low BOD levels, indicating little organic pollution of the water environment. Only samples 2 and 8 had higher BOD concentration downstream than upstream. In sample 12, the BOD downstream was in line with many other results. The large difference between the two suggests either a sampling or an analytical issue.

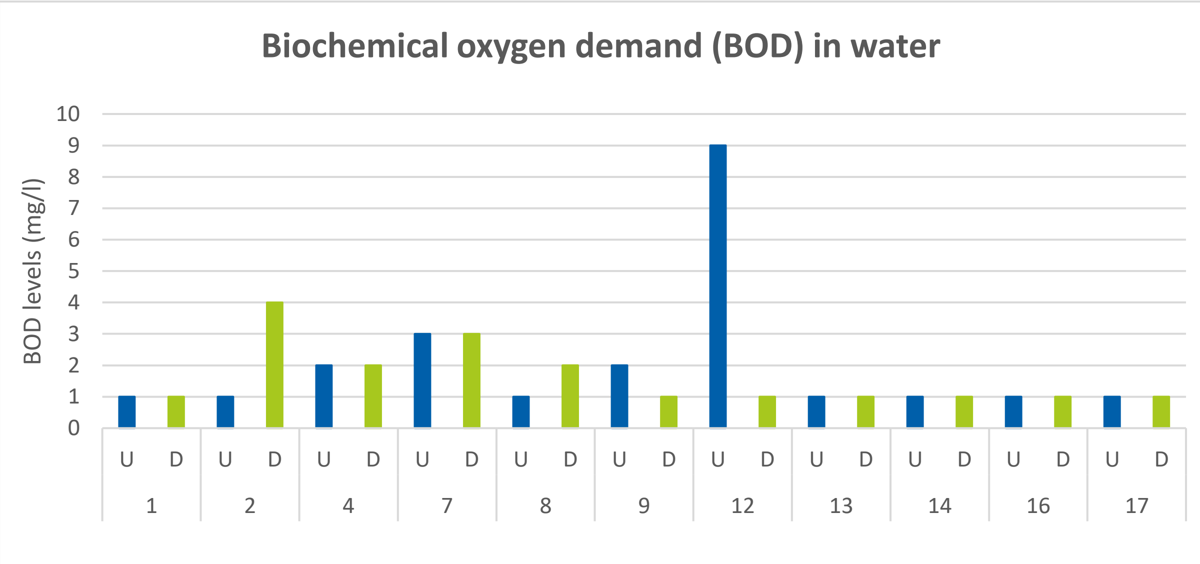


Figure 11 Biological oxygen demand, BOD (mg/l) for all samples

Ammonium nitrogen concentrations were generally low. Many results were below 0.1mg/l, hence graphs are not included. There was little difference between upstream and downstream samples.
Presumptive *E. coli* and coliform units were variable across the samples, ranging from 34 to over 1,000 cfu/100ml. The mean results calculated for Table 9 showed some increase in both *E. coli* and presumptive coliforms in downstream samples compared to upstream. However, many of the results were above the upper level of detection (100 and 1,000 cfu/g) for the analyses undertaken. Because of this, graphs are not included and the mean figures should be treated with caution. Detection levels were changed by the laboratory during the project, which makes meaningful comparison of results impossible.

7 DISCUSSION

7.1 Soil analyses

In this section, the results from this study are compared with typical UK results based on Table 3 Soil pH and Indices – grassland from Professional Agricultural Analysis Group Collation of data from routine soil analysis in the UK.

pH

Results for pH from this study are compared with typical UK results in Table 10.

For most farms, pH was in line with expected values. Table 8 showed a slight numerical increase in pH on range land compared to the control. The land used for ranging should not receive any fertiliser or manure, other than direct deposits of manure from the hens and any other livestock utilising the same area. Table 10 shows that some higher pH levels are reported in other UK grassland samples.

A pH of 6.50 and above was found on five range areas and three control areas. Higher pH might in part be explained by soil type, current or historic management practices. Further investigations would be needed to fully understand the underlying reason for high pH on these farms.

Table 10 Comparison of soil pH results from this study with typical UK grassland results

Soil pH								
	<5.00	5.00 - 5.49	5.50 – 5.99	6.00 - 6.49	6.50 - 6.99	7.00 - 7.49	7.50 - 7.99	>8
% samples (UK)	2%	14%	34%	28%	13%	4%	2%	1%
% samples (sampled farms - control)	0%	12%	35%	35%	12%	6%	0%	0%
% samples (sampled farms - range)	0%	12%	41%	18%	29%	0%	0%	0%

Phosphorus

Results for P Index from this study are compared with typical UK results in Table 11.

The target index for phosphorus (P) for mineral soil is 2 (16-25 mg/l). Overall, P concentration in the sampled soil was in line with recommendations for agricultural land. Compared to the UK indices for grassland, control samples were fairly similar to the proportion of indices observed. Range samples however had a higher proportion of samples in index 3. Slightly higher indices for P were expected for range areas as by contrast the controls were in general, unmanaged land.

Table 11 Comparison of soil phosphorus (P) index from this study with typical UK grassland results

	P index						
	0	1	2	3	4	5	>5
% samples (UK)	11%	21%	27%	26%	9%	3%	2%
% samples (sampled farms - control)	6%	24%	29%	41%	0%	0%	0%
% samples (sampled farms - range)	0%	12%	24%	65%	0%	0%	0%

Potassium

Results for K Index from this study are compared with typical UK results in Table 12.

The target index for potassium (K) is index 2- (121-180 mg/l). K indices were slightly higher for range than control samples, which is to be expected with the presence of the birds on the range and the unmanaged nature of the controls. UK grassland has predominantly indices of 1 (34%) or 2- (26%) while the farms samples had mostly indices 2 and 3 for range areas. Overall (as for P), K concentrations on average appear to be slightly higher for range areas than controls. All are within the levels expected of agricultural land. It is not clear why potassium levels are higher on both the range and control groups than the UK grassland average.

Table 12 Comparison of soil potassium (K) index from this study with typical UK grassland results

	K index							
	0	1	2-	2+	3	4	5	>5
% samples (UK)	8%	34%	26%	14%	14%	3%	1%	0%
% samples (sampled farms - control)	0%	12%	35%	41%	12%	0%	0%	0%
% samples (sampled farms - range)	0%	6%	29%	18%	29%	18%	0%	0%

Magnesium

Results for Mg Index from this study are compared with typical UK results in Table 13. A very high proportion of the samples for both control and range had an Mg index of 3 (65% and 82%, respectively), which is higher than the UK average of 39%.

Table 13 Comparison of soil magnesium index from this study with typical UK grassland results

Mg index								
	0	1	2	3	4	5	6	>6
% samples (UK)	0%	3%	28%	39%	16%	8%	5%	1%
% samples (sampled farms - control)	0%	0%	35%	65%	0%	0%	0%	0%
% samples (sampled farms - range)	0%	0%	18%	82%	0%	0%	0%	0%

7.2 Water analyses

Phosphate and potassium

Elevated levels of phosphate in fresh waters can give rise to the problem of eutrophication, causing excessive growth of algae and plants. This adversely affects the quality of the water and our uses of it, as well as damaging aquatic life. The natural levels of phosphate (i.e. from rivers with no anthropogenic inputs) usually range from 0.005 to 0.05mg/l. Of the farms sampled, nine had phosphate levels at or less than 0.1 mg/l. Government guidance recommends that rivers should not exceed annual mean phosphate concentrations of 0.1mg per litre. The underlying reasons for the higher concentrations of total phosphorus in two samples i.e. 7 (upstream and downstream) and 12 (upstream only) are unknown.

Only sample 7 had a K concentration higher than 5 mg/l (downstream, 5.1mg/l, upstream, 4.6mg/l). Unlike nitrogen and phosphorus, losses of potassium to water are generally not an environmental concern in the UK[38].

Nitrogen

High levels of nitrate nitrogen are a concern in terms of abstraction for drinking water treatment. They can also contribute to eutrophication in lakes, estuaries and coastal waters. As part of the Nitrate Pollution Prevention Regulations 2015[39], the Nitrates Directive was established and gives a standard limit of 50 mg/l of nitrate. This is equal to 11.3 mg/l of total inorganic nitrogen, the level used to show that water is polluted.

In this study, all farm nitrate nitrogen levels were substantially below the threshold of 11.3mg/l. The highest concentration was observed in sample 14 (4.2mg/l upstream and 4.4mg/l downstream).

[38] https://www.pda.org.uk/pda_leaflets/29-potash-and-the-environment/

[39] Statutory Instrument 2015/668

Biochemical Oxygen Demand (BOD)

BOD is an indicator of organic pollution of the water environment. The higher the BOD, the greater the potential for oxygen levels in the water to fall, which can stress or, in extreme cases, kill aquatic life. Ideally watercourses should have a BOD of less than 1. However, the test sensitivity provided only results above 2 mg/l. Results of samples that were below the limit of detection are assumed to be half the limit of detection and therefore given as 1 mg/l.

In Figure 12, the BOD levels found in this study are compared with Water Framework Directive pollution thresholds of 'moderately polluted' (2-8mg per litre) and 'very polluted' (above 8mg per litre). Only one sample crossed the 'very polluted' threshold and this was one collected upstream.

Eight of the samples had a BOD level at or below 2 mg/l (samples 1, 4, 8, 9, 13, 14, 16 and 17).

Sample 2 was the only one to have a much higher BOD level downstream of the farm (classed as 'moderately polluted') than upstream, although sample 8 also appeared to have been marginally higher. In sample 12, BOD levels were lower downstream (< 2 mg/l) than upstream (9 mg/l – very polluted). These results are somewhat inexplicable and not consistent with a hypothesis that elevated BOD levels are derived from range run-off.

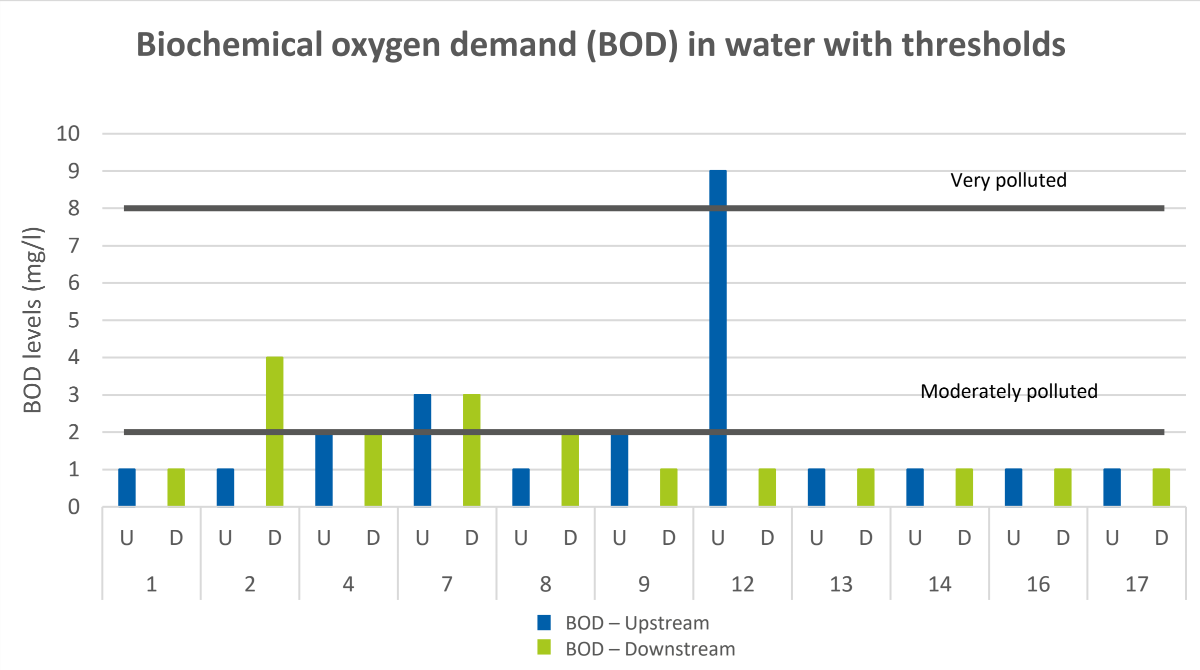


Figure 12 BOD levels upstream (U) and downstream (D) with pollution thresholds

Coliform and *E. coli*

Interpretation of Coliform and *E. coli* counts is difficult as the upper level of detection varied during the project and the results are not sufficiently precise. Future studies should relax the upper level to make the data more precise and facilitate interpretation.

8 CONCLUSIONS

This study involved 14 different free range egg production units, all of which had been identified as 'high risk' within the Wye and Usk catchment area. In total, paired soil samples were taken on 17 occasions and water samples on 11. Soil samples were collected on two occasions from three farms. The work was carried out in three phases, interrupted partly by two Avian Influenza Housing Orders. However, a consistent approach to sampling and analysis (except for the microbiological analysis) was able to be maintained throughout the project.

The soil sample results generally follow logical trends and were broadly as expected. Whilst mean soil nutrient levels for phosphorus and potassium on poultry range land are slightly elevated in comparison with the unmanaged land of the controls, the increase in nutrient levels is relatively modest. The overall results are within the range which might be expected of managed agricultural soils across England and Wales, as shown by comparison with the PAAG soil analysis data survey. Mean soil pH was a little higher on range than control land but still slightly low in comparison to UK grassland averages.

The water sample results are more difficult to interpret. Some anomalies are apparent in the findings and this is partly due to the inherent variability of water sampling. In some cases, analysis results were close to the limit of detection and so small differences can result in illogical trends. The water analysis results from one site (sample 12) were both atypical and inconsistent and may reflect analytical error, sampling variability or a combination of both. Specific local issues could also have contributed to the findings. Further investigation and re-sampling would be required to clarify this.

Based on all analyses, the mean total phosphorus (P) level in water was lower downstream (0.07mg/l) than upstream (0.11) but in both sets of samples, reported levels of dissolved P exceeded total P. This should not be the case. Closer examination indicated that the findings were heavily influenced by the results from sample 12 (see above). An analytical error is suggested, because of the respective levels of total and dissolved P. If this sample was removed from the analysis, there was little difference in the mean upstream and downstream samples. Importantly, the findings do not indicate any noticeable overall increase in total P in water downstream, compared to upstream.

In total, the results do not appear to show that the range land of the majority of the units studied had any significant direct impact on the quality of the watercourses sampled.

Mean nitrate levels from downstream samples were slightly higher than upstream samples and although the range of nitrate levels was considerable (from 0.1mg/l to 4.4mg/litre), levels are low in comparison with Water Framework Directive limits. Both BOD and change in BOD were generally low.

The units sampled were selected as being potentially higher risk sites, and in theory should present an increased likelihood of issues than a random selection of farms. Whilst the number of units studied was limited, the soils findings are likely to be reasonably robust, since nutrient levels in soil are relatively stable and do not fluctuate on a day to day basis. Water data is less reliable since the water sampled will only be present at or adjacent to the site for a matter of minutes or hours, and a single water sample can only provide a momentary snapshot, which may not be representative. More detailed and extensive water quality monitoring work would be required to substantiate the findings of this study, including a comprehensive time-series of samples from a larger number of sites. Overall, neither the 17 soil samples nor the 11 water sample pairs showed any obvious indication of a link between water quality and range areas.

APPENDIX 1 SOIL AND WATER SAMPLING SUMMARY

Sample Ref.	Soil sampling		Water sampling	
	Date	Conditions and notes	Date	Conditions and notes
1	12 July 2021	The control sample was taken from an area of grassland grazed by sheep that does not receive additional manure or fertiliser applications	21 October 2021	Samples were taken roughly 24 hours following the last rainfall. The stream was settled with a steady flow of clear water.
2	13 July 2021	The control sample was taken from an area of grassland that is not grazed by livestock and does not receive manure or fertiliser applications	20 October 2021	Heavy rainfall had fallen the previous night. The river had high water levels and a strong flow of water.
3	12 July 2021	The control sample was taken from an area of grassland that is not grazed by livestock and does not receive manure or fertiliser applications	Water sample not collected	
4	12 July 2021	The control sample was taken from an area of grassland that is not grazed by livestock and does not receive manure or fertiliser applications	21 October 2021	Samples were taken roughly 24 hours following the last rainfall. The stream was settled with a steady flow of clear water.
5	19 July 2021	The control sample was taken from an area of grassland that is not grazed by livestock and does not receive manure or fertiliser applications	Water sample not collected	
6	19 July 2021	The control sample was taken from an area of grassland that is not grazed by livestock and does not receive manure or fertiliser applications	Water sample not collected	
7	20 July 2021	The control sample was taken from an area of grassland that is not grazed by livestock and does not receive manure or fertiliser applications	20 October 2021	Heavy rainfall fell the previous night. The river had high water levels and a strong flow of water.
8	20 July 2021	The control sample was taken from an area of grassland grazed by sheep that does not receive additional manure or fertiliser applications	21 October 2021	Samples were taken roughly 24 hours following the last rainfall. The stream was settled with a steady flow of clear water.

Sample Ref.	Soil sampling		Water sampling	
	Date	Conditions and notes	Date	Conditions and notes
9	5 September 2022	The control sample was taken from an area of grassland grazed by sheep that does not receive additional manure or fertiliser applications	5 September 2022	Samples were taken roughly 24 hours following heavy rainfall the previous night. The stream was settled with a steady flow of clear water.
10	24 August 2022	The control sample was taken from an area of grassland that is lightly grazed by sheep that does not receive manure or fertiliser applications	Water sample not collected.	
11	24 August 2022	The control sample was taken from an area of grassland that is not grazed by livestock and does not receive manure or fertiliser applications	Water sample not collected.	
12	20 September 2022	The control sample was taken from an area of grassland that is not grazed by livestock and does not receive manure or fertiliser applications	20 September 2022	Samples were taken roughly 48 hours following last heavy rainfall. The river was settled with a flow of clear water.
13	20 September 2022	The control sample was taken from an area of grassland that is not grazed by livestock and does not receive manure or fertiliser applications	20 September 2022	Samples were taking roughly 48 hours following last heavy rainfall. The stream was settled with a steady flow of clear water
14	16 February 2023	The control sample was taken from an area of grassland that is not grazed by livestock and does not receive manure or fertiliser applications	16 February 2023	Samples were taken within 48 hours of last rainfall. The river was settled with a flow of clear water.
15	22 February 2023	The control sample was taken from an area of grassland that is not grazed by livestock and does not receive manure or fertiliser applications	22 February 2023	No water samples taken (no accessible water course)
16	20 March 2023	The control sample was taken from an area of grassland that is not grazed by livestock and does not receive manure or fertiliser applications	20 March 2023	Samples were taken within 48 hours of last rainfall. The river had high water levels and a strong flow of water.

Sample Ref.	Soil sampling		Water sampling	
	Date	Conditions and notes	Date	Conditions and notes
17	5 June 2023	The control sample was taken from an area of grassland grazed by horses that does not receive additional manure or fertiliser applications	5 June 2023	No rainfall for at least 48 hours prior to sampling. The river was settled with a steady flow of clear water.

Notes

Samples 5 and 17 were collected from the same farm

Samples 10 and 14 were collected from the same farm

Samples 11 and 15 were collected from the same farm

APPENDIX 2 SOIL SAMPLING RESULTS

Sample Ref.	Soil pH		Phosphorus (P) Index		Potassium (K) Index		Magnesium (Mg) Index	
	Control	Range	Control	Range	Control	Range	Control	Range
1	5.6	5.1	1	3	2-	2-	3	2
2	6.0	5.4	2	2	2-	1	2	3
3	5.9	5.9	3	3	1	2-	2	2
4	5.6	5.9	3	3	3	2+	3	3
5	5.0	5.9	2	3	3	4	2	3
6	5.6	5.7	2	2	2+	3	3	3
7	5.8	6.5	3	3	2+	3	3	3
8	5.2	5.7	3	3	2+	3	3	3
9	6.1	6.1	1	1	2-	2-	3	3
10	6.0	6.5	0	3	1	3	3	3
11	6.1	5.9	1	2	2-	2+	3	3
12	7.1	6.3	3	2	2+	2+	2	3
13	6.8	6.9	3	3	2+	4	2	2

Sample Ref.	Soil pH		Phosphorus (P) Index		Potassium (K) Index		Magnesium (Mg) Index	
	Control	Range	Control	Range	Control	Range	Control	Range
14	6.1	6.4	2	3	2-	4	2	3
15	6.5	5.6	2	1	2+	2-	3	3
16	5.5	6.5	1	3	2-	3	3	3
17	6.3	6.6	3	3	2+	2-	3	3
Mean	**5.95**	**6.05**	**2**	**3**	**2+**	**3**	**3**	**3**

APPENDIX 3 WATER SAMPLING RESULTS

Sample Ref.	Sample collection point*	Total P (mg/l)	Dissolved P (mg/l)	Total K (mg/l)	Nitrate Nitrogen (mg/l)	BOD** (mg/l)	Ammonium Nitrogen (mg/l)	Presumptive *E. coli* (cfu/100ml)	Presumptive Coliforms (cfu/100ml)
1	U	<0.1	<0.1	0.8	1.1	<2	<0.1	380	610
	D	<0.1	<0.1	2	1.4	<2	<0.1	400	970
2	U	<0.1	0.1	1.6	0.4	<2	<0.1	>1000	>1000
	D	<0.1	0.1	1.6	0.4	4	<0.1	>1000	>1000
3	Water samples not collected								
4	U	<0.1	<0.1	1.6	3.9	2	<0.1	760	>1000
	D	<0.1	<0.1	1.8	3.8	2	<0.1	>1000	>1000
5	Water samples not collected								
6	Water samples not collected								
7	U	0.2	0.2	4.6	2.5	3	0.1	>1000	>1000
	D	0.2	0.3	5.1	2.9	3	0.1	>1000	>1000
8	U	<0.1	<0.1	2.1	0.8	<2	<0.1	>1000	>1000
	D	<0.1	<0.1	2.8	2.5	2	<0.1	580	>1000
9	U	<0.1	0.1	1.3	<0.1	2	<0.1	>100	>100
	D	<0.1	0.1	4.9	2.5	<2	<0.1	>100	>100
10	Water samples not collected								
11	Water samples not collected								
12	U	0.5	0.5	2.7	<0.1	9	0.2	>100	>100
	D	<0.1	1.4	3.7	3.7	<2	<0.1	>100	>100
13	U	<0.1	<0.1	1.9	0.3	<2	0.1	>100	>100
	D	<0.1	<0.1	2.2	0.3	<2	0.1	>100	>100

Sample Ref.	Sample collection point*	Total P (mg/l)	Dissolved P (mg/l)	Total K (mg/l)	Nitrate Nitrogen (mg/l)	BOD** (mg/l)	Ammonium Nitrogen (mg/l)	Presumptive *E. coli* (cfu/100ml)	Presumptive Coliforms (cfu/100ml)
14	U	<0.1	<0.1	1.7	4.2	<2	<0.1	34	42
	D	<0.1	<0.1	1.8	4.4	<2	<0.1	77	>100
15	Water samples not collected								
16	U	0.1	0.2	1.7	0.9	<2	<0.1	>100	>100
	D	0.1	0.2	1.8	0.9	<2	<0.1	>100	>100
17	U	<0.1	<0.1	1.6	1.5	<2	<0.1	>100	>100
	D	<0.1	<0.1	1.6	1.6	<2	<0.1	>100	>100
Mean Upstream		0.11	0.13	1.96	1.43	2.09	0.07	425	468
Mean Downstream		0.07	0.23	2.44	2.19	1.70	0.06	446	547
Difference (Upstream vs Downstream)		0.04	-0.10	-0.48	-0.76	0.39	0.01	-21	-79

* Water samples were collected either upstream (U) of the farm or downstream (D)

** Biochemical oxygen demand (BOD)