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Herefordshire Council Interim Phosphate Delivery Plan

Stage 1 – Guidance on calculating phosphate budgets for new developments draining to the River Wye SAC

Report for Herefordshire Council

Ricardo for Herefordshire Council – ED14585

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Executive summary

The River Wye Special Area of Conservation (SAC) is a higher-level national network site[1] (hereafter national sites) that supports a diverse and rare ecology; however, the ecology of the SAC is under pressure due to phosphorus (P) pollution from point and diffuse sources. Following the Court of Justice of the European Union (CJEU) ruling known as the 'Dutch Nitrogen Case'[2], mitigation to achieve 'nutrient neutrality' is required for new developments that would otherwise contribute additional nutrient loads to a European designated site that is close to unfavourable condition or in unfavourable condition due to nutrient pollution. Thus, all new developments that increase wastewater discharges to parts of a SAC that are close to or in unfavourable condition due to nutrient pollution must be able to demonstrate nutrient neutrality in order to be compliant with the 'Habitats Regulations' as demonstrated through a Habitats Regulations Assessment (HRA).

The first step in demonstrating nutrient neutrality for new developments in the Wye SAC catchment is the production of a phosphate budget. Following advice from Natural England (Natural England, 2020), this report details a methodology for calculating a phosphate budget for new developments, including the rationale behind the values chosen as inputs to the various components of the phosphate budget.

The phosphate budget is calculated in four stages as the balance between:

1. The increase in P loading to National sites that result from the increase in wastewater from a new development, which is based on population increase, water use and nutrient concentrations in discharges from wastewater treatment works (WwTW) and package treatment plants.
2. The P export from the past and present land use of the development site.
3. The P export from the future mix of land use on the development site e.g. urban land, greenspace.
4. Calculation of the net change in P loading to a designated site using the outputs from Stages 1-3, i.e. the P budget, which includes the addition of a 20% precautionary buffer.

Inputs to the various components of each of these four stages were determined using scientific literature, best practice industry guidelines, secondary data and modelling. Where estimates for an input were subject to uncertainty, the precautionary principle was applied in order to determine a suitable value. The values recommended are in Table 1.1. It should be noted that the Natural England guidance on which this methodology is based only covers nutrient budget calculations for residential developments. Agricultural and industrial development that may subject to an HRA due to increased nutrient loading is subject to ongoing guidance development.

The inputs into the Stage 1 phosphate budget calculations incorporate data from the most recent census (2011) on occupancy rates, per person water usage based on industry best practice water efficiency standards that have been adopted in the 2015 Herefordshire Local Plan and the phosphate concentration in the treated wastewater from the development. The latter input is determined by the type of treatment applied to wastewater at the receiving treatment works, with guidance also provided for new developments that will be served by package treatment plants.

The Stage 2 phosphate budget calculations account for the phosphate load from the current land use on the development site. This phosphate load is offset against the new phosphate load from the development. Phosphate export coefficients are provided for greenfield and urban land based on values determined through literature review and secondary data. For agricultural land, Farmscoper[3] modelling was used to determine phosphate export coefficients for the 9 farm types detailed in Natural England's (Natural England, 2020) advice. Sensitivity testing of the Farmscoper model was used to determine suitably precautionary values for agricultural phosphate export, with these values taking

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[1] Prior to Brexit these sites were part of the Natura 2000 network and generally referred to as "European designated sites".

[2] Joined Cases C-293/17 and C-294/17 Coöperatie Mobilisation for the Environment UA and Others v College van gedeputeerde staten van Limburg and Other

[3] Farmscoper Version 4 produced by ADAS and available to download from: https://www.adas.uk/Service/farmscoper, accessed on: 18/01/2021

account of emerging research highlighting long-term issues related to legacy phosphate leaching from post-agricultural soils.

Stage 3 of the phosphate budget calculations accounts for the phosphate export from the mix of urban and greenspace land uses on the post-development site. These inputs use the urban land use and greenspace phosphate export coefficients determined in Stage 2 of this methodology.

The difference between the new phosphate load from a development (Stages 1 and 3) and the phosphate load from previous land use on the development site (Stage 2) results in the net change in phosphate loading to the River Wye SAC (Stage 4). There are uncertainties inherent in all of the inputs used in Stages 1-3 of the phosphate budget calculation methodology. This uncertainty is recognised by Natural England through the addition of a 20% precautionary buffer to the net change in phosphate loading calculated in Stage 4. If the final output from the phosphate budget calculations results in additional phosphate loading to the areas of the River Wye SAC that in unfavourable condition or close to being in unfavourable condition, the additional phosphate load will need to be mitigated so as to reduce phosphate to at least the pre-existing load, thus achieving nutrient neutrality.

Table 1.1: Summary of key values advised for phosphorus budget calculations

Stage	Value type	Component	Value	Units
1	**Population**	Occupancy rate	2.3	Persons/dwelling
		Water usage	120	Litres/day
2	**Agricultural phosphorus export coefficients**	Variable – dependant on combinations of rainfall, soil drainage and farm type		kg P/ha/year
2 & 3	**Non-agricultural export coefficients**	Greenspace	0.02	kg P/ha/year
		Urban land	Variable	
		Woodland	0.02	
		Shrub	0.02	
		Water	0.00	
		Community food growing	Variable	

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Glossary

Abbreviation	Definition
P	Phosphorus
TP	Total Phosphorus
TRP	Total Reactive Phosphorous
SRP	Soluble Reactive Phosphorus
STP	Soluble Total Phosphorus
EMC	Event Mean Concentration
CJEU	Court of Justice of the European Union
EC	European Commission
SPA	Special Protection Area
SAC	Special Area of Conservation
ONS	Office for National Statistics
WwTW	Wastewater Treatment Works
NRFA	National River Flow Archive
RBD	River Basin District

Abbreviation	Definition
NMP	Nutrient Management Plan
SANG	Suitable Alternative Natural Greenspace
OC	Operational Catchment

1 Introduction

As a “competent authority” under the “Habitats Regulations” (The Conservation of Habitats and Species Regulations 2017 (as amended)), Herefordshire Council have to perform a Habitat Regulations Assessments (HRA) screening (HRA Stage 1) of relevant planning applications to assess the possibility that the plan or project may have a “Likely Significant Effect” (LSE) on a higher-level national network site[1] (hereafter, National site). In this context, ‘significant’ means the plan or project has some potential, in the absence of any mitigation[4], to adversely affect the ecology of a site to such an extent that it could impede the attainment of conservation objectives for that site. If LSE is concluded by the screening stage, then a full Appropriate Assessment (HRA Stage 2) is required to confirm that adverse effect on site integrity. Unlike the screening stage, mitigation measures can be included at the Appropriate Assessment stage.

Herefordshire Council is currently facing limitations on their ability to grant planning permission to new housing developments due to the implications of a ruling in the Court of Justice of the European Union (CJEU) known as the “Dutch Nitrogen Cases”[2]. This ruling has changed the way HRAs consider the potential impact that could arise from increased nutrient loading to National sites protected under the Habitats Regulations. It is now considered that each new development which increases the number of overnight stays, and thus increases the production of wastewater and associated nutrient loading to National sites already in unfavourable condition due to such nutrients, may not be legally consented. Furthermore, the ruling suggests that a proposed project or plan cannot rely, for mitigation purposes, on external programmes (i.e. that are not part of that project or plan) unless there is certainty that mitigation will be delivered before the impacts of the development come into effect. This is because the HRA process is precautionary and must eliminate any reasonable uncertainty over effects on a National site.

The River Wye Special Area of Conservation (SAC) is a National site that covers the whole of the River Wye and the stretch of the River Lugg downstream of Hope under Dinmore. The areas of the River Lugg that are within the Wye SAC are currently in unfavourable condition as a result of excess nutrients (phosphorous (P)). Furthermore, the Upper Wye, upstream of the confluence with the River Lugg is close to unfavourable status due to excess P loading. Herefordshire Council has issued a position statement in agreement with Natural England that details the impact of the Dutch Nitrogen Cases on HRAs of new planning applications, with a focus on the River Lugg which is currently exceeding the River Wye SAC targets for P concentrations (Herefordshire Council, 2020). The position statement notes the uncertainty associated with the current actions to reduce P inputs to the Wye and Lugg that are detailed in the River Wye SAC Nutrient Management Plan (NMP). This uncertainty means that the NMP cannot be relied on to provide mitigation for adverse effects on the integrity of the River Wye SAC that may arise from additional loading of P from new planning applications. Whilst Herefordshire Council seek a long-term solution to this issue, an interim approach is needed to demonstrate that new residential developments are “nutrient neutral”. A key component of evidencing nutrient neutrality is a site-specific P budget that can support an HRA of new planning applications. The P budget will show whether a new development will result in net additional P entering the River Wye SAC and therefore show the amount of P mitigation required at the Appropriate Assessment stage to achieve nutrient neutrality, thus removing the risk of adverse effects on National site integrity.

1.1 Purpose of the report

Following the Dutch Nitrogen Cases, Natural England has provided a methodology for calculating P budgets for new developments within the River Great Stour catchment in Kent (Natural England, 2020). This report aims to sets out a methodology for calculating a P budget for new developments within the River Lugg and River Wye catchments. The methodology in this report is based on the methodology detailed for the Stour catchment, however the inputs to the nutrient budget calculations have been updated to account for factors that are relevant to the River Wye and Lugg catchments. This report

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[4] Since 2018, the ruling for People Over Wind and Sweetman (‘Sweetman II’) vs Coillte Teoranta, Case C-323/17 confirmed that that mitigation can no longer be considered in HRA screening (HRA Stage 1) and must be reserved for the Appropriate Assessment stage.

provides details of the methodology and the rationale used to generate new, River Wye and Lugg specific inputs for the P budget calculator. A background to nutrient neutrality and the River Wye catchment is provided in Section 2. An overview of the methodology that underpins the P budget and the rationale behind the selection of the various inputs to the budget is provided in Section 3. A conclusion is provided in Section 4.

2 Background to Nutrient Neutrality and the River Wye Catchment

2.1 The Dutch Nitrogen Cases

The 2018 CJEU ruling in the Dutch Nitrogen Cases[2] concerns nitrogen pollution from agricultural sources affecting protected heathland sites in the Netherlands. However, the concepts and principles used in the judgment apply to other nutrients, such as phosphates, and their impacts on other National sites, such as the River Wye SAC. The key point from the Dutch Nitrogen Cases are:

1. Where the conservation status of a National site's qualifying feature (i.e. species or habitat) is already unfavourable (e.g. exceedance of critical nutrient thresholds), the possibility of consent for activities that add further pollutant loading is extremely limited. In other words, it is generally not permissible to permit a project which might alone or in combination give rise to any appreciable increase in a pollutant on an already-overloaded site.
2. Mitigation measures that are *part of the project or plan* can be taken into account at the Appropriate Assessment stage. But reliance on wider programme measures and autonomous measures *which are not part of the individual project being assessed* need careful consideration as to their certainty. Furthermore, mitigation measures should be secured before they can be taken into account, and the expected benefits should be certain at the time any consent is granted. (i.e., one cannot normally rely on measures yet to be secured that are not an inherent part of the project.)[5]

The ruling has led to greater scrutiny of plans or projects that will increase the nutrient loads to:

- Special Protection Areas (SPA) designated under the Habitat Regulations
- Special Areas of Conservation (SAC) designated under the Habitat Regulations
- Sites designated under the Ramsar Convention (1971), which as a matter of national policy are afforded the same protection as if they were designated under the Habitat Regulations

As a result, Natural England has advised Herefordshire Council and several other local authorities across England to stop the determination of planning applications that result in an increase in residential dwellings and subsequent increases in nutrient loading to National sites, unless the developments can demonstrate nutrient loading that is necessarily limited in order to remove the risk of adverse effects on site integrity. Most guidance on how to achieve the necessary limitation on nutrient loading to remove adverse effects refer to developments achieving "nutrient neutrality".

Box 1: Definition of nutrient neutrality.

Nutrient neutrality involves avoiding excess nutrient loading arising from new developments in a wastewater catchment that drains to a European designated site. The development must be able to evidence achievement of no net increase of phosphate and/or nitrogen in a National site. Mitigation to achieve nutrient neutrality can be through on-site and off-site measures that reduce the development's export of nutrients and/or offsets such increase through reductions elsewhere.

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[5] It is noted that the exact legal interpretation of whether mitigation can be *secured* in order to allow planning permission or has to be *delivered* is still being debated and there is a lack of case law to support one interpretation or the other.

In the River Wye SAC, P is the key nutrient of concern and Natural England have released guidance on how to develop P budget calculators that can be used to determine whether a new development results in an increase of P entering a designated site and therefore if mitigation is required to achieve nutrient neutrality (Natural England, 2020).

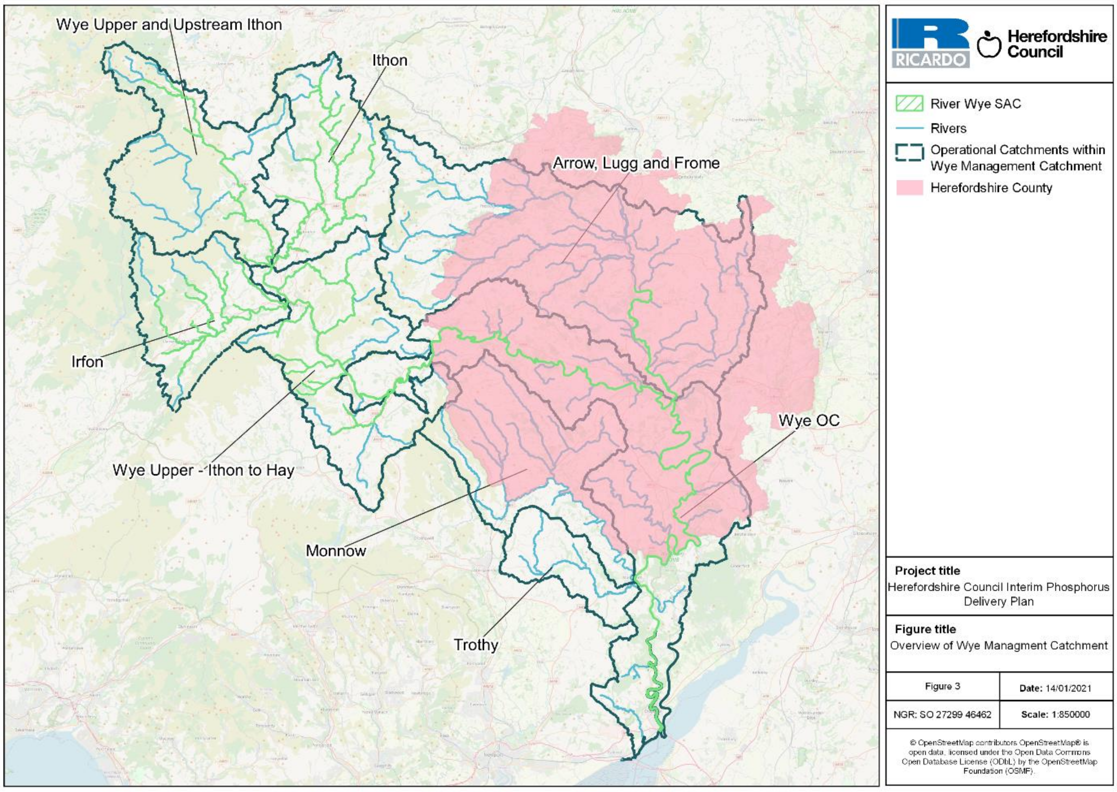
2.2 River Wye SAC and Phosphorous Pollution

The River Wye rises in the Plynlimon mountains, Wales, flowing ~215 km in broadly south-east direction to discharge into the Severn Estuary (Jarvie, et al., 2003). The Wye is a large river with a catchment area of 4136 km^2 (Jarvie, et al., 2005). There is a marked difference in precipitation across the catchment, with a three-fold decrease in mean annual rainfall between the uplands in the north-west (2450 mm) and the lowlands in the east (717 mm). Land use in the Wye is dominated by agriculture, with the type of agriculture varying largely due to topography (Jarvie, et al., 2003). Sheep farming is more prevalent in the upland west of the catchment and arable and dairy farming dominates in the lowland eastern areas of the catchment.

The River Lugg is the major tributary of the River Wye, with a catchment area of 1077 km^2 and a length of ~101 km from its source near Pool Hill in Powys, Wales (Jacobs, 2015). The Lugg is characterised by both upland and lowland river types. The upland areas of the catchment are dominated by grassland and woodland, with livestock production as the main agricultural land use. Arable land use increases in the middle and lower reaches of the Lugg, with livestock production switching to dairy and pig and poultry units also present, particularly in the River Arrow and Pinsley Brook sub-catchments (Rivers Trust, 2011). Arable land use in the lower Lugg catchment includes crops such as potatoes, maize, grazed root crops and soft fruit (Jacobs, 2015). These crops increase the risk of P pollution issues due to areas of exposed soil and intensive agricultural practices that increase sediment bound and dissolved P runoff to river systems.

The high conservation value of both the River Wye and River Lugg has been recognised through the designation of many Sites of Special Scientific Interest (SSSIs), with the River Wye and the lower part of the River Lugg, downstream of Hope under Dinmore (Figure 2.1), designated under the European Habitats Directive as a SAC. The site spans 2147.64 hectares across the Welsh counties of Monmouthshire and Powys and the English counties of Gloucestershire and Herefordshire. The SAC drains a large catchment with some significant tributaries, such as the Rivers Lugg, Elan, Irfon, Lynfi and Monnow. The site is characterised by inland waterbodies (52.5%), broad-leaved deciduous woodland (12.3%), improved grassland (10.4%) and coastal wetlands (9.5%). The varied habitat of the River Wye is host to a wide range of flora and fauna.

Figure 2.1: Overview of the Wye Management Catchment



The primary reason for the River Wye SAC designation is its specific habitat type, defined as: "Water courses of plain to montane levels with the water-crowfoot (*Ranunculion fluitantis*) and starwort (*Callitricho-Batrachion*) vegetation" as well as secondary "Transition mires and quaking bogs". These water courses can support a range of species that are also considered as "qualifying features" for the SAC. These include the white-clawed (or Atlantic stream) crayfish (*Austropotamobius pallipes*), sea lamprey (*Petromyzon marinus*), brook lamprey (*Lampeta planeri*), river lamprey (*Lampetra fluviatilis*), thwaite shad (*Alosa fallax*), allis shad (*Alosa alosa*), Atlantic salmon (*Salmo salar*), bullhead (*Cottus gobio*) and otter (*Lutra lutra*).

However, both the Wye and Lugg face pressures from P pollution. The Lower River Wye and River Lugg were designated "Eutrophic Sensitive" areas under the Urban Wastewater Treatment Regulations (1994), due to P inputs from wastewater treatment works (WwTW) (Jarvie, et al., 2003). These are known as "point source" P inputs and are most significant in areas of greater population density. As such, several larger towns in the upper River Wye sub-catchment result in a predominance of P sources from WwTW, whereas agricultural diffuse sources of P dominate in the River Lugg catchment (Atkins, 2014). Within the Lugg catchment, there is also a marked downstream increase in P concentrations, with previous research showing concentrations of total reactive phosphorous (TRP) increasing from 0.05 mg TRP/l in the upper Lugg to 0.2 mg TRP/l in the lower Lugg due to high P concentrations in various tributaries that enter the Lugg in its middle to lower reaches (Jarvie, et al., 2003). These increases of P in the Lugg have been attributed to a combination of intensive agriculture and/or small WwTW that are unlikely to have P removal processes to limit P in their discharge to rivers. It has also previously been noted that the effluent from the Cadbury's chocolate factory near Leominster may also be an important source of P to the middle and lower reaches of the Lugg (Dean, et al., 2009).

Elevated levels of nutrients such as nitrate and phosphate can lead to eutrophication – the process by which excessive nutrients interfere with competitive interactions between plants and algae leading to a dominance of algal species. Elevated levels of algae can result in diurnal decreases in dissolved oxygen due to algal respiration during darkness and algae die-off, resulting in a subsequent spike in microbial degradation of dead algae that can significantly reduce dissolved oxygen concentrations in a river. Changes to competitive interaction between plant species and algae-driven decreases in dissolved oxygen concentrations can have wide ranging impacts on river ecosystems. In the River Wye

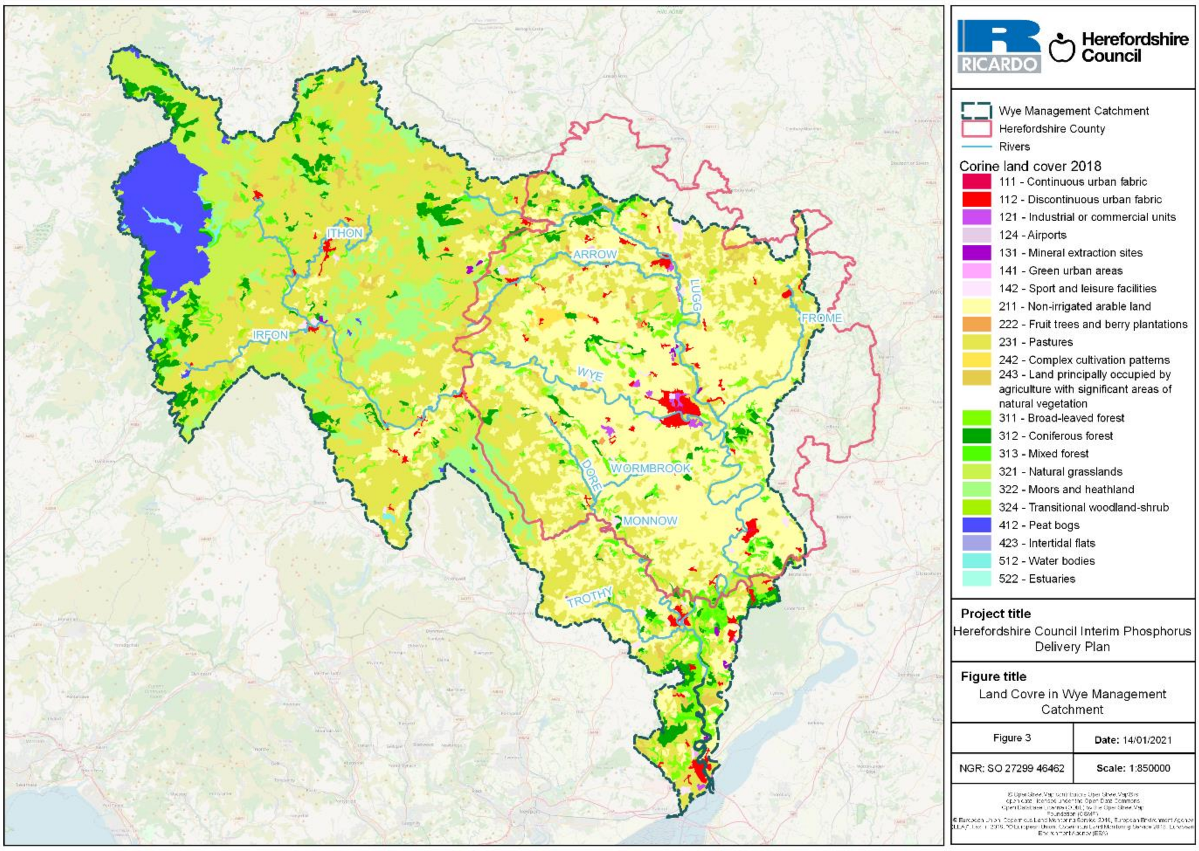
SAC, the key nutrient of concern is P. In December 2019, numerous sub-catchments of the upper River Wye SAC were found to be non-compliant with conservation targets for P[6]. The River Wye (between Hay-on-Wye and the River Lugg confluence) is close to exceeding the target in some monitoring locations and so is partially fulfilling the Natural England conservation objectives. The River Lugg section of the SAC is exceeding the phosphate target associated with being in favourable condition. Exceedance of the P targets for the Wye SAC has resulted in eutrophication, negatively affecting the qualifying features of the SAC and impacting the site's ecological integrity. This in turn leads to the site being in "unfavourable condition" and breaching the statutory protections afforded to it by the Habitat Regulations.

The P targets for the Wye SAC are measured as concentrations of SRP. The River Wye SAC favourable condition P targets are:

- River Wye from English/Welsh Border to River Lugg confluence – 0.03 mg SRP/l
- River Wye downstream of River Lugg confluence – 0.05 mg SRP/l
- River Lugg (from Leominster to Wye confluence) 0.05 mg SRP/l

Exceedance of the P target in the River Lugg is a result of water pollution from both 'point' sources and 'diffuse' sources. River Lugg current phosphate sources are 66% agriculture, 25% sewage treatment works, 9% other[7]. Figure 2.2 shows the extent of different types of agricultural land use in the Wye Management Catchment.

Figure 2.2: Landcover in the Wye Management Catchment mapped using CORINE land cover data (CEC, 1994).



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[6] See Compliance Assessment of the River Wye SAC Against Phosphorus Targets, accessed from: https://naturalresources.wales/evidence-and-data/research-and-reports/water-reports/river-wye-compliance-report/?lang=en, accessed on: 12/03/2021.

[7] See: Nutrient Management Plan Board Agenda and papers July 2020, accessed from: https://www.herefordshire.gov.uk/sitesearch?q=nutrient+management+plan+board#tab2 , access on: 18/01/2021

2.3 The River Wye Nutrient Management Plan (NNP) and Nutrient Neutrality

Failure of the P target in the River Lugg section of the Wye SAC and potential failure of the P target in the Upper Wye sub-catchment resulted in the creation of the River Wye NMP (Atkins, 2014). The NMP identified the key sources of P in the Upper Wye sub-catchment and River Lugg catchment and suggested potential solutions to tackling the different sources of P within the Wye SAC catchment. For mitigation of point source P inputs from WwTW, their scenarios were based around the adoption of Best Available Technology (BAT) for P treatment at key WwTW that serve the largest populations in the Wye SAC catchment. Suggestions for mitigation of diffuse agricultural pollution were based on catchment management through catchment sensitive farming. The different modelled scenarios of catchment sensitive farming resulted in a wide range of potential reductions in P loading from diffuse agricultural sources, from a minimum estimate of a 3% reduction in in-river P concentrations to a maximum of 40%. It was also noted that these were likely to be upper estimates as they rely on farmers implementing the catchment sensitive farming practices in full over a long period of time.

In the context of the Dutch Nitrogen Case's ruling, the uncertainty in the magnitude of P reductions that will be delivered by the actions detailed in the NMP means that they can no longer be relied upon to provide mitigation of increased P loading from new projects and plans under an HRA (Herefordshire Council, 2020). In order for a development to achieve nutrient neutrality, there is a now a requirement to show, beyond reasonable scientific doubt, and using suitably precautionary methods, that a development will not result in an increase in nutrient loading to the River Wye SAC. The first step in evidencing nutrient neutrality for developments in the River Wye SAC catchment is the calculation of a P budget for the development. If the development is found to result in a surplus P load that will discharge to the River Wye SAC, this surplus load will need to be mitigated to remove as much or more P from the catchment, thus achieving nutrient neutrality and compliance with the Habitats Regulations.

3 Phosphate budget calculations

The following sub-sections detail a methodology for calculating P budgets for new developments. The methodology follows the Stages for calculating a P budget detailed by Natural England for the Stour catchment and the Stodmarsh SAC (Natural England, 2020). The P budget calculations are comprised of the following four Stages:

1. The increase in P loading to National sites that result from the increase in wastewater from a new development, which is based on population increase, water use and nutrient concentrations in discharges from wastewater treatment works (WwTW) and package treatment plants/septic tanks.
2. The P export from the past and present land use of the development site.
3. The P export from the future mix of land use on the development site including onsite mitigation, e.g. urban land, greenspace.
4. Calculation of the net change in P loading to a designated site, i.e. the P budget, which includes the addition of a 20% precautionary buffer.

For each of the steps within these core components, different data inputs are required. The nature of these inputs means that most of them are based around sets of assumptions. For example, the water use figures for a property are based on the continued use of more water efficient fittings and in lieu of site-specific monitoring data for P loadings, suitable estimates of P export for different land types are used. Natural England provided a set of inputs that could be used for to calculate P budgets for new developments in the Stour and Stodmarsh catchments (Natural England, 2020). However, these inputs were developed specifically for local context of the Stour and Stodmarsh. Therefore there is a requirement to determine new input values relevant to the local development and environmental context of the River Wye SAC so that P budgets calculated for new developments in the Herefordshire Council area are robust enough to be used in an HRA. The following sub-sections provide a brief methodology for determining these new input values, followed by a breakdown of the core components of the nutrient budget into the four stages and the attendant steps required to calculate the nutrient budget. For each step, a rationale for the figure(s) that go into the nutrient budget is described.

3.1 Methodology

The input values required for each stage of a P budget have been determined through either a literature review, available data or modelling. Where values have been determined through a literature review, the review has only used values found in studies published in academic journals or from best practice industry guidance. These sources are subject to significant scrutiny through peer review processes that provide greater confidence in their quoted values or in the methods they detail to derive different input values. Various input values were not able to be determined though a literature review but did have datasets available from which they could be derived. These include occupation rates for new dwellings and the concentration of P in WwTW discharges. And, to determine the current P export from agricultural land that is being converted to an urban land use, a modelling exercise was conducted using the Farmscoper[3] model, which can be used to estimate the P export from different farm types and was also used by Natural England to determine the P export for agricultural land in the Stour catchment (Natural England, 2020).

3.2 Stage 1: Calculate additional Phosphorus load from the development

3.2.1 Step 1: Calculate additional population

The first stage in determining the additional P load associated with a development is to calculate the additional population that will be contributing wastewater. Natural England recommends using the average occupancy rate of 2.4 persons per household as calculated by the Office for National Statistics (ONS) (Natural England, 2020). Natural England have indicated that whilst they will only support an occupancy rate of 2.4, an occupancy rate specific to a local authority area can be used if sufficient evidence exists to support this figure. The 2011 census found that the county of Herefordshire had an average occupancy rate of 2.3 persons per household[8]. It has also been confirmed that both Herefordshire Council and Dwr Cymru (Welsh Water) use an occupancy figure of 2.3 in relation to Section 106 calculations within the planning system and for determination of population growth, respectively[9]. It should be noted that the national average occupancy rate of 2.4 is derived from 2011 census data. As such, it is deemed that the more specific value for Herefordshire provides a more accurate estimate of occupancy rates in the areas of the Wye SAC within Herefordshire.

The Natural England methodology assumes that all residential developments are creating new housing stock that will be filled by inward migration or internal population growth within an authority area. This is a fair assumption unless a new housing development is directly replacing old housing stock and the new housing stock is being populated by internal migration. If sufficient evidence can be provided that the population of a new development is derived in some proportion from internal migration and thus the net population increase is lower than it would be if the new housing stock is filled purely by population growth, this could be taken into account in the P budget by reducing the average occupancy rate. However, this scenario is considered to be unlikely as the Herefordshire Local Plan indicates an expected internal 12% population growth between 2011-2031 (Herefordshire Council, 2015). The use of an occupancy rate lower than 2.3 due to internal migration within Herefordshire would need to be assessed on a case-by-case basis and supported by sufficient evidence. Similarly, if a development comprises a majority of one-bedroom flats, a value lower than 2.3 could be proposed noting this would need to be assessed on a case-by-case basis dependant on the mix of dwelling sizes within a development. The 2.3 occupancy rate is also potentially going to change when the results of the 2021 Census are released and this input could be reviewed then these new data are made available.

3.2.2 Step 2: Water usage per person

The second step in the nutrient budget calculations accounts for the water use per person in the new development, ergo additional flow of wastewater that will be draining to a WwTW and thus increasing

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[8] See Table H01UK, 2011 Census: Households with at least one usual resident, household size and average household size, local authorities in the United Kingdom, available here. (Accessed 14/12/2020)
[9] These values were confirmed via emails from Herefordshire Council on 12/02/2021 and from Dwr Cymru on 15/02/2021.

the flow and associated P load from a WwTW. In guidance for Stodmarsh, Natural England recommends a water usage standard of 110 litres per person per day (l/p/d) (Natural England, 2020). This figure is based on the optional requirement outlined in the 2015 version of the Building Regulations Part G (Building Regulations 2010. Approved document G, 2015). This water efficiency standard follows a fittings approach in which there is a maximum consumption allowed for kitchen and bathroom fittings. However, ongoing work by Ricardo for Natural England has highlighted a change in guidance to only use the 110 l/p/d figure if the local planning authority (LPA) adopts a policy requirement for new developments to be built with a 100 l/p/d water efficiency standard[10]. Where LPAs adopt a 110 l/p/d policy, Natural England advise the use of 120 l/p/d. This approach is intended to be precautionary and recognises that people may change water efficient fittings for less efficient fittings over the lifetime of a development.

Herefordshire Council has adopted the 110 l/p/d water efficiency standard as a policy (Policy SD3) in their Local Plan (Herefordshire Council, 2015) and thus it will be a planning condition of new developments in the Wye SAC catchment. It is noted that whilst current water consumption in the Dwr Cymru supply areas is ~140 litres per person per day (WWT, 2019), new developments will be required to meet the 110 l/p/d standard in order to obtain planning permission and thus the 120 l/p/d figure is considered to be appropriate for use in the P budget methodology.

This report recognises that water usage values lower than 110 litres per person per day are achievable, however they must be maintained for the lifetime of the development (treated as 80-125 years for the purposes of an HRA). Previous consultation with Natural England has raised concerns about residents changing ultra-water efficient kitchen and bathroom water fittings for less efficient fittings, therefore increasing the flow of water and associated P load from a WwTW. For this reason, it is recommended that the 120 litres per person per day figure is used as the water usage input for new developments.

3.2.3 Step 3: P load in treated effluent exiting WwTWs or package treatment plants

Wastewater from a new development will ideally discharge to a mains sewer for subsequent treatment at a WwTW where treatment to remove P is likely to be greatest and most consistent. New developments in rural areas without connections to mains sewers will need to be connected to a package treatment plant or septic tank. The treated effluent from WwTWs or package treatment plants is enriched in P and its discharge into rivers provides the pathway for P pollution from a new development to impact on the Wye SAC. The P budget therefore needs an input of the concentration of P in the treated effluent discharge from a WwTW or package treatment plant as the final input to Stage 1 of the nutrient budget calculations. It is also noted that whilst package treatment plants can discharge to rivers, they may also discharge directly to ground. Septic tanks are also permitted to discharge ground. Where a package treatment plant or septic tank discharges to ground, it is possible the retention of phosphorous that can be achieved by soil means that LSE on the Wye SAC can be avoided. Natural England has provided guidance that a small discharge of < 2 m^3/day from a septic tank or package treatment plant will result in a development being P neutral if it meets the following criteria:

- The drainage field is more than 50 m from the designated site boundary (or sensitive interest feature) **and**;
- The drainage field is more than 40 m from any surface water feature e.g. ditch, drain, watercourse, **and**;
- The drainage field in an area with a slope no greater than 15%, **and**;
- The drainage field is in an area where the high water table groundwater depth is at least 2 m below the surface at all times **and**;
- The drainage field will not be subject to significant flooding, e.g. it is not in flood zone 2 or 3 **and**;
- There are no other known factors which would expedite the transport of phosphorus for example fissured geology, insufficient soil below the drainage pipes, known sewer flooding,

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[10] Ricardo are engaged in production of a generic nutrient neutral methodology for Natural England.

conditions in the soil/geology that would cause remobilisation phosphorus, presence of mineshafts, etc **and**;

- To ensure that there is no significant in combination effect, the discharge to ground should be at least 200 m from any other discharge to ground.

If *all* the above criteria can be met for a package treatment plant or septic tank, Natural England suggest that there is currently no further requirement for an HRA to determine nutrient neutrality for the development. Meeting these criteria will have to be determined on a site-by-site basis and it is noted that the competent authority will need to determine whether they agree with the above criteria for no LSE from phosphorous discharge to ground rom package treatment plants and septic tanks. It also noted that the Environment Agency has a presumption for mains sewer connections where possible and will only accept connection to a package treatment plant for a new development where developers and/or planning authorities have shown this is the most appropriate sewage treatment solution (Natural England, 2020). Natural England have provided guidance on how new developments can determine if they meet all of the above criteria for no LSE from connection to a package treatment plant or septic tank. This guidance is provided in Appendix A3 for ease of reference.

Guidance on how to select a P concentration value for wastewater discharge from WwTWs with P permits, WwTWs without a P permit and package treatment plants is provided below.

3.2.3.1 WwTWs with P permits

For new developments with mains sewer drainage to a WwTW, the concentration of P in WwTW effluent discharges to the River Wye SAC is primarily contingent on whether the WwTW has a permit limit for P on its discharge, i.e. whether the Environment Agency has imposed a maximum concentration of P allowed in the WwTW discharge.

Dwr Cymru is the sewerage undertaker for the parts of the Wye SAC catchment in the Herefordshire Council area. Data provided by Dwr Cymru show that the majority of the WwTWs within this area have P permit limits, however three WwTWs are scheduled for upgrades over the next water company investment cycle and may not be operating with a P permit limit until 2025 (Table 3.1). Where a new development is being connected to a WwTW with a P permit limit that is not being upgraded as part of the Water Industry National Environment Programme (WINEP), i.e. there is no new proposed P limit from 2025, the input to Step 3 of the first stage of the nutrient budget calculations should be the current P limit listed in Table 3.1. Where a development is connecting to a treatment works that is being upgraded and the development is scheduled to be occupied before 2025, a two-stage nutrient budget should be completed as follows:

- A development with a lifespan of 125 years is completed on the 01/01/2022 and will discharge, for example, to the Eign WwTW with a permit limit of 1 mg P/l, changing to 0.4 mg P/l in 2025.
- A three-year budget from 2022-2025 using the Eign WwTW P permit of 1 mg P/l is calculated and short-term measures can be used to mitigate this load.
- A 122-year budget using the lower limit of 0.4 mg P/l should be calculated with different, long-term mitigation measures able to be applied to achieve nutrient neutrality in perpetuity.

All P permit limits are to be adjusted by a factor of 0.9 (Natural England, 2020). The factoring of the P consent limit value accounts for WwTWs normally being operated to leave 10% headroom between the actual P concentration in the discharge and the permit level. Natural England also notes that a WwTW may be operating with more than 10% permit headroom, however in these cases there is uncertainty over the P concentration in the discharge as a WwTW may reduce the amount of treatment applied to influent wastewater and allow the concentration in the effluent discharge to remain close to or at 90% of the P permit level. In order for the input to Stage 1, Step 3 to be suitably precautionary, it is recommended to follow Natural England's advice to use a value of 90% of a WwTW P permit level, even if the WwTW that a new development is connecting to has P permit headroom.

Table 3.1: WwTW within the Herefordshire Council area and River Wye SAC catchment, their current P consent limit and proposed P consent limits that will be implemented by 2025.

WwTW	Sub-Catchment of Wye SAC WwTW discharges to	Current P limit (mg P/l)	Proposed P limit (mg P/l) by 2025
Eign	Upper Wye	1	0.4
Hereford (Rotherwas)	Upper Wye	1	0.4
Kingstone & Madley	Upper Wye	5	2
Leominster Worcester Road	Lugg	1	0.5
Bromyard	Lugg	1	1
Moreton-on-Lugg	Lugg	1	1
Kington	Lugg	1	1
Weobley	Lugg	5	1.5
Pontrilas	Lower Wye	5	1.8
Lower Cleeve (New)	Lower Wye	2	2

3.2.3.2 WwTWs without P permits

For WwTWs without P permits, the concentration of P in the treated effluent from the works will depend on the P concentration in the influent. Natural England advises that the WwTW effluent P concentration value for WwTWs with no P permit should be determined from best available evidence (Natural England, 2020). Neither Dwr Cymru nor the Environment Agency routinely monitor P in the effluent from WwTWs without P permits. For new developments discharging to any of these three WwTWs, it will therefore be necessary to determine an approximate Total P concentration in the final effluent streams from these works based on the type of treatment used at each works. This approach follows Natural England's advice for the Stour catchment (Natural England, 2020).

In addition to the works scheduled for upgrades and P permits by 2025 (Kingstone & Madley, Weobley, Pontrilas; Table 3.1), a further 32 treatment works in the Lugg catchment do not have P permits and are not currently scheduled for upgrades to have P permits. These 32 WwTWs are listed in Appendix A1. Dwr Cymru provided the treatment types at each of these works and an assessment was conducted to determine if a P concentration in the final effluent from these works could be determined from the literature. However, it is apparent that the P concentration in final effluent is too dependent on both the P concentration in the influent and the sub-type of different treatments, e.g. biofilters (Li, et al., 2014; Gao, et al., 2016) or activated sludges (Kocadagistan, et al., 2005; Li, et al., 2020), to be determined from a literature review. Natural England guidance for the Stodmarsh SAC suggested a value of 8 mg P/l is used for WwTWs without permit limits (Natural England, 2020). This research has analysed data on non-permit limited WwTWs operated by Dwr Cymru that indicates a value of 8 mg P/l is likely an overestimate for the Herefordshire area. Through consultation with Natural England, it has been decided that a value of 5 mg P/l in the effluent from non-permit limited WwTWs is likely to provide a suitably precautionary input for this step of the P budget methodology. Dwr Cymru has also informed Herefordshire Council that they will be collecting more data on P concentrations in effluent from non-permit limited WwTWs. This data should be used as part of an ongoing review of the 5 mg P/l value recommended in this P budget methodology, in order to reduce uncertainty.

It is recognised that for the Kingstone & Madley, Weobley and Pontrilas WwTWs, the P concentration in final effluent is likely to reduce markedly once these works have been upgraded to account for the new P permit conditions (Table 3.1). As such, the total P load over the lifetime of a development will be substantially lower than if the non-permit limited P concentration for these works is used. If a new development will connect to one of these three works before 2025, then the same two-stage approach to calculating the P budget for permit limited WwTWs that are being upgraded is recommended (see Section 0).

3.2.3.3 Package treatment plants and septic tanks

Where connecting a new development to mains sewers is not feasible, any development that will discharge treated wastewater directly to a surface waterbody is required to install package treatment plants under Environment Agency General Binding Rules[11]. Where discharge from an onsite wastewater treatment system is to ground, either package treatment plants or septic tanks can be installed. It should be noted that the Environment Agency has a preference for package treatment plants over septic tanks due to data that suggests they have, on average, lower P concentrations in their effluent[12]. However, it is noted that the efficiency of P removal by septic tanks and package treatment plants is dependent on the type of system and that some septic tanks can achieve greater levels of P removal than less efficient package treatment plants. Where package treatment plants or septic tanks will discharge to a drainage field that does not meet all of the criteria for no pathway to impact (see Section 3.2.3), there is a requirement to determine the additional P load in wastewater from the new development.

The P load from package treatment plants or septic tanks is derived by multiplying the effluent flow rate by the concentration of P in the effluent. Flow rates and P concentrations from package treatment plants or septic tanks are not constant (May & Woods, 2016) and deriving a daily estimate of load based on effluent flow rate and P concentration is therefore prone to large uncertainties. However, on an annual basis it is safe to assume that differences in daily loads due to fluctuating flow rates and P concentrations will average out and therefore load can be calculated using the 120 l per person per day water use figure (see Section 3.2.2) and the total phosphorous (TP) concentration detailed in a package treatment plant or septic tank specification, assuming a figure for TP concentration in final effluent is provided.

The Natural England (2020) methodology for P load calculations from package treatment plants and septic tanks recommends using an annual TP load in wastewater based on the annual TP production per person from human excreta and detergent use (the two sources of P in wastewater). This annual TP load per person is then reduced by a fixed percentage based on the efficiency of P removal by the treatment system being installed. Natural England (2020) cites an annual TP load per person of 0.99 kg TP/year, taken from May et al (2015). This value is within the range reported in a review of P emissions factors for human excreta and detergents from various studies suggesting total P emissions per person of 0.69-1.16 kg P/year (Naden, et al., 2016). Naden et al's (2016) study also highlighted that the detergent component of human P emissions has fallen notably from a historic high in the 1980s, whilst research by Forber et al. (2020) has suggested that P loads in human excreta are likely to increase over time as more people switch to plant-based diets. This indicates the uncertainty associated with estimates of TP resulting from human emissions.

Based on the above analysis, it is recommended that the P budget calculations use a TP load from a package treatment plant or septic tank that is calculated using 120 l per person per day water use and the specified TP concentration in the effluent from the chosen treatment system. The specified TP concentration should be verified by supporting evidence from the manufacturer based on laboratory testing of effluent either whilst the treatment system was being designed, or from monitoring data from real-world uses of the treatment system. Assuming a verifiable TP concentration in the treatment system effluent can be provided, load derivation using concentration and flow rate is recommended over the Natural England (2020) methodology. This is due to the uncertainties in human P emissions factors detailed above and the subsequent uncertainty this introduces to annual TP load estimates that are based on the efficiency of the treatment system and associated percentage reduction of annual human P emissions. However, it is recognised that data on TP concentrations in final effluent from package treatment plants and septic tanks may not be available, as P emissions from these treatment systems are not regulated (May & Woods, 2016). If data on the TP concentration in effluent from a treatment system is not available, a default value of 9.7 mg P/l should be used for package treatment

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[11] See: Septic tanks and treatment plants: permits and general binding rules, accessed from: https://www.gov.uk/permits-you-need-for-septic-tanks/general-binding-rules, accessed on: 21/12/2020.

[12] See: Septic tank and package treatment plants: liquid effluent pollutants and typical concentrations. Accessed from: https://www.gov.uk/government/publications/values-for-groundwater-risk-assessments/septic-tank-and-package-treatment-plants-liquid-effluent-pollutants-and-typical-concentrations, accessed on: 12/03/2021.

plants (May & Woods, 2016) and 11.6 mg P/l for STs (O'Keeffe, et al., 2015). These values are derived from reviews of P concentrations in package treatment plant and septic tank effluent.

It should be noted that there are onsite wastewater treatment solutions that can achieve low concentrations of TP in their final effluent. For example, all of the BioKube products, which vary in sizes from 5-10000 PE, can produce effluent with < 1.1 mg TP/l, according to their own research[13]. It is also noted that package treatement plants or septic tanks that dischage to ground may be able to achieve further reductions in P export from a development as a large proportion of P is retained in by soil. Even better retention of P in drainage fields can be achieved through the use of filter media with high P sorption capacity. However, there is a requirement for suitable drainage field management plans to be put in place in order to secure the reduction in P export over in perpetuity.

3.2.4 Step 4: Calculate Total Phosphorus that would exit the WwTW after treatment

The final step in Stage 1 is to calculate the TP exiting the WwTW. This can be achieved by multiplying the estimated total water usage of the proposed development by the appropriate concentration of TP. This value then needs to be converted to the total export of TP from the WwTW in kilograms per year. A worked example of a theoretical development in Herefordshire can be found in Table 3.2. This will be used throughout for clarity.

Table 3.2: Worked example of Stage 1 nutrient loading calculation. A theoretical new development of 2500 dwellings is discharging to a WwTW that has a 1.5 mg TP/l limit with an average population size of 2.3 persons per household.

Step	Value	Unit	Explanation
Development Proposal	1000	Residential dwellings	The number of new dwellings.
Step 1 (additional population)	2300	Persons	2.3 x 2500 = 5750
Step 2 (wastewater volume)	276,000	litres/day	2300 persons x 120 litres = 276,000 litres (If necessary, subtract volume from displaced population).
Step 3 (receiving WwTW TP discharge)	1.35	mg TP/l	90% of 1.5 mg TP/l
Step 4 (TP discharged after WwTW treated)	372,600	mg TP/day	Step 2 x Step 3 = 1.35 mg TP/l x 276,000 = 372,600
Convert mg/TP to kg/TP	0.37	kg TP/day	Divide by 1,000,000
Convert kg/TP/day to kg/TP/year	136.09	kg TP/year	Multiply by 365.25 days

3.3 Stage 2: Calculate existing P load from current land use

All land uses/land covers result in a certain quantity of P export to river systems, e.g. the Rivers Wye and Lugg. The magnitude of this P export is generally lowest for natural land covers and highest on agricultural and urban land uses where fertilisers, animal waste, detergents and vehicle emissions provide large sources of P. Stage 2 accounts for the P losses associated with the current land use within the boundary of a plan for which the P budget is being calculated. If the land use within the plan boundary changes, there is an associated change in P export (in kg P/ha/year) from the area of land

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[13] See: Cleaning results for al 3800 BioKube systems in Denmark, January 2021, available from: https://www.biokube.com/download/biokube-technical-library/, accessed on: 22/02/2021

being developed. This change in P export from land use change is offset against the increase in P load that will come from the additional wastewater generated by the new development.

For changes of agricultural land to urban land use through housing development, Natural England used the Farmscoper model in order to generate P export coefficients for different types of farming within the River Stour catchment (Natural England, 2020). Farmscoper is an industry-standard modelling tool that can be used to estimate the export of nutrients from farms at various scales and with minimal to no additional data requirements. P export estimates from Farmscoper at the catchment scale for the River Wye are broken down into the following farm types:

- Cereals
- Dairy
- General Cropping
- Horticulture
- Pig
- Lowland Grazing
- Less Favoured Area Grazing
- Mixed
- Poultry

It is thus recognised that any estimates of P export for agricultural land uses made using a method other than Farmscoper must be at least as specific in terms of farm type, as greater generalisation of farm types will result in greater uncertainty in P export coefficients.

An assessment of previous literature to determine P export coefficients has highlighted various issues with the use of previously published values. Jarvie et al (2010) studied two small streams in the Wye catchment, the Dinedor and the Kivernoll and found losses from all land in these sub-catchments of 0.56 and 0.50 kg TP/ha/year, respectively. Although being based in the Wye catchment, this study did not elucidate the P losses from specific land covers/farm types within mixed land use sub-catchments. Similarly, the River Wye Nutrient Management Plan (Atkins, 2014), whilst more specific in terms of estimates of P loss from different agricultural land uses, did not provide sufficient granularity to cover the farm types detailed in Natural England's advice (Natural England, 2020). White and Hammond (2006) collated research on phosphorus export coefficients for various land cover types to assess phosphorus losses at the River Basin District scale. The values for the Severn River Basin District in which the Wye Catchment is located are shown in Table 3.3. Although this research differentiated various different land covers, it lacks the spatial resolution for applicability to sub-catchments of the Wye that fall within Herefordshire Council's jurisdiction. Furthermore, this study used values derived from studies in other areas of the UK – the phosphorus export coefficient for urban land was sourced from a study completed in 1987 and based in Scotland – and changes to farming practices mean older studies are unlikely to accurately represent the current P export from different farm types. Based on the above research, it is apparent that an approach that provides more farm type-specific P export values at higher spatial resolution is required.

Table 3.3: Land cover export coefficients in the Severn River Basin District after White & Hammond (2006)

Land Cover	TP export coefficient (kg P/ha/year)
Broad-leaved and mixed woodland	0.02
Coniferous woodland	0.02
Arable cereals	0.90
Horticulture: Root crops	0.90
Horticulture: Field vegetables	0.90
Orchard	0.02
Set aside grass (ley)	0.02
Improved grassland	0.80
Grass set aside	0.00

Land Cover	TP export coefficient (kg P/ha/year)
Neutral grass	0.02
Calcareous grass	0.02
Acid grass	0.02
Bracken	0.02
Dense dwarf shrub heath	0.02
Open dwarf shrub heath	0.02
Fen, marsh and swamp	0.00
Bogs (deep peat)	0.00
Water	0.00
Inland bare ground	0.70
Continuous urban	0.83

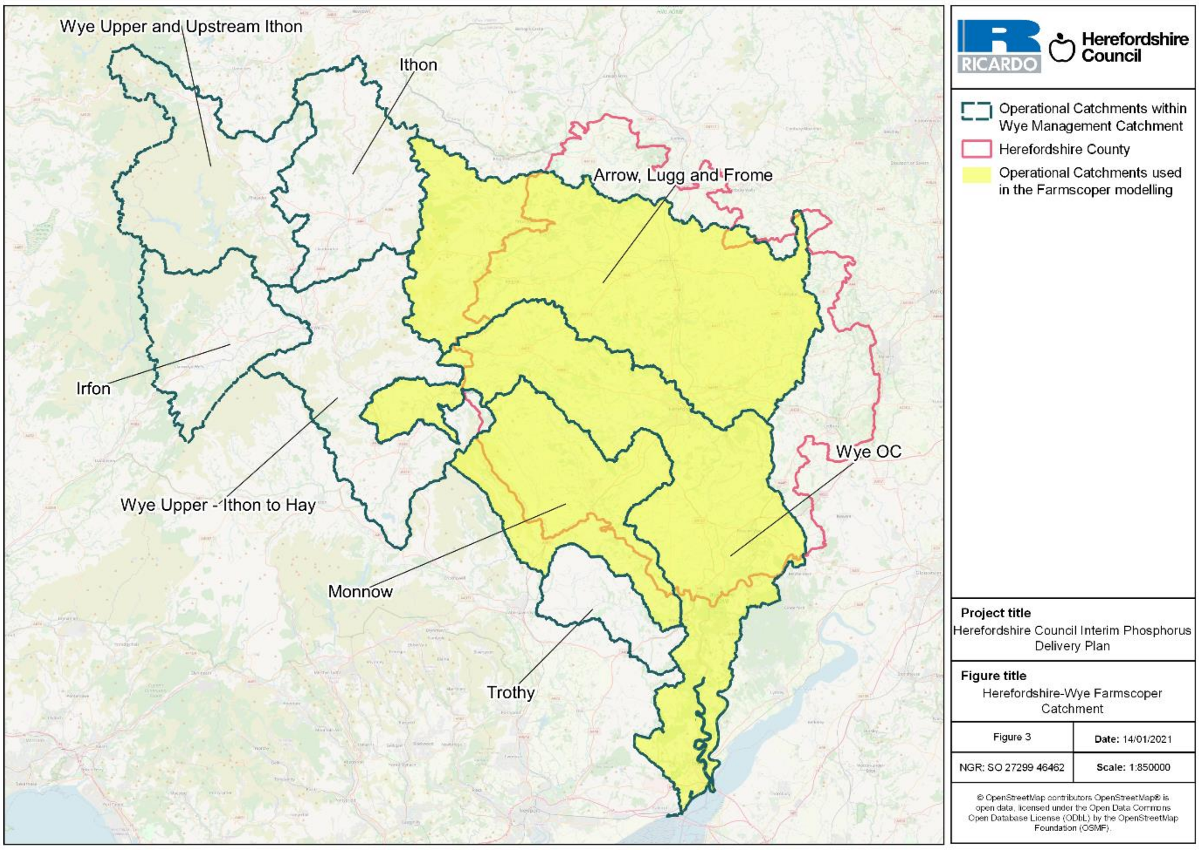
*The export coefficients detailed in this table may be of use when considering the likely level of background P export from land used for mitigation. Options for P mitigation are covered in detail in Stage 2 of the Interim Phosphate Delivery Plan.

The most accurate method for determining P export from current land use would be from site-specific monitoring and/or modelling investigations. However, conducting such investigations is onerous and expensive, and therefore places an unrealistic burden on developers. Natural England's use of Farmscoper in their Stodmarsh (Natural England, 2020) and Solent nutrient neutrality advice notes recognises that this is the most practical method for estimating P export from different farm types at the catchment scale. As such, a Farmscoper modelling exercise has been carried out in order to determine P export coefficients to use as input to the Stage 2 calculations. An overview of the Farmscoper modelling exercise is in the following sections, with more detail on the methodology and results provided in Appendix 2.

3.3.1 Farmscoper modelling to derive P export coefficients for farm types in the River Wye Catchment

Farmscoper v4 was used to derive agricultural export coefficients. The tool uses the 2015 June Agricultural Survey data and the PSYCHIC model of P leaching (Davison, et al., 2008) to generate P export coefficients, with no other data inputs required. Farmscoper's Upscale tool was run at the scale of the three operational catchments (OCs) that are within both the River Wye Management Catchment and the Herefordshire Council Boundary. These OCs are the Arrow Lugg and Frome, the Monnow, and the Wye OC (Figure 3.1).

Figure 3.1: The operational catchments used in Farmscoper modelling, shown alongside all the operational catchments that comprise the Wye Management Catchment. The Herefordshire County border is overlain on these catchments.



The default operation of the model produces multiple estimates of baseline P exports with limited application of on farm mitigation measures to reduce diffuse P loading. The estimates of P export are provided for combinations of farm type, soil drainage characteristics and rainfall. The baseline Farmscoper model for an OC can be re-run using the Farmscoper Evaluate tool, which incorporates mitigation methods that reduce diffuse P pollution from farms (Gooday, et al., 2015). For each single combination of farm characteristics, the Farmscoper Evaluate model run produces three P export estimates: the baseline, one accounting for "prior implementation" of mitigation measures that accounts for "present day" mitigation measure implementation since the baseline (noting that this version of Farmscoper was released in 2015), and the other based on "maximum implementation" of mitigation measures. Neither the "prior implementation" nor "maximum implementation" scenario is likely to be truly representative of the current (2021) implementation of mitigation measures due to greater uptake of catchment sensitive farming methods and a change in the regulatory minimum requirements of mitigation since 2015.

It is recommended that the P export coefficients generated by Farmscoper's 'prior implementation' scenario are used as input to the P budget calculations. This recommendation is based on a sensitivity analysis of the variability in P export coefficients generated by the Farmscoper's mitigation scenarios, as well as consultation with Natural England. Details of the sensitivity analysis are provided in Appendix 2. In summary, as well as the in-built 'prior implementation' and 'maximum implementation scenarios', two bespoke scenarios based on expert judgement of low and high increases in uptake of mitigation measures between 2015-2021 were run and the difference in P export coefficients relative to Farmscoper's baseline output was analysed. The mean percentage decrease in P export relative to baseline showed an 11.4% reduction for the "prior implementation" (2015) scenario, followed by the bespoke 2021 low and high uptake scenarios (13.1% and 13.4% reductions, respectively), with the "maximum implementation" scenario resulting in a notably higher average reduction (45.9%) in P export coefficients.

With higher estimates of increased mitigation measure uptake in the bespoke 2021 scenarios, the reductions in P export are on average only 2% greater than the 'prior implementation' scenario when compared to the baseline. It is important to note that the 'prior implementation' scenario is based on the minimum regulatory requirements for diffuse pollution mitigation in 2015, whereas the bespoke 2021 scenarios were based on best estimates of current mitigation measure implementation in the Herefordshire Council area. This means agricultural P emissions estimated under the 'prior implementation' scenario provide the best available evidence for the agricultural P inputs to the P budget methodology, although it is recognised that these export coefficient will be slight overestimates due to increases uptake of mitigation measures between 2015-2021. Natural England have also indicated that they do not see maintenance of existing levels of P export from agriculture as predicted in the 'prior implementation' scenario as hindering restoration of the River Wye SAC. As such, the P export coefficients provided by the 'prior implementation' scenario should be used as input to the P budget methodology.

The Natural England guidance for Stodmarsh recommends that P export values output from 'prior implementation' scenario for each combination of farm type, soil drainage and rainfall are averaged (Natural England, 2020). Due to the large variation in P export associated with soil drainage and rainfall volumes for a single farm type, it is recommended that the P export coefficients for specific combinations of farm characteristics are used. Herefordshire Council and local developers can find this information for a development site online via the Soilscapes dataset[14] for soil drainage and the National River Flow Archive for rainfall[15]. These datasets have been confirmed as suitable for the purpose of determining the correct agricultural P export coefficient from Farmscoper through consultation with Natural England and ADAS Ltd. (who developed Farmscoper). There are detailed instructions on how to find the required data in the 'Phosphate Budget Calculator' tool that accompanies this report.

Consultation with the Wye and Usk Foundation has highlighted concerns about the potential impacts that legacy P may have after a cessation of agricultural activity removes the source of P from a land parcel. Legacy P is P that is bound within soils and may continue to leach from land after agricultural activity has stopped. Unpublished data from the RePhokus research project[16] has suggested that legacy P may account for up to 40% of the P by volume in agricultural soils, creating a persistent source of P even after agricultural activity has ceased on a development site. This potentially persistent P source is not accounted for in Farmscoper and needs to be considered in the nutrient budget calculations, as the methodology assumes that P export ceases as soon as agriculture at a development site stops. There is a paucity of research on P leaching rates from formerly agricultural sites that have been converted to urban land use, with most related studies focussing on issues like P export from urban gardens (e.g. Small, et al., 2019) or the concentration of P in urban runoff (e.g. Yang & Toor, 2018). However, although there is risk of continual leaching of legacy P from a post-development site, this risk is deemed to be relatively small. This is due to the two pathways for P export from a site, soil erosion and de-sorption of P in surface runoff and de-sorption of P in sub-surface flow, being reduced considerably by increases in impervious surfaces during conversion to urban land use.

3.3.2 P export from urban land uses

Development sites in urban areas may comprise a mix of land uses. For the purpose of calculating a P budget for development site, these land uses are classified as follows:

- Residential
- Commercial/industrial
- Open urban land
- Greenspace, e.g. parks, sports fields or other green infrastructure managed for recreation
- Community food growing, e.g. allotments

The following sub-sections detail P export values, or how to derive these values, for each of the above land uses. The values will be used as inputs to the P budget.

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[14] See: http://www.landis.org.uk/soilscapes/index.cfm#, accessed on 12/03/2021.
[15] See: https://nrfa.ceh.ac.uk/data/search, accessed on 12/03/2021.
[16] Details of the project can be found at http://wp.lancs.ac.uk/rephokus/ (Accessed on: 12/01/2021).

3.3.2.1 Calculating P export from residential, commercial/industrial and open urban land

The Natural England advice document for the Stour catchment recommends using the P export coefficient in White and Hammond (2006). This value is based on a 1987 study from Scotland (Bailey-Watts et al, 1987) and therefore it is unlikely to be representative of current nutrient losses from urban land in the Wye Catchment. Instead, it is recommended to use a P export coefficient estimated by calculating the annual urban run-off for the site and multiplying this value by an event mean concentration (EMC) for P found in urban runoff from the relevant urban land use, following Zhang et al (2014) and Mitchell et al (2005). It should be noted that this is also the approach being applied in Defra Science Project WQ0223 on source apportionment of diffuse pollution[17]. By multiplying the concentration of P assumed to be in urban runoff by runoff rate for that are, a load of P per unit area (in kg/ha) is calculated. EMCs are available for residential, commercial/industrial and open urban land (Table 3.4). The relevant EMC in Table 3.4 is used in the equations detailed below.

Table 3.4: Event mean concentrations for P runoff from different urban land uses.

Land use	Event mean concentration (mg P/l)
Residential	0.41
Commercial/industrial	0.30
Open urban land	0.22

To calculate urban runoff, the HR Wallingford Modified Rational Method (DoE, 1981) should be used (Equation 1). For the use of Equation 1 in this method, urban areas are assumed to be 80% impermeable land, which is suggested as the area of impermeable surfaces in urban areas when urban creep reaches a maximum (Gorton, et al., 2017).

As, an example of the application of Equation 1 to calculating urban P loading in a residential area, the annual average rainfall of 813 mm in the Lugg catchment (based on rainfall data for the Lugg at Lugwardine NRFA flow gauge[18]) is used. This results in a catchment wetness index of 41 (as recommended by Zhang et al, 2014, for rainfall values in excess of 748mm). This results in an annual average runoff of 397 mm per square metre of urban area. As 1 mm of water over 1 m^2 is equal to a litre of water, multiplying the litre equivalent of runoff (see Box 2) by the EMC of 0.41 mg TP/l, and converting to kilograms per hectare, gives an annual urban P export coefficient of 1.63 kg TP/ha/year. This calculation can be viewed in Box 2. This value is more than the value used in White and Hammond (2006) but is based on locally specific information and is therefore more accurate and more precautionary. It should be noted that when calculating a P budget for a specific development, the local average annual rainfall value for your development site and the relevant EMC should be used to calculate the P load input for this part of the P budget. Instructions on how to get the local average annual rainfall value are included in the 'Phosphate Budget Calculator' tool that accompanies this report. This tool also implements the required equations in order to derive the P export value from residential, commercial/industrial or open urban land. For sites that contain a mix of residential, commercial/industrial and open urban land uses, the dominant land use should be used.

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[17] This project is currently unpublished, however extracts from the project confirming the use of the recommended method have been obtained via the Environment Agency.

[18] See: Lugg at Lugwardine catchment info accessed here: https://nrfa.ceh.ac.uk/data/station/spatial/55003, accessed on: 18/01/2021

Equation 1 – The Wallingford Modified Rational Method for calculating urban runoff

$$L = R * Pr$$

Where:

L = annual average runoff (mm)

R = annual average rainfall (mm)

Pr = percentage runoff (%)

$$Pr = 0.829 * PIMP + 0.078 * U - 20.7$$

$PIMP$ = the percentage of land that is impervious (whole number)

U = catchment wetness index. Calculated by (use 41 if rainfall over 748 mm):

$$U = -129.5 + (0.424 * R) - (2.28 * 10^{-4} * R^2) - (4.56 * 10^{-8} * R^3)$$

Box 2: Worked example of the calculation behind the urban phosphorus losses in the Wye catchment based on Zhang et al (2014) after HR Wallingford method (DoE, 1981)

- The calculation of annual average runoff is:

$$L = R * Pr$$

Where:

L = annual average runoff (mm)

R = annual average rainfall (mm) = 813 mm

Pr = percentage runoff (%)

$$Pr = 0.829 * PIMP + 0.078 * U - 20.7$$

$PIMP$ = the percentage of land that is impervious (whole number %) = 80%

U = catchment wetness index. = 41

Therefore:

$$L = 813 * (0.829 * 80 + 0.078 * 41 - 20.7) = 813 * 48.8\% = 396.9\ mm$$

Note:

1 mm ≡ 1 mm/year ≡ 1 mm/m²/year ≡ 1 l/m²/year ≡ 10000 l/ha/year

- Multiplying annual average runoff per hectare by the EMC for phosphate of 0.41 mg P/l (Mitchell et al, 2005) gives the annual phosphorus export rate:

$$3968903 * 0.41 = 1627700\ mg/ha/year$$

Note:

1kg ≡ 1000000 mg

Therefore:

Urban phosphorus losses = ***1.63 kg P/ha/year***

3.3.2.2 P export from greenspace

Natural England advises that for development sites that are greenfield land but that *have not been in agricultural use* for the last ten years and are not subject to unmanaged recreational use (like dog walking without dedicated dog waste bins), a baseline nutrient leaching value of 0.14 kg P/ha/year should be used (Natural England, 2020). This is based on assumptions regarding P inputs, nutrient retention, and phosphorus losses. Firstly, it is assumed that phosphorus inputs from pet waste will be 1.21 kg/ha/year, which was the average across catchments of various sizes in a US based study (Hobbie et al, 2017). The second assumption is that greenfield land will retain 90% of this phosphorus resulting in a leaching of 0.12 kg/ha/year from pet waste. Finally, the natural land export coefficients of 0.02 kg/ha/year are assumed (Johnes et al, 1996) and added to the previous leaching value.

Following consultation with Natural England, a new approach to setting the P export coefficient for greenspace has been determined. It has been recognised that the approach detailed in Hobbie et al. (2017) is contingent on housing density and that the study was based in a part of America with a much lower average housing density than is seen in Herefordshire. As pet ownership scales with population, which in turn scales with housing density, the P input values from pet waste detailed in Hobbie et al. (2017) would also require scaling up to account for greater housing densities. When scaled up to the average housing density in Herefordshire, the P input value from pet waste is increased nearly 5-fold, which in turn results in near 5-fold increase in P export from greenspace relative to the value suggested in the Stodmarsh guidance.

It has also been noted that the EMC used to calculate P export from residential land (0.41 mg P/l) is considerably higher than the EMC for commercial/industrial (0.22 mg P/l) and open urban land (0.30 mg P/l). In residential areas, the key additional sources of P are detergent use and pet waste. The sampling strategy for the derivation of the EMCs recommended in this methodology is only available in an unpublished database of over 70 studies of P concentrations in urban runoff, which was used to derive the EMCs detailed in Mitchell (2005), and which are used here. As surface runoff can only be sampled by collecting water in surface drains or through a dedicated surface runoff collection experimental setup, it is assumed that at least some runoff and the associated P load from greenspace in residential areas would have been used to determine the residential EMC. Furthermore, pet waste inputs are not restricted to greenspaces within an urban area. It is therefore assumed that the pet waste inputs associated with housing and population are, at least in part, captured in estimates of P export calculated from the EMC for residential urban land use (see Section 3.3.2.1). Thus, the use of a housing density weighted estimate of P input to greenspace is likely to result in double counting some or all of the P associated with pet waste that is the key driver of P export from greenspace in the Stodmarsh methodology. As such, it has been agreed with Natural England that greenspace should use the natural land P export value of 0.02 kg P/ha as the input value for greenspace in the P budget methodology.

3.3.3 P export from community food growing

There is a paucity of research on P export from community food growing, with no studies of P leaching from community food growing found. As such, if community food growing provision has been incorporated into the pre-development site, it is recommended to use the P export value from Farmscoper modelling (see Section 3.3.1) for general cropping on free draining soil, using the rainfall value previously determined the development site. The General Cropping farm type has been selected as the closest arable farm type to the mixed fruit and vegetable crops typical of community food growing. Free draining soils have been selected as land used for community food growing is unlikely to be under drained. The P export value for community food growing will therefore be variable, depending on rainfall. The accompanying 'Phosphate Budget Calculator' tool will calculate the P export associated with community food growing if this land use is present on a development site.

3.3.4 Worked example of Stage 2 calculations

A worked example to calculate the phosphorous load from existing land use is set out in Table 3.5.

Table 3.5: Worked example of Stage 2 calculations for previous land uses

Step	Value	Unit	Explanation
Step 1 (total area of existing land)	10	Hectares	Area of land within site boundary.
Step 2 (identify land type and areal extent of the land cover)	Cereals – 10	Hectares	The land classes and extents within the site.
Step 3 (confirm phosphorus loss from land type, soil drainage and rainfall)	Cereals, rainfall: 700 to 900 mm, soil drainage: Drained for Arable – 0.68	kg P/ha/year	P export derived from Farmscoper modelling and varies depending on soil drainage and rainfall.
Step 4 (calculate load from current land use)	6.8	kg P/year	10 ha x 0.68 kg P/ha/year = 6.8 kg P/year
Phosphorus losses from previous land uses	**6.8 kg P/year**		

3.3.4.1 Exception to Stage 2 and Stage 3 calculations

If a development site is on brownfield land where there is no capacity to incorporate other land uses in the post-development site, for example the pre-development site is 100% residential and is being redeveloped without the addition of any greenspace or other non-residential land use, there is no change in land use between the pre- and post-development site. As such, the P export pre- and post-development is un-changed and *both* Stage 2 and Stage 3 can be skipped as the only net change in P loading associated with the development comes from increased wastewater. However, if there is land use change on a brownfield site, for example a previously commercial/industrial site is changed to a residential site, the Stage 2 and Stage 3 calculations should be completed as it will be necessary to account for changes in P export between the pre- and post-development site land uses.

3.4 Stage 3: Adjust load to account for new land uses within the proposed development

Post-development, a development site will be either 100% urban land or a mix of urban land use and greenspaces. The purpose of Stage 3 of the nutrient budget calculations is to account for diffuse phosphorous losses from the mix of new land uses on the development site. This includes the phosphorous load from the new urban development and from the new open space including any greenspace or nature reserves as identified within the redline boundary of the scheme. Nature reserves should use the greenspace P export coefficient detailed in Section 3.3.2.2. Pre-existing waterbodies and areas of wetland are not to be included in these calculations as they are assumed to result in no net increase in P loading to the environment.

The P export rates associated with urban development is described in Section 3.3.2. Urban development includes the built form, gardens, road verges and small areas of open space within the urban fabric. Sources of P from these areas include animal waste, fertilisation of lawns and gardens, inputs to surface water sewers and car emissions. It is recognised that sewer misconnections can create an additional source of P from urbans areas, however it is assumed that new developments will be sufficiently tested such that P loading from misconnections can be assumed to be zero.

Natural England's advice also discusses a P export coefficient value for Suitable Alternative Natural Greenspace (SANG). SANG is defined as an area of greenspace aimed at protecting designated sites by attracting potentially damaging recreational activities such as dog walking away from ecologically sensitive areas. There are various standards associated with SANG, such as the provision of minimum length circular walks (to encourage dog walking) and a ratio of 8 ha SANG per 1000 population[19]. These standards therefore require parcels of SANG land to be of a certain size that is unlikely to be compatible with all development sites. Furthermore, Natural England's (2020) advice makes reference to both SANG and simply "natural greenspace", interchangeably. As such, this methodology does not provide a separate value for SANG and instead recommends using the P export coefficient for greenspace detailed in Section 3.3.2.2. As SANG is likely to be subject to similar P sources as greenspace, e.g. predominantly from pet waste, if a development site does include SANG as a land use, it is recommended to use the greenspace P export coefficient detailed above.

A worked example of this stage can be viewed in Table 3.6. The urban P load from the future urban residential area uses used the P export coefficient determined in Section 3.3.2.1 detailed above. It should be noted that the P load from a new development could be reduced considerably through the use of Sustainable Drainage Systems (SuDS). SuDS that are optimised for P removal can result in P reductions of ~90%, which would result in a considerable reduction in the P load from the new development and subsequently reduce the amount of mitigation required by developers.

Table 3.6: Worked example of Stage 3 calculations for new land uses

Step	Value	Unit	Explanation
Step 1 (new urban area)	8	Hectares	Area of development that will change to urban land use
Step 2 (phosphorus load from future urban residential area)	13.04	kg P/year	8 ha x 1.63 kg P/ha/year = 13.04 kg P/year
Step 3 (area of new greenspace land)	2	hectares	Area of development that will change to greenspace land
Step 4 (phosphorus load from new greenspace)	0.04	kg P/year	2 ha x 0.02 kg P/ha/year = 0.04 kg P/year
Step 5 (combine phosphorus loads)	13.08	kg P/year	Sum loads from urban and greenspace land
Phosphorus losses from new land uses	**13.08 kg P/year**		

3.5 Stage 4: Net Change and calculation of the budget

The final stage of the P budget calculations calculates the phosphorus budget for the development (i.e. the net change in total phosphorus load to the Wye SAC that will result from the new development). The net change is a difference between the new phosphorus load from wastewater and new land uses on the development site, and the P load from existing land use(s) on the development site. This is

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[19] These standards appear to be generally accepted in local authority planning documents, e.g. Thames Basin Heaths Special Protection Area Supplementary Planning Document (Accessed 12/01/2021).

calculated by subtracting the estimated load from existing land uses from the loading estimated for the new development.

The figures of phosphorus losses used in this study are based on the best available evidence, research, and modelling, however there is still uncertainty associated with the estimates of P export detailed in Stages to 1 to 3 of this methodology. This uncertainty has been recognised in the Natural England (2020) P budget methodology through the addition of a 20% precautionary buffer to the output from the P budget, assuming the P budget exceeds zero, i.e. there is a net surplus of P export from the new development. A negative output for the P budget, i.e. a P budget deficit, means there is no need for mitigation.

Consultation with Natural England regarding the 20% buffer has highlighted that the figure of 20% is based on expert judgement following assessments of the various sources and magnitudes of uncertainty associated with the nutrient budget methodology detailed for the Solent and Stodmarsh designated sites. A formalisation of the rationale behind the 20% buffer is forthcoming but has yet to have been published and it is recognised that the 20% buffer could be revised up or down as guidance on the nutrient neutrality issue evolves. This study has adopted values for certain aspects of the nutrient budget methodology, such as P export from agricultural land use and urban land use, that are more precautionary than those used in Natural England (2020). Thus, the 20% buffer is likely to provide sufficient precaution to the P budget output and subsequently avoid risks of underestimating P loading to the Wye SAC and associated challenges to HRAs of new developments.

A worked example of the Stage 4 calculations is shown in Table 3.7. In the example, 170.85 kg P/year would need to be mitigated for the proposed development to demonstrate nutrient neutrality.

Table 3.7: Worked example showing the calculation of the phosphorus budget for the theoretical new housing development used throughout

Step	Value	Unit	Explanation
Step 1 (phosphorus load from wastewater in Stage 1)	136.09	Kg P/year	See value in Table 3.2.
Step 2 (calculate net change in losses from land use change)	-6.28	kg P/year	Subtract load from existing land uses from new land uses. See Table 3.5 and Table 3.6. 6.8 kg P/year - 13.08 kg P/year = -6.28 kg P/year
Step 3 (determine phosphorus budget)	142.37	kg P/year	Subtract Step 1 from Step 2 of this table. 136.09 kg P/year - -6.28 kg P/year = 142.37 kg P/year
Step 4 (add precautionary 20% buffer)	170.85	kg P/year	If the output of Step 3 is > 0 142.37 x 1.2 = 170.85 kg P/year
Phosphorus budget with 20% buffer	**170.85 kg P/year**		

4 Conclusion

The requirement for new developments that increase overnight stays in Herefordshire to achieve nutrient neutrality has placed a significant burden on Herefordshire Council in their role as the Competent Authority in planning applications. The methodology and its associated inputs detailed in this report are based around advice on calculating nutrient budgets for the Solent and Stour from Natural England as the statutory consultee on nature conservation. It is recognised that a suitably precautionary P budget for new developments is required to contribute to mitigation of adverse effects on site integrity in the River Wye SAC as a consequence of additional P loading.

The methodology detailed in this report incorporates best available evidence in the determination of inputs to the various components of the P budget. It is recognised that uncertainty in these inputs remains in almost all cases and thus the recommended inputs are aimed at being suitably precautionary to meet the tests of an HRA. The P budgets calculated using this methodology will be a key component of HRAs of nutrient neutrality development.

It is recognised that the recommendations detailed in this report are accurate at the time of publication, but that changes to the drivers of the inputs to P budgets may require periodic updates to the methodology as new evidence becomes available. For example, occupancy rates are based on 2011 Census data, with a new census scheduled for March 2021. This occupancy rate figure should be reassessed once the new census data is made available. However, the majority of the inputs detailed in this methodology have been considered in context of the 80-125-year lifetime of a development and should be relatively robust to changes, with the 20% buffer providing an additional layer of precaution to P budget estimates.

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Appendices

A1 Wastewater Treatment Works without P Permits – Lugg Catchment

The treatment works listed in Table A1.1 will need to have a P concentration in their final effluent determined through consultation with Dwr Cymru (Stage 1, Step 3 of P budget calculations; see Section 3.2.3.2).

Table A1.1: List of WwTW in the Lugg Catchment that do not have P permits and are not scheduled for P permit upgrades in the next water company investment cycle.

Treatment works name	Waterbody works discharges to
SHOBDON	Pinsley Bk - source to conf R Lugg
KINGSLAND	Pinsley Bk - source to conf R Lugg
LUSTON & YARPOLE	Ridgemoor Bk - source to conf R Lugg
PEMBRIDGE	Arrow - conf Gilwern Bk to conf R Lugg
BODENHAM	Lugg - conf R Arrow to conf R Wye
TARRINGTON	Tarrington Bk - source to conf R Frome
LYONSHALL	Curl Bk - source to conf R Arrow
DILWYN	Tippets Bk - source to conf Stretford Bk
PENCOMBE	Lodon - source to conf R Frome
MORDIFORD (NR HEREFORD) SUFTON RISE	Lugg - conf R Arrow to conf R Wye
DORMINGTON	Frome - conf Tedstone Bk to conf R Lugg
TITLEY SWK	Arrow - conf Gilwern Bk to conf R Lugg
STOKE LACY WESTBURY	Lodon - source to conf R Frome
IVINGTON (NR LEOMINSTER)	Honeylake Bk - source to conf Little Arrow
PIPE & LYDE (N OF HEREFORD)	Moreton Bk - source to conf R Lugg
OCLE PYCHARD	Withington Marsh Bk - source to conf R Little Lugg
MORDIFORD (NR HEREFORD) PENTALOE CLOSE	Pentaloe Bk - source to conf R Wye
STANFORD BISHOP (SE OF BROMYARD)	Frome - conf Tedstone Bk to conf R Lugg
EDWYN RALPH	Frome - source to conf Tedstone Bk
SPARRINGTON	Lugg - conf R Arrow to conf R Wye
BREDENBURY (GRENDON FIRS)	Lodon - source to conf R Frome
WESTON BEGGARD	Frome - conf Tedstone Bk to conf R Lugg
PRESTON WYNNE	Little Lugg - source to conf R Lugg
MONKHIDE (NEE OF HEREFORD)	Lodon - source to conf R Frome
STOKE EDITH	Frome - conf Tedstone Bk to conf R Lugg
STRETTON GRANDISON (NEE OF HEREFORD)	Frome - conf Tedstone Bk to conf R Lugg
MUCH COWARNE MILL CROFT	Lodon - source to conf R Frome
STOKE LACY CRICKS GREEN	Frome - source to conf Tedstone Bk
MUCH COWARNE MOOR END	Frome - conf Tedstone Bk to conf R Lugg
ULLINGSWICK DINMARSH	Little Lugg - source to conf R Lugg
WOLFERLOW	Tedstone Bk - source to conf R Frome
BULLOCKS BRIDGE (NR ULLINGSWICK)	Little Lugg - source to conf R Lugg

A2 Farmscoper Sensitivity Testing

Farmscoper is a decision support tool that allows assessment of the effectiveness of agricultural diffuse pollution mitigation measures (Gooday, et al., 2015). Phosphorous export within Farmscoper is calculated by the PSYCHIC model, which represents the key processes that result in P sources on a farm being transported off a farm as P export (Davison, et al., 2008). As a "process-based" model, PSYCHIC will take a set of initial conditions describing types of farming and associated P sources and apply various equations that represent the processes that mobilise P in surface runoff and sub-surface flow in order to calculate a P export rate for different farm types (in kg/ha). Farmscoper contains data on these initial conditions taken from the agricultural census and is therefore able to run the PSYCHIC model without the requirement of additional data collection to parameterise the model. The agricultural census data contained within Farmscoper v4 (the version used in this study) is from the 2015 agricultural census and it is therefore important to recognise the likely changes to farming to practices and associated changes in P sources that will introduce uncertainty to the P export outputs generated by Farmscoper. Further uncertainty is introduced to the outputs from Farmscoper produced by the PSYCHIC model due to necessary simplifications of processes that govern P export, wider catchment descriptors that are not accounted in the model and short-term variability in the drivers of P export (Strömqvist, et al., 2008). This study found that testing of PSYCHIC model P estimates against measured data in the Wye catchment resulted in the model generally underestimating P concentrations and loads. However, Farmscoper and, by extension the PSYCHIC model, is an industry-standard tool for estimating P export rates from agricultural land use and there is a lack of other available tools for this purpose. It will thus be necessary to account for the uncertainty inherent in the estimates of P export that will be used in this P budget methodology.

Agricultural census data has been split at various spatial scales within Farmscoper, with subsets of agricultural census data provided for various scales of hydrological unit. Single Water Framework Directive waterbodies are the smallest hydrological unit scale that can be run with agricultural census data, however at this scale the outputs are generalised to only four types of farming and are therefore not specific enough to match the 10 farm types detailed in Natural England advice (Natural England, 2020). In the Natural England advice documents, Farmscoper is applied at the management catchment scale using the Farmscoper Upscale tool. This tool has the ability to generate P export coefficients from agricultural census data at spatial scales down to Operational Catchments. Operational Catchments are the hydrological units for major tributaries of large rivers such as the Wye. The Wye Management Catchment has eight operational catchments (see Figure 3.1).

Natural England's advice for the Stour applied Farmscoper at the scale of the Stour Management Catchment. However, as the area under Herefordshire Council's jurisdiction covers only 42.2% of the Eastern and Southern areas of the Wye Management Catchment, it is unnecessary to provide values for the whole catchment. As such, this study has chosen to run Farmscoper for the relevant Operational Catchments of the Wye that are within Herefordshire Council's jurisdiction. These Operational Catchments are the Arrow Lugg and Frome, the Monnow and the Wye OC (see Figure 3.1). There are areas to the West and South of the chosen Operational Catchments that fall outside of the Herefordshire Council boundary (see Figure 3.1). However, these areas are relatively small (accounting for 28.2% of the combined area of the three operational catchments) and are unlikely to have farming activities that differ significantly enough to have a notable impact on the P export estimates derived by the model.

Farmscoper incorporates mitigation methods that reduce diffuse P pollution from farms (Gooday, et al., 2015). The default operation of the model produces multiple estimates of P exports for various combinations of farm type, soil drainage characteristics and rainfall. For each single combination of farm type, soil drainage and rainfall, the model produces three P export estimates: a baseline, one accounting for "prior implementation" of mitigation measures that accounts for "present day" levels of measures implementation since the baseline (noting the latest version of Farmscoper was published in 2015), and the other based on "maximum implementation" of mitigation measures. Neither the "prior implementation" nor "maximum implementation" scenario is likely to be truly representative of the current (2021) implementation of mitigation measures, with greater uptake of catchment sensitive farming methods since 2015 resulting in the "prior implementation" mitigation scenario likely overestimating P export, whilst the “maximum implementation” scenario represents unrealistic uptake of mitigation measures and lower P export estimates than are likely to be presently being achieved.

In order to account for potential uncertainty surrounding the “prior implementation” and “maximum implementation” P export outputs from Farmscoper, a sensitivity test of the model was conducted using uplifts to the “prior implementation” mitigation measures scenario. This bespoke mitigation scenario was intended to assess the sensitivity of Farmscoper to likely increases in the uptake of mitigation measures between 2015 and 2021.

The impact of different levels of uptake of mitigation measures on P export from each farm type was assessed against the baseline P export for a given farm type by calculating percentage change in P export coefficients. For all mitigation scenarios, a reduction in the P export coefficient was observed against the baseline. The mean percentage change in P export coefficients from the baseline was also as expected for each scenario, with the lowest change (11.4% reduction) seen for the “prior implementation” (2015) scenario, followed by the bespoke 2021 low and high uptake scenarios (13.1% and 13.4% reductions, respectively), with the “maximum implementation” scenario resulting in a notably higher average reduction (45.9%) in P export coefficients.

Initially the baseline phosphorus export coefficients within the model were generated. This first run assumes no mitigation measures are in place and gives baseline values for phosphorus export for each farm type. The model was then run with the default mitigation methods in place based on the 2015 June Agricultural Survey (JAS) data and a scenario in which mitigation methods are fully implemented. Neither the “prior implementation” or “maximum implementation” scenarios are likely to represent the current (2021) uptake of P export mitigation measures. In order to test the sensitivity of Farmscoper to the potential uptake of mitigation measures since 2015, bespoke scenarios based on estimated low and high increases in uptake of mitigation measures in Herefordshire between 2015 and 2021 were developed. These scenarios were determined using expert judgement from Ricardo’s agricultural consultants.

The Farmscoper Upscale tool does not allow mitigation uptake values to be edited and run for whole catchments, although bespoke mitigation scenarios can be run for individual combinations of farm type, soil drainage and rainfall. The combinations of farm type, soil drainage and rainfall results in Farmscoper Upscale generating 170 estimates of P export when run for a whole catchment. Sensitivity analysis of all 170 P export coefficients was beyond the scope of this project and was also unnecessary as the majority of farms within each farm type are represented by a relatively small number of combinations of soil drainage and rainfall and thus the sensitivity of the most well represented combinations of rainfall and soil drainage for each farm type will provide a suitable indication of model sensitivity.

To test model sensitivity, Farmscoper was iterated over three combinations of each of the ten farm types. The three iterations for each farm type were

1. The combination of soil drainage and rainfall with the highest farm count;
2. The combination of soil drainage and rainfall with the second highest farm count;
3. The combination of soil drainage and rainfall with maximum P export coefficient.

Updates to the uptake in mitigation measures between 2015 and 2021 included a range of low estimations and high estimations for specific methods to further assess the sensitivity of the model to changes in uptake of mitigation measures. In total, thirty separate model runs were completed with the updated values. These results can be seen in

.

On average, the export coefficients with mitigation measures updated for 2021 were 1.7% lower than the 2015 values and 13.3% lower than the baseline. The phosphorus export coefficients derived from the high estimations of increases in the uptake of mitigation measures since 2015 were on average 0.21% less than the low estimate, despite six measures being increased by at least 5%. This suggests a generally low sensitivity of the model too small to moderate increases in the uptake of mitigation measures. The estimated increase uptake of mitigation measures in the 6 years from 2015 to 2021 caused a decrease in average P export of 1.7%. This highlights a relatively small change from the 2015 “prior implantation” scenario and as Natural England have indicated that the current levels P loading from agriculture in the Wye SAC are not sufficient to hinder the site’s conservation objectives, it is recommended that the “prior implementation” scenario outputs are used in P budget calculations. This will also mean that the Farmscoper outputs will be based on the 2015 regulatory requirements for mitigation measure implementation.

Table A2.1: The thirty combinations of farm type, precipitation band, and soil type modelled in Farmscoper using all mitigation scenarios used to sensitivity test the model.

Farm type	Climate (mm)	Soil type	Farm Count	Area per Farm	Type	Annual P export (kg)	P export coefficient (kg P/ha/year)	Percentage change from baseline
Cereals	700 to 900	Free Drain	80	111.2	Baseline	15.3	0.14	
					2015 standard implementation	14.1	0.13	7.9
					2021 Update - Low	13.8	0.12	9.7
					2021 Update - High	13.8	0.12	10.0
					Maximum implementation	6.3	0.06	58.6
Cereals	700 to 900	Drained for Arable	59	111.2	Baseline	78.0	0.70	
					2015 standard implementation	75.3	0.68	3.5
					2021 Update - Low	74.4	0.67	4.6
					2021 Update - High	74.2	0.67	4.9
					Maximum implementation	49.6	0.45	36.4
Cereals	900 to 1200	Drained for Arable and Grass	1	111.2	Baseline	190.4	1.71	
					2015 standard implementation	187.4	1.69	1.6
					2021 Update - Low	186.0	1.67	2.3
					2021 Update - High	185.6	1.67	2.5
					Maximum implementation	137.7	1.24	27.7
General	700 to 900	Free Drain	123	61.4	Baseline	6.9	0.11	
					2015 standard implementation	6.1	0.10	11.7
					2021 Update - Low	6.1	0.10	12.8

Farm type	Climate (mm)	Soil type	Farm Count	Area per Farm	Type	Annual P export (kg)	P export coefficient (kg P/ha/year)	Percentage change from baseline
					2021 Update - High	6.0	0.10	13.2
					Maximum implementation	3.4	0.06	50.7
General	700 to 900	Drained for Arable	79	61.4	Baseline	32.2	0.52	
					2015 standard implementation	29.1	0.47	9.5
					2021 Update - Low	28.7	0.47	10.7
					2021 Update - High	28.6	0.47	11.1
					Maximum implementation	19.2	0.31	40.3
General	1200 to1500	Drained for Arable and Grass	1	61.4	Baseline	123.5	2.01	
					2015 standard implementation	116.3	1.89	5.9
					2021 Update - Low	115.2	1.88	6.8
					2021 Update - High	114.9	1.87	7.0
					Maximum implementation	85.2	1.39	31.0
Horticulture	700 to 900	Free Drain	67	52.1	Baseline	3.3	0.06	
					2015 standard implementation	3.0	0.06	9.7
					2021 Update - Low	3.0	0.06	11.1
					2021 Update - High	2.9	0.06	11.5
					Maximum implementation	1.6	0.03	50.8
Horticulture	700 to 900	Drained for Arable	52	52.1	Baseline	15.8	0.30	
					2015 standard implementation	14.8	0.28	6.3
					2021 Update - Low	14.7	0.28	7.3
					2021 Update - High	14.6	0.28	7.6

Farm type	Climate (mm)	Soil type	Farm Count	Area per Farm	Type	Annual P export (kg)	P export coefficient (kg P/ha/year)	Percentage change from baseline
					Maximum implementation	10.6	0.20	33.0
Horticulture	1200 to1500	Drained for Arable	1	52.1	Baseline	47.9	0.92	
					2015 standard implementation	44.6	0.86	6.9
					2021 Update - Low	44.1	0.85	8.0
					2021 Update - High	43.9	0.84	8.3
					Maximum implementation	31.6	0.61	34.1
Pig	700 to 900	Free Drain	8	45.6	Baseline	8.4	0.18	
					2015 standard implementation	7.2	0.16	13.6
					2021 Update - Low	7.0	0.15	15.9
					2021 Update - High	7.0	0.15	16.3
					Maximum implementation	3.4	0.07	59.8
Pig	700 to 900	Drained for Arable	8	45.6	Baseline	37.7	0.83	
					2015 standard implementation	34.4	0.76	8.7
					2021 Update - Low	33.9	0.74	10.1
					2021 Update - High	33.8	0.74	10.4
					Maximum implementation	23.2	0.51	38.5
Pig	700 to 900	Drained for Arable and Grass	2	45.6	Baseline	49.0	1.07	
					2015 standard implementation	46.3	1.02	5.5
					2021 Update - Low	45.4	1.00	7.3
					2021 Update - High	45.3	0.99	7.5
					Maximum implementation	32.1	0.71	34.4

Farm type	Climate (mm)	Soil type	Farm Count	Area per Farm	Type	Annual P export (kg)	P export coefficient (kg P/ha/year)	Percentage change from baseline
Poultry	700 to 900	Free Drain	44	138.9	Baseline	57.2	0.41	
					2015 standard implementation	46.9	0.34	17.9
					2021 Update - Low	44.9	0.32	21.4
					2021 Update - High	44.9	0.32	21.5
					Maximum implementation	21.8	0.16	61.9
Poultry	700 to 900	Drained for Arable	19	138.9	Baseline	133.9	0.96	
					2015 standard implementation	113.4	0.82	15.3
					2021 Update - Low	110.8	0.80	17.3
					2021 Update - High	110.5	0.80	17.5
					Maximum implementation	60.5	0.44	54.9
Poultry	900 to 1200	Drained for Arable	2	138.9	Baseline	238.4	1.72	
					2015 standard implementation	205.4	1.48	13.9
					2021 Update - Low	198.1	1.43	16.9
					2021 Update - High	197.5	1.42	17.2
					Maximum implementation	109.8	0.79	53.9
Dairy	700 to 900	Free Drain	18	119.4	Baseline	39.4	0.33	
					2015 standard implementation	29.0	0.24	26.6
					2021 Update - Low	27.9	0.23	29.3
					2021 Update - High	27.8	0.23	29.4
					Maximum implementation	13.8	0.12	65.0
Dairy			21	119.4	Baseline	68.8	0.58	

Farm type	Climate (mm)	Soil type	Farm Count	Area per Farm	Type	Annual P export (kg)	P export coefficient (kg P/ha/year)	Percentage change from baseline
	700 to 900	Drained for Arable			2015 standard implementation	54.1	0.45	21.4
					2021 Update - Low	52.9	0.44	23.2
					2021 Update - High	52.8	0.44	23.3
					Maximum implementation	26.2	0.22	62.0
Dairy	700 to 900	Drained for Arable and Grass	4	119.4	Baseline	205.6	1.72	
					2015 standard implementation	188.5	1.58	8.3
					2021 Update - Low	183.7	1.54	10.7
					2021 Update - High	183.2	1.53	10.9
					Maximum implementation	107.3	0.90	47.8
LFA	900 to 1200	Free Drain	52	60.9	Baseline	16.2	0.27	
					2015 standard implementation	13.4	0.22	17.4
					2021 Update - Low	13.1	0.22	19.0
					2021 Update - High	13.1	0.22	19.0
					Maximum implementation	8.0	0.13	50.4
LFA	900 to 1200	Drained for Arable	82	60.9	Baseline	20.8	0.34	
					2015 standard implementation	17.6	0.29	15.3
					2021 Update - Low	17.3	0.28	17.1
					2021 Update - High	17.3	0.28	17.1
					Maximum implementation	10.0	0.16	52.1
LFA	Over 1500	Drained for Arable	3	60.9	Baseline	162.8	2.67	
					2015 standard implementation	157.1	2.58	3.5

Farm type	Climate (mm)	Soil type	Farm Count	Area per Farm	Type	Annual P export (kg)	P export coefficient (kg P/ha/year)	Percentage change from baseline
		and Grass			2021 Update - Low	155.3	2.55	4.6
					2021 Update - High	155.2	2.55	4.6
					Maximum implementation	131.4	2.16	19.3
Lowland	700 to 900	Free Drain	339	33.3	Baseline	6.8	0.21	
					2015 standard implementation	5.1	0.15	25.5
					2021 Update - Low	4.9	0.15	27.6
					2021 Update - High	4.9	0.15	27.6
					Maximum implementation	2.7	0.08	61.0
Lowland	700 to 900	Drained for Arable	212	33.3	Baseline	8.8	0.26	
					2015 standard implementation	6.9	0.21	21.5
					2021 Update - Low	6.7	0.20	23.6
					2021 Update - High	6.7	0.20	23.7
					Maximum implementation	3.5	0.11	60.0
Lowland	900 to 1200	Drained for Arable and Grass	13	33.3	Baseline	50.3	1.51	
					2015 standard implementation	47.6	1.43	5.3
					2021 Update - Low	46.8	1.41	6.8
					2021 Update - High	46.8	1.40	7.0
					Maximum implementation	37.9	1.14	24.7
Mixed	700 to 900	Free Drain	98	96.7	Baseline	15.6	0.16	
					2015 standard implementation	13.5	0.14	13.5
					2021 Update - Low	13.1	0.14	16.2

Farm type	Climate (mm)	Soil type	Farm Count	Area per Farm	Type	Annual P export (kg)	P export coefficient (kg P/ha/year)	Percentage change from baseline
					2021 Update - High	13.1	0.14	16.3
					Maximum implementation	6.5	0.07	58.2
Mixed	700 to 900	Drained for Arable	67	96.7	Baseline	49.2	0.51	
					2015 standard implementation	45.4	0.47	7.7
					2021 Update - Low	44.5	0.46	9.6
					2021 Update - High	44.3	0.46	9.8
					Maximum implementation	27.9	0.29	43.2
Mixed	900 to 1200	Drained for Arable and Grass	3	96.7	Baseline	159.7	1.65	
					2015 standard implementation	153.7	1.59	3.7
					2021 Update - Low	151.5	1.57	5.1
					2021 Update - High	151.2	1.56	5.3
					Maximum implementation	114.3	1.18	28.4

A3 Natural England Guidance on “Thresholds for insignificant levels of phosphorus discharges to ground for Wye/Lugg – March 2021”

Summary of evidence

Septic tank systems or package treatment plants that discharge to ground via a drainage field should pose little threat to the environment, because much of the P discharged is removed from the effluent as it percolates through the soil in the drainage field. The risk of water pollution by these types of discharges to ground depends on a range of factors that affect their success or failure and can be summarised by three key factors[20]:

1. improper location
2. poor design
3. incorrect management

Phosphorus is removed from the effluent within the drainage field through retention in the soil through sorption within the aerated soil zone. How much phosphorus is removed within the aerated soil zone will depend on the soil type and the soil phosphorus characteristics, pH, texture, and the hydraulic loading rate. P sorption can be reversed and P desorption can occur in certain conditions e.g. change in redox conditions[21]. For the drainage field to work effectively the drainage field needs to have acceptable year round percolation rates which will be influenced by the soil type, as if they drain too quickly or to slowly effective phosphorus removal will not take place. In addition if infiltration rates are lower than the loading rate of the effluent into the drainage field then hydraulic failure can occur which results in the effluent being discharged over the soil surface. Therefore correct design of the system is important. The Building Regulations[22] set out design and construction standards for septic tanks, package treatment plants and drainage fields. In relation to drainage fields they include the need for a percolation test, a method for how this should be undertaken and the minimum and maximum percolation values (V_p) which ensure that the drainage field effectively removes pollutants. This is then used to calculate the size of the drainage field required for the size of the household it will be serving.

As the evidence has shown that it is the aerated soil zone of the drainage field which provides the function in terms of removing the phosphorus from the effluent before it enters a receiving water body (surface or groundwater), any enhanced connectivity to a water body, which short circuits this process, is probably one of the main factors that causes pollution of SSSIs by these systems[23] [24]. Therefore it will be important that the drainage field is sited far enough away from any watercourse, ditch, drain etc. as well as that it is not in a location where the groundwater is high enough that comes into connection with this aerated zone. In addition seasonal flooding can wash out the contents of the tanks. Slope also affects the way the drainage field functions, with steeper slopes having a higher risk of run off.

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[20] MAY, L., PLACE, C., O’MALLEY, M. & SPEARS, B. 2015. *The impact of phosphorus inputs from small discharges on designated freshwater sites*. Natural England Commissioned Reports, NECR 170.

[21] Mary G. Lusk, Gurpal S. Toor, Yun-Ya Yang, Sara Mechtensimer, Mriganka De

& Thomas A. Obreza. 2017. *A review of the fate and transport of nitrogen, phosphorus, pathogens,*

and trace organic chemicals in septic systems, Critical Reviews in Environmental Science and

Technology, 47:7, 455-541,

[22] Building Regulations, Drainage and Waste disposal (2015), Document H, Section H2.

[23] MAY, L., WITHERS, P.J., STRATFORD, C., BOWES, M., ROBINSON, D. & GOZZARD, E. 2015. *Development of a risk assessment tool to assess the significance of septic tanks around freshwater SSSIs: Phase 1 – Understanding better the retention of phosphorus in the drainage field*. Natural England Commissioned Reports, NECR171

[24] MAY, L., DUDLEY, B.J., WOODS, H. & MILES, S. 2016. *Development of a Risk Assessment Tool to Evaluate the Significance of Septic Tanks Around Freshwater SSSIs.* NECR 222

There is also some evidence that density (i.e. number) of these types of systems in an area also has a bearing on the risk of pollution. In general, lower densities of tanks tend to cause less contamination of downstream water bodies than higher densities of tanks.

Proposed thresholds

Small discharges to ground i.e. less than 2m^3/day[25] that are within the surface or groundwater catchment of a designated site will present a low risk that the phosphorus will have a significant effect on the designated site where certain conditions are met:

a) The drainage field is more than 50m from the designated site boundary (or sensitive interest feature) [26] **and**;
b) The drainage field is more than 40m from any surface water feature e.g. ditch, drain, watercourse[27], **and**;
c) The drainage field in an area with a slope no greater than 15%[28], **and**;
d) The drainage field is in an area where the high water table groundwater depth is at least 2m below the surface at all times[29] **and**;
e) The drainage field will not be subject to significant flooding, e.g. it is not in flood zone 2 or 3 **and**;
f) There are no other known factors which would expedite the transport of phosphorus[8] for example fissured geology, insufficient soil below the drainage pipes, known sewer flooding, conditions in the soil/geology that would cause remobilisation phosphorus, presence of mineshafts, etc **and**;
g) To ensure that there is no significant in combination effect, the discharge to ground should be at least 200m from any other discharge to ground[30].

A GIS layer is available[31] which looks at conditions b, c and d above only, for the whole of England. Where this layer indicates that there is a low risk, then the three conditions (b, c & d) above can be considered to be met. Where there is a high or medium risk identified, then one or more of the three conditions (b, c & d) will not be met. This GIS layer can be shared with the EA and Local Authorities with the relevant data licence via our GI team, but not with developers due to the terms in the data licence. If site specific monitoring/modelled data is presented for conditions b, c or d which provides greater certainty than the national dataset used to produce the risk map, then this can override the risk map. It may be time consuming and/or costly to undertake site-specific monitoring that provides certainty for some of the conditions such as groundwater depth, due to the inherent variability over time and therefore the need for any monitoring to cover a long enough time period (several years) and to a sufficient frequency to determine the highest groundwater depth. So it is acceptable to rely on modelled or national dataset where these are the best available data and scientifically robust.

To consider the other three conditions (a, e and f) other data sources will need to be considered. Condition a, can be looked at through using the designated site data layer and calculating the distance

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[25] A limit of 2m3/day is used based on this being the size used for discharges to ground in the General Binding Rules and is representative of the size of the majority of the septic tanks investigated within NECR171, from which most of the criteria are based.
[26] 50m is the distance as which no phosphorus signal was detected at this distance (NECR171 and NECR222)
[27] 40m is the distance that represents a low risk, based on there was a weak phosphorus signal this distance for some of the small discharges (NECR171 and NECR222)
[28] 15% is the slope that represents a low risk based on the methodology outlined in NECR222.
[29] 2m is the groundwater depth that represents a low risk, based on very low levels being detected in soil at depth below this (NECR171 and NECR222)
[30] The 200m is based on the 50m distance where no phosphorus signal was detected (NECR171) for each septic tank. So for two drainage field areas not to overlap they need to be at least 100m apart. A safety factor of two is then applied to ensure that in the long term there will be the certainty that the effective drainage field phosphorus retention areas don't overlap. This also ensures that the maximum density of these systems is no more than one for every 4ha (or 25 per km2), as identified in NECR170.
[31] LPAs can request the GIS layer for the England sewage discharge risk map from Natural England. The dataset is called - Small_Sewage_Discharge_Risk_Zone_Map_England_NE.

from the site boundary. Condition e can use the EA flood risk maps (https://flood-map-for-planning.service.gov.uk/). Condition f should make use of any sewer flood data, information on local geology, groundwater phosphorus concentration monitoring within the catchment or other local information which it is readily available. Elevated concentrations of phosphorus in groundwater would indicate phosphorus transport being expedited in that the phosphorus is not being absorbed to the soil effectively or being remobilised. It can be assumed that phosphorus is not remobilised unless there is existing evidence at the discharge location or within the wider catchment which suggest that this may be occurring in the same conditions to those present at the location of the proposed discharge. Such evidence could include investigations, known soil or geological conditions or groundwater water quality data from similar soil/geological conditions within the catchment.

As not all of the phosphorus will be retained by the soil, condition g is to ensure that there is no in combination or cumulative effect from a number of these discharges in an area which together could add up to have a significant effect.

If conditions a to g are all met this represents a low risk that phosphate will reach the site, and not zero risk. There will be further processes of dilution and attenuation between the drainage field and the site, which will provide further reduction and the current evidence would suggest that the scale of any inputs from these sources would not be significant.

Where best available evidence indicates that these conditions are met, Natural England can advise that, in its view, a conclusion of no LSE alone and in combination for phosphorus can be reached in these circumstances. Where uncertainty remains so LSE cannot be ruled out or evidence exists that there is a risk of phosphate from small discharges to ground causing a significant effect to a designated site (e.g. from SAGIS modelling or monitoring investigations), then our advice should be that there is a LSE or LSE cannot be ruled out and an AA should be undertaken. Where evidence is presented which provides certainty that there will be no LSE even though the these condition are not met e.g. better local information, then we can advise no LSE. This will be determined on a case by case basis.

The competent authority, as the decision maker, will need to determine whether it agrees with NEs advice.

For developments which allow for increases in the number of people that will be served by an existing discharge to a drainage field, it will be important to consider whether the existing system has sufficient capacity in its design to accommodate the increase, without increasing the risk of pollution.

The evidence underpinning these thresholds will be periodically reviewed and the thresholds will be amended as necessary to take account of any new evidence.

This approach does not apply to nitrogen as it does not get taken up by the soil like phosphorus.

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