Interim Phosphate Delivery Plan Stage 2

Mitigation options for phosphate removal in the Wye Catchment

Report for Herefordshire Council

Ricardo for Herefordshire Council – ED14585

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Executive Summary

Herefordshire Council is facing limitations on housebuilding due to the implications of the Court of Justice of the European Union (CJEU) ruling known as the 'Dutch Nitrogen Case'[1]. This ruling requires all new developments that are likely to affect the River Lugg sections of the River Wye Special Area of Conservation (SAC) to be "nutrient neutral"[2] in order to comply with the "Habitats Regulations"[3]. Nutrient neutral development is required for a Habitats Regulations Assessment (HRA) to be able to show that new development will not result in adverse effects on the site integrity of the River Wye SAC owing to increases in phosphorous loading to the River Wye through increases in wastewater generated by the new development. Evidencing nutrient neutrality for phosphorus comprises calculation of a phosphorous budget, a methodology for which is presented in Stage 1 of the Herefordshire Council Interim Delivery Plan (IDP) (Ricardo, 2021). Assuming the phosphorous budget for a development shows that the development will result in a net increase in phosphorous loading to the River Wye SAC, the developer will need to mitigate this additional phosphorous load.

This report has presented a review of phosphorous mitigation options that could be used to deliver the reductions in phosphorous loading to the River Wye that will make a development nutrient neutral. The review began with a long list of options presented for the River Avon SAC (Wood, 2019). Many of the options presented in Wood (2019) would not stand up to the scrutiny of the HRA tests following the Dutch Nitrogen Case. We used these tests in order to select a shortlist of options that may pass the HRA tests. Shortlisted options were subject to a detailed review of the evidence base to support them, in the context of the HRA tests. This exercise allowed for a set of options to be determined that provides the greatest potential for mitigation of phosphorous loading to the Wye SAC. The outputs from this review are summarised in short fact files for each option in order to highlight the key considerations related to each option and the likelihood that the option will pass the HRA tests and enable compliance with the Habitats Regulations.

The key recommendations from this study are as follows:

- Wetlands at WwTWs treating final effluent are likely to provide the best current strategic mitigation options.
- Other, smaller wetland schemes distributed around the River Wye catchment may also provide viable mitigation options.
- Riparian buffer habitats and short-rotation coppice may provide alternative natural solutions, but they likely require a better evidence base or period of monitoring to ensure efficacy.
- High-efficiency package treatment plants provide a viable engineered mitigation option in the eventuality that natural solutions are deemed too uncertain.
- All measures will require maintenance/management plans to be secured to ensure they continue to deliver mitigation in perpetuity.

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[1] 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

[2] Although the "Dutch Nitrogen Case" refers of nitrogenous nutrients, in the River Wye SAC the phosphorous is the nutrient of concern and the river is failing its target for phosphorous and not nitrogen.

3 The Conservation of Habitats and Species Regulations 2017 (as amended)

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Glossary

Abbreviation	Definition
LSE	Likely significant effects
HRA	Habitats Regulations Assessment
WwTW	Wastewater treatment works
TP	Total phosphorous
FWS	Free-water surface wetland
HF	Horizontal flow wetland
Grey literature	Literature from sources that have not been subject to extensive peer review. Grey literature is generally produced through commercial work as opposed to academic articles or industry best practice documents.
Blue-green infrastructure	Natural and semi-natural areas that incorporate vegetation and water.
ODT	Oven dry tonnes – used as a means of quantifying crop size for short rotation coppice harvests.

1 Introduction

1.1 Mitigation to achieve Nutrient Neutral development

A detailed background to the issue of nutrient neutrality in the River Wye Special Area of Conservation (SAC) catchment is provided in the Stage 1 Interim Delivery Plan report (Ricardo, 2021). In summary, following a ruling in the Court of Justice of the European Union (CJEU) known as the "Dutch Nitrogen Cases"[1], Herefordshire Council is currently facing limitations on new housebuilding. The joined "Dutch Nitrogen Cases" have resulted in changes to the way Habitat Regulations Assessments (HRAs) consider the potential impact that could arise from increased nutrient loading (e.g. nitrogen and/or phosphorous) to designated sites protected under the Habitats Regulations[3] or Ramsar Convention (hereafter, "National Network sites"). New development which increases the number of overnight stays and thus increases the production of wastewater and associated nutrient loading to European sites already in unfavourable condition or close to unfavourable condition due to such nutrients may not be legally consented.

The increases in nutrient loading from wastewater will cause HRA screening (HRA Stage 1) to conclude a "Likely Significant Effect" (LSE) on the European site, i.e. the River Wye SAC in this case, into which the additional wastewater is discharged. In this context, 'significant' means a 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 an LSE is concluded by the HRA screening stage, then a full Appropriate Assessment (HRA Stage 2) is required to confirm any adverse effect on site integrity. Unlike the screening stage, mitigation measures can be included at the Appropriate Assessment stage. In the case of the River Wye SAC, the nutrient of concern is phosphorous. Thus, in order for new developments to comply with the Habitats Regulations through an HRA, there is a requirement to determine and secure appropriate mitigation that will result in no net increase in phosphorous loading to the River Wye SAC. Currently this requirement is targeted specifically at the River Lugg catchment which is failing to meet the SAC phosphorous targets.

There are numerous potential options that could be used to offset the additional phosphorous load from a new development, however many approaches may not provide the certainty in magnitude and longevity of phosphorous removal that is required for mitigation to be deemed compliant as part of an HRA. As such, there is need to identify mitigation measures that not only have potential to remove phosphorous from the environment but will also pass the tests set by an HRA of nutrient neutrality.

1.2 Key HRA tests of mitigation schemes

For a mitigation scheme to be deemed compliant with the Habitats Regulations, it will be required to pass the following tests:

1. The scale of phosphorous reductions that can be achieved by a mitigation scheme are based on *best available evidence*.

2. The available evidence for a mitigation scheme suggests the scheme will be effective *beyond reasonable scientific doubt*.

3. The estimates for phosphorous reductions suggested for the scheme are *precautionary*, in line with the Precautionary Principle.

4. The reductions in phosphorous loading can be secured *in perpetuity* which, for the purposes of a housing development is considered to be 80-125 years.

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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.

A mitigation scheme may combine different individual types of mitigation measure that may be effective for less than 125 years in isolation but, if used consecutively, will be able to provide mitigation for Nutrient Neutrality in perpetuity. It is also possible for there to be uncertainty in meeting all of these tests for a proposed mitigation measure on the proviso that a suitable fallback mitigation is available in the event that the first choice option should fail one of the HRA tests. This provides for the possibility of pursuing less certain mitigation schemes that may have other associated benefits, as long as a Habitats Regulations compliant mitigation scheme is available as a fallback and can be implemented before any harm occurs to a National Network site.

The HRA tests detailed above provide a framework within which to assess the evidence base for different mitigation measures. This assessment will determine whether, in theory, the mitigation measure can deliver reductions in phosphorous loading to achieve nutrient neutrality. Natural England has also provided a list of principles to guide the proper application of mitigation measures to achieve nutrient neutrality. These principles have been included in Appendix A1 and should be applied to any mitigation measures that are taken forward in Herefordshire.

1.3 Purpose of this report

This report aims to provide an assessment of potential options for mitigating phosphorous loading to the River Wye SAC that will result from new housing developments. It follows the Stage 1 Interim Delivery Plan (IDP) report (Ricardo, 2021) which provides a methodology for calculating phosphorous budgets for new developments in the Herefordshire Council area. The phosphorous budget outputs will provide the amount of phosphorous that will require mitigating for a new development. This report is intended to provide a reference for determining suitable mitigation options that can be used to offset the additional phosphorous load from a new development, as well as a reference for assessing potential strategic options. It is structured as follows:

- *Section 2* details the **methodology** used in study.
- *Section 3* provides a short overview of the shortlisted mitigation measures via a **series of fact files**.
- *Section 4* provides the core **evidence base and detailed review** that underpins the fact files in Section 3.
- *Section 5* holds the **conclusion and recommendation**.

1.4 Short-term mitigation options

This report does not provide an assessment of short-term mitigation options, as they do not pass the in perpetuity test for HRA compliance. The focus of this report is on long term mitigation solutions that can be used to secure phosphorous reductions at timescales that are practical to support development. However, there are some short-term mitigation options that can deliver phosphorous mitigation quickly and could potentially be used in the interim whilst larger, strategic schemes are being established. Consultation with Natural England has highlighted short-term mitigation measures can have a role in developments achieving nutrient neutrality.

Short-term mitigation options could aim to tackle key sources of phosphorous export to the environment. This could involve working with farmers to put in place temporary solutions that go beyond wider efforts to reduce silt runoff and the associated phosphorous pollution. Other technologies to reduce phosphorous loading from surface runoff, such as surface runoff filtration devices (e.g. Penn, et al., 2012) or vortex seprators for removing silt from urban runoff, could be applied. There is also the potential to deploy in-river solutions, such as silt traps, which remove silt and its associated phosphorous load from river environments. These solutions will require consistent maintenance and would also likely need to be monitored to establish the amount of phosphorous reduction they can achieve.

2 Methodology

The different mitigation methods for assessment were chosen through an initial critical review of an extensive list of potential phosphorous mitigation options detailed in a previous study for the River Avon

SAC catchment (Wood, 2019). Many of these options were deemed to be clearly non-compliant with HRA tests detailed above. Those options that were deemed to have potential to comply with the HRA tests were selected for further literature review to assess the evidence base that could support these options. A further search was also conducted to identify any options that were not present in the River Avon assessment.

A critical analysis of literature on each option was conducted in the context of the HRA tests, in order to determine whether a mitigation option could be recommended. Literature searches were limited as much as possible to studies published in academic journals or 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. Where grey literature was used, appropriate consideration was given to the veracity of the information in these sources.

2.1 Selection of mitigation options

The options appraisal of mitigation options for the River Avon SAC (Wood, 2019) was used to select an initial long list of mitigation options for the River Wye SAC. From this long list, a short list of potential mitigation options was selected based on the potential of the options to meet the HRA tests. A summary of the long list and short list are provided below.

2.1.1 Mitigation options long list and selection of the mitigation options shortlist

A similar analysis as presented here assessing phosphorous mitigation measures for the River Avon SAC was previously conducted by Wood (2019). This report contains a list of phosphorous mitigation measures that could be employed to reduce phosphorous loads to the River Avon SAC. The measures detailed within this document were used as a long list of mitigation options for the River Wye SAC. It was clear from analysing the theoretical potential of these options that many of the measures suggested by Wood (2019) would not pass the key HRA tests, or simply lacked feasibility within the River Wye SAC catchment. Those measures were removed from the long list to create a shortlist for further investigation.

The long list of mitigation options was as follows:

- Water efficiency measures
- Increasing the proportion of green infrastructure, such as Sustainable Drainage Systems (SuDS)
- Wetland creation
- Riparian buffer creation
- Taking agricultural land out of production
- Woodland creation
- Onsite wastewater treatment
- Short rotation coppice
- Reducing the intensity of agricultural production
- Transporting excess phosphorous from dairy farms to arable farms
- Make available compost to improve soil condition
- Regulatory controls on agricultural phosphorus
- Diverting surface water flows away from the sewage network
- Addressing misconnections
- Reduce leakage from the foul sewage network
- Reduce leakage from potable water supply
- Increased treatment of effluent

A targeted literature review was used to identify other options not in the long list derived from Wood (2019) that could be added to the shortlist, based on the same high-level assessment of whether these measures would meet the HRA tests.

2.1.2 Overview of the mitigation options shortlist

The mitigations measures that were short-listed for detailed review are:

- Water efficiency measures – reduction in household water usage and associated phosphorus loading
- Onsite wastewater treatment using package treatment plants – removal of phosphorous from wastewater
- SuDS – using green drainage infrastructure to remove phosphorous from urban runoff
- Wetland creation – vegetated waterbodies and non-vegetated ponds that retain phosphorous
- Agricultural abandonment and woodland planting – reduction in farm phosphorous inputs and exports
- Riparian buffer creation – vegetated riverside land parcels that retain phosphorous
- Short Rotation Coppice – production of energy crops that remove phosphorous from land when harvested.

3 Mitigation Options Fact Files

The sub-sections below are supported by a detailed review of each of the mitigation measures. The detailed review can be found in accompanying sub-sections to this report in Section 4 and be used to examine the supporting evidence that underpins the recommendations made in the fact files.

In each of the fact files, the mitigation measures are given a spatial scale required for delivery. The spatial scales are defined as:

- Small – 0-0.5 ha, or applicable at the household scale.
- Medium – 0.5-2 ha of land required.
- Large – 2 ha+ of land required.

3.1 Onsite measures

3.1.1 Water efficiency measures summary

Reducing water usage reduces phosphorous loading from WwTWs by reducing the flow of wastewater to a treatment works and thus reducing the load. However, it is important to note that increasing water efficiency will only reduce phosphorous loading at works that have phosphorous permits. At WwTWs without phosphorous permits, the greater concentration in phosphorous in influent wastewater means there is negligible impact on reductions in phosphorous loads in the treated effluent wastewater. Water efficiency measures typically involve installation of water efficient bathroom and kitchen fittings. The effectiveness of this method is difficult to measure without household monitoring using smart meters and the potential for changes to less water efficient fittings within the lifetime of a development raises questions over whether this mitigation measure would pass the test of in perpetuity reduction in phosphorous loading. Where a development is council owned, greater control over the fittings used could be achieved, which may increase the viability of this measure. The considerations in the fact file assume the development is under majority private ownership. It is also noted that the water efficiency measures would need to reduce per person water usage below the 120 litres per person per day that is used to calculate a phosphorous budget (see the Interim Delivery Plan Stage 1 report; Ricardo, 2021).

See Section 4.1.1 for detailed review of water efficiency measures for phosphorous mitigation.

Table 3.1: Water efficiency measures fact file

Key option considerations	
Summary description of option	• Per capita water usage is reduced, reducing phosphorous loading where developments drain to WwTWs with phosphorous permits.
Deliverability of option	• Identify water saving products and install in homes. • Monitoring of water usage and WwTW phosphorous loads would be required. • Uncertainty arises from potential removal/replacement of efficient fittings.
Stakeholders for engagement	• Developers, homeowners, water companies, local authority planners.
Likely HRA test compliance	• Unlikely to be compliant. • Would require water use monitoring and the ability to enforce water use based on monitoring data
Spatial scale	• Small
Community benefit	• Improvement in sustainability as well as water quality
High-level cost estimate	• Reductions from 110 litres to 80 litres may cost £900-£2697 per home, depending on household size

3.1.2 Onsite wastewater treatment summary

Package Treatment Plants (PTPs) are small wastewater treatment systems that are used for developments in locations that cannot be connected to mains sewerage. It should be noted that where developments can reasonably connect to mains sewerage, they are expected to by the Environment Agency. The final effluent phosphorous concentration is dependent on the device used and there are now highly efficient systems available that can reportedly achieve phosphorous concentrations of < 1.5 mg P/l. Effluent discharge to a well-designed and maintained soakaway or a wetland system could achieve nutrient neutrality.

See Section 4.1.2 for detailed review of onsite wastewater treatment measures for phosphorous mitigation.

Table 3.2: Onsite wastewater treatment fact file

Key option considerations	
Summary description of option	• Domestic wastewater is treated on site and discharged to a drainage field, wetland or watercourse.
Deliverability of option	• Identify PTPs with verifiably low phosphorous concentration in their effluent. • Land required for installation of PTP. • Monitoring of effluent and all maintenance requirements, including chemical dosing and annual servicing/desludging. • Potential requirement to replace PTP if lifetime of system is less than lifetime of development (80-125 years). • Stakeholders include developers, homeowners, installation and maintenance contractors, Environment Agency.
Stakeholders for engagement	• Developers, homeowners, installation and maintenance contractors, Environment Agency.

Key option considerations	
Likely HRA test compliance	• Compliance is likely if a scheme is well designed. • There is an evidence base to support efficacy of PTP system, with or without combinations with drainage fields/wetlands. • Maintenance agreements can secure mitigation in perpetuity.
Spatial scale	• Small to medium, depending on inclusion of drainage fields/wetlands.
Community benefit	• PTPs alone have limited additional community benefits. • With constructed wetlands some additional amenity value is possible.
High-level cost estimate	• Dependent on population size and device used although costs are in the £10k-100k range.

3.1.3 Sustainable Drainage Systems (SuDS)

SuDS are an onsite solution for mitigating phosphorous loads in surface runoff from a development site. They are incorporated into the drainage design for a new development as a means of reducing surface water runoff rates and downstream flood risk, however SuDS can also have additional benefits for water quality, including the removal of phosphorous. There are various different components that can be incorporated into a SuDS design and help to remove phosphorous, however many of the components do not have a strong evidence base to support the efficiency (as a percentage reduction in phosphorous) each type of component could achieve. Constructed wetlands incorporated within a SuDS design have the most evidence to support their use for phosphorous removal and are likely to be able to play a role in mitigation for nutrient neutrality in the Wye SAC catchment. The key consideration in the use of SuDS and wetlands is scaling of the system such that it receives sufficient runoff to result in meaningful reductions in phosphorous loading. As an example, a hypothetical 100 dwelling development would generate ~12 kg P/year that would require mitigation, thus requiring an ~0.7 ha wetland draining ~17 ha of urban land to offset the additional phosphorous load from the new development. This suggests that the design of SuDS to intercept runoff from land outside of development redline boundary is likely to be needed. The long-term performance of SuDS would also need to be secured through maintenance agreements.

See Section 4.1.3 for detailed review of SuDS measures for phosphorous mitigation.

Table 3.3: SuDS fact file

Key option considerations	
Summary description of option	• SuDS comprise a range of different types of blue-green infrastructure to reduce runoff rates and provide natural water quality treatment, including phosphorous removal.
Deliverability of option	• SuDS systems require design specific to a development site, including assessment of hydraulic characteristics of the site. • Hydraulic characteristics of a site can be determined using standard methods and will determine the scale of different SuDS components. • Components of SuDS design will need to be chosen to maximise phosphorous removal. • Monitoring of the system will be required to determine efficacy of phosphorous removal. • Maintenance will be required to ensure the system continues function effectively for phosphorous removal. • As the amount of phosphorous in urban runoff from a single site is likely to be less than the amount produced in wastewater, it is likely that SuDS will need to be designed to take runoff from areas outside a

Key option considerations	
	development site redline boundary in order to provide sufficient mitigation.
Stakeholders for engagement	• Developers, homeowners, lead local flood authority, installation and maintenance contractors, Environment Agency.
Likely HRA test compliance	• Compliance is likely if a scheme is well designed and scaled appropriately. • There is an evidence base to support the use SuDS wetlands to phosphorous removal. • Maintenance agreements can secure mitigation in perpetuity.
Spatial scale	• Medium
Community benefit	• Reductions in flood risk and water quality pressures. • Increased amenity value • Increased wildlife habitats • More greenspace within development sites.
High-level cost estimate	• ~£25-£30 per m^3 of treated water and decennial maintenance cost of ~£5000.

3.2 Offsite measures

3.2.1 Agricultural land abandonment and woodland planting/reversion to semi-natural habitat

Fertilisation and animal waste enrich agricultural land with phosphorous and increase phosphorous loading relative to natural background levels. The main reductions in phosphorous leaching to the environment from agricultural land abandonment come from halting fertiliser applications and removing animal waste inputs, thus providing phosphorous offsetting for new developments. Woodland planting can be used to secure agricultural land abandonment without land purchase, as it is easy to confirm that reforested land is remaining out of agricultural use. If land is being purchased, reversion to woodland or other semi-natural habitats, including orchards, can be used to secure the conversion from agricultural use. Woodland planting or facilitating the reestablishment of semi-natural vegetation cover may also increase phosphorous uptake in the short-term, This could be important in tackling problems around legacy phosphorous, which is the phosphorous load that gets left in the soil by agriculture and can potentially result in phosphorous export to remain elevated above natural background levels for a period of the order of 20 years after the cessation of agricultural practices. Other short-term management practices such as planting cover crops to avoid soil erosion can be used limit the problems of legacy phosphorous leaching. It should be noted that woodland planting or semi-natural revegetation have large uncertainties associated with scale of reductions in phosphorous loadings it can achieve and thus the number of “credits” a reforestation-type scheme would provide in the short-term. These uncertainties could require monitoring and an effective ‘fall-back’ or supplementary option.

See Section 4.2.1 for detailed review of Agricultural land abandonment and woodland planting for phosphorous mitigation.

Table 3.4: Agricultural land abandonment and woodland planting fact file

Key option considerations	
Summary description of option	• Agricultural land is removed from production to decrease phosphorus export rates. • Woodland planting on abandoned land will likely result in faster and greater reductions in phosphorous export.

Deliverability of option	• Appropriate land would need to be identified and purchased. • Woodland planting without land purchase would need long-term binding agreement from farmers. • Management plans to ensure no reversion to land uses with intensive phosphorous input.
Stakeholders for engagement	• Farmers/landowners, local Wildlife Trusts, Woodland Trust, National Farmers Union, catchment partnerships
Likely HRA test compliance	• Would require monitoring to determine short-term reductions in phosphorous export • Maintenance agreements would be required and need to be secured contractually to cover the mitigation scheme in perpetuity.
Spatial scale	• Variable spatial scale dependent on the size of the development and farm.
Community benefit	• Provision of amenity areas. • Wildlife habitat created. • Flood attenuation. • Depending on the size it could be used as suitable alternative natural greenspace (SANG) to mitigate recreational demand/impacts from new development.
High-level cost estimate	• Estimated average cost of agricultural land (all types) is £13300-21500 per hectare. • Average rental cost of agricultural land in England is £170-231 per hectare.

3.2.2 Riparian buffers

A riparian buffer is a thin strip of land with permanent vegetation cover that runs along the edge of a river, separating the river from adjacent land uses. These buffers reduce surface flow rates and promote various mechanisms of phosphorous removal that lead to an improvement in river water quality. The main phosphorous removal mechanisms in riparian buffers are sediment capture, soil sorption and plant uptake. Riparian buffers can also provide additional reductions in phosphorous loading to rivers through the stabilisation of riverbanks and reduced bank erosion with associated particulate sources of phosphorous. Median total phosphorous retention rates of 67% in riparian buffers have been reported (Hoffmann et al., 2009). However, riparian buffers require maintenance in perpetuity to stop them from switching from a sink to a source of phosphorous (Weigelhofer, et al., 2018). Maintenance mainly requires annual cutting and removal vegetation (Hille, et al., 2018). The potential application of riparian buffers in wider catchment management plans to reduce diffuse pollution also requires consideration to remove the risk of double counting the potential phosphorous reductions provided by riparian buffers. Riparian buffers could provide a short-term, easy to implement measure for use whilst long-term measures are being established.

See Section 4.2.2 for detailed review of riparian buffers for phosphorous mitigation.

Table 3.5: Riparian Buffers fact file

Key option considerations	
Summary description of option	• Thin strips of vegetated land along river edges reduce the phosphorous associated with agricultural diffuse pollution.
Deliverability of option	• Appropriate land would need to be identified and purchased if necessary. • Monitoring of the buffer would need to be completed to ensure continued functionality.

	• Vegetation needs to be planted in buffer strips and removed annually.
Stakeholders for engagement	• Environment Agency, landowners, Wye and Usk Foundation, catchment partnership.
Likely HRA test compliance	• There is evidence to support the potential reduction in phosphorous that could be achieved. • Monitoring and maintenance required to meet "in-perpetuity" requirements. • Riparian buffers could be used as a short-term mitigation measure. • A fallback mitigation option may be needed if reduction in efficacy is seen over time through monitoring.
Spatial scale	• Medium
Community benefit	• Improved amenity value of rivers. • Wildlife habitat created and in-river habitat improved. • Reductions in river erosion and associated impacts. • Flood attenuation.
High-level cost estimate	• Costs are of the order of £500 per ha per year.

3.2.3 Short Rotation Coppice (SRC)

Energy crops such as poplar and willow can be grown on former arable land or on riparian buffer strips. These crops can remove up to 15.8 kg P per 10 oven dry tonnes (ODT) per hectare per year (Potter, 1999). They can be grown in phosphorous enriched soils without any fertiliser inputs and their uptake of phosphorous and subsequent removal through harvesting could provide a reduction in phosphorus loading to the Wye above simple agricultural land abandonment. Depending on the soil phosphorous content, SRC plantations may start requiring additional nutrient inputs before the end of their productive life. There is a potential to use sewage sludge for fertilisation in a closed-loop system of nutrient use, though caution will be required to ensure crops are not over-fertilised, which could result in phosphorous leaching from the plantation. Harvesting needs to be completed every 2-4 years. Harvested crops can be sold as fuel, which then removes phosphorous from the catchment system. SRC plantations may only remain productive for 30 years before the trees may need replacing.

Table 3.6: SRC fact file

Key option considerations	
Summary description of option	• Growing energy crops takes agricultural land out of production and absorbs soil phosphorous. • SRC could be planted on riparian buffer strips
Deliverability of option	• Assess whether eligible for subsidy under Energy Crops Scheme and apply if eligible. • Appropriate land would need to be identified and purchased if necessary. • Soil sampling required to assess the amount of phosphorous that may be removed by SRC. • Identify the type of SRC crop for planting. • Identify market for selling crop • Harvest every 2-4 years is required over a ~30-year lifetime of the crop. • Little maintenance is required.

Key option considerations	
	• Planting SRC on riparian buffers may provide the best long-term reductions in phosphorous loading to the Wye.
Stakeholders for engagement	• Landowners, Defra, Environment Agency.
Likely HRA test compliance	• Monitoring to assess the efficacy of the scheme may be required. • The ~30-year period of productivity of a single SRC planation would require more mitigation/replanting of trees to maintain mitigation in perpetuity. • After SRC has removed legacy phosphorous stock from soil, the amount of “credits” from a scheme may reduce. This would need to be factored into the annual “credits” made available by an SRC scheme.
Spatial scale	• Farm scale
Community benefit	• Carbon neutral energy source provided • SRC crops can be used in biomass boilers, which could provide a neighbourhood scale energy and nutrient neutrality scheme.
High-level cost estimate	• Estimated cost of agricultural land (all types) is £13,300-21,500 per hectare • Average rental cost of agricultural land in England is £170-231 per hectare per year • Annual harvesting costs • In 2008 it was estimated that SRC can make £116/ha/year over a 16-year life cycle and thus would require subsidy to avoid financial loss if only considering the sale of the crop.

3.2.4 Wetlands

Wetlands can be deployed either “in catchment” to remove phosphorous from surface runoff or stream flow, or to remove phosphorous from final effluent at WwTWs or package treatment plants. They comprise constructed waterbodies designed to filter and treat water pollutants found in domestic sewage, municipal sewage, industrial effluent, stormwater runoff, and agricultural runoff. The main phosphorous removal mechanisms in wetlands are sedimentation of particulate phosphorous, sorption (binding) of dissolved phosphorous to sediment and plant uptake of bioavailable phosphorous (Kadlec & Wallace, 2008). These processes are affected by many wetland and water quality characteristics including: wetland size, flow velocity through the wetland, water retention times, water and air temperature, types of vegetation, wetland management regimes, concentrations of phosphorous in the inflow to the wetland and the type of wetland. Due to the highly variable nature of these key characteristics, reported phosphorous removal rates are also highly variable. Reviews of wetland studies have reported median removal rates of around 60% of the inflow phosphorous concentrations for urban wetlands (Strecker, et al., 1992; Shatwell & Cordery, 1999) and 46% for wetlands with a variety of sources of water (Land, et al., 2016). However, given the elevated concentrations of phosphorous in inflows to wetlands, especially from WwTWs effluent, even a 46% treatment efficiency provides a significant mitigation potential and it is likely that efficiencies > 46% can be achieved through suitable design.

As sedimentation is the main phosphorous retention mechanism in wetlands, they can switch from a sink to a source of phosphorous (Sharpley, et al., 2013; Land, et al., 2016). Therefore, desilting/desludging needs to be completed to ensure optimal phosphorous removal in perpetuity (Woods-Ballard, et al., 2015). Vegetation also needs to be managed to remove phosphorous accumulated in vegetation from being re-released when it dies and decomposes in the wetland (Kadlec & Wallace, 2008). Wetlands will also need comprehensive wider management plans that include disposal of removed sediment and vegetation in ways that do not recirculate phosphorous through the

Wye catchment. Assuming these maintenance requirements can be secured in perpetuity, wetlands provide a very promising mitigation option that can provide significant reductions in phosphorous loading to the Wye SAC.

Table 3.7: Wetlands fact file

Key option considerations	
Summary description of option	• WwTW final effluent, surface water runoff flows or river flow is diverted through a wetland system designed to remove phosphorous and other pollutants before water is discharged to a surface water body. • Phosphorous is removed through sedimentation, sorption and plant uptake.
Deliverability of option	• Site needs to be selected, hydraulic loading and phosphorous inputs need to be calculated and wetland designed by expert designers[5]. • Continued monitoring and maintenance to ensure phosphorous removal in line with design specifications. • Prior monitoring of the river water quality (upstream and downstream of potential discharge points) is recommended. • There is high variability in phosphorous removal rates reported in the literature. Median removal rates of around 50% seem to be achievable with good maintenance. Much higher (circa 90%) rates have been reported. • May require seasonal trimming and removal of vegetation. • Desilting/desludging at around a 10-year timescale (provided design adheres to best management practices). Timescales vary dependant on design.
Stakeholders for engagement	• Dwr Cymru Welsh Water and Severn Trent Water for wetlands at WwTWs, wetland design, constructions and maintenance contractors, catchment partners, landowners, Wye and Usk Foundation, Environment Agency, Natural England.
Likely HRA test compliance	• Assuming suitable maintenance regime can be secured and the efficiency of phosphorous removal is verified, then HRA test compliance is likely.
Spatial scale	• Variable spatial scale dependent on the size of the development, catchment area, hydraulic loading rate etc. Likely to be 0.1-10 hectares.
Community benefit	• Amenity areas provided. • Wildlife habitat created. • Flood attenuation. • Improvements to general river water quality.
High-level cost estimate	• SuDS wetland: £25-30/m^2 • Rural wetland: £4-100/m^2 • This study has seen estimates of WwTWs wetlands schemes in Herefordshire of the order of £210k-230k for construction and maintenance.

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[5] See https://www.constructedwetland.co.uk/ for list of constructed wetland professionals to support design, construction and maintenance.

4 Detailed Review of Mitigation Options

4.1 Onsite measures

4.1.1 Water efficiency measures

Increased water usage efficiency in households will lead to a reduction volume of wastewater generated by single households and thus reduce the additional volume of wastewater requiring treatment. If a new development drains to a wastewater treatment works (WwTW) with a phosphorous permit that limits the concentration of phosphorous in the final effluent from the works, a reduction in the volume of wastewater will result in a reduction in phosphorous loading from a WwTW. However, reducing the volume of domestic water use whilst per person domestic phosphorous outputs remain the same will result in an increase in the concentration of phosphorous in wastewater. Studies of the efficiency of phosphorous removal in WwTWs (e.g. Gao, et al., 2016; Kocadagistan, et al., 2005) have highlighted that for treatment processes that do not include phosphorous stripping, the final effluent phosphorous concentration is dependent on the influent concentration. Therefore, increasing the concentration of phosphorous wastewater by decreasing water use may result in no net change to the phosphorous load exiting a WwTW that does not have a phosphorous permit limiting phosphorous concentration in final effluent. The following review of the potential use of water efficiency measures is thus based on the assumption that a development implementing water efficiency measures will connect to a WwTWs with a phosphorous permit. Based on this assumption, water efficiency measure could potentially be used for phosphorus mitigation.

Improving water efficiency involves using water efficient bathroom and kitchen fittings that have a maximum water flow rate. This mitigation measure has the added benefit of contributing to water sustainability. However, from the perspective of an HRA, the efficacy of this method is uncertain because fittings may be changed by the homeowner for less water efficient devices. Whilst water usage values lower than 120 litres per person per day (the value recommended for use in the phosphorous budget calculations; Ricardo, 2021) are achievable, they must be maintained “in perpetuity” over the lifetime of the development (treated as 80-125 years for the purposes of an HRA).

The cost of increasing water efficiency beyond the recommended 120 l/person/day to 80 l/person/day is estimated to be between £900-£2697 for a one-bedroom apartment to a four-bedroom detached house, respectively[6]. Typically, the fittings approach is used in conjunction with a rainwater harvesting scheme or greywater reuse scheme. Assuming the water supplied by rainwater harvesting schemes or greywater reuse is supplied to a property through water efficient fittings then rainwater harvesting, or greywater reuse should not have any impact on the stated reductions in water use.

Assuming a new development is connected to a permitted treatment works with a final effluent concentration of 1.5 mg TP/l that is operating at 90% capacity to allow headroom within works (Natural England, 2020), the concentration in final effluent would be 1.35 mg TP/l. Taking the reduction of 30 l/person/day would equate to a daily reduction of 40.5 mg TP per person, or a 14.8 g TP annual reduction. In a development of 1000 people, a reduction of 14.8 kg/TP/year could be achieved.

As well as a water efficient fittings-based approach in a new development, existing households can be retrofitted with water saving products. The H_2eco project in South Essex, one of the largest water efficiency incentives in the UK, installs water efficient retro fit devices to households, as well as offering water savings advice. Analysis of this project showed that households that participated in the programme reduced their per capita consumption by approximately 15% at a cost of around £110 per household (Manouseli, et al., 2019). In the 2019/2020 reporting year Dwr Cymru Welsh Water recorded a measured per capita consumption of 131.19 litres[7]. Implementing a water efficiency incentive as effective as the H_2eco project could therefore provide per capita water savings 19.7 litres. Estimating phosphorous reductions from these figures would not be accurate due the purely hypothetical nature of

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[6] See: Advice on water efficient new homes for England, accessed from: https://www.waterwise.org.uk/knowledge-base/advice-on-water-efficient-new-homes-for-england-september-2018/, accessed on: 17/01/2021.

[7] See: Annual Performance Report 2019-20 Part 4 – Additional regulatory information, accessed from: https://corporate.dwrcymru.com/en/library/annual-performance-reports, accessed on: 20/01/2021

the strategy, the variability of WwTW permitted limits and the actual household water usage. However, implementing these measures in properties that are already draining to permitted WwTWs could reduce phosphorous loadings at relatively low cost.

Water efficiency measures, either applied in new developments or retrofitted to existing properties may provide a tangible approach to mitigating phosphorous loading, however the requirement to prove efficacy in perpetuity is a key limiting factor. A potential solution to this issue could be found by using smart meters to track water usage. However, this will also require the ability to take enforcement action if households increase the water usage above the rate required for mitigation. Smart meters may also have the additional benefit of driving additional reductions in water use. A trial by Anglian Water suggests smart water metering reduces usage by 3-4%[8].

4.1.2 Onsite wastewater treatment

Septic tanks (STs) and package treatment plants (PTPs) are two different types of onsite wastewater treatment systems that are normally used for developments that cannot connect to mains sewerage. STs collect sewage and allow the particulate matter to settle and decompose through biological processes. Both the settling of solids and biological processes result in some reduction in the total phosphorous concentrations in ST effluent, however these reductions tend not to be a significant with studies of total phosphorous concentrations in ST influent and effluent suggesting reductions of the order of 26% (O'Keeffe, et al., 2015). PTPs are self-contained sewage treatment systems that can include additional processes which reduce phosphorous concentrations more than the simple settlement and decomposition processes used in STs. However, it is also noted that some PTPs achieve phosphorous concentration in their effluent that are no better than STs. It is important to choose a PTP that has been designed for additional phosphorous removal. The effluent from STs or PTPs can be discharged away from the tank to a drainage field. Under the general binding rules for STs and PTPs, PTPs can also discharge directly to surface water[9].

Previous studies have indicated uncertainty in the average phosphorous load from STs and PTPs and have also suggested that phosphorous loads from STs are generally higher than from PTPs (May, et al., 2015; Lowe, et al., 2007). Although PTPs are generally thought to provide better quality final effluent than STs, it is noted that the information available on phosphorous concentrations in their effluent is more limited as phosphorous concentrations in effluent are not subject to regulation in England (May & Woods, 2016). A small study in England found that the average concentrations of total phosphorous in PTP discharges are about 9.7 mg P/l (May & Woods, 2016), however newer systems are able to achieve significantly lower phosphorous concentrations. The BioKube septic tank conversion unit[10] reports achieving phosphorous concentrations < 1.5 mg P/l in final effluent and testing of effluent from 2300 BioKube units reported an average concentration of 1 mg P/l[11]. These values are provided by the manufacturer and should be carefully verified; however, they do suggest using a PTP that discharges straight to drainage fields significantly reduces the amount of offsite mitigation that would otherwise be required.

Drainage fields for PTPs are to be designed in accordance with Section H of the Building Regulations (Section 1.26 onwards)[12], with a minimum distance of 10 metres from watercourses. The soil that effluent drains through results in significant phosphorous retention, although how much phosphorous is retained by soil adsorption is highly dependent on the local hydraulic conductivity, soil saturation, maintenance regimes, and the height of the water table (May, et al., 2015). Although soil soakaways have the potential to remove the majority of phosphorus from PTP or ST effluents, phosphorus has been found to travel at least 30 metres from a septic tank, which means consideration is required of proximity to local watercourses (May, et al., 2015). However, assuming robust evidence of the

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[8] See: Smart Metering of Energy and Water, accessed from: https://post.parliament.uk/research-briefings/post-pn-471/, accessed on: 20/01/2021

[9] See Septic tanks and treatment plants: permits and general binding rules, available from: https://www.gov.uk/permits-you-need-for-septic-tanks/general-binding-rules, accessed on: 11/02/2021

[10] See: https://www.wte-ltd.co.uk/biocube_septic_tank_conversion.html, accessed on: 11/02/2021

[11] See: https://sites.create-cdn.net/sitefiles/28/3/9/283903/Leaflet_BioKube.pdf, accessed on: 11/02/2021

[12] See: Herefordshire Council Sustainable Drainage Systems (SuDS) Handbook, accessed from: https://www.herefordshire.gov.uk/downloads/download/1863/sustainable_drainage_systems_handbook, accessed on: 17/01/2021.

phosphorous retention capacity of local soil and a suitable maintenance regime to maintain this retention capacity in perpetuity, the combination of efficient PTPs and drainage fields may provide enough mitigation for a development to achieve nutrient neutrality.

As an alternative to discharging the PTP or ST effluent to a drainage field comprising local soils, effluent can be discharged to a soakaway composed of a filter material (Renman & Renman, 2010). Renman and Renman (2010) found 560 kg of Polonite (2-5 mm diameter) serving effluent from an ST had an average of 90% phosphorous retention over a two-year period for a single household. This equated to around 70,000 litres of sewage with an average influent of concentration of 5.61 mg P/l. A review of the efficacy of various filter materials found gravels, sands and soils have generally low sorption capacity (< 0.5 g/P kg), whereas fine (< 1 mm) blast furnace slag, fly ash, and Polonite have high phosphorous sorption capacities (> 1 g P/kg) (Cucarella & Renman, 2009). Assuming a new development of 100 dwellings, a population of 230 people and water usage of 120 litres/person/day, an efficient PTP with a final effluent of 1.5 mg/l and a filter sorption capacity of 1 g P/kg, just under 1.6 tonnes of a filter material would be required to retain the annual phosphorus load from wastewater. The filter material has a finite phosphorous sorption capacity and would therefore need to be replaced annually, with a suitable maintenance and disposal agreement secured in perpetuity.

Treated effluent from PTPs or STs can also be given tertiary treatment by routing effluent through reed beds and constructed wetlands prior to discharge. An investigation of a vegetated swale system in Warwickshire, built to treat effluent from a septic tank serving around 35 people, found inlet-outlet phosphorus reductions of 98.4% (18 to 0.28 TP mg/l) (Abrahams, et al., 2017). This system incorporated permaculture design techniques which produced fruit and willow coppicing for sale or consumption. However, these systems can switch from a sink to a source of phosphorus if environmental conditions change, or if drainage sites become saturated (May, et al., 2015). The uptake of phosphorous by wetlands can also be improved by using blast furnace slag, which has been found to have sorption capacities as high as 44 g P/kg when used as a substrate for constructed wetlands (Cucarella & Renman, 2009). If this figure is accurate, < 0.3 tonnes would be needed to offset the annual phosphorous loading from the 100 dwellings example detailed above and 1 tonne of blast furnace slag substrate would reach its phosphorous storage capacity and need replacing every three years. Wetlands are discussed further in Sections 4.1.3 and 4.2.4.

PTPs with proven, high phosphorous removal rates may provide a means to substantially reduce the amount of offsite mitigation required for a new development and if combined with well-designed and maintained drainage fields or wetlands, these solutions could provide mitigation that achieves nutrient neutrality. Maintenance of PTPs and STs typically requires annual desludging and servicing, though this frequency is dependent on the population served and the system used. Contractual maintenance agreements would need to be established and adhered to, both for the treatment system and any tertiary treatment using drainage fields or wetlands. These maintenance agreements will also require consideration of disposal of sewage sludge and phosphorous-saturated soils and sediments so as to not simply recirculate the retained phosphorous within the Wye SAC catchment. The biproducts of these systems are likely to either be treated as sewage sludge or controlled waste, both of which have specific disposal requirements that will require consultation with the Environment Agency when drawing up maintenance agreements.

4.1.3 Sustainable Drainage Systems (SuDS)

Sustainable Drainage Systems (SuDS) are onsite water management solutions that use natural physical and biological processes to provide environmental benefits such as reducing flood risk, providing additional habitats for wildlife and water quality improvements, including the removal of phosphorous. Examples of SuDS include:

- Wetlands: shallow ponds and reed beds that provide stormwater attenuation, sediment settlement and pollutant removal.
- Swales: vegetated linear conveyance/storage channels that attenuate flows, promote infiltration and settlement of pollutants.
- Trees: trees reduce flows through interception and evapotranspiration and improve water quality through root uptake of pollutants.

- Permeable pavements: pavements and hard surfaces that allow infiltration or temporary water storage.
- Soakaways: excavations filled with rubble that promote percolation.
- Rain gardens or filter strips: vegetated land parcels that reduce flows and act as filters.
- Green roofs and living walls: vegetated roofs and walls of buildings that reduce runoff.
- Bioretention systems: shallow planted depressions that can filter water and treat pollution.

The key considerations for choosing SuDS components that will have greater benefits for phosphorous removal is to have a SuDS system that promotes infiltration of water, allows for settlement of sediment and provides an environment for plant growth. These three processes can remove phosphorous from the environment. Swales, bioretention systems and rain gardens or filter strips are best at supporting these processes. These SuDS components are best used in "treatment train" that links them together and ideally would terminate in a constructed wetland prior to discharge to a waterbody. Constructed wetlands are thought to provide the most benefit in terms of phosphorous removal (Bastien, et al., 2010). Surface flow (SF) or free-water surface (FWS) wetlands are most commonly used in the UK for urban runoff treatment. These are similar to natural marshes, comprising basins planted with emergent, submergent and/or floating wetland macrophyte plants.

A review of 26 studies conducted on constructed wetlands in the US found a median TP removal rate of 58% (mean of 57.2%) and a median wetland area: watershed ratio of 3.65% (Strecker, et al., 1992), i.e. on average, the area of the wetland occupied 3.65% of the area it drained. Studies in Sydney have indicated average removal rates in urban FWS wetlands of 60% TP during small to medium sized storm events but with very variable performance during high intensity and/or duration events (Shatwell & Cordery, 1999). It is likely urban wetland systems are likely to provide better removal rates than the rates recorded in these studies as knowledge and understanding of wetland design, maintenance requirements and phosphorus removal mechanisms has improved in the last 30 years. The concentration of phosphorous in urban runoff entering a wetland is estimated at 0.31 mg TP/l (Mitchell, 2005; Zhang, et al., 2014), which when combined with the average urban runoff rate for Herefordshire corresponds to an annual loading of 1.23 kg TP/ha/year (See IDP Stage 1; Ricardo, 2021). Therefore, assuming a phosphorous removal rate of 58% (the lower and more precautionary estimate from the literature), 0.71 kg TP/ha/year can be mitigated through the use of wetlands in SuDS to treat urban runoff. To put this figure into context, a hypothetical phosphorous budget for a medium housing density, 100 dwelling development on a 2-ha site would generate a surplus of ~12 kg P/year. To mitigate this additional phosphorous load, a ~0.7 ha wetland would need to drain an urban area of around 17 ha. However, this does not preclude SuDS from playing a role as a mitigation measure. Any removal of phosphorous that can be achieved through well-designed SuDS could play a part in developments achieving nutrient neutrality and as new developments should be including SuDS as part of their drainage design as standard, maximising the potential for phosphorous removal should be seen as an imperative. Retro-fitting SuDS in urban areas also has the potential to provide much larger drainage areas and thus greater potential for load reductions.

The performance of SuDS for phosphorous removal is intrinsically linked to their design. The SuDS manual (Woods-Ballard, et al., 2015) specified various considerations for wetland design. Wetlands should include a sediment forebay, permanent pool, attenuation storage volume (additional volume for excess rain) and an aquatic bench (shallow planting zone). It should have a flow path length: width ratio of at least 3:1. The maximum depth of the permanent pool should not exceed 2 metres to allow oxygen to reach the bottom of the pool. Flood attenuation should provide a volume capacity for up to 10, 30- or 100/200-year return period rainfall events.

Regular and systematic wetland maintenance is also essential in order to ensure the longevity of high phosphorus removal performance in urban wetlands. A full list of maintenance requirements for ponds and wetlands can be seen in the SuDS Manual (Woods-Ballard, et al., 2015), though in summary regular maintenance includes litter and debris removal, functionality inspections and sediment removal from forebays. Desilting/dredging is required when the main pool volume is reduced by 20%. With well-designed source control this may only be required every 25-50 years. If phosphorous enriched sediment is allowed to accumulate the wetland can become a source of 'legacy' phosphorous (Sharpley, et al., 2013; Land, et al., 2016). It has been suggested that over a 25 – 30 year lifetime the full maintenance and operational costs could well be nearly equivalent to the initial construction costs (Ellis, et al., 2003).

Silt removal should be conducted on < 30% of the area at one time to minimise disturbance (Woods-Ballard, et al., 2015).

Removal of green waste and sediments during wetland maintenance also requires consideration of appropriate disposal procedures. Green waste can be composted, although precaution should be taken if the resulting phosphorous-enriched compost is to be used in the Wye SAC catchment, as this may simply recycle the phosphorous back into the catchment. It is uncertain whether dredged sediment from SuDS ponds and wetlands could be reused in the environment due to possible contaminants, such as heavy metals and hydrocarbons, which are highly dependent on the urban land use (industry, residential etc.) (Woods-Ballard, et al., 2015). A study of two constructed wetlands in London recorded elevated trace and heavy metal contaminants in wetland sediments (Scholes, et al., 1998). Dredged material should therefore be assessed and tested to determine if re-use is possible, or if disposal as ‘contaminated waste’ is required (Woods-Ballard, et al., 2015). The SuDS Manual provides a sediment categorisation and disposal decision tree (Woods-Ballard, et al., 2015). Previously dredged material has been deemed suitable for urban landscaping (Güzel, et al., 2019). Ideally dredged sediment could be used as fertiliser, particularly in phosphorous depleted catchments. However, a recent UK study of 10 edge-of-field farm wetland systems concluded that dredged sediments have little value as fertiliser, as their bioavailable (available to plants) phosphorous concentrations are similar to those seen in the surrounding fields (Ockenden, et al., 2014). Instead it was recommended that dredged sediment could be used as topsoil as it would have sufficient available phosphorous to support plant growth.

Full cost breakdowns of different SuDS options can be found in ‘Cost estimation for SuDS - summary of evidence’ (Keating, et al., 2015). The initial costs of a constructed wetlands are estimated to be £25-£30 per m^3 of treated water. Annual maintenance costs are estimated at £200-250 per year for the first 5 years (declining to £80-100 per year after 3 years and noting that this figure is from 2015). This is assumed to cover:

- Monthly - litter and debris removal, grass cutting of landscaped areas.
- Half yearly - grass cutting of meadow grass.
- Annual - manage vegetation including cut of submerged and emergent aquatic plants and bank vegetation removal.

The costs for urban constructed wetlands over a 10-year window are predicted to be around £5,000 for removal of silt, repairs to structural elements and replacement vegetation planting (e.g. Keating, et al., 2015).

4.2 Offsite measures

4.2.1 Agricultural land abandonment and woodland planting/reversion to semi-natural habitat

Agricultural land abandonment reduces phosphorus loading through reduction in the use of phosphate-rich fertilisers and production of animal waste. Soil erosion and associated phosphorus mobilisation is also likely to decrease with time as soil is stabilised by more continuous vegetation cover. Reversion of previously agricultural land to a more natural state will eventually reduce phosphorus leaching to natural background rates. However, unpublished research from Lancaster University[13] has raised issues around the impacts of legacy phosphorus, which adds a time lag to when previously agricultural land will reach natural background levels of phosphorous loss. A study in New Zealand estimated that following cessation of phosphorous applications to grassland, the time taken for legacy soil phosphorous concentrations to reduce to levels that have less potential to enrich surface runoff is 23–44 years (Dodd, et al., 2012). McCollum (1991) found that after the last phosphorous application it took > 17 years for phosphorous concentrations within a fine sandy loam in an arable system in the United States to decline from 99 g P/m^3 to the agronomic optimum value of 20–25 g P/m^3. Models of Irish soils at two sites estimated a period of 7-15 years for phosphorus to decline from 14.3 and 8.3 mg/kg Morgan-P to 7.5 and 4.7 mg/kg Morgan-P (Schulte, et al., 2010). Morgan-P is a measure that is used in Ireland

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[13] Outputs from the RePhokus project have been shared with stakeholders in the Wye SAC catchment and brought to the attention of this project.

to quantify the bioavailable phosphorous in soil, with Olsen-P being the UK equivalent to Morgan-P. The values cited in Schulte et al. (2010) are equivalent to 46 and 31 mg/kg Olsen-P at the start of the period of soil phosphorous decline and 27 and 17 mg/kg Olsen-P at the end of the study. The average phosphorus content in Wye topsoil samples has previously been measured as 51.5 mg/kg Olsen-P and 44.6 mg/kg Olsen-P for arable and pastures, respectively (Owens, et al., 2006).

Based on these studies of phosphorous legacy periods and the soil Olsen-P in the Wye catchment, phosphorus loadings may tail off to background level over a period of the order of 20 years. Calculations of phosphorus loading reductions from agricultural land abandonment need to account for this lag time by assuming that phosphorus loading from abandoned land may be elevated above background levels for a period of the order of 20 years, unless monitoring can prove otherwise or the land is managed in a way that actively promotes phosphorous uptake by vegetation and reduces the risk of soil erosion. Simple solutions like cover crops and drain blocking on drained land are known to be effective at reducing the phosphorous export from former agricultural land in the short-term. It should be noted, however, that even with the management techniques, legacy phosphorous results in uncertainties on the scale of phosphorous reduction that agricultural land abandonment can achieve in the short- to medium-term. The issue of legacy phosphorous adds certain limitations to the use of agricultural land abandonment for phosphorous mitigation and this issue is compounded by the small phosphorous exports rates typical of agricultural land relative to the high loading rates from additional wastewater.

Using the hypothetical phosphorus budget surplus of 12 kg P/year (see above, Section 4.1.3) and the Herefordshire average agricultural phosphorous export rate of 0.27 kg P/ha/year, this relatively small, 100 dwelling development would require abandonment of ~44 ha of farmland. The average cost of purchasing ‘all types’ agricultural land is £16530 per ha, prime arable is £21500 per ha, grade 3 arable is £18060 per ha, and grade 3 arable grassland is £13300 per ha[14]. In 2018, the average rent for Full Agricultural Tenancy agreements was £170 per hectare, and the average rent for Farm Business Tenancy agreements was £231 per hectare[15]. Based on the average value for ‘all types’ of farmland, abandoning ~44 ha would cost in the region of £750,000 and may require an interim mitigation solution to cover the period effected by the legacy phosphorous issue. It is noted however, certain farm types with associated rainfall envelopes and soil types have significantly greater phosphorous export and would therefore provide much more cost-effective mitigation. For example, lowland grazing in areas that see 900-1200 mm annual rainfall on the “drained for arable and grass” soil type[16] has a phosphorous export coefficient of 1.43 kg p/ha/year (See Appendix A2 in Ricardo, 2021). This export rate is reduced by 0.02 kg p/ha/year to account for natural background phosphorous export (see Herefordshire IDP Stage report; Ricardo 2021), thus requiring 8.5 ha of land to mitigate 12 kg P/year at an approximate cost of £142,000 based on average farmland costs[15]. It is also noted there are only 13 farms covering 33.3 ha that have this particular combination of rainfall and soil types that drive higher phosphorous export and that in general, farm types that have the highest phosphorous export rates are rare within the Herefordshire Local Authority area.

If agricultural land abandonment schemes are pursued, it is advised that farm types with the highest phosphorous export coefficients possible are targeted and bespoke Farmscoper modelling exercises for the land under consideration are conducted to provide the best estimate of possible phosphorous reductions. In lieu of bespoke Farmscoper modelling outputs, the phosphorus export coefficients detailed in the Stage 1 IDP report (Ricardo, 2021) can be used, with appropriate consideration of the ~20 year lag period for land to return to natural background phosphorus export. Woodland planting on agricultural land could accelerate the transition back to more natural soil phosphorous export, however there is uncertainty around the time taken for tree planting to reduce phosphorous loading from natural levels and different studies have reported increases, decreases and no effect of afforestation on total phosphorous in soils (Deng, et al., 2017).

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[14] See: Market in Minutes: GB Farmland – summer 2020, available from: https://www.savills.co.uk/research_articles/229130/302436-0, accessed on: 26/01/2021

[15] See: Farm Rents – England 2018, available from: https://www.gov.uk/government/statistics/farm-rents, accessed on: 26/01/2021

[16] In the Farmscoper tool used to derive estimates of phosphorous export from different types of agricultural land, farm types are categorised by rainfall band and soil type.

Natural England's advice for the Stodmarsh SAC suggests that woodland planting could be used to secure land use change from agricultural land uses without necessitating land purchase (Natural England, 2020). They note that maintenance of land use change by woodland planting can be easily verified and state the requirement for 20% canopy cover at maturity, equating roughly 100 trees per ha, to class an area of land as changed from agricultural use. There would also be a preference towards planting native tree species that are typical of the local biogeographical setting, such as oak, ash and hazel. However, there is a paucity of research assessing the reductions in phosphorous loading to rivers that is associated with planting mixed-species native UK woodlands. Research in test catchments such as Pontbren, Wales have highlighted the impacts of tree planting, such as reductions in runoff generation (Marshall, et al., 2014), which in turn are likely to reduce fluxes of soil-bound and dissolved phosphorous, but this study has not found substantive quantitative evidence of reductions in phosphorous loading in UK environments that can be achieved through woodland planting.

Research into the impacts on total phosphorous in soils following reforestation of grassland using conifers, including the UK native *Pinus sylvestris*, has indicated that, in general, reforestation reduces total phosphorous (Chen, et al., 2008). However, the size of the effect was dependent on a range of local factors including prior land use, climate, soil properties and tree species planted. This finding was echoed in the results of a global meta-analysis that analysed the results of sampling from 220 independent sampling sites reported in 108 research papers to estimate changes phosphorous dynamics following afforestation (Deng, et al., 2017). This study reported average reductions in total phosphorous stocks (kg/ha) in the top 20 cm of mineral soil of 12.3%, although this estimate has around a 50% margin of error. However, Deng et al. (2017) noted large differences in the percentage reductions in total phosphorous from afforestation in relation to specific variables. For example, previous land use was determined to be the most important variable controlling total phosphorous reductions, with 23.1% and 10.5% reductions reported for former grassland and cropland, respectively. Whereas when controlling for climate, sites in the "temperate maritime" climate zone that UK sites in the study fell within showed a 9.8% reduction in total phosphorous following afforestation.

These studies highlight the uncertainties associated with reductions in phosphorous loading that could be achieved from woodland planting and thus the difficulties in determining, *a priori*, the amount of phosphorous "credits" that could be achieved through woodland planting mitigation schemes. This is not to say that reforestation cannot or should not be pursued and thought should be given to how wider reforestation efforts being driven by government policy[17] could be contributed towards to secure reductions in phosphorous loading as well as biodiversity gains. However, there will be a requirement for further monitoring and research to quantify the reductions in phosphorous loadings that could be achieved by woodland planting, and thus the "credits" these schemes can provide for mitigation for nutrient neutrality.

The same set of considerations as detailed for woodland planting are required if agricultural land is allowed to revert to semi-natural habitats. There is a general lack of research on the amount of additional phosphorous would be retained by vegetation in semi-natural habitats and unlike woodland planting, land would need to be taken out of ownership by a farmer and managed, for example as a nature reserve, in order to reduce the risk of land being put back into agricultural use. However, it is likely that managing land back to semi-natural habitat would help to speed up the transition to natural background levels of phosphorous export.

4.2.2 Riparian buffers

Riparian buffers are vegetated strips that are typically thin, unfarmed and tillage-free land parcels between agricultural areas and rivers (Weigelhofer, et al., 2018) There are opportunities within the Herefordshire-Wye Catchment to create riparian buffers along rivers, especially where agricultural land borders a river with limited space between field margins and the river banks. Sedimentation of particulates and their associated sorbed phosphorous load in surface runoff is the main phosphorous retention mechanism in buffer strips (Hoffmann et al, 2009). Vegetation also increases surface roughness, reducing runoff rates and helping to retain phosphorous in soils by promoting greater infiltration. Uptake of phosphorous by plants in riparian buffers also has the potential to temporarily

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[17] E.g. Government launches new scheme to boost tree-planting, accessed on: 16/02/2021.

immobilise and remove phosphorous from soil. These processes combine such that riparian buffers can reduce the total phosphorous load to river channels.

A review of ten different studies of riparian buffers of various widths and vegetation compositions found generally high retention of total phosphorous (32–93%; median = 67%) and more variable retention or net release of dissolved reactive phosphorous (−71-95%; median = 65%) (Hoffmann et al., 2009). Research has indicated that phosphorus removal is greatest during the first few meters of buffer strip. A study of a grass buffer found 66% of phosphate was removed eight metres into the strip and by 16 metres 95% was removed (Vought, et al., 1994). To obtain maximum nutrient retention a buffer width of 10-25 metres is needed, alongside high stem density vegetation (Vought, et al., 1994).

Vegetated riparian buffer strips also provide habitats for wildlife and can increase riverbank erosion resistance, resulting in wider environmental benefits. Riparian vegetation protects streambanks by dissipating the energy in river flows and though stabilisation of soil by roots (Cooper, et al., 1990). It has been estimated that river channel banks and sediments can contribute 21, 30, 36, 37, and 43%, respectively, of the total particulate phosphorous fluxes based on studies on the Garren Brook, Dore, Frome, Stretford Brook, and Worm Brook sub-catchments of the Wye (Walling, et al., 2008). By stabilising riverbanks against erosion, vegetated riparian buffer strips therefore have the potential to decrease the riverine particulate phosphorous sources, particularly with strategic site planning and management, although the reductions in phosphorous loading that would be delivered are difficult to measure and quantify.

Management of riparian buffers for phosphorous mitigation is required as unmanaged buffer strips do not usually provide a permanent sink for phosphorous (Weigelhofer, et al., 2018). Phosphorous accumulated in soil increases the phosphorous pool in riparian buffer soils increases phosphorous solubility and the risk of release to the adjacent river (Fox, et al., 2016) and buffers with elevated soil phosphorous concentrations have been reported as sources of soluble phosphorous (Hille, et al., 2018). The issues of phosphorous accumulation in buffer strip soils can be ameliorated using planting and harvesting of fast-growing species that remove accumulated phosphorous and reduce phosphorous saturation, thus decreasing dissolved phosphorous losses from the buffer strip (Vought et al. 1994). It is also noted that topsoil removal has been found to have a marginal effect on reducing phosphorus leaching from buffer strips (Hille, et al., 2018). There is also the potential to combine buffer strips with the growth of energy crops, with energy crops grown in a buffer strip helping to uptake more phosphorous (Vought, et al., 1994). A buffer strip-energy crop scheme would also come with associated maintenance and harvest regimes.

As an example of the potential number of phosphorous “credits” that could be achieved using riparian buffer strips, a theoretical 10-hectare arable field growing cereals with an export coefficient of 0.32 kg P/ha/year would export 3.2 kg/ha/year. Assuming a total phosphorous retention rate of 67% (the median from Hoffman et al, (2009)) and a riparian buffer 316 m long and 20 m wide has the potential to remove 2.14 kg TP/ha/year. The riparian buffer would cover a 0.6 ha area. Long-term monitoring is recommended in order to assess the continued functionality of these systems. Management, including periodic harvesting of vegetation, would be required secure the mitigation in perpetuity and harvested vegetation would need to be disposed of outside of the Wye catchment to circumvent the eventual return removed phosphorous to the Wye through phosphorous cycling. There is also a requirement to consider whether riparian buffer strips at proposed locations are already part of catchment management plans to reduce agricultural diffuse pollution and thus specific use for nutrient neutrality could risk double counting of phosphorous reductions, which could be subject to legal challenge.

4.2.3 Short Rotation Coppice (SRC)

SRC produces energy crops through high density planting of high-yielding varieties of poplar or willow. Planting is normally from cuttings. Trees are left to grow on for between 2 and 4 years before being harvested. The root is left in the ground and produces more shoots that grow for a further 2 to 4 years until the next harvest. These 2- to 4-year cutting cycles take place until yield declines and the crop is replaced. SRC can remain productive for up to 30 years before the original trees require replacing

(Tubby & Armstrong, 2002). Grants are available through the Energy Crop Scheme run by Defra[18]. SRC crops can provide a renewable energy source that produce very low net CO_2 emissions and low levels of nitrogen and sulphur pollutants. The trees uptake phosphorus from soils, which is subsequently removed from the phosphorus cycle when the trees are harvested.

There are also examples of using SRC plantations for wastewater treatment. In Canada, an SRC plantation of willow in a two-hectare plot was irrigated with treated wastewater (Amiot, et al., 2020). Irrigation had an equivalent loading of 120 kg P/ha/year and the SRC crop had a total phosphorous removal efficiency of 98%. The efficiency of phosphorous removal depends on various parameters including soil conditions, plant physiological characteristics and wastewater hydraulic loading rates. This suggests that SRC plantation sited next to WwTWs could provide a form of tertiary treatment and produce an energy crop with benefits to carbon emissions reductions. There would be a need to explore the regulatory implications of using treated wastewater for this purpose.

SRC could also be used in conjunction with agricultural land abandonment. In two UK trials of SRC on land previously used for arable cropping, one using poplar, the other using willow, there was no significant increase in yield through fertilisation in the first ten years of crop management (Mitchell, et al., 1995). This was likely due to the accumulated nutrients in the soil from the previous arable land use and associated fertiliser inputs. It has been recommended that UK Index 3 soils[19] do not need to have fertiliser applied to stimulate SRC growth (Johnson, 1999). The average phosphorous content in arable soils in the Wye catchment have previously been reported at 0.36 mg P/kg, which is within the range of phosphorous concentrations expected for Index 3 soils (Owens, et al., 2006), although it is noted that this is a relatively old study soil phosphorous concentrations in the Wye catchment may have changed. SRC crops are reported to remove up to 15.8 kg P per 10 oven dry tonnes (ODT)/ha/year (Potter, 1999). Trials in the UK have shown that up to 15-18 ODT/ha/year can be achieved under certain conditions and 25 ODT/ha/year may be achievable through specialised breeding (Karp 2009). The average produce of SRC in the UK has been previously found to be 8.1 ODT/ha/year for willow (Mitchell, et al., 1999). Taking the lower estimates of ODT detailed above, an average ODT yield of 11.6 ODT/ha/year is estimated. Based on the annual phosphorous removal rate of 15.8 kg P per 10 ODT/ha/year, an SRC plantation could remove ~18 kg P/ha/year from previously arable land, without requiring fertilisation. It is unclear how long an SRC plantation would be able to continue providing sufficient yields using only the legacy nutrients left in soils after cessation of agriculture. However, some initial soil sampling to determine nutrient concentrations at potential SRC sites could provide an indication of both the potential for actively removing legacy phosphorous from the Wye catchment and also provide an indication of how long an SRC crop may be able to be grown for before requiring fertilisation.

4.2.4 Wetlands

For the purpose of this report, offsite wetlands are divided into two types: wetlands “in catchment”, which can be created on previous farmland, on the floodplain, or anywhere else in the catchment where a flow pathway can be intercepted in order to feed the wetland; and at WwTWs where they are fed by final effluent and used as a tertiary sewage treatment. These types of wetlands are described separately below.

4.2.4.1 In catchment wetlands

These wetlands follow the same principles as wetlands in an urban context (see Section 4.1.3), although they can also be connected to rivers and used to treat river water, as well as being fed by surface runoff and/or sub-surface flow. There are three major wetland designs, SF and FWS wetlands (as described in Section 4.1.3), and subsurface flow (SSF) wetlands where the influent flows into the wetland below the surface of a substrate. In SSF wetlands, phosphorous removal occurs through substrate percolation and through root uptake of plants grown within the substrate. There are two types of SSF wetland (Ellis, et al., 2003):

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[18] See: https://www.gov.uk/guidance/industrial-energy-and-non-food-crops-business-opportunities-for-farmers, accessed on: 16/02/2021

[19] Index 3 soils are enriched in nutrients and are less likely to show increases in crop yields from additional fertiliser application.

- Horizontal flow (HF) wetlands – flow passes through an inlet and flow through the substrate and root bed horizontally. These are also known as Reedbed Treatment Systems or Kickuth-type.
- Vertical flow (VF) wetlands – the surface of the substrate is flooded and water percolates down into bed.

It is noted that FWS wetlands are closest in type to the majority of natural wetlands, such as bogs, swamps and marshes, and provide a greater range of habitats and therefore biodiversity benefits than SF and SSF wetlands. This increased biodiversity means FWS wetlands are also likely to provide greater amenity value.

Rural FWS design should mainly be in accordance with the SuDS manual (Woods-Ballard, et al., 2015). In addition, Ellis et. al (2003) recommend a minimum contributing area of 8-10 hectares or 1.5-2 hectares for “pocket” wetlands, a minimum of 40-50% open water with 35-40% of surface area being shallow pool, 10/15% of surface area being deep pool (0.5-2 metres), and a sediment forebay of 10-15% of the total wetland cell area. The main plant species used in wetlands for wastewater treatment is the common reed (*Phragmites australis*) and reedmace (*Typha latifolia and Typha angustifolia*), although there are many other plant varieties that can be used (Ellis, et al., 2003). Wetland management should follow the same procedures as detailed in Section 4.1.3. The sedimentation rates in wetlands collecting runoff from agricultural land will be highly dependent on local soils and subsequent concentrations of suspended sediment in runoff feeding the wetland (Ockenden, et al., 2014). This may alter the frequency with which desilting is required form the decennial frequency suggested for wetlands in urban SuDS.

In a review of the efficacy of phosphorous removal in 51 “in catchment” wetlands, the median removal efficiency was 46%, and the removal rate significantly correlated with inlet concentration, hydraulic loading rate (HLR), air temperature, and wetland area (Land, et al., 2016). Based on this information, it is likely that removal rates will increase with higher phosphorous concentrations and with larger wetland designs (area and volume). A review of 11 studies of hybrid wetlands in Poland consisting of two or three pools with vertical and/or horizontal flow found total phosphorous removal rates range from 48.2 to 99.5% with an average of 89.3%, corresponding to a phosphorous load removal rate of 0.08 – 0.64 g P/m^2/year with an average of 0.23 g P/m^2/year (Jóźwiakowski, et al., 2019). A review of 282 FWS wetlands reported median a phosphorous load removal rate of 6 g P/m^2/year (Kadlec & Wallace, 2008). The differences in load removal rates reported in these studies is likely reflective of different phosphorous concentrations in inflows to the wetlands.

A four year study of a 1.2 ha wetland system comprising 5 ponds in Northern Ireland treating dairy farm runoff experienced consistent annual total phosphorous reductions of 91.2-96.4% (Forbes, et al., 2011). This relatively consistent efficiency in reductions was observed despite loadings ranging from 8.7-31.8 g P/m^2/year (100-400 kg P/year). This system was estimated to cost an initial £29000-£40000 in design and construction costs (in 2015), with ongoing annual costs of £300 (Mackenzie & McIlwraith, 2015).

An investigation of a small roadside linear pond (ca. 30 m length, 4 m width, 1.5 m depth) in the River Wensum catchment, UK, draining 24 hectares of arable fields and roads recorded an annual total phosphorous accumulation of 7253 kg of sediment (305 kg sediment/ha/year) and associated 11.6 kg TP (0.5 kg TP/ha/year) that was bound to this sediment (Cooper, et al., 2019). Removal of the sediment would remove the associated phosphorous load. The system cost £3411 to install (£1400 for design, £2011 for construction in 2016). The cost of sediment removal every 2–3 years of operation, based on measured accumulation rates of 12.15 m^3/year, was estimated to be approximately £145–£182 per year based on costs between 2016-2019. This suggests small rural linear wetlands have the potential to offer significant phosphorous credits for mitigation.

The evidence above suggests that in catchment wetlands have the potential to be highly effective forms of mitigation, but this is highly dependent on the design, location and management of these systems. Management also needs to consider the disposal of dredged sediments and harvested vegetation to remove the risk of re-circulating the removed phosphorous within the Wye catchment. There is also a requirement to understand the retention of phosphorous by a wetland, which would need to be determined by monitoring of inflows, outflows and potentially of removed sediment. The potential costs of wetlands vary depending on the complexity of the wetland system. The Wildfowl and Wetlands trust estimate that wetlands cost between £4 per m^2 for simple linear ponds £100 per m^2 for complex multi-celled constructed wetlands (based on costs in 2015; Mackenzie & McIlwraith, 2015).

4.2.4.2 Wetlands at WwTWs

By routing the final effluent from a WwTW though a wetland, the wetland can be used as a form of tertiary wastewater treatment. The final effluent would normally discharge directly to a river and thus the outflow from the wetland would also discharge directly to the same river. Among the different constructed wetlands (CWs) systems treating domestic wastewater, a two stage vertical flow (VF) CW is the most common design (Troesch, et al., 2016). VF wetlands are mainly used for primary or secondary treatment, FWS wetlands are often used for tertiary treatment, and HF CWs are often used for urban runoff treatment (Vymazal, 2010). In a review of wetland phosphorous removal efficiencies, the rate for secondary treatment of domestic wastewater was 68% (4 studies), and 46% in tertiary domestic wastewater treatment (5 studies) (Land, et al., 2016).

A four-year study of a 1750 population equivalent (PE) FWS wetland system (loaded at 1200 PE and based on European estimated BOD of 0.06 mg/l[20]) for primary domestic wastewater treatment in Ireland found a 91.4% removal rate (16.4 g TP/m^2/year) (Dzakpasu, et al., 2015). The average influent and effluent concentrations were 7.7 and 0.5 mg TP/l, respectively. This wetland system comprises two sedimentation ponds (for alternating desludging regimes), followed by a sequence of five shallow and vegetated wetland cells. The area of the wetland is 3.25 ha with a curtilage area of 6.74 ha. A negative relationship was found between high effluent flow volumes and phosphorous removal rates, indicating the requirement to manage flow volumes through the system to retain optimum phosphorous removal efficiency. It was concluded that high phosphorous retention can be maintained if hydrological factors can be managed.

In a 15 year study of a Kickuth-type constructed wetland in Poland, serving 800 PE with a daily flow of 116 m^3/day (0.12 MLD) and pre-treatment settling, TP removal was around 60% in the first two years, rapidly declining until the effluent TP was higher than the influent after 8 years as the sorption capacity was reached (Mucha, et al., 2017). This study highlights the variability in potential efficiencies of wetlands as a phosphorous treatment method and possible issues with the Kickuth Horizontal Flow 'Root Zone Method' design.

There are various products for WwTW wetland treatment available. For example, the Phragmifiltre® is a reed bed technology that provides complete treatment of macerated or raw sewage in one wetland system, with no pre-settlement and using little to no energy[21]. This was recently used in a vertical flow aerated wetland for Severn Trent Water, though no phosphorous removal rates are given[22].

Accurate estimation of phosphorous removal rates and thus the "credits" achievable by a wetland taking WwTW final effluent is difficult due to the wide range of technologies available, variable phosphorous loading rates and the variable sizes of population served by different WwTWs. However, taking the lowest and most precautionary treatment efficiency detailed in Land, et al., (2016), phosphorous removal is likely to be at least 37% of the influent load. Taking the average total phosphorous concentration from non-permitted WwTWs final effluent of 8 mg TP/l detailed for Stodmarsh (Natural England, 2020), even small WwTWs discharging around 1 MLD would remove ~2.96 kg P/day (1081 kg P/year). Well-designed wetland systems treating WwTW final effluent could achieve significantly more credits.

As with in catchment and SuDS wetlands, wetlands treating final effluent from a WwTW would require monitoring and maintenance. Monitoring should be used to confirm the amount of phosphorus "credits" the system is achieving and is also required for compliance with environmental permitting. Maintenance is needed to periodically remove sediments that can result wetlands turning from a sink to a source of phosphorous. Recommendations for wetland maintenance suggest sediment removal could be

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[20] See Glossary of terms related to Urban Waste Water, accessed from: https://ec.europa.eu/environment/water/water-urbanwaste/info/glossary_en.htm, accessed on: 19/01/2021

[21] See Phragmifiltre Technology Information, available here: https://armreedbeds.co.uk/projects/phragmifiltre/, accessed on: 26/01/2021

[22] See Case study: Severn Trent Water, Hulland Ward, available here: https://www.enviropro.co.uk/entry/140452/ARM-Ltd/Vertical-flow-aerated-wetland-for-Severn-Trent-Water/, accessed on: 26/01/2021

required at a minimum of every ten years, although well-designed wetlands may be able to be desilted less often (Ellis, et al., 2003; Woods-Ballard, et al., 2015). A maintenance schedule with sediment removal on a decennial timescale should provide a precautionary approach to maintenance that ensures wetlands continue to function optimally, although the time between sediment removal could be extended through effective wetland design and evidence to support slower sedimentation rates and thus longer periods between desilting. It is also recommended that monitoring data is used to determine the equilibrium phosphorous removal rate once the wetland has been built and is fully operational. Departures from this equilibrium removal rate could be used in an adaptive management regime whereby reductions in phosphorous removal below the equilibrium rate trigger maintenance. This would provide an additional layer of security to ensure the phosphorous removal rate achieved by the wetland is secured in perpetuity. There is also a requirement to ensure that removed sediment and vegetation is deposed of in a way that does not recirculate removed phosphorous within the Wye catchment. This report has seen correspondence with the Environment Agency that indicates the removed sediment can be treated as sewage sludge under the Sludge Use in Agriculture Regulations 1989 and can therefore be spread onto land as fertiliser. If the sediment is being spread onto land within the Wye catchment, consideration should be given to ensuring that it replaces the use of other fertilisers to avoid potential net increases in phosphorous loading to the Wye.

5 Conclusion and Recommendations

This assessment has analysed a range of mitigation options that can be used to mitigate the increase in phosphorous loading from new development to the River Wye and thus aid developers to achieve nutrient neutrality for new housing developments. The analysis of potential options was conducted in the context of key HRA tests in order to determine the suitability of different mitigation measures. It is important to recognise that to be compliant with the Habitats Regulations, the efficacy of a mitigation measure needs to be demonstrable using *best available evidence* in order to show *beyond reasonable scientific doubt* that the mitigation measure will achieve the required phosphorous reductions. The estimates of reductions that can be achieved by a mitigation also need to be suitably *precautionary* and the mitigation measure needs to remain effective *in perpetuity* (80-125 years).

Using these tests as guiding principles, a long list of mitigation options was reduced to a shortlist by removing options that clearly had too much uncertainty to evidence reductions in phosphorous beyond reasonable scientific doubt and/or had clear issues with offering reductions in phosphorous loading to the Wye in perpetuity. Each option retained in the shortlist was split into two categories, onsite and offsite options, and was subject to a detailed review of available literature to determine if the option could stand up to the HRA tests.

The review of shortlisted options highlighted that within the onsite options, water efficiency measures are likely to struggle to evidence their efficacy in perpetuity, whilst SuDS that are only treating urban runoff from the development site are unlikely to be able to achieve a large enough reduction in phosphorous for a site to achieve nutrient neutrality, but could reduce the amount of reliance on offsite mitigation. Of the offsite mitigation measures, SRC has a more limited evidence base to support the magnitude of phosphorous removal that this option could achieve and there are uncertainties about the ability for SRC to operate in perpetuity, although replanting of SRC plantations may provide a solution to the in-perpetuity issues. Agricultural land abandonment, whilst likely to pass the HRA tests, suffers from issues surrounding legacy phosphorous leaching which creates uncertainties over when the land will start achieving maximum “credits” (i.e. effectiveness) and is also likely to need significant quantities of agricultural land to be abandoned at very high costs.

High efficiency PTPs that can treat phosphorous in wastewater down to very low concentrations are likely to provide a viable onsite solution to achieve nutrient neutrality, especially if combined with well-designed soakaways or wetlands to provide tertiary treatment. Within the offsite measures, wetlands are the most promising mitigation option that have a good evidence base, can deliver significant reductions in phosphorous, especially when connected to a final effluent discharge from a WwTW and should pass the in perpetuity test assuming that suitable maintenance plans are secured. Using wetlands “in catchment” or as part of SuDS design that takes runoff from a wider urban area than just the development site may also be viable options, although they may provide smaller reduction in phosphorous loading than wetlands at WwTWs as the inflows will be sporadic and likely less enriched with phosphorous than wastewater. Finally, riparian buffers have a good evidence base in terms of their ability to remove phosphorous but are harder to quantify the actual reductions in phosphorous loading that they could achieve on an annual basis. However, combining SRC and riparian buffers could provide a continual source of phosphorous removal with associated benefits to river channel and carbon emission reductions.

Based on the analysis presented in this report, the following recommendations are made:

- Wetlands at WwTWs are likely to provide the best strategic mitigation option, with the potential to offer a significant number of phosphorous “credits” to offset phosphorous from new developments.
- Consideration should be given to small wetland schemes “in catchment”, pond or linear wetland features that can be built alongside roads, that could be quick to deliver, cheap and provide a good number of “credits”.
- Deployment of FWS wetlands “in catchment” to intercept surface water runoff in areas of known high phosphorous sources could also provide good mitigation solutions whilst also providing additional habitat and amenity benefits.
- The riparian buffer and SRC hybrid option is likely to require more research, but could provide another solution to remove notable amounts of phosphorous with other additional environment benefits.
- Further research is required to truly understand the legacy phosphorous issue in the Wye catchment and the time it would take for phosphorous export to revert to background levels after the cessation of agriculture.
- More research into the potential phosphorous removal from reforestation would potentially help provide support to reforestation schemes through using developer contributions and provide wider environmental net gain.
- High efficiency PTPs provide a robust onsite engineered solution, but it is suggested that approaches with additional nature benefits should be considered where possible.

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Appendices

A1 Nutrient Neutrality Principles

The following principles have been set out by Natural England as part of an ongoing project to provide national guidance on the nutrient neutrality issue. These principles are reproduced verbatim and should be used to guide the use of mitigation measures to achieve nutrient neutrality.

Natural England states:

Where neutrality measures are needed, the purpose of these mitigation measures is to avoid impacts to the designated sites, rather than compensating for the impacts once they have occurred.

Any neutrality measures relied on in an Appropriate Assessment (AA) should:

1. Have sufficient scientific certainty at the time of the AA that the measures will deliver the required reduction to make the plan or project ‘neutral’;
2. Have sufficient practical certainty at the time of the AA that the measures will be implemented and in place at the relevant time, e.g. secured and funded for the lifetime of the development’s effects.
3. Be preventive in nature so as to avoid effects in the first place rather than offset or compensate for damage. Consideration will therefore need to be given as to (i) when the measures will come online and into effect and (ii) when the pollutants come online as the impact may be phased and take place over the lifetime of a development, rather than on day one. It may be that a range of measures may be needed to address impacts over time.
4. Not undermine the objective of restoring the site to favourable conservation status by making the ‘restore’ objective appreciably more difficult or prejudicing the fulfilment of that objective. For example, where there is only a limited pool of measures available for addressing an existing exceeded threshold and these are used to enable growth rather than bring the site into favourable condition, this may undermine the ‘restore’ objective. The key question would be whether, in fact, there is actually a limited pool of measures in the relevant circumstances.
5. Not directly use or double count measures that are already in place or must be put in place to protect, conserve, or restore the site (to meet article 6(1)(2) requirements) in order to justify new growth. For example, those measures that have been identified in a DWPP as needed to restore the site (such as wastewater treatment work upgrades that do not take account of growth) cannot also be used as mitigation for development[23].
6. Be carefully justified together with calculations of the change in the nutrient contribution before and after the development taking account of any mitigation on land outside the development. Over-estimating the existing nutrient contribution from development land or mitigation land outside the development site and/or under-estimating the nutrient contribution from the development to reduce the scale of nutrient reduction mitigation needed to meet ‘nutrient neutrality’ would not satisfy the precautionary requirements of the Habitats Regulations. The nutrient neutrality methodology for the Solent [superseded by the Herefordshire methodology, which is aligned to forthcoming national guidance] is an example of how calculations can be undertaken (Solent Nutrient Neutrality methodology and calculator) – This Solent approach can be used as a starting point for other areas but must be adapted to apply to the specific local circumstances of the area.
7. Ensure that there is no real risk that the existing land use, which may be maintained by neutrality (or betterment), undermines the conservation objective to ‘restore’ the site to favourable conservation status. This applies to the existing land use at the development site and at any off-site mitigation land. See Annex 2 for further details.

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[23] These improvements under article 6(1)(2) obligations may give context to the environmental condition of the site. At the time of AA, where these measures can be accurately and soundly established to change the baseline, Natural England considers that the impact of the plan or project can be considered against that changed baseline.

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