NUTRIENT MITIGATION OPTIONS TECHNICAL REVIEW

Guidance on phosphorus mitigation options for use in Carmarthenshire, Pembrokeshire, and Ceredigion

Report for: Carmarthenshire County Council

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Executive Summary

This document is an extended version of the original technical review for the nutrient mitigation options for Carmarthenshire County Council (CCC). This document therefore acts as a definitive nutrient mitigation report for Ceredigion Country Council (CeCC) and Pembrokeshire County Council (PCC) as well as CCC.

All three councils are facing barriers to consenting planning applications due to the implications of the Court of Justice of the European Union (CJEU) ruling known as the 'Dutch Case'[1]. In accordance with this ruling, new developments that are likely to affect European designated sites must remove or offset the additional nutrient loading caused by a development in order to comply with the Habitats Regulations[2]. By offsetting additional nutrients from new development, additional housing can be shown to be 'nutrient neutral', which in turn will show that this housing will not result in adverse effects on the site integrity of European sites within Carmarthenshire due to increased nutrient inputs.

The requirement for nutrient neutral development applies to new planning applications that may increase phosphorus (P) loading to the Afonydd Cleddau / Cleddau River Special Area of Conservation (SAC), Afon Tywi / River Tywi SAC, the Afon Teifi / River Teifi SAC and the Afon Gwy / River Wye SAC. Evidencing nutrient neutrality for P comprises calculation of a P budget, in kilograms of total phosphorus (TP) per year, using new nutrient budget calculator for the three counties. Assuming the P budget for a development demonstrates that the development will result in a net increase in P loading to the European sites of concern, the developer will need to mitigate this additional P load.

This report comprises a technical review of nutrient mitigation options for use in the three counties. A shortlist of mitigation options that may be appropriate has been identified from a longlist of potential options. The shortlisted options are:

- Private sewerage drainage fields
- Private sewerage upgrades
- Wetlands
- SuDS
- Buffer strips
- Agricultural land use change
- River channel re-naturalisation
- Terrestrial sediment Traps
- Drainage Ditch Blocking
- Engineered logjams

A review of these mitigation options was completed in order to assist key stakeholders and decision makers in selecting appropriate mitigation solutions. This review provides details on the processes and factors that affect P removal in each of the solutions. For each solution, a set of practical considerations was provided. These practicalities will impact how the solution is deployed and how effective it might be. All the solutions will require some long-term maintenance and monitoring to remain effective over their lifetime. Key considerations on maintenance and monitoring were elaborated for each solution.

The review of mitigation options has highlighted that private sewerage drainage fields, wetlands, SuDS and agricultural land use change are likely to be able to be designed in a manner that will enable predictions of how much P these solutions can remove prior to deploying them. However, it should be cautioned that agricultural land use change schemes that simply remove agriculture from production will be prohibitively costly given the relatively low amount of TP that comes from an average hectare of agricultural land use. Agroforestry (a sub-type of agricultural land use change) may provide a more viable agricultural land use change solution as it enables farmers to continue farming whilst changing how land is managed to reduce P pollution. However, predicting the scale of P reduction from agroforestry schemes is difficult and may require monitoring of a scheme to determine how much TP it can remove.

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

Buffer strips have an evidence-base that may allow for choosing a precautionary estimate of TP removal efficiency, though these solutions may also need monitoring to initially quantify the scale of TP reduction they can deliver. Terrestrial sediment traps, river channel re-naturalisation, drainage ditch blocking and engineered logjams all have an evidence-base that supports their capacity to remove P from the environment, but these solutions will need monitoring to quantify the scale of TP removal they can deliver. Furthermore, logjams should generally be seen as only a temporary measure related to TP removal.

In order to highlight how open-source datasets can be used to start targeting mitigation deployment, catchment nutrient sources were assessed, and stalled housing applications / strategic allocations were mapped and their locations compared to potential locations where certain types of mitigation scheme could be deployed. Estimates of potential reductions that a treatment wetland at a Wastewater treatment works (WwTW) could deliver were calculated using freely available data. These WwTWs were then mapped and ranked by the mitigation opportunity. This exercise showed that Llandovery WwTW, Tregaron WwTW and Letterston West WwTW appear to provide the most opportunity for a treatment wetland.

An exercise was also conducted using the Working with Natural Processes (WWNP) geospatial dataset that contains information on areas where solutions such as buffer strips, drainage ditch blocking and sediment traps can be targeted[3]. This dataset was used to highlight an approach to targeting deployment of these solutions within the three councils. This exercise highlighted how proposals for deploying these solutions could be developed.

Proposals for mitigation solutions will need to provide detailed information on how a scheme will be developed in order to provide sufficient evidence that the scheme will deliver P mitigation. A general framework has been suggested that can help to shape these proposals. It provides key areas such as feasibility assessments, design and maintenance planning that will need to be considered for the successful deployment of a mitigation solution.

Successful deployment of mitigation solutions will also require working with key delivery partners. The potential delivery partners for each type of solution have been outlined, along with the roles in delivering mitigation. It is likely that all schemes will require engagement with/by the councils, Natural Resources Wales, the Nutrient Management Board and developers. Other stakeholders like landowners / land managers, Dwr Cymru Welsh Water and environmental NGOs are likely to also have a role in delivery of specific solutions.

[3] See: WWNP Riparian Woodland Potential, available here: https://www.data.gov.uk/dataset/517b89ab-7209-4b71-b888-2af956a7a1bc/wwnp-riparian-woodland-potential, WWNP Floodplain Reconnection Potential, available here: https://www.data.gov.uk/dataset/11873c69-d971-44ce-a648-872da9be847f/wwnp-floodplain-reconnection-potential and WWNP Runoff Attenuation Features 1% AEP, available here https://www.data.gov.uk/dataset/0b21fa23-6cd9-4d9e-9299-92c7d981616e/wwnp-runoff-attenuation-features-1-aep

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GLOSSARY

Abbreviation	Definition
CCC	Carmarthenshire County Council
CC	County Council
CeCC	Ceredigion County Council
PCC	Pembrokeshire County Council
P	Phosphorus
TP	Total Phosphorus
SAC	Special Areas of Conservation
CJEU	Court of Justice of the European Union
LPA	Local Planning Authority
NRW	Natural Resources Wales
WwTW	Wastewater Treatment Works
PTP	Package Treatment Plants
ST	Septic Tank
HRA	Habitat Regulations Assessment
AA	Appropriate Assessment
LSE	Likely Significant Effects
WFD	Water Framework Directive
SuDS	Sustainable Urban Drainage Systems
HOST	Hydrology of Soil Types
MC	Management Catchment
RBD	River Basin District
WSM	Weighted sum model

1 THE REQUIREMENT FOR NUTRIENT NEUTRALITY

1.1 THE DUTCH CASE

The recent (2018) ruling in the European Court of Justice[4] referred to as 'The Dutch Case' or 'The Dutch Nitrogen Cases' resulted in a change to how the Habitat Regulations (as amended, 2017) are applied to plans or projects in the catchments of European Designated sites (hereafter, European sites) that are under pressure from pre-existing levels of nutrients.

The Dutch Case was concerned with the potential detrimental effects of nutrient loading from agricultural practices in the Netherlands on European Designated sites. However, the legal interpretation of The Dutch Case now requires local planning authorities to consider the impacts from new plans and projects that may generate additional nutrient inputs to European sites.

1.2 MEANING AND SIGNIFICANCE OF THE DUTCH CASE

Following the Dutch Case, Natural Resources Wales (NRW) issued interim planning advice in relation to new planning applications that have the potential to increase P levels in rivers that are designated as Special Areas of Conservation (SACs)[5] *and* are under pressure from elevated nutrient concentrations. This interim advice has presented a significant barrier to the councils being able to determine new planning applications.

The three councils (CCC, PCC and CeCC) administrative boundaries contain various SAC rivers and/or their catchments that are under pressure from high levels of existing nutrient input. The additional nutrient load from the increase in wastewater and/or the change in land use created by a new plan or project can create an 'impact pathway' that will exacerbate the problems related to nutrient loading that are currently seen in the SAC rivers. This impact pathway is shown diagrammatically in Figure 1-1.

The existence of this impact pathway for nutrients from a new development will result in an HRA finding 'Likely Significant Effects' on the ecology of the three counties' European sites due to increased nutrient inputs. The two key nutrients that are output by new developments are nitrogen (N) and P. The SAC rivers in the boundaries are under pressure from P.

An HRA comprises two key stages: Screening and Appropriate Assessment (AA). The Screening stage involves identifying whether a project or plan could infringe on the management objectives of a European site or significantly impact the quality of the site. Therefore, the existence of a nutrient impact pathway needs to be determined in this opening stage. The key factors to consider when assessing whether this pathway exists are:

1. Whether the development is within a catchment that drains to an affected European site.
2. Whether the receiving Wastewater Treatment Works discharges to an affected European site.
3. Whether the development will lead to an increase in 'overnight stays'.
4. Whether the development will lead to an increase in the number of people coming into the catchment of the SAC river from outside of the catchment.

If the answer is yes to either 1, or the answer is yes to 2 *and* 3 or 2 *and* 4 as outlined above, the second stage of the HRA process, an AA, will need to be completed. The first step in an AA that is applying nutrient neutrality is to understand whether a development will cause additional nutrient inputs to a European site. This requires calculation of the amount of nutrients a new residential development will create, otherwise known as a nutrient budget. Where a nutrient budget calculation shows that a development a plan or project will add additional nutrients to the European site, it will not be possible to conclude no 'Adverse Effect on Site Integrity' on the site if no mitigation is put in place. Thus, in order

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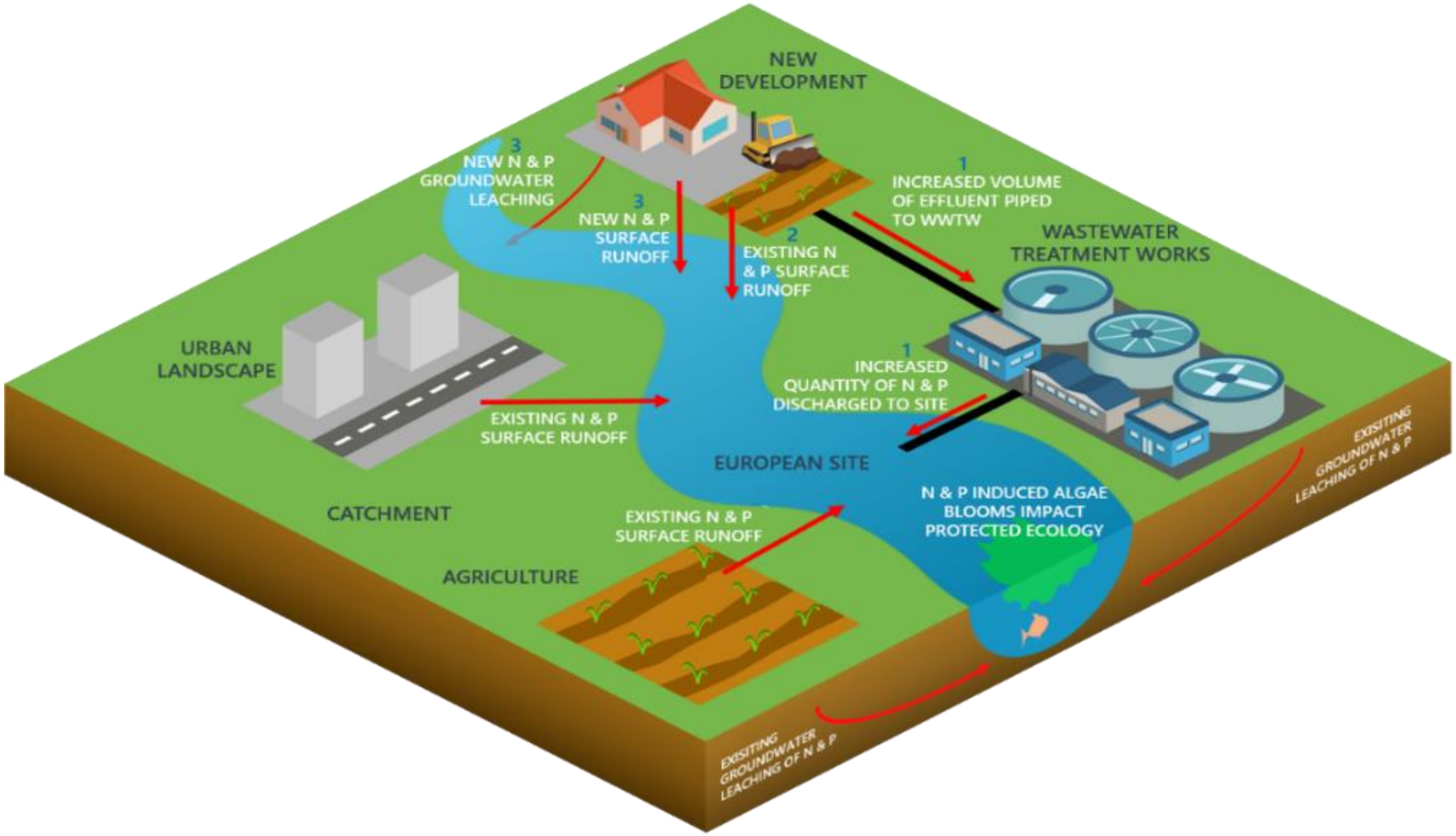
[4] Joined Cases C-293/17 and C-294/17 *Coöperatie Mobilisation for the Environment UA and Others v College van gedeputeerde staten van Limburg and Other* (the Dutch Nitrogen cases)

[5] See Natural Resources Wales (NRW) interim advice for planning applications that have the potential to increase phosphate levels in river Special Areas of Conservation (SACs), available here: https://cdn.cyfoethnaturiol.cymru/media/693022/interim-planning-advice-following-river-sac-compliance-report.pdf?mode=pad, accessed on: 17/11/2021

to conclude no ‘Adverse Effect on Site Integrity’ due to nutrient impacts, mitigation of nutrients to achieve ‘Nutrient Neutrality’ needs to be secured. The output from a nutrient budget will determine the annual amount of mitigation required to achieve Nutrient Neutrality for a plan or project.

Figure 1-1 Diagram showing potential nutrient impact pathways



1.3 EUROPEAN SITES IN CARMARTHENSHIRE, CEREDIGION, AND PEMBROKESHIRE

The Afonydd Cleddau / Cleddau Rivers SAC, Afon Tywi / River Tywi SAC, the Afon Teifi / River Teifi SAC and the Afon Gwy / River Wye SAC are European sites that are in unfavourable condition or are close to unfavourable condition due to excessive P levels. Parts of the catchments of these European sites are within the CCC, PCC and CeCC administrative boundaries. If a development is within these catchments, a P budget will need to be completed in order to consider if the developer will cause adverse effects on site integrity due to increased nutrient loading to the SAC rivers. Figure 1.2 shows the location of these sites

These rivers support a wide range of habitats and species between them, including:

- An abundance of water-crowfoots; white-flowered species which can be found as floating mats typically in the first half of summer.
- Fish species such as Brook Lamprey, Sea Lamprey, River Lamprey, Bullhead, Atlantic Salmon, Twaite Shad, and Allis Shad.
- White-clawed crayfish.
- Otters.
- Floating water plantain.

Increased levels of P entering aquatic environments via surface water and groundwater can severely threaten the sensitive habitats and species within each SAC. The elevated levels of nutrients can cause eutrophication, leading to algal blooms which disrupt normal ecosystem function and cause major changes in the aquatic community. These algal blooms can result in reduced levels of oxygen within the water, which in turn can lead to the death of many aquatic organisms including invertebrates and fish.

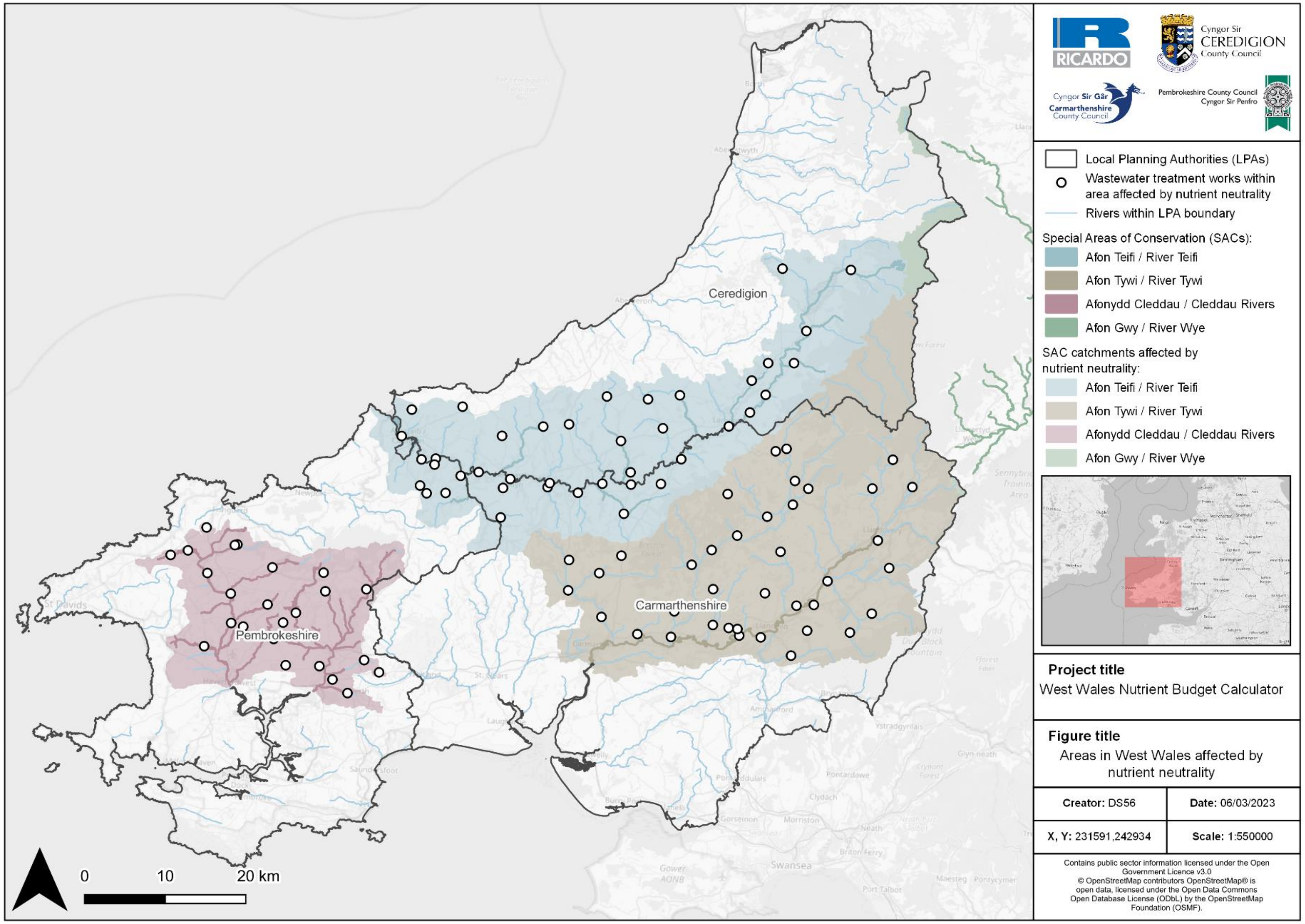
The habitats and species within these rivers that result in their respective designations as a SAC are referred to as 'qualifying features'. Not all of these qualifying features will be sensitive to changes in nutrients within these rivers. When completing an HRA involving nutrient neutrality, councils must identify and screen out qualifying features that are not sensitive to nutrients via an HRA. Developers will be asked to submit information to support this process.

More detailed information on the qualifying features of the SAC can be found in the following links:

- Afonydd Cleddau/ Cleddau Rivers[6]
- Afon Teifi/ River Teifi[7]
- Afon Tywi/ River Tywi[8]
- River Wye/ Afon Gwy[9]

[6] See Afonydd Cleddau/ Cleddau Rivers, available here: https://sac.jncc.gov.uk/site/UK0030074, accessed on: 10/02/2021.
[7] See Afon Teifi/ River Teifi, available here: https://sac.jncc.gov.uk/site/UK0012670, accessed on: 10/02/2021.
[8] See Afon Tywi/ River Tywi, available here: https://sac.jncc.gov.uk/site/UK0013010, accessed on: 10/02/2021.
[9] See River Wye/ Afon Gwy, available here: https://sac.jncc.gov.uk/site/UK0012642, accessed on: 10/10/02/2021.

Figure 1.2 A map showing the affected LPAs, the European Designated sites with nutrient issues and their catchments, and the affected WwTW



1.4 PURPOSE OF THIS DOCUMENT

This document is an updated and expanded version of the original technical review of the nutrient mitigation options for CCC to incorporate CeCC and PCC. The impact of the Dutch Case has stalled numerous planning applications across the three LPAs. Therefore, a consistent approach to implementing nutrient mitigation schemes is required. The impact for each of the three councils is highlighted as follows:

The CCC Local Development Plan (LDP)[10] has identified 15,778 units / dwellings as needed during the 2006-2021 plan period (around 1000 a year).

Note: CCC is in the process of preparing their second deposit revised LDP for a release in Autumn 2023[11]. The Housing and Economic Growth Report[12] which accompanies the new LDP provides a range of demographic predictions to estimate housing demand. The principal projection suggests 697 dwellings may be needed each year to match demand.

Based on an average of around 1 kg TP/year produced by each new dwelling (typical for a non-permit limited WwTW), and assuming this annual figure will continue after the planning period, an estimated additional **697 kg TP/year** of mitigation will be required every year in order to meet the requirement for P neutral development, if the development was located in a SAC catchment with nutrient pressures.

The CeCC LDP[13] for the 2007-2022 plan period estimated that 6544 units / dwellings will be needed during the Local Plan period (around 440 a year).

Note: the project steering group informed Ricardo that the build rates of new development have been slower than planned and that population growth estimations have changed since the initial LDP[14]. As such, it is expected that around 150 new dwellings will be constructed each year.

This equates to an additional **150 kg TP/year** of mitigation that may be required every year in order to meet the requirement for P neutral development, assuming 1 kg TP/year is produced by each new dwelling.

The PCC LDP[15] has made provision for 7300 units / dwellings for the remainder of the plan period (2011-2021). This equates to approximately 730 units per year.

Note: PCC is in the process of developing a new LDP and have informed Ricardo that building rates are lower than planned. Analysis of the delivery rate between 2013-2021 found that on average 400 new dwellings were delivered each year[16].

Following the assumptions laid out above, it is likely that an additional **400 kg TP/year** will require mitigation every year to meet the requirement for P neutral development. As such, there is an urgent requirement to identify P mitigation solutions that are appropriate for PC.

This report aims to provide a review and associated guidance on a range of mitigation measures that can be used mitigate the additional P loading that will be generated by new development for each of the three councils. A range of mitigation options have been reviewed, starting with a longlist of options. Options that clearly did not have a sufficient evidence-base or that would not be able to provide quantifiable reductions in TP loading to the councils' SAC rivers were removed from the longlist to

[10] See: Carmarthenshire Local Development Plan, available here: http://www.cartogold.co.uk/CarmarthenshireLDP/english/text/00_Contents.htm, accessed on 05/05/2022

[11] See: Local Development Plan 2018 – 2033, available here: https://www.carmarthenshire.gov.wales/home/council-services/planning/local-development-plan-2018-2033/

[12] See: Housing and Economic Growth Report, available here: https://www.carmarthenshire.gov.wales/home/council-services/planning/local-development-plan-2018-2033/development-of-an-evidence-base/

[13] See: Ceredigion Local Development Plan (LDP) Volume 1 Strategy and Policies, available here: https://www.ceredigion.gov.uk/resident/planning-building-control-and-sustainable-drainage-body-sab/planning-building-control/ceredigion-local-development-plan/adopted-ceredigion-local-development-plan-ldp/, accessed on 10/03/2023

[14] An email was sent to Ricardo on the 21/07/23 which detailed revised allocation figures compared to the original LDPs.

[15] See: Pembrokeshire Local Development Plan, available here: https://www.pembrokeshire.gov.uk/adopted-local-development-plan, accessed on 10/03/2023

[16] The average rate has been calculated without the inclusion of the delivery figures from 2019-2020 as these values were affected by the COVID-19 pandemic,

provide a shortlist of viable mitigation options. This shortlist was subjected to a more thorough review process to establish whether the evidence-base underpinning each option is sufficient to show it can provide P removal *beyond reasonable scientific doubt.*

A summary of each options mitigation potential and other key considerations is provided for each option in a succinct summary table (Section 3). A detailed review of each option in Section 4 then provides information on the processes active in each option that remove or immobilise P, the different types of each option, factors that affect the efficacy of an option, practical considerations if deploying an option and long-term maintenance and monitoring requirements. A mapping exercise was then conducted in order highlight approaches to identifying key locations where different mitigation options could be deployed (Section 5). To facilitate the development of mitigation proposals, a generic framework for developing a proposal is detailed in Section 6. In Section 7, a summary of potential mitigation delivery partners for each option is provided, with a summary of the report provided in Section 8.

2. METHODOLOGY

The sections below describe the methodology used to identify a longlist of mitigation options, and the rationale underpinning the section of a shortlist of mitigation options. The approach undertaken to complete a literature review of the shortlisted mitigation options is described. The mapping exercise used to identify locations of mitigation solutions is detailed.

2.1 INITIAL SCREENING

Initially, a longlist of potential mitigation options was compiled following a review of the P mitigation measures for the River Avon SAC (Wood, 2019), a literature review of various unpublished reports by Ricardo, and expert knowledge of nutrient mitigation measures. This longlist details an array of potential phosphorus removal mitigation options that work in theory, however many of these options are unlikely to be viable in practice within the affected areas of the 3 councils. The longlist is provided in Appendix 1 along with a brief explanation of the reason for rejection against the rejected options. Retained options were compiled into a shortlist on which to target a more detailed review. This review is summarised for each option in Section 3 with a detailed review of how each mitigation solution in Section 4.

2.2 DETAILED REVIEW

The detailed review of each mitigation option provides the rationale and evidence behind the selection of shortlisted mitigation options. Searches for academic literature were made using the Google Scholar academic search engine by entering keywords and phrases associated with the topic. Searches for grey literature used the Google search engine. Articles were initially screened by examining the relevance of the abstract, with articles with details relevant to P mitigation in their abstracts retained for a full review.

The review focussed on studies that evaluate the efficacy of a mitigation measure by providing a measure of P removal based on the change between influent TP load or concentration and effluent TP load or concentration. These studies allow for a percentage efficiency of TP removal to be determined, which can be used for estimating potential reductions. However, the effectiveness of measures is affected by a range of factors including study location and seasonality, and hence the review prioritised the inclusion of papers that had a monitoring period longer than one-year and were UK based. However, this was not always possible. Catchment management solutions are often created for reasons other than nutrient removal, such as flood risk mitigation or biodiversity enhancement, however these were still included in this review if data on nutrient removal were also reported.

There are multiple forms of phosphorus within the aquatic environment. These include dissolved forms, suspended solids, phosphorus sorbed (bound) to soil particles, phosphorus within biomass structures and phosphorus contained within the structure of soil particles (Kadlec and Wallace, 2009). For the purposes of assessing the efficacy of phosphorus removal, this review focussed on studies that reported results for total phosphorus (TP), which includes both dissolved and particulate forms of P. This aligns with the outputs from nutrient budget calculations using the West Wales nutrient budget calculator, which are also reported as a load of TP requiring mitigation.

A large variation is expected in the efficacy of nutrient mitigation solutions because of the variety of independent natural processes taking place as well as the combination effects of these processes. The main phosphorus removal processes for mitigation measures typically include:

- Sedimentation
- Plant uptake
- Sorption
- Precipitation

For a given mitigation measure, a combination of the following physical factors may affect these processes and therefore the efficacy of the measure:

- Inlet nutrient concentration

- Design of the mitigation measure
- Age of the mitigation measure
- Topography
- Vegetation characteristics (species, age, percentage cover)
- Soil characteristics (soil type, particle size, hydraulic conductivity, existing nutrient concentration)
- Geology
- Maintenance regime

The aim of this review was to provide information on the following areas:

- Process of P removal;
- Types of solution;
- P removal rate or removal efficiency; typically the results are reported quantitatively as g/m^2/year or as a percentage of the inlet load;
- Factors that affect the efficacy of a solutions ability to remove P;
- Practical considerations for location selection;
- Maintenance / management requirements.

2.3 MAPPING EXERCISE TO HIGHLIGHT APPROACHES TO LOCATING POTENTIAL MITIGATION OPTIONS

A mapping exercise using GIS was performed in order to highlight potential locations where certain types of mitigation solution could be deployed. The intention of this exercise was not to provide a detailed mapping of all the possible areas across the 3 councils where mitigation solutions could be deployed, but rather to highlight how open-source datasets can be used to help ID potential locations for further investigation.

The boundaries for each of the 3 councils were used as the study areas for the purposes of this assessment. Geospatial data were downloaded from the Welsh geodata portal[17]. The datasets used in this methodology can be seen in Appendix 2. Microsoft Excel was used for data analysis and QGIS Desktop was used for mapping and geospatial processing. A dataset of stalled applications in the administrative boundaries of CCC and PCC were mapped based on the postcode of the application.

2.3.1 Mapping potential mitigation areas

2.3.1.1 Identifying locations of mitigation options at point sources

The Consented Discharges to Controlled Waters with Conditions[18] dataset contains information on WwTW discharges in Wales. This dataset includes information such as the location of the WwTW and the conditions of the permits. Conditions typically include limits on water quality parameters and daily discharge flow volumes. This dataset was first filtered to only contain sewage disposal works and converted to CSV. One dataset was created with all combined sewage overflows (CSOs), sewage pumping stations (SPS) and private sewerage discharges removed. There are two main reasons for removing these discharges. Firstly, the loading from CSOs is highly variable and so it is very difficult to quantify the reductions achieved through treating the effluent. Private sewage TP loading is likely to be extremely low per site and so a lot of small-scale treatment solutions would be needed. It is for these reasons that the focus is on WwTWs where the mitigation potential is much larger. This condensed dataset allowed for the identification of WwTWs that could be targeted with mitigation options.

[17] See: DataMapWales, available here: https://datamap.gov.wales/, accessed on: 14/04/2023

[18] See: Consented Discharges to Controlled Waters with Conditions ,available here: https://datamap.gov.wales/layers/geonode:nrw_water_quality_permits, accessed on: 18/11/2022

The refined WwTW datasets were mapped using the national grid reference (NGR) and clipped to the catchment boundaries of the affected WFD Waterbody Catchments that drain directly to affected European sites, or to tributaries which eventually drain to European sites. The list of these WFD waterbodies can be viewed in the accompanying Nutrient Budget Calculator Guidance Document[19]. See Figure 1.2 for the WwTW locations. The daily dry weather flow maximum limits[20] for the WwTW within the affected areas were used to estimate the total annual phosphorus loading. Multiplying the dry weather flow maximum limit by the permitted TP limit or the default TP concentration of the final effluent (8 mg/l) and the number of days in a year produced an estimate of the total annual TP loading. DCWW is working with NRW to update the P permits for some WwTW within the study region. DCWW has published a list of proposed P permits at these works[21]. As such, if the proposed permit is lower than the current permit or default value, these lower values are used to calculate the total annual P loading from a WwTW. This data was then used to target a shortlist of WwTWs with high TP loadings that would produce the biggest TP reductions with a mitigation solution in place.

A weighted sum model (WSM) was developed in order to determine the optimal WwTW to implement a point source mitigation solution. Initially, the estimated TP load was ranked in ascending order per SAC catchment. For Pembrokeshire, the Afon Cleddau SAC was split into two, the Eastern Cleddau and the Western Cleddau. The relative position of the WFD waterbody catchment that the WwTW is situated within was quantified by calculating and ranking the distance of the catchment from the mouth of the SAC and ranking (in descending order) the cumulative area. This was completed in order to highlight key areas in the upper catchment as the benefit from nutrient mitigation in these areas propagates downstream, thus unlocking development. A source apportionment dataset was used to identify the cumulative areas of the WFD waterbody catchments[22]. A weighted sum of the TP load and position in the catchment was completed and the outputs ranked in order to highlight WwTW to target.

2.3.1.2 Fish Farms

Fish farms have significant potential for TP mitigation through taking a farm out of aquacultural production. A search of fish farms was completed using the Welsh discharge consents register, as most fish farms require consents to discharge to rivers. This search returned one fish farm with a daily flow permit that drains to one of the SACs - Lyn y Fan Trout Hatchery Llangadog (4800 m^3 a day flow permit).

2.3.1.3 Private sewerage upgrades

The Welsh consented discharges register was used to identify and map the private sewerage systems within the SAC catchment with nutrient issues. The permitted daily flow limits and permit dates were extracted to assess potential systems to target.

2.3.1.4 Diffuse Mitigation solutions

JBA Consulting have produced a dataset titled Working With Natural Processed (WWNP) that has mapped the opportunity locations for different natural flood management (NFM) techniques[23]. Some of these NFM techniques may also provide benefits for TP removal, such riparian buffers and runoff attenuation features that can trap sediment. The WWNP dataset shows locations of high surface water runoff accumulation across the land surface. These locations of flow accumulation show areas within catchments where it may be possible to temporarily store water during rainfall events using runoff attenuation features. These data were used to map and identify possible locations for runoff attenuation features in Carmarthenshire that can be used for slowing surface water flow pathways and thus

[19] See: Original Carmarthenshire Nutrient Budget Calculator Guidance, available here: https://www.carmarthenshire.gov.wales/media/1227826/nutrient-budget-calculator-guidance-document-updated.pdf

[20] The dry weather flow maximum limit is the total volume of water that can be legally discharged in dry weather conditions.

[21] See the DCWW Phosphorus Programme List, available here: https://corporate.dwrcymru.com/en/community/environment/river-water-quality/sac-rivers#:~:text=To%20understand%20Dwr%20Cymru%E2%80%99s%20contribution%20to%20the%20phosphorus,known%20as%20SAGIS%20(Source%20Apportionment%20Geographical%20Information%20System). (published 27/02/23).

[22] See: Source apportionment of annual nutrient and sediment loads to rivers in England and Wales, from the SEPARATE framework, available here: https://www.data.gov.uk/dataset/3e698568-8492-4dfd-aa11-3439d77cd71a/source-apportionment-of-annual-nutrient-and-sediment-loads-to-rivers-in-england-and-wales-from-the-separate-framework

[23] See: WWNP Runoff Attenuation Features 1% AEP - Wales, available here: http://lle.gov.wales/catalogue/item/WWNPRunoffAttenuationFeatures1/?lang=en, accessed on: 01/02/2022

retaining P, using features like wetlands, detention ponds and silt traps that promote sediment deposition. A dataset that identifies areas of potential riparian woodland planting[24] was used to highlight areas next to rivers that are not currently wooded but have the potential to be turned into riparian buffers.

The WWNP datasets have been used to highlight target areas suitable for deploying certain types of catchment management solutions for TP removal. In this report these are:

a) Areas suitable for riparian buffer planting as shown by the Riparian woodland planting opportunity areas in the WWNP data
b) Areas where runoff attenuation features could be deployed, as these show areas in the landscape where surface water flows accumulate and so could be good target locations for deploying measures that help to trap sediment.

A WSM was developed to target WFD waterbody catchments with a large opportunity for both riparian woodland planting and runoff attenuation features. Initially, a source apportionment dataset[22] was used to map and rank the total agricultural TP load per WFD waterbody catchment. Additionally, average export coefficients for TP were calculated using the source apportionment data and the area of agricultural land within each waterbody and subsequently mapped. The position of the waterbody catchment within the larger SAC was quantified and ranked using the approach outlined in Section 2.3.1.1. The area of riparian woodland planting opportunities was calculated and ranked at the WFD waterbody catchment scale. A weighted sum of the agricultural TP load, waterbody catchment position, and the area of riparian woodland opportunities was calculated, and the outputs ranked.

2.3.1.5 Mapping stalled planning applications and housing allocations to target areas needing mitigation solutions

CCC and PCC provided a database of planning applications that are currently stalled in the planning process. These datasets contain information on the type of planning application, the status of an application and the cause of barriers to the application being consented. Locations were mapped of housing developments that were stalled because of P only and ones that were stalled but not with P as the main cause. These development sites were mapped using the postcode of the application. The CeCC housing allocation areas were identified in the LDP and mapped as points. These datasets provide a visual representation of proposal and plans to assist with mitigation planning.

[24] See: WWNP Riparian Woodland Potential – Wales, available here: https://lle.gov.wales/catalogue/item/WWNPRiparianWoodlandPotentialWales/?lang=en, accessed on: 10/02/2022

3. MITIGATION OPTION GUIDANCE SUMMARIES

The sections below provide summaries of the shortlisted mitigation solutions. Each solution has a set of descriptors that provide high-level information on key aspects of each solution that should be considered when determining if the solution will be deployed. The shortlisted mitigation solutions are as follows:

- Private sewerage drainage fields
- Private sewerage upgrades
- Wetlands
- SuDS
- Buffer strips
- Agricultural land use change
- River channel re-naturalisation
- Terrestrial sediment Traps
- Drainage Ditch Blocking
- Engineered logjams

For each of these options, a detailed review of the theory behind how they function as a P mitigation solution is provided in Section 4. The tables in the following sub-sections contain summary information for each the mitigation solution. These tables contain a brief summary description of the mitigation option, its maintenance requirements and the additional benefits that an option may provide. Additional benefits may include NFM, biodiversity enhancement, amenity value, carbon sequestration and additional pollutant removal amongst others.

Further detail on each mitigation option is provided based on a qualitative scoring system under the following categories:

Development scale provides an indication of the size of a development that a mitigation option may feasibly be able to serve. The small category would be the equivalent to a minor development. The medium and large categories would be the equivalent to a major development[25], but they split to provide more detailed classifications:

- Small – 0-9 dwellings/units or <0.5 ha
- Medium – 10-99 dwellings/units or 0.5-2 hectares.
- Large – 100+ dwellings / units or 2 hectares.

Spatial scale considers the area that is likely to be needed to deploy the solution. The categories 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.

P removal efficiency indicates the potential amount of TP that a well-designed application of the mitigation solution should be able to remove. This is described as percentage reduction of the TP that enters the solution. If a solution can achieve high percentage reduction in TP, it still needs a high TP load to enter the mitigation system in order to provide a large amount of P mitigation. The categories are defined as:

- Low – <33%
- Medium – 33-67%

[25] See: Pre-application Community Consultation: Best Practice Guidance for Developers, available here: https://gov.wales/planning-major-developments-guidance-pre-application-consultation, accessed on: 05/04/2022

- High – 67-100%

Longevity considers the timescale over which a mitigation measure will continue to function effectively without requiring maintenance. The categories are defined as:

- Low – <10 years
- Medium – 10-50 years
- High – 50+ years

Certainty describes how predictable the reductions in TP that a mitigation solution can deliver are. The categories are defined as:

- Low – Unpredictable
- Medium – Some uncertainty
- High – Predictable performance

3.1 PRIVATE SEWERAGE WITH DRAINAGE FIELD

Key option considerations	
Summary description of option	• The effluent of a private sewerage system, such as a package treatment works (PTP), is diverted to a drainage field. A drainage field is a network of discharge pipes laid in trenches under the ground surface so that effluent can be discharged to the ground. • The percolation of effluent through the soil immobilises any sediment bound P, and the soluble P is bound to soils and sediment.
Maintenance requirements	• Interannual/annual servicing • Interannual/annual desludging of sewerage treatment system • Chemical dosing (if applicable) • Monthly checks of drainage field for water logging
Potential additional benefits	• No additional environmental benefits
Development scale	• All development sizes
Spatial scale	• Small / medium
P removal efficiency	• High
Longevity	• Low
Certainty	• High

3.2 PRIVATE SEWERAGE UPGRADES

Key option considerations	
Summary description of option	• Aging private sewerage systems, such as a PTP or a septic tank, is replaced with a modern private sewerage system with certified TP removal rates.
Maintenance requirements	• Interannual/annual servicing • Interannual/annual desludging of sewerage treatment system • Chemical dosing (if applicable) • Monthly checks of drainage field for water logging
Potential additional benefits	• No additional environmental benefits
Development scale	• All development sizes
Spatial scale	• Small / medium
P removal efficiency	• High
Longevity	• Low
Certainty	• High

3.3 WETLANDS

Key option considerations	
Summary description of option	• Wastewater, surface runoff or streamflow is discharged to a constrained area that is saturated or permanently inundated. • Sediment-bound P is deposited within the wetland and soluble P is adsorbed onto the surface of soils particles. • Plant roots uptake P and incorporate it within their structure.
Maintenance requirements	• Desilting/desludging every 10 years (timescales dependent on wetland type, design and management practices). • Seasonal trimming and removal of vegetation. • Annual visual inspections • Monitoring of inlet water quality and outlet water quality is recommended. • Replacement of bed material that is saturated with P (if using an artificial bed material is used for the purposes of removing P),
Potential additional benefits	• Subsurface flow wetlands (See Section 4.5) can provide carbon sequestration and additional pollutant removal. • More natural wetlands with an open body of water can provide NFM, biodiversity enhancement, amenity value, carbon sequestration, and additional pollutant removal.
Development scale	• Medium / large
Spatial scale	• Small / medium
P removal efficiency	• Medium
Longevity	• High
Certainty	• High

3.4 SUDS

Key option considerations	
Summary description of option	• SuDS is a general term for a variety of different mitigation measures that capture urban runoff and mimic natural drainage processes in urban environments. • SuDS reduce flow velocities and facilitate infiltration and bio-filtration. Sediment-bound P can be deposited at low flow velocities. • Soluble P is adsorbed onto the surface of soils particles when water infiltrates or is bio-filtered. • Plant roots uptake P and incorporate it within their structure.
Maintenance requirements	• Certain SuDS features may need desilting. • Seasonal trimming and removal of vegetation. • Monthly/seasonal litter and debris removal. • Annual visual inspections • Monitoring of inlet water quality and outlet water quality is recommended.
Potential additional benefits	• NFM, biodiversity enhancement, amenity value, carbon sequestration and additional pollutant removal.
Development scale	• All sizes
Spatial scale	• Small / medium
P removal efficiency	• High
Longevity	• High
Certainty	• Medium

3.5 BUFFER STRIPS

Key option considerations	
Summary description of option	• Thin, vegetated land parcels that intercept surface runoff and sub-surface flow pathways. • Sediment-bound P is deposited as surface flow velocities are reduced. • Soluble P is adsorbed onto the surface of soils particles. • Plant roots uptake P and incorporate it within their structure.
Maintenance requirements	• Vegetation management (review annually).
Potential additional benefits	• NFM, biodiversity enhancement, carbon sequestration and additional pollutant removal.
Development scale	• Small / medium
Spatial scale	• Medium
P removal efficiency	• Medium
Longevity	• High
Certainty	• Medium

3.6 AGRICULTURAL LAND USE CHANGE

Key option considerations	
Summary description of option	• Agricultural land use change can comprise agroforestry (silvopasture), short rotation coppice (SRC), converting agricultural land to woodland, or a switch to less intensive farming practices. • The aim of this measure is to reduce the P inputs to agricultural land and reduce mobilisation of sediment through more natural land management systems or growing and harvesting specific plants and trees to remove P stored in soil.
Maintenance requirements	• Seasonal/interannual vegetation management • Harvesting of plants/trees, if appropriate.
Potential additional benefits	• NFM, biodiversity enhancement, amenity value, carbon sequestration and additional pollutant removal.
Development scale	• Small / medium
Spatial scale	• Large
P removal efficiency	• Low
Longevity	• High
Certainty	• High

3.7 RIVER CHANNEL RE-NATURALISATION

Key option considerations	
Summary description of option	• The aim of river restoration is to return river reaches to a more natural state. This can facilitate natural processes that remove nutrients from river water. • River restoration techniques are varied and may involve reconnection of a river to the floodplain, re-meandering a channelised section, creating berms and riffle-pool systems and riparian vegetation planting. • These techniques promote processes that remove P from river water by increasing sediment deposition and increasing the contact time of water with riverbed and bank sediments that can in turn remove dissolved P.
Maintenance requirements	• Adaptive management regime depending on location and degree of re-naturalisation.
Potential additional benefits	• NFM, biodiversity enhancement, amenity value, carbon sequestration and additional pollutant removal.
Development scale	• Medium
Spatial scale	• Medium
P removal efficiency	• Variable – dependent on design and available P in river water
Longevity	• High
Certainty	• Low

3.8 DRAINAGE DITCH BLOCKING

Key option considerations	
Summary description of option	• This involves blocking drainage ditches, typically in agricultural environments, by creating an impermeable dam (or similar) which disrupts flow and raises the water table level. • Sediment-bound P is immobilised and sorption of dissolved P can increase. • Increased plant uptake of P
Maintenance requirements	• Low maintenance, mainly requiring visual inspection and likely low frequency repairs if a scheme is well designed.
Additional benefits	• NFM, biodiversity enhancement, additional pollutant removal.
Development scale	• Small / medium
Spatial scale	• Small
P removal performance	• Low
Longevity	• High
Certainty	• Low

3.9 ENGINEERED LOGJAMS

Key option considerations	
Summary description of option	• Temporary solution comprising leaky dams made of logs, branches and woody debris are constructed in order to simulate a natural logjam or beaver dam. • This can slow flows and help to re-naturalise a river reach. • P removal is enhanced through sediment deposition and P adsorption to sub-surface sediments.
Maintenance requirements	• Well-designed schemes will need little maintenance and may self-stabilise and reinforce themselves over short lifetime. Adaptive management needed in case repairs are needed.
Additional benefits	• NFM, biodiversity enhancement, carbon sequestration and additional pollutant removal.
Development scale	• Small / medium
Spatial scale	• Small / medium
P removal performance	• Low – P can become remobilised following the breakdown of a logjam
Longevity	• Low
Certainty	• Low

3.10 TERRESTRIAL SEDIMENT TRAPS

Key option considerations	
Summary description of option	• Temporary or permanent barriers made of geotextiles or other permeable materials that allow water through but trap sediment. • Temporary detention ponds that capture runoff and trap sediment in the process • Typically, the sediment source is from diffuse agricultural sources. • Sediment-bound P is immobilised.
Maintenance requirements	• Sediment fences require little maintenance if left to be buried by accumulated sediment. • For continued functionality, sediment can be removed once the fence is buried
Potential additional benefits	• Additional pollutant removal
Development scale	• Medium
Spatial scale	• Small
P removal efficiency	• Medium
Longevity	• Low / medium
Certainty	• Low

4. DETAILED REVIEW OF MITIGATION OPTIONS

The following sub-sections provide a detailed review of each of the shortlisted mitigation options summarised in Section 3. This review provides details on the process of TP removal active in a given mitigation option. The types of a mitigation solution where different types are available. Factors that impact the efficacy of solution. Practical considerations for each solution and any long-term maintenance requirements.

4.1 PRIVATE SEWERAGE WITH FIELD DRAINAGE

4.1.1 Process of removal

The process of removal in a private sewerage system is dependent on the type used. Both STs and PTPs are not typically designed for P removal, though there is generally some incidental reduction in P. The main process of P removal is the settlement of organic matter via gravity as solid waste is settled out within the system. If chemical dosing is used in a PTP, chemical precipitation of P will be the main removal process.

The effluent from a PTP or ST can be discharged to a field drainage system. The private treatment system discharges treated effluent via a network of perforated pipes laid underground. The pipes are laid in specialised backfilled trenches (equivalent to soakaways). The effluent discharges slowly and percolates through the soils. P is subsequently adsorbed to sediments and soils. However, drainage fields eventually become saturated with P and cease to function effectively or potentially become a source of P to the environment (May, et al., 2015).

4.1.2 Types of private sewerage drainage field systems

Drainage field systems have to adhere to the Building Regulations 2010 Drainage and Waste Disposal Part H (rules and regulations begin in section 1.26)[26]. The material used to backfill drainage field trenches where pipes are laid can be selected for maximum P removal. Instead of discharging the effluent straight to local soils, a filter material can be used with high P sorption capacity (the ability of a material to bind with P). Previously, a study using a filter media called Polonite (with grains of 2-5 mm diameter) observed a 90% TP reduction over a two-year monitoring period (Renman and Renman, 2010). A review of various filter materials found gravels, sands and soils generally have a low sorption capacity (< 0.5 grams of TP per kg), whereas fine (< 1 mm) blast furnace slag, fly ash, and Polonite have high phosphorous sorption capacities (over 1 gram of TP per kg) (Cucarella & Renman, 2009). Assuming a single development needs to mitigate 1 kg TP/year. A tonne of filter material with high sorption capacities may be needed for one year of TP mitigation. Lightweight expanded clay aggregates (LWAs) are another potential filter material with a high P sorption capacity and a potential to be recycled. A study of nine private sewerage systems discharging to drainage fields comprising Filtralite™ (an LWA) reported removal capacities of 7.5 grams P/kg (Jenssen et al, 2010).

Treated effluent from private sewerage systems can also be diverted through a wetland to remove P. A previous study of a swale drainage system recorded phosphorus reductions of 98.4% (18 to 0.28 TP mg/l) (Abrahams, et al., 2017). However, a wetland system is likely to be more costly than a drainage field and require more maintenance for the same P removal performance.

4.1.3 Factors affecting efficacy

The TP removal performance of both STs and PTPs is very uncertain due to the different manufacturers, types of systems, sizes, population served, treatment processes, and maintenance regimes. P loads from STs are typically higher than from PTPs (May, et al., 2015; Lowe, et al., 2007). The assumed average TP concentration from a PTP is 9.7 mg/l (after May & Woods, 2016). However, a manufacturer may specify a lower concentration of TP in the final effluent. It is important to choose a system that has

[26] See: Part H: drainage and waste disposal, available here: https://gov.wales/building-regulations-approved-documents, accessed on: 06/06/2022

been designed for additional P removal in order lessen the additional amount of P removal required from a drainage field. The amount of settled organic matter (sludge) in a private sewerage system be affect its performance. Therefore, desludging the system according to the manufacturers specification is crucial to maintain functionality.

The drainage field performance is strongly affected by the soil type. A study of 24 septic systems in Canada recorded average phosphorus retention of 97% at sites located on non-calcareous sediments and 69% at sites where the sediments were calcareous (Robertson, 2019). Soils with a high sorption capacity will perform better. Once the sorption capacity is reached the P begins to spread further into unsaturated soils. Soils and filter material will eventually become saturated with P, leading to a migratory effluent plume. An effluent plume originating from a septic tank was recorded moving towards a water body at one-metre per year (Robertson, 2008).

Hydraulic conductivity refers to a soil's ability to drain water. Soils with low hydraulic conductivity is at risk of becoming saturated faster, which can result in overland flow of sewage effluent that has not had sufficient subsurface time to undergo P removal. Hydraulic conductivity decreases with decreasing soil particle size, i.e. sandy soils have higher hydraulic conductivity than clay soils, though conversely the P sorption potential of soils tends to increase as particle size decreases. Soil saturation can also occur if the distribution pipes become blocked by oils, fats and food waste. Therefore, it is important to regularly check that the drainage field is functioning correctly.

The age of the private sewerage system and the drainage field can affect performance. Depending on the material used, the system may begin to deteriorate over time and leak untreated effluent with plastic, fibre glass, and concrete lasting longer than steel (May et al, 2015). Increased usage of the drainage field with time can result in the soils or filter materials sorption capacity being reached. Materials with a higher sorption capacity than the local soils can be used as discussed above. However, these materials will also have a finite P sorption capacity and will therefore decrease in efficacy over time.

4.1.4 Practical considerations

A drainage field's soil composition and drainage characteristics should be well understood. The water table must not come within 2 metres of the ground surface at any time. The topography of the site should be considered as drainage fields should comprise a network of perforated pipes laid in a uniform gradient (trenches should not be steeper than 1:200). The full design specifics of a drainage field can be seen in The Building Regulations 2010 Drainage and Waste Disposal Part H[26]. This document states a drainage field must be at least 10 m from any watercourse or permeable drain, 50 m from boreholes or abstraction points, 15 m from buildings, sufficient distance from other drainage fields, and not in a Zone 1 groundwater protection zone. Considering, the ability for an effluent plume to migrate towards a watercourse (Roberston, 2008; May et al, 2015), the potential for P pollution would be reduced by locating the field even further from a watercourse than 10 m.

The regulations also state that the drainage field should be downslope of groundwater sources, away from water supply pipes and away from any roads or paved surfaces. The design and construction of a drainage field should ensure that the pipe perforations discharge effluent into soils under aerobic conditions. An inspection or a sample chamber should be installed between the septic tank and the drainage field.

The size of a drainage field can be estimated using the following equation:

$$At = p * Vp * 0.25$$

Where:

At = area of drainage files in square-metres

P = number of persons served

Vp = Percolation value

The percolation value is calculated from the results of a percolation test. Suitable values are in the region of 12-100 [26]. Therefore, for single household, with an average occupancy rate of 2.3 the drainage field size would need to be between 6.9 and 57.5 m^2, depending on the hydraulic conductivity.

4.1.5 Long term maintenance and monitoring requirements

Desludging of the private sewerage system to the manufacturers specification is essential. Monitoring of the drainage field influent is recommended to understand how effective the private sewerage system is, and to make assumptions about the TP loading to the drainage field. Monthly checks of the drainage field water level is recommended in order to spot potential issues with the system becoming saturated. Servicing is needed if a problem is encountered such as pipe blockages. Soil samples prior to implementation and annually post-implementation would provide information about the soil P dynamics. If a filter material with a high P sorption capacity is being used, this material should be replaced once its P saturation limit is reached. Checking when a filter material has reached its saturation limit will require testing of the material. The waste products of these systems are likely to either be treated as sewage sludge or controlled waste, both of which have specific disposal requirements.

The lifecycle of STs and PTP are estimated to be between 10-40 years. Systems over 30 years old are 12 times more likely to cause water pollution issues than systems less than 10 years old (May et al, 2015). This figure is highly dependent on the materials used, the manufacturer guidelines, and the maintenance regime. A drainage field is assumed to have a 10 to 20-year lifespan. Assuming the private sewerage system and a drainage field would last 20 years, it may be necessary to replace and relocate a drainage field at least four times during the lifetime of a development to ensure P removal in perpetuity.

In order to provide a precautionary management plan, a lifespan towards the lower end of the range of drainage field lifespans should be assumed. However, monitoring can demonstrate that the systems lifespan has not been reached. The concentration of TP in the influent and effluent should be assessed at least annually to ensure the private sewerage system is treating the wastewater to the desired standard. Monitoring of the drainage field will involve taking soil samples before and after the construction of the drainage field and analysing the samples for the TP load held within the soil. Sample analysis will need to be conducted in a manner that can ascertain whether the soil has reached sorption capacity. Understanding the drainage fields sorption capacity will indicate how far the drainage field is through its lifespan. Should the soil P continue to increase at a steady rate, it is unlikely the soils sorption capacity has been reached. A detailed sampling strategy will be required to produce an accurate assessment of whether a drainage field has reached sorption capacity.

4.2 PRIVATE SEWERAGE UPGRADES

4.2.1 Process of removal

The process of removal in a private sewerage system is dependent on the type used. Both STs and PTPs are not typically designed for P removal, though there is generally some incidental reduction in P. The main process of P removal is the settlement of organic matter via gravity as solid waste is settled out within the system. If chemical dosing is used in a PTP, chemical precipitation of P will be the main removal process.

4.2.2 Types of private sewerage upgrades

Private sewerage upgrades involve upgrading existing STs or PTPs. This upgrade process will involve either installing new nutrient removal technology or improving existing nutrient removal technology at existing PTPs or STs.

4.2.3 Factors affecting efficacy

The P removal performance of both STs and PTPs is very uncertain due to the different manufacturers, types of systems, sizes, population served, treatment processes, and maintenance regimes. TP loads from STs are typically higher than from PTPs (May, et al., 2015; Lowe, et al., 2007). The assumed average TP concentration from a PTP is 9.7 mg/l (after May & Woods, 2016). However, a manufacturer may specify a lower concentration of TP in the final effluent. For example, all of the BioKube products, which vary in sizes from 5-10000 population equivalent (PE, can produce effluent with < 1.2 mg TP/litre according to their own research[27]. Moreover, some PTP manufacturers claim effluent TP concentrations of <1 mg TP/l. For example, some of the GRAF UK products claim the final effluent has been tested to be 0.4 mg TP/l[28].

It is important to choose a system that has been designed for additional P removal in order lessen the additional amount of P removal required from a drainage field. The amount of settled organic matter (sludge) in a private sewerage system be affect its performance. Therefore, desludging the system according to the manufacturers specification is crucial to maintain functionality.

4.2.4 Practical considerations

The type of system and nutrient removal technology being used to replace a treatment system should be well understood. This will impact the discharge quality of the effluent, specifically the TP load discharged from the system. A strong understanding of effluent TP loads will help to interpret whether a drainage field would be well placed at the discharge site to provide further nutrient mitigation. There is a positive correlation between the mitigation capacity of a drainage field and the discharge concentration of TP from a private sewerage system. A drainage field is therefore best placed at the discharge site of a PTP/ST with high effluent TP concentrations.

If upgrading a chemical PTP, aluminium treatment should not be used due to the likelihood of detrimental impacts on the surrounding environment. Where other chemicals are used instead, correct dosing at all times in perpetuity must be carried out with no ecological impact on the environment.

If upgrading a biological PTP, it must be ensured the residents in dwellings linking to the private sewerage system being upgraded are not using chemicals or detergents which have the potential to negatively impact treatment. The nutrient removal technology in place must be well understood to ensure that the expected nutrient removal efficacy is maintained.

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[27] See: Cleaning results for al 3800 BioKube systems in Denmark, January 2021, available from: https://www.biokube.com/download/biokube-technical-library/, accessed on: 06/04/2023

[28] See: Catalogue Wastewater Treatment Solutions, available here: https://www.graf.info/en/wastewater-treatment.html, accessed on: 06/04/2023

4.2.5 Long term maintenance and monitoring requirements

Regular servicing, monitoring, and maintenance of upgraded private sewerage systems is essential. The specific requirements to meet these needs will vary from scheme to scheme depending on the system and nutrient removal technology employed. Regardless of the system specifications, regular checks and sampling is essential to ensure that the expected nutrient removal capacity is maintained. See Section 4.1.5 for more detailed information on the management, maintenance and monitoring requirements of private sewerage systems.

4.3 AGRICULTURAL LAND USE CHANGE

4.3.1 Process of removal

Agricultural land use change can either involve the cessation of agricultural practices on previously agricultural land or a change to the way agricultural land is managed while still remaining in agriculture. Cessation of agriculture removes the main inputs of P (fertiliser and animal waste) into agricultural land. This removal of P inputs is the main process that provides a reduction in P loading to the environment and it is relatively easy to evidence the scale of P reduction through the use of agricultural export coefficients like those utilised in the Carmarthenshire Nutrient Budget Calculator. Where agriculture is ceased and previous agricultural land is allowed to rewild or is planted with woodland, vegetation communities will generally return to a more natural state.

This has the added benefit of supporting the removal of TP from surface and sub-surface flow pathways that may be intercepted by the rewilded / woodland planted land area through a reduction in soil erosion and an increase in the uptake of P by vegetation. It should be noted, however, that currently quantifying this additional benefit is difficult as there is a need to determine influent and effluent TP load to a rewilded area before and after rewilding in order to determine the change caused by the change in vegetation.

Agroforestry can be described as a farming system where trees are planted within the areas used for arable food or livestock production. Agroforestry is often differentiated from silvo-pasture (the combination of livestock pastures with trees) and silvo-arable farming (the combining of arable agriculture with trees). These farming styles are designed to optimise the benefits from natural biological interactions within a farmed landscape (Briggs, 2012), which include TP removal. The key difference between standard agricultural land and agroforestry is the presence of phreatophytic (deep routed) trees that can access previously inaccessible nutrients. Uptake of nutrients by vegetation is therefore a key mechanism by which P is removed from the soil system in land managed as agroforestry. P losses are also reduced through a reduction in soil erosion as trees slow the flow of surface water runoff and increase soil infiltration rates, which in turn reduces losses of P from land managed as agroforestry when compared with traditional agriculture.

4.3.2 Types of agricultural land use change

As described above, the two main types of agricultural land use change for P removal are cessation of agriculture followed by rewilding or woodland planting, and agroforestry. Agroforestry can be further differentiated to systems in which trees are incorporated into a farming system producing livestock or arable crops but without seeking to harvest products from the trees, or systems where the trees are the main source of a harvestable product. Short-rotation coppice (SRC) is an example of an agroforestry system that involves growing trees in order to harvest energy crops such as poplar and willow. These crops have been reported to remove up to 15.8 kg TP per 10 oven dry tonnes per hectare per year (Potter, 1999).

4.3.3 Factors affecting efficacy

Where agriculture is being ceased and the main process of P removal is stopping input of P from agricultural practices, the main factor affecting the efficacy of a mitigation scheme will be the intensity of P inputs from current agricultural land use. More intense agricultural systems will have higher P inputs and thus potentially better targets for the cessation of agriculture. Where agricultural land use change involves a move to agroforestry, the most important factor is the plant tree species used and the time taken to become established. An endemic mixture of plants and trees should be grown with deep rooted trees that can utilise the nutrients in the permanently saturated phreatic zone. Trees that grow faster will also remove and store nutrients more quickly than slower growing trees. A tree density of 80 - 120 trees/ha is recommended as the best bio-physical density for crop and tree growth, whilst no industry standard recommendation has been made regarding nutrient removal (Briggs, 2012).

Table 4-1 outlines the percentage removal efficiencies extracted from literature for agroforestry. The values included are those that were retained following removal of studies that had monitored agroforestry sites for less than a year, did not account for seasonality, and did not have repeatable methods. The resultant information provided in the table provides an overview of the range of percentages that potential schemes can expect to achieve.

Table 4-1 Percentage removal efficiencies as extracted from literature

% TP removal efficiency	Number of study sites	References
4.95	3	(Zhang, et al., 2007)
71.94	3	(Xia, et al., 2013)

4.3.4 Practical considerations

Any agricultural land use change mitigation scheme should target the farm types with the highest TP export coefficients. Farmscoper modelling outputs in the West Wales Nutrient Budget Calculator can be used to guide which farm types have the highest TP export. However, a more accurate assessment using a field-scale Farmscoper modelling exercise would help to fully understand the scale of TP reductions that could be achieved.

Historic application of animal excretions, manure and fertiliser can result in store of P building up in soils (referred to as 'legacy P') that can continue to be released for a period of time. The lag time for the legacy P store to return to background levels is uncertain and highly variable. Various studies have reported that it could take between 7-44 years for legacy soil TP concentrations to reduce to background levels (McCollum, 1991; Schulte et al., 2010; Dodd et al., 2012). As such, calculations of TP loading reductions from agricultural land use change schemes should account for legacy P by assuming a lag time of 20 years, unless monitoring can prove otherwise. Soil erosion reduction techniques, such as sediment fences or bunds, cover crops and drainage ditch blocking can be implemented to reduce this lag time, though monitoring would likely be required as evidence that these techniques are effective.

According to the Agricultural small area statistics for 2019, there is approximately 218,159, 171,821 and 147,264 hectares of farmed land in Carmarthenshire, Ceredigion and Pembrokeshire, respectively. However, taking agricultural land out of production may prove to be a costly P mitigation option. A search of farm prices in Carmarthenshire suggests grassland is likely to cost over £10,000 per hectare. The TP export coefficients used in the West Wales Nutrient Budget Calculator suggest that livestock farming on grassland has a TP export of between 0.15-2.69, 0.08-2.64, and 0.10-2.77 kg TP/ha within the administrative boundaries of CCC, CeCC and PCC, respectively (depending on rainfall and the drainage). This highlights the potential high costs of generating P mitigation through the cessation of agriculture.

4.3.5 Long-term maintenance and monitoring requirements

For schemes that are just stopping agricultural production, it would be beneficial to support early vegetation establishment that will help to evidence that the land is no longer being farmed. Planting woodland or other vegetation communities that are not compatible with farming can provide an easy means to show that formerly agricultural land is no longer being farmed and thus the P mitigation has been secured. Depending on whether the agricultural cessation schemes are being managed to return land to a specific semi-natural habitat type or simply to allow it to rewild naturally will determine whether or not more active long-term maintenance is required. Agroforestry systems may require greater maintenance and management which will be performed as part of the management of an agricultural system. It may be appropriate to implement an adaptive management plan that is more rigorous initially to target the removal of invasive species with the aim of quickly depleting the legacy P reserves.

Baseline values representative of the nutrient input from current agricultural land uses are needed to determine the efficacy of the solution once the scheme is in place. These values could be determined through monitoring, which should take place for a minimum of a year with monthly measurements taken to calculate the influent and effluent nutrient loads from the system prior to any land use change. Models of agricultural diffuse pollution that generate export coefficients could also be used to determine the TP output from an agricultural site prior to land use change. If a precautionary nutrient removal percentage is established with NRW prior to implementing the scheme, monitoring will likely be required to check compliance. If no percentage is chosen in advance, a long-term monitoring implementation will be needed to compare against the baseline and establish the nutrient reduction from the scheme. Long-term monitoring should start with at least a monthly frequency. This frequency may be able to be reduced if a solution settles into a more stable pattern of TP export once the scheme is established. This will account for any lag times associated with the scheme, ensuring credits are allocated after the system is fully functional. The monitoring method must provide an appropriate experimental design which collects enough data to be confident in characterising the surface and subsurface flows and concentrations across the site.

4.4 BUFFER STRIPS

4.4.1 Process of removal

The main mechanism of P removal in buffer strips is via sorption to sediments and soils. For this to occur, terrestrial overland flows must infiltrate into soils, providing dissolved P a chance to bind to subsurface sediments. The availability of P sorption sites in soil is determined by soil chemistry and assuming sorption sites are available, chemical sorption onto the surface of sediments occurs quickly (Reddy, et al., 1998). If there is a significant residence time of water in the subsurface of a buffer, P can diffuse into porous Al- and Fe- oxides. This is a much slower process, often taking days and it reduces the lability of the adsorbed P, rendering it temporarily insoluble and inaccessible to plants. The effectiveness of both the initial sorption and the physical penetration of P into soil particles is dependent on soil type (Environment Agency, 2015). There is little clarity as to what the ideal residence time is for water in a buffer. Literature suggests that the longer the residence time, the more likely it is for P to be immobilised for a longer period of time (Reddy, et al., 1998). It is worth noting that there is potential for P sorption sites in soils to become saturated, preventing sediments from mitigating any further nutrient pollution. Under these circumstances it is possible for P to start leaching from soils, temporarily rendering the buffer strip as a source of P.

Sediment deposition also plays a large role in attenuating the impacts of nutrient run-off. The process occurs when sediment-bound P entering the buffer strip via terrestrial overland flows is deposited, immobilising P within the local environment (Mainstone & Parr, 2002). This occurs in areas of greater surface roughness, caused by variations in vegetation types and particularly larger woody vegetation, whereby surface flow velocities and energy available for sediment transport are reduced. This causes the deposition of particulates and their adsorbed P. This mechanism of P removal may only be temporary, as resuspension can occur if surface runoff events are sufficient to cause soil erosion and re-suspend sediment bound P for transport into rivers.

Phosphorus is a key nutrient for biomass production in plants. The presence of plants within a buffer strip therefore affects the nutrient attenuation capacity of the solution, with more plants allowing for a greater uptake (Cole, et al., 2020). This process, however, also acts only as a short-term sink unless appropriate maintenance is carried out. For example, harvesting and removal of biomass from the catchment must take place to prevent decomposition and remobilisation of nutrients to the local environment.

4.4.2 Types of Buffers

Buffer strips can either be located within fields or at field margins away from watercourses, which are often referred to as windbreaks or shelterbelts, or they can be located at field margins along watercourse where they are referred to as riparian buffers. In both locations, the overall processes that remove P in a buffer remain relatively similar, though the efficacy of the solution is dependent upon the local environmental conditions. It should also be noted that typically shelterbelts have been implemented to provide shelter wind and protect agricultural soil from erosion. To achieve this, they are often located at the upwind edge of a field (Forestry Commission, 2022), which may not necessarily be the optimal position for maximising nutrient mitigation benefits from a buffer strip. Most studies of the efficacy of buffer strips for nutrient removal focus on riparian buffer strips. Owing to their location next to watercourses, riparian buffers are more likely intercept greater amounts of surface runoff and subsurface flows, resulting in greater amounts of nutrient removal than shelterbelts. As such, there is less evidence on the efficacy of shelterbelts for nutrient removal.

4.4.3 Factors affecting efficacy

Presence of vegetation is essential when implementing a buffer strip to attenuate nutrient pollution. In riparian buffers vegetation promotes nutrient uptake as well as stabilising riverbanks against erosion, reducing nutrient bound sediment losses to rivers (Haycock, 1997). The scale of nutrient uptake by vegetation also dependent upon plant type as uptake is only active during the growing season when plants accumulate biomass. Vegetation management is also important to prevent a buffer from becoming a source of P to the surrounding environment (discussed further below).

Buffer width has been found to have a considerable effect on the efficacy of a buffer for P removal. As well as allowing increased sediment deposition and infiltration to occur, wider buffers promote greater hydraulic residence times. This allows nutrients infiltrating subsurface sediments a greater chance of chemical sorption as well as complete physical adsorption, which renders the P fixed for a longer period of time. There is little clarity on the ideal width for a buffer, though a minimum of 6 m has been suggested for optimal nutrient retention when implemented in line with other design criteria (Wilkinson, et al., 2020). It has, however, been suggested that buffer width accounts for less than a third of sediment trapping capacities, with local environmental conditions, such as soil type, slope and rainfall intensity having notable influences (Wilkinson, et al., 2020).

Based on work (currently unpublished) by EnTrade, nutrient removal estimates for buffer strips of different widths have been derived with regression equations. EnTrade's assessment deems the minimum suitable width to be 10m and outlines that the nutrient retention capacity of a buffer strip increases with width. In order to comply with existing agricultural regulations whereby buffer strips of up to 2m can be required, the nutrient reduction calculated for the first 2m of a buffer was deducted from the nutrient removal estimate of each width. This process ensures that estimates are suitably precautionary.

Table 4-2 outlines the percentage removal efficiencies extracted from literature. The values included are those that remained after removing studies that did not sample a buffer for more than a year, account for seasonality of have repeatable monitoring methods. They values provided in the table below show an overview of the range of percentages that potential schemes can expect to achieve.

Table 4-2 Percentage removal efficiencies as extracted from literature

% P removal efficiency (TP)	Number of study sites	Location	References
10.9	3	Canada	(Vanrobaeys, et al., 2019)
80.9	2	USA	(Peterjohn & Correll, 1984)
84.5	1	USA	(Lee, et al., 2003)
89	1	USA	(Schwer & Clausen, 1989)

4.4.4 Practical considerations

Optimum buffer strip design should aim to decrease surface runoff velocities, increase infiltration and maximise resident time of water in the subsurface. The infiltration capacity of soils is heavily dependent upon the local gradient and soil type, which in turn affects the extent to which nutrient mitigation takes place within a buffer strip. Steep gradients (>10°) and poorly draining soils cause reductions in the infiltration rate of overland flow. Increasing buffer width to more than 6 m can help to mitigate these risks (Aberdeenshire Council, 2015), though it is generally advisable to select sites for buffers that are relatively flat and on freely draining soils if possible. Soil type also affects the chemical processes that immobilise P in soils. Clay soils have a high specific surface area, providing more P sorption sites and thus promoting the conditions required for immobilising P in soil. However, clay soils also have poor drainage and thus will limit infiltration capacity. Ideally a balance will be met to allow for optimal drainage as well as P sorption capacity, which is likely to be seen in loamy soils that are mix of sand, silt and clay particles.

Soil type, gradient and buffer width will interact to impact the residence time of water within buffers. Longer residence times are more likely to promote P removal by soils. Sandy soils on steep gradients will result in the higher subsurface flow velocities and shorter residence times, whereas shallow gradients and silty or clay soils will increase residence times. Wider buffers will increase residence times in all situations. Finally, the type and density of vegetation planted in a buffer will impact both how much P is taken up by vegetation and how the buffer reduces overland flow velocities and promotes sediment deposition. Fast growing tree species or other woody vegetation will have the optimal impact for both uptake of P and reducing flow velocities in the buffer. Considerations should also be given to density of tree planting so that tree canopies do not shade out understory vegetation, which can result in bare soil within a buffer that would increase the risk of soil erosion and associated P transport. Vegetation species planted in buffer strips should be native varieties that will help to improve the biodiversity benefits a buffer can deliver.

4.4.5 Long-term maintenance and monitoring requirements

To help a buffer strip to remain effective in perpetuity, management and maintenance may be required to permanently remove P from a catchment. If a buffer strip is planted with annual plants, vegetation removal of dead plants should be scheduled for the end of the growing season. This will prevent decomposition and remobilisation of nutrients back into the surrounding environment. Management may also be required to remove plants like nettles, brambles and invasive species that may colonise the buffer area before native vegetation can establish. For perennial plants, the extent to which P is removed from the system is dependent upon the longevity of the plants, how much biomass is shed over time and how this biomass is managed. Long-term maintenance plans to remove biomass shed by perennial plants should be put in place to reduce the risk of P being remobilised after it has been stored in biomass. These plans should involve periodic harvesting and appropriate disposal of harvested biomass in a way that does not simply recirculate the nutrients within the same catchment system.

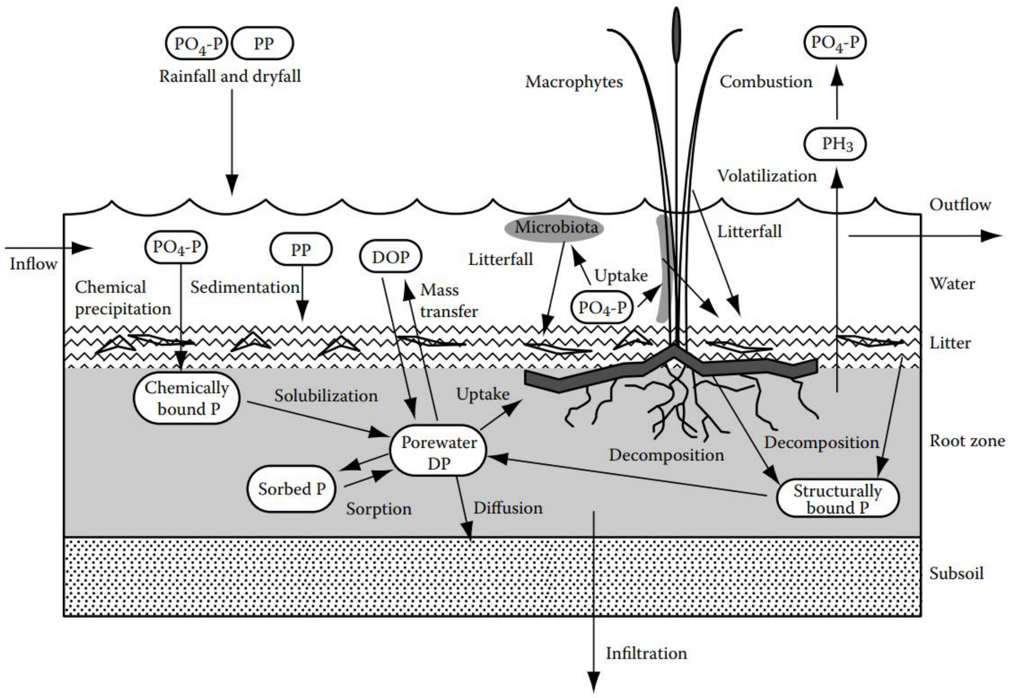
Baseline values representative of the nutrient concentrations entering and exiting the buffer strip are required to be able to monitor the efficacy of the solution once the scheme is in place. If a precautionary nutrient removal percentage is established with NRW prior to implementing the scheme, monitoring will likely be required to check compliance. If no percentage is chosen in advance, concentration results acquired from longer term monitoring after implementation need to be compared against the baseline to establish the nutrient reduction potential. The monitoring method must provide a reasonable experimental design which collects enough data to be confident in characterising the surface and subsurface flows and concentrations across the buffer strip. Monitoring of TP load reductions achieved by the buffer should be conducted with at least monthly frequency to calculate the influent and effluent nutrient loads. It is highly recommended for monitoring programmes for run over multiple years to determine any lag times associated with the scheme and ensure the scheme continues to deliver the required mitigation. It may be possible to reduce monitoring frequency if a stable pattern of TP removal by a buffer is determined from higher frequency monitoring, with lower frequency monitoring used as part of an adaptive management system that will increase monitoring frequency if deviations from established TP removal patterns are observed.

4.5 WETLANDS

4.5.1 Process of removal

There are three primary phosphorus removal mechanisms in wetlands (Kadlec & Wallace; 2009): sorption of phosphorus to soils and sediments, uptake and incorporation of phosphorus by flora and fauna (biomass storage), and burial of sediments (sedimentation/accretion). Sorption and biomass storage have limited retention capacity and can become saturated (although secondary processes, such as sedimentation, can remove saturated components), whereas sedimentation/accretion is indefinite provided there is storage capacity within the wetland. Particulate settling can rapidly remove large amounts of phosphorus from water carrying high amounts of suspended sediment. There may also be redistribution of phosphorus stores within a wetland that affect its availability and mobility (see Figure 4-1). There is a large body of literature that supports the use of wetlands for nutrient removal (Kadlec & Wallace, 2009; Forbes et al, 2011; Land, et al., 2016) and provided they are designed correctly, wetlands can provide significant nutrient removal benefits with relatively high certainty.

Figure 4-1 A diagram showing the P fluxes within a wetland (from Kadlec and Wallace, 2009).



4.5.2 Wetland types

Wetlands are traditionally configured so water flows through from an inlet to an outlet. They can comprise a singular wetland 'cell' or a chain of connected cells. Typically, TP concentrations will decrease along the flow path through a wetland as the process detailed above take effect. There are many different wetlands configurations that are categorised based on the water source, the type of flow through the wetland and the vegetation used.

Treatment Wetlands comprise natural or constructed wetlands that are designed and managed to improve the water quality of a known inflow rate and quality to a desired standard. These systems are referred to as 'closed' because the characteristics of the inflow are tightly controlled by the source of water to the wetland. Wetlands removing TP from the final effluent at WwTWs are examples of 'closed', Treatment Wetland systems because the characteristics of the water entering the system (the influent) are known and will not vary markedly over time.

Wetland systems treating non-controlled sources of water such as agricultural runoff can be referred to as 'Other Wetlands'. These systems are typically designed and managed to receive and treat influent with more dynamic water volumes and more variable water quality parameters, e.g. surface runoff or stream flow. This distinction between wetland types based on the source of the influent has a significant impact on the ability to predict the quantity of TP a wetland will remove. Variable inflow rates and water quality make it very difficult to predict how much TP ‘Other Wetlands’ will remove. Treatment Wetlands with known inflow rates and inflow water quality allow for much more accurate prediction of TP removal capacity based on appropriate design. Both Treatment and ‘Other Wetlands’ also have a various sub-categories based on their specific design.

There are two main sub-categories of wetland include: surface flow wetlands and subsurface flow wetlands. Free water surface (FWS) wetlands are the most common surface flow wetland. These comprise areas of open water and are most similar to a natural wetland. FWS wetlands can be further split according to the mix of emergent plants, submerged plants and floating vegetation that are planted in the wetland. They are often used as tertiary treatment of domestic wastewater, urban runoff and agricultural runoff. These wetlands provide the most ancillary benefits due to the provision of biodiversity improvements and amenity value.

There are two main types of subsurface wetlands, horizontal subsurface flow (HSSF) wetlands and vertical flow (VF) wetlands. HSSF wetlands are designed so water flows laterally through a planted bed from the inlet to the outlet. Treatment occurs as water moves horizontally through the bed of the wetland. In comparison, VF wetlands discharge water over a permeable substrate planted with vegetation. Water treatment occurs through percolation through the root zone. Both subsurface flow wetlands can be used for the primary treatment of wastewater. It is possible to treat raw sewage with specific configurations of VF systems.

Although there is a distinction between wetlands dependent on the way in which water flows through the system and is thereby treated, in most cases there will be some percolation of flow through wetland beds although liners and low permeability substrates are often used to limit infiltration. It is also noted that combinations of different wetland configurations may be used in a chain of wetland cells. These are considered hybrid systems and commonly make use of a VF wetland stage followed by a series of HSSF wetlands.

4.5.3 **Factors affecting efficacy**

The TP removal ability of wetlands is extremely variable as a result of the number of factors. There is high variability in phosphorous removal rates reported in the literature. Although median TP removal rates of around 50% have been reported in a key review of wetland efficacy (Land, et al., 2016), also noting that greater removal efficiencies can be achieved through good design and maintenance. Well-designed systems that incorporate best practice and utilise multiple wetland cells in sequence can achieve TP removal rates of around 90%. For example, a four-year study of a 1.2 ha wetland system with five cells treating dairy farm runoff observed annual TP removal rates of 91.2-96.4% (Forbes, et al., 2011). The success of TP removal through sedimentation, plant uptake, sorption and precipitation is dependent on the following (Land et al, 2016):

- Type of wetland
- Hydraulic loading rate (HLR)
- Influent TP concentration
- Water source
- Size and shape (area, depth, length)
- Flow pattern and hydraulic efficiency
- Water residence time
- Age
- Sediment / soil type
- Vegetation type and coverage
- Fauna
- Management regime

A selection of these key factors that affect efficacy and that can be accounted for through wetland design are elaborated further below.

4.5.3.1 Type of wetland:

Subsurface flow (HSSF and VF) wetlands have been reported to remove as 70% of TP (significantly more than the reported by Land et al, 2016 FWS median removal efficiency of 50%) although they are rarely designed with phosphorus retention as a primary performance objective. Whilst such wetlands can be designed with TP retention in mind with the use of a high P sorption capacity substrate material such material has a finite sorption capacity and requires periodic removal and replacement. In reality, the TP removal performance of HSSF wetlands, like most wetlands, is variable and has been found to reduce overtime as sorption capacities of the substrate are reached. VF wetlands require more frequent maintenance than an HSSF wetland, however HSSF wetlands typically require a larger area than VF.

It is possible to improve the performance of wetlands with mechanical or chemical processes, albeit with a higher construction cost and a higher operating cost than passive wetlands. For example, wetlands can be built with reactive media in the substrate that will remove soluble phosphorous through the formation of insoluble complexes of metal phosphates (Jenssen et al, 2010). Aeration of the substrate (achieved through pumping air to the base of the wetland) can also be used to increase mixing of water and increase oxidation-reduction potential, which has been found to improve P removal (Vera et al, 2014).

4.5.3.2 Hydraulic loading rate and influent TP rate

The HLR (expressed in m/d) is calculated by dividing the influent discharge by the wetland area. The hydraulic loading rate multiplied by the inlet concentration will provide the TP loading rate of a wetland. The HLR thus affects the amount of TP in the system, which affects the removal capacity of the wetland and informs the management regime. The TP removal performance increases with decreasing load rate as water is held in the system for longer periods of time, allowing greater time for removal processes to act on the TP load entering the wetland. The impact of higher HLRs was seen in a pilot scale hybrid wetland system consisting of a FWS cell connected to a subsurface flow wetland treating water from a fish farm (Lin et al, 2002). This study reported a drop in TP removal efficiencies from 71.2% to 31.9% as the HLR increased from 2.3 to 13.5 cm/day. Therefore, a wetland optimised for TP removal should consider maintaining a low HLR.

The phosphorus loading rate (PLR) is calculated by multiplying the inlet concentration by the HLR. Higher inlet concentrations are positively correlated with TP removal efficiency and high TP loading rates generally result in higher removal rates (Land et al., 2016). Thus, wetland design would benefit from a high inlet concentration of TP whilst aiming to keep HLR as low as possible.

4.5.3.3 *Size, shape and depth*

Wetland design should aim to maximise the residence time of the effluent from the inlet to the outlet in order to maximise treatment efficacy. The size and shape of a wetland will influence residence times. The HLR decreases as wetland area (size) increase relative to the influent flow rate, with lower HLRs resulting in higher residence times. Thus, wetlands should be sized in order to minimise the HLR. Wetland shape will also affect how flow is distributed across the wetland and thus impact residence times. A wetland should be shaped in order to avoid flow moving quickly through a central area from inlet to outlet, in order to increase residence time of water within the wetland. The SuDS manual (Woods-Ballard, et al., 2015) specifies various good practice techniques for wetland design. This guide suggests that wetlands should have a flow route length to width ratio of at least 3:1, highlighting the importance of increasing flow route length in order to increase water residence times. The SuDS manual also suggests that wetlands should not exceed 2 metres in depth to facilitate oxygen circulation to the wetland bed, with shallower wetlands promoting greater oxygen circulation.

4.5.3.4 Velocity:

The inflow rate and the shape of the wetland will influence the velocity of water flow. The distribution of water tends to be more uniform at low velocities. Low velocities are also necessary to avoid re-suspension of sediments. The resuspension of sediments has been suggested to occur at velocities of over 0.2 m/s (Olin et al, 2000), though this will depend on the dominant sediment size within a wetland.

Existing FWS wetlands typically operate at velocities lower than 0.001 m/s (Kadlec & Wallace, 2009). Large wetlands in Florida designed to control P are subject to a maximum velocity threshold of 0.03 m/s. This indicates that high velocities pose risks to the ability for wetlands to retain P that has been stored in sediments.

4.5.3.5 Vegetation

P is an essential nutrient for plant growth. Plant root systems absorb P and incorporate it within the plant structure. Seasonal die-off of vegetation can bury nutrients within the wetland, however decomposition of vegetation can result in the remobilisation of nutrients previously stored in vegetation. Seasonal vegetation removal is the most effective means to completely remove P stored in vegetation from the wetland system. It is important to select vegetation that has high P removal capacity but is native to area where a wetland is being deployed. Phragmites species are common reeds that are often used to plant wetlands, especially subsurface flow wetlands (Kadlec & Wallace, 2009). However, Phragmites can out compete other vegetation leading to a reduction in P removal, especially in FWS wetlands (Avers, 2007). If a wetland is being created to have biodiversity and social amenity co-benefits, vegetation communities should be selected carefully and managed to maximise TP removal and other co-benefits.

4.5.4 **Practical considerations**

Good wetland design should provide a detailed plan that describes how the wetland has been designed to maximise P removal efficacy by controlling for the factors detailed above. This design should also account for the topography of the proposed wetland site. For example, the slope of the surrounding land should not result in surface runoff draining into the wetland as this may comprise treatment efficiency. Ideally a wetland should also be sited where topography allows a wetland to be gravity fed, as this will typically require less maintenance than a pumped system and will be cheaper to operate. A topographic survey of a prospective wetland site should therefore be completed in order to understand the flow pathways and help inform a wetland feasibility assessment.

Soil type where a wetland system is being constructed is also important. The hydraulic conductivity of soil can be used to calculate water losses through leakage and inform the design of the wetland. Where wetlands are being located on permeable soils, wetlands may need to be lined with impermeable material such as clay. Peatland soils should be avoided due to their higher environmental and ecological value. Wetland design should include an analysis of soils on at a proposed wetland site. As water that infiltrate into soils may percolate through underlying geological strata and potentially into an aquifer, the geology and hydrogeology of a site should also be considered when assessing wetland feasibility. Hydrogeological assessments should consider groundwater vulnerability to remove the risk of a wetland causing pollution to any aquifers that may impact water resources.

There are various regulatory requirements that must be considered prior to deploying a wetland. For example, flood risk at proposed wetland site is very important. If a wetland is in Flood Zone 2 or 3 then a flood risk assessment should be completed. Flooding a wetland has the potential to mobilise a large store of P through resuspension of accreted sediment. Additionally, flood defence consents may be required from the EA if the works are to be carried out within 8m of a main river. The requirement for abstraction licences must also be considered and engagement with the relevant regulator should be evidenced for each permit or licence required.

Consideration should be given to whether a proposed wetland has any environmental designations, e.g. SSSI, National Nature Reserve etc. Developing wetlands on sites designated for historical and/or archaeological importance should also be considered and avoided where possible. If possible, the previous land use on a proposed wetland site should be determined to assess the likelihood of ground contamination and legacy P causing problems with water quality of water discharged from the wetland.

4.5.5 **Long term maintenance and monitoring requirements**

Monitoring of a wetland is essential to assess TP removal efficacy. The wetland design process should incorporate suitable allowances for uncertainty that means predicted TP removal estimates from a wetland are suitably precautionary. As such, design calculations of TP offsetting delivered by a wetland are likely to be underestimates. This means that monitoring of a wetland once operational may show that it is delivering more TP offsetting than estimated as part of the design process. Monitoring should assess the influent load entering the wetland and the effluent load exiting the wetland. This will allow calculation of the removal of TP being achieved by the wetland and would ideally be carried out at least monthly, however more frequent monitoring would be beneficial. An adaptive monitoring regime may be possible whereby frequency of monitoring can be reduced from a higher to lower frequency if the monitoring data shows that changes in TP removal efficiency occur with a predictable temporal pattern, e.g. seasonal changes. In contrast, a reduction in TP removal efficacy may indicate that the current management plan is not suitable and needs to be reviewed.

Wetlands may require seasonal vegetation management. The removal of vegetation may provide additional P removal from the system. Wetland proposals should include maintenance plans that will support maintenance of design specifications, which will in turn help to retain TP removal efficiency.

Sedimentation is one of the main P removal processes in FWS wetlands. Therefore, space for accretion needs to be provided through desilting/desludging to maintain the functionality of P removal via this mechanism. If this is not completed, wetlands can switch from a sink to a source of P (Sharpley, et al., 2013; Land, et al., 2016). Wetland proposals should detail comprehensive management plans that include disposal of removed sediment in ways that do not reintroduce removed P to the affected catchment. Desilting/desludging frequency varies dependent on the design and the loading, although it has been suggested that removal of sediment will not be required before 10 - 15 years depending on the sedimentation rates (Ellis et al, 2003). A well-designed wetland may need desilting/desludging when the main pool volume is reduced by 20% and could be carried out every 25-50 years with effective pre-treatment (Woods-Ballard et al, 2015). Visual monitoring should be carried out regularly to assess the bed level and plan a sediment removal regime accordingly.

4.6 SUDS

4.6.1 Process of removal

The main process of removal in SuDS are very similar to those described above for buffers (Section 4.4) and wetlands (Section 4.5), with the specific processes active within a SuDS design dependent on the SuDS features used. SuDS are traditionally used for flood management although they can contribute to significant water quality improvements. SuDS promote the infiltration of water and thus sorption of P to soils, slow runoff velocities to encourage sediment deposition and provide an environment for plant growth and concomitant nutrient uptake. These three processes can immobilise and remove phosphorous from the environment.

4.6.2 Types of SuDS

There are a range of different types of SuDS. Types of SuDS that can provide some benefit for P removal are as follows:

- Wetlands – shallow ponds and reed beds that provide stormwater attenuation, sediment settlement and pollutant removal.
- Bioretention systems – shallow planted depressions that can filter water and treat pollution:
  - Detention basins – a vegetated depression that captures rainfall and slowly drains it to act as a pollution filter.
  - Retention ponds – a larger depression that is permanently inundated and will retain sediments and associated pollution.
- Swales – vegetated linear conveyance/storage channels that attenuate flows, promoting infiltration and the settlement of pollutants.
- Permeable pavements – pavements and hard surfaces that allow infiltration and filtering of pollutants.
- Soakaways – excavations filled with rubble that receive piped runoff to promote percolation and filter pollutants.
- Filter drains – excavated ground backfilled with permeable material allowing runoff to percolate and allowing some or all of it to soak away into soil layers, filtering pollutants. Runoff that does not infiltrate into a filter drain should be discharged to a swale or other SuDS component if possible.
- Rain gardens or filter strips – vegetated land parcels that reduce flows, act as filters for pollutants and store P through uptake by vegetation.
- Green roofs and living walls - vegetated roofs and walls of buildings that reduce runoff and promote deposition of sediment bound pollution, as well as P removal by plant uptake.

4.6.3 Factors affecting efficacy

Like wetlands, the P removal performance of SuDS is controlled by their design. If wetlands are being incorporated into a SuDS design, the same factors detailed in Section 4.5.3 are relevant. The SuDS manual details key design considerations and best practice guidelines (Woods-Ballard, et al., 2015). The type of SuDS used will influence P reductions that can be delivered by a SuDS design. Wetlands, bioretention systems, swales and filter drains are likely to provide the best P reductions because they facilitate the two key P removal processes, sedimentation and sorption.

Site characteristics, such as the site area and type of urban land use that SuDS are draining will affect the amount of P available for removal and thus the amount of P removal that SuDS can deliver. More freely draining soils that allow SuDS components that encourage infiltration will increase the likelihood of P removal through binding to sediments. Sediment retaining/trapping SuDS features will decrease in P removal effectiveness if too much sediment accumulates. Without desilting/sediment removal sediment-bound P may become remobilised.

The use of a SuDS treatment train providing a mixture of P removal methods can enhance overall performance. Including a permanent wetland or pond feature within a SuDS treatment train is likely to maximise the P removal potential of a SuDS design (Bastien, et al., 2010). Modelled performances of

SuDS treatment trains with wetland systems in a series provides the most TP removal (around 70%) (Bastien, et al., 2010).

4.6.4 Practical considerations

The concentration of TP in urban runoff often peaks during the early stages of a rainfall event in what is termed the 'first flush'. It is essential that SuDS are designed to capture and retain at least the water volume associated with the first flush. The annual loading of TP to a SuDS train will need to be calculated in order to understand the potential reduction in TP that the SuDS can achieve. A site-specific export coefficient can be identified using the West Wales Nutrient Budget Calculator, though onsite monitoring is preferable. SuDS should be designed to be able to treat the runoff volume generated from the catchment that drains to them without becoming over saturated. Over saturation will limit or stop water infiltrating into the ground, decreasing P sorption rates and may reduce the system's ability to slow flows, in turn decreasing sedimentation of sediment-bound P.

4.6.5 Long term maintenance and monitoring requirements

The requirement for routine maintenance of SuDS is dependent on the SuDS features used. A full breakdown of SuDS maintenance requirements can be seen in Keating et al (2015) and Woods-Ballard et al (2015). Most systems require the removal of green waste and debris on a monthly basis (Keating, et al., 2015). Regular grass cutting and weed removal should be carried out in order to prevent the system becoming overgrown with unwanted and unproductive vegetation. Visual inspections and reporting of the vegetation, water quality, water depth and bed level water should be completed regularly. Desilting/sediment removal may be required in features that are designed to accumulate sediment to avoid remobilisation of sediment-bound P. Appropriate disposal of sediments should be conducted in order to reduce the risk of recirculating sediment-bound P within the same river catchment. It is possible that the dredged sediments will have to be disposed of as hazardous waste. The SuDS Manual provides a sediment categorisation and disposal decision tree (Woods-Ballard, et al., 2015). Other required maintenance may include vegetation replacement and/or removal depending on vegetation type, blockages and cleaning soakaways and other subsurface drainage features.

Whilst it may be possible to stipulate the efficacy of a SuDS design for P removal before it is built, it would be highly beneficial to monitor the system in order to determine the actual TP removal performance. Sampling of urban runoff prior to it entering SuDS features and sampling of treated runoff at the point where it discharges to a watercourse should provide a general understanding of the TP load reduction caused by a SuDS design. Sampling programmes will ideally be reactive to rainfall events of different magnitudes in order to capture the variability of urban surface water runoff pollution.

4.7 RIVER CHANNEL RE-NATURALISATION

4.7.1 Process of removal

P sorption to sediments is the primary process driving nutrient removal from river systems. Sorption can occur within channelised and natural / restored rivers, though the process is enhanced in natural / restored reaches due the increased contact of river flow with hyporheic sediments (i.e. those that site at the surface/groundwater interface where mixing occurs). The initial physical sorption of P happens quickly, whilst longer residence times are required for dissolved P to complete penetration into sediment particles and chemically lock P within sediments for a longer period of time (Johnston & Dawson, 2005). This process is reversible, however, with desorption occurring if the P concentration of overlying water drops below a threshold. This threshold is dynamic as the P sorption capacity of sediments changes over time.

P uptake by vegetation and P deposition by sedimentation also facilitate nutrient removal from river flows. These processes are enhanced by re-naturalisation schemes that increase habitat heterogeneity and floodplain reconnection. Greater habitat heterogeneity in restored rivers will generally increase in-channel and marginal vegetation densities which in turn increases the assimilation of P by biomass. However, most vegetation in rivers is short lived and assimilated nutrients are likely to be remobilised when vegetation dies and decomposes. Increased vegetation densities in rivers will also slow flow and result in greater deposition of sediment and associated P. Burial of sediment-bound P can help to increase the longevity of this P store but it is also reversible, with the potential for remobilisation of sediment-bound P likely under high flow events due to bed and bank erosion. Floodplain reconnection schemes that increase the connectivity of river flow with the floodplain during flood events can also promote sediment deposition and P removal, though this P store can also be remobilised during high flow events (Sharpley, et al., 2013).

4.7.2 Types of river channel re-naturalisation

Channel re-naturalisation seeks to reinstate natural processes in anthropogenically modified river channels through the re-establishment of natural channel forms and habitats. There are many types of approaches that can be applied and are often completed in conjunction with other mitigation options described in the document. The River Restoration Centre's Manual of River Restoration Techniques[29] provides an overview of many channel and floodplain re-naturalisation techniques.

In the context of P removal, floodplain reconnection is the scheme with the most evidence supporting its nutrient mitigation capacities. Floodplain reconnection aims to increase lateral connectivity by hydrologically reconnecting floodplains, or alternatively wetlands, unused tributary channels, and oxbow lakes. The overall aim is to re-naturalise channel form, rectify anthropogenic disconnect between rivers and riparian corridors, and create ecologically functional floodplains. This helps to increase the regularity of lateral inundation, allowing wetlands and native vegetation to recolonise naturally whilst encouraging the river to return to its natural, heterogeneous state, pre-channelisation. This supports natural processes, some of which drive nutrient reductions in naturally functioning rivers.

4.7.3 Factors affecting efficacy

The key requirement for promoting nutrient removal in this context is the reinstatement of habitat and geomorphic diversity. Techniques focussed on maximising channel form heterogeneity are likely to increase the potential for hyporheic exchange between benthic and riparian sediments. Natural channel complexity increases flow turbulence, resulting in greater exchange of water with the hyporheic zone. Increased heterogeneity can occur as a result of introducing vegetation, re-meandering, riffle and pool sequences and tributary channel reconnection, amongst other techniques. This enhanced geomorphic diversity can promote nutrient removal through reduced velocities increasing the residence times of water within a river reach. Increased residence times will generally allow more time for P removal processes to occur.

[29] See: https://www.therrc.co.uk/manual-river-restoration-techniques, Accessed on: 23/06/2022

The initial TP concentrations prior to channel and floodplain naturalisation in a given reach is important to understand in optimising the success of a river restoration scheme for nutrient removal (Bernhardt & Palmer, 2011). Harper et al. (1999) suggest P removal to function best when TP concentrations are above 0.3 µg/l. P adsorption to sediments is likely to still occur under low concentrations, albeit at a reduced rate as the chemical process constantly seeks to equilibrate the TP concentration in overlying water with that of benthic/riparian sediments. Riverbed sediment type also affects P sorption capacity as certain sediment types, such as clay, has significantly more sorption sites available for nutrient retention than others. As such awareness of bed sediment types is essential to aid the process of producing P reduction estimates and of siting restoration schemes in areas that likely to promote P removal.

Where vegetation abundance increases, this will also help to promote the hydrodynamic processes that increase transient storage, reduce velocities, and increase the abundance of organic debris within the channel. These secondary processes help to increase rates of P sorption and deposition, so whilst plant uptake does not contribute significantly to P removal, vegetation can play a large role in other nutrient removal processes through increasing channel heterogeneity.

River and flood re-naturalisation schemes are likely to have the greatest benefit for nutrient removal if the main source of nutrient pollution enters the river upstream rather than at some point along the restored reach. This ensures maximum concentrations to support the various processes that remove P as well as providing the nutrients with the longest period of time possible to be immobilised/removed.

To be able to achieve the greatest quantity of P removal possible, it is recommended that consideration is given towards all of the above factors expected to affect the efficacy of the given solution. Currently there is no industry standard regarding the design of larger scale river and floodplain re-naturalisation schemes to support the achievement of nutrient removal and literature on the estimated potential for nutrient removal is lacking. As such, baseline and longer-term monitoring will be required prior to and following the implementation of a scheme in order to determine how much TP the scheme is removing.

4.7.4 Practical considerations

All river channel re-naturalisation schemes require design which will differ depending on the type of re-naturalisation that is proposed. In general, a well-designed river channel re-naturalisation will need to consider the river environment, including flows, sediment type, slope, riverbank material, channel morphology and various other factors. The core design objective of a re-naturalisation scheme should be to encourage the development of natural processes that attenuate nutrient pollution, and the design of the scheme should show how this will be achieved within a given river environment.

Baseline monitoring should be conducted to determine the nutrient concentration in the proposed reach for re-naturalisation. Rivers with very low nutrient concentrations will both have low nutrient loads for removal but will also likely have lower rates of TP removal, as chemical P removal rates in sediments often increase with increasing TP concentration up to a limit imposed by the physical and chemical characteristics of the sediment and chemical characteristics of river water. As such, re-naturalisation schemes in rivers with low TP concentrations may limit the utility of channel re-naturalisation for the purpose of P mitigation.

Floodplain topography will need to be assessed in re-naturalisation schemes that aiming to reconnect rivers with their floodplains. Gently sloping floodplain topography will be most beneficial for sedimentation and associated P removal during flood events. This also shows the need allow ‘room for the river’ within a river corridor. Floodplain reconnection should also aim to understand the current and previous land use around the river to ascertain if legacy P stored with soils may be remobilised when a restored river floods.

Any alterations to a river channel will require engagement and permissions from NRW. Flood risk increases associated with floodplain reconnection will need to be considered and most re-naturalisation schemes will require a flood risk assessment. Increased flood risk and the associated loss of land will also likely require engagement with landowners / land managers. Any schemes requiring large-scale alterations to channel planform are likely to require earthworks, which will in turn require construction and environmental management plans, as well as potentially requiring planning permission. As it is likely re-naturalisation scheme will be carried out within a designated sites (a SAC river) or supporting habitat for a SAC river, there will also be a requirement to consider any potential risks to the protected features of the designated site.

4.7.5 Long-term maintenance and monitoring requirements

Whilst such re-naturalisation schemes should ideally be self-maintaining, in reality they are likely to require adaptive management for longer term sustainability. Short-term monitoring of a scheme after it has been established will help to determine how effective the scheme is at P removal. It is recommended that a scheme is monitored in order to determine the nutrient removal benefit on a seasonal basis and in response to land use / management changes within a river catchment. Long-term monitoring programmes would be highly beneficial to determine the effectiveness of a river restoration scheme for TP removal, with the results from sampling programmes being fed into an adaptive management system. Flow measurements and water quality samples (measuring total phosphorus) should be taken upstream and downstream of a restored river reach in order to assess the scale of TP reduction a scheme may achieve, which should be referenced against the TP load recorded in a baseline survey.

Visual inspections to check whether a scheme is meeting its design objectives is also highly beneficial as this will help to establish any adaptive management requirements to support ongoing nutrient benefits. The specific requirements of these inspections will depend on the type of techniques uses and the scale of the scheme. The following visual checks are suggested:

- Periodicity of lateral inundation: A floodplain reconnection scheme should be assessed to ensure that lateral inundation is occurring periodically as opposed to either constantly or only during low frequency, high magnitude flood events.
- Vegetation: If floodplain, benthic or riparian vegetation is planted it should be monitored, especially during the establishment phase. Replanting should take place if die back occurs and plants don’t naturally regrow, for example.
- Invasive species should also be identified early and removed against where necessary.

4.8 DRAINAGE DITCH BLOCKING

4.8.1 Process of removal

The primary mechanisms for P removal by drainage ditch blocking is sediment deposition and sorption of dissolved P to sediments. Sorption of dissolved P requires longer residence times in order for P to be chemically bound within sediments (Johnston & Dawson, 2005). Removal of P by deposition entails placing a barrier (blocking the ditch) to slow flow and prevent downstream transport of sediments. The sorption process is enhanced in blocked drainage ditches, through increased contact time with particulate material, resulting from increased surface roughness and reduced flow velocities. Increased surface roughness decreases the sediment transport capacity of the stream, resulting in immobilization of P within the environment (Reddy, et al., 1998).

P uptake by vegetation also facilitates P removal while also increasing the surface roughness of the sediment and increasing hydrological heterogeneity. However, aquatic vegetation typically has a relatively short lifespan and will degrade, therefore P removal by plants can be short lived. Upon decomposition, P assimilated by uptake in aquatic plants can be readily re-mobilised in aquatic environments (Yoon, et al., 2014).

4.8.2 Types of drainage ditch blocking

Drainage ditch blocking aims to create a water-tight dam which results in water table rise caused by non-continuous flow. There are many types of dam material which can be used to create a drainage ditch block such as turf, plastic pilling, plywood, wooden plank, corrugated Perspex, heather bales, and straw bales or any combination (Ramchunder, et al., 2009; Armstrong, et al., 2010). Each dam material will have different desired outcomes and implications for use which will affect the decision-making process for which schemes will be most appropriate for nutrient neutrality. Implications relate to the suitability of the environment, as not all dam types are suitable. Poor choice of dam material for the surrounding topography of the environment is what often leads to dam failure, for example plywood dams are likely to be more suited to very wet peatlands than a heather bale dam. Dam failure has obvious implications for P removal efficiencies; therefore it is an important factor to consider, to ensure greater likelihood of ditch blocking/dam success (Armstrong, et al., 2010).

4.8.3 Factors affecting efficacy

Nutrient removal in drainage ditches by ditch blocking is reliant on several factors. The main factor is to reduce flow velocities and increase transient storage by increasing hydrological heterogeneity (Ramchunder, et al., 2009). Drainage ditch blocking practices that focus on facilitating reductions in flow velocity within a ditch are likely to increase the contact time and spatial extent of flow through soils and sediments. Although the chemical sorption of P to sediments is a quick reaction, the full, slow phase physical process of P penetration into soil particles can take days (Reddy, et al., 1998). This slow phase P penetration immobilises P for longer, hence it is importance to slow flow through a ditch in order to increase transient storage of water in soils that the ditch is draining. Geomorphic characteristics can also have an influence on P removal. Drainage ditches that create shallower wider pools upstream of the ditch block create conditions that allow for increased contact time of water with sediments, which will generally promote greater P removal (Armstrong, et al., 2010).

Drainage ditch blocking schemes will have the greatest P removal efficiency in ditches with soil types that promote P sorption. Soils with high specific surface areas, such as clay soils, have significant quantities of sorption sites with which to bind P (Reddy, et al., 1998). However, P sorption can be inhibited by the organic matter content of soil. Organic matter competes for sorption sites and can also alter sorption sites, both of which prevent the sorption of P to soils while also potentially causing P release (Reddy, et al., 1998).

Schemes that implement vegetation cover around blocked drains encourage conditions for increased surface roughness, flow velocity reduction and reduced sediment transport capacity (Holden, 2009). The process of P removal via plant uptake is also increased in ditch blocks that facilitate revegetation by creating pools with favourable conditions for plant growth (Armstrong, et al., 2010).

There is limited research available regarding the effectiveness of drainage ditch blocking practices for TP removal. The majority of studies focus on other environmental or water quality parameters such as DOC concentration or vegetation density, or studies were conducted in peatlands which may not be transferrable to other upland or lowland environments. Furthermore, the majority of studies take place in non-UK countries, with little certainty regarding the transferability of the results to the UK environment. Due to the lack of available literature regarding the estimated potential of nutrient removal within ditch blocking schemes, a percentage estimate for TP removal efficiency was unable to be determined, however the literature suggests that drainage blocking will deliver some P removal benefits. To determine the efficacy of ditch blocking schemes, baseline and long-term monitoring is required both prior to and post-implementation.

4.8.4 Practical considerations

Drainage ditch blocking aims to create a watertight dam that will hold water in a ditch and thus promote processes that remove P from agricultural drainage. The design of a ditch blocking scheme will need to consider ditch geometry and materials that will be suitable for blocking the ditch. Choice of materials should consider the hydrology of the ditch to reduce the risk of the dam being washed away during heavy rainfall events.

A ditch blocking scheme will need to determine the TP loading rate to the ditch and the TP load of water exiting the ditch in order to determine how much TP the scheme is removing. This will require a suitable monitoring programme.

Ecological surveys should be conducted to determine whether the change in habitat within the ditch may have negative impacts on any protected habitats or species. It is also likely that blocking a drainage ditch may result in localised flooding of surrounding agricultural land during rainfall events. This will require engagement with landowners / land managers to ensure they will not object to the loss of land during wet weather.

4.8.5 Long-term maintenance and monitoring requirements

A well blocked ditch should need little long-term maintenance. Sediment accumulation and vegetation growth are likely to help reinforce the ditch block. Visual inspection of the block should be carried out periodically during rainfall events to check that the block is still effectively damming water. The required frequency of these checks will be dependent on the dam material used, with non-natural materials like Perspex sheets likely to need less frequent inspections assuming they are installed securely. Wooden dams are most likely to need repair as they are subject to bowing and distortion of the wood.

Visual inspections may indicate the need for management of vegetation to either remove vegetation if it is significantly decreasing the amount of water that the blocked ditch can hold to replanting if vegetation has been lost or has not successfully established vegetation. Sediment accumulation may also decrease the amount of water than can be held behind blocked ditches and monitoring the level accretion would help to determine either then sediment may need to be removed from a ditch or when the ditch may stop functioning as effectively for sediment and P storage.

Monitoring will be required to quantify the amount of TP that is removed by a blocked drainage ditch. This monitoring programme will need to determine the influent TP load to the ditch, which will need a sampling design that can quantify the influent flow rate and the TP concentration of influent water. Sampling of flow rate and TP concentration in the ditch network downstream of the dam will enable a quantification of the TP load reduction caused by a ditch blocking scheme. The TP load entering a blocked ditch and the process that immobilise TP within a ditch will very seasonally and in response changes in surrounding land management. Monitoring programmes should be established that will enable management and maintenance efforts to be targeted over the lifetime the solution. Sampling programmes will need to be reactive to rainfall events in order to sample runoff entering and exiting a blocked ditch.

4.9 ENGINEERED LOGJAMS

4.9.1 Process of removal

Engineered logjams mimic the environmental conditions produced as a result of dams formed by beavers. The nutrient removal processes are thus very similar between the two systems and beaver dams can provide an analogue for logjams. Sedimentation, chemical sorption, and biomass assimilation are the three P removal processes caused by logjams. Sedimentation occurs as a result of reduced velocities and increased channel heterogeneity which together reduce the sediment transport capacity of the channel, causing deposition of sediment bound P. Nutrient removal is also facilitated by sorption of P to deposited sediments and debris, encouraged by the increased contact time with particulate material caused flowing flow behind engineered or natural dams. Logjams can also promote removal of P via uptake by vegetation. Increased vegetation growth in the pools and wetlands that form behind logjams can also contribute to greater surface roughness, further increasing the potential for sediment deposition and storage of associated nutrients.

4.9.2 Types of logjam

Engineered logjams consist of a series of dams placed along a stretch of river, each reducing flow velocities by temporarily retaining a small body of water behind the dam in the form of a pool. Engineered logjams are mainly made of large wood such as whole tree trunks, logs or branches and debris such as fresh or decomposed organic matter (Herrera Environmental Consultants, 2006). Depending on the type of logjam constructed as well as the construction materials there will be different desired outcomes and implications regarding nutrient removal capacity. Depending on the surrounding topography and hydrology of the site, the type of engineered logjam will differ. Log steps and valley jams are more applicable for grade control whereas the design of jams on the outside of meanders or on the edge or banks are more applicable for flow manipulation (Herrera Environmental Consultants, 2006). This potentially could affect the removal capacities of the scheme as the type of dam that may be more effective at P removal may not be achievable to build within the constraints of the site. This will affect the decision-making process regarding which dam type will be the most appropriate for achieving nutrient neutrality.

Furthermore, research indicates that owing to the short-term nature of the predominant P removal processes (deposition and sorption), there is potential for remobilisation of nutrients under instances of flooding. Due to this, these schemes should not be implemented as long-term solutions for P mitigation. However, with careful design and a strong understanding of the system's hydromorphology, these schemes can be suitable as short-term mitigation measures.

4.9.3 Factors affecting efficacy

The size of pools that form upstream of either engineered or natural beaver dams will influence the nutrient removal capacity of the system, with large ponds holding more sediments and associated nutrients (Puttock, et al., 2018). Large and shallow ponds are favourable for P removal due to the large surface area to volume ratios, which increase transient storage of water within sediments and hence support the nutrient removal processes that occur in the hyporheic zone (Roberts, et al., 2007).

There is also a need to understand the hydrology of a stream where a logjam will be deployed so that the dam structure will not be washed out during periods of high flow (Lammers & Bledsoe, 2017). As such, logjams are best suited to small watercourses < 2 m (Eden Rivers Trust, n.d.).

Vegetation density within the pools formed upstream of dams will influence the system's capacity for P retention, with removal rates being positively correlated with the quantity of vegetation. This is achieved via nutrient assimilation, reduced velocities, and the resulting prolonged contact of nutrients with vegetation and P sorption sites.

Research regarding engineered logjams is not comprehensive enough to be able to establish suitably precautionary nutrient removal estimates prior to implementation. This is in part due to the short-term nature of the predominant P removal processes and the subsequent risk of remobilisation if deployed as long-term mitigation measures. As such, these schemes are suggested as short-term measures and monitoring will be required before and after the scheme is introduced to determine the quantity of P removal a logjam scheme has achieved.

4.9.4 Practical considerations

Engineered logjams will need design details that show how they will mimic the environmental conditions created either by beavers or in-channel natural process via trees falling, that result in P removal by sedimentation, chemical sorption and biomass assimilation. Designs will need consider site-specific characteristics, including the geomorphology and hydrology of the river that is being dammed. These factors will be very important to ensure that a logjam is designed in a way that stops it getting washed away in high flows.

The characteristics of riverbeds should also be considered in order to maximise P removal potential. For example, clay bed streams are less suitable as they result in less hyporheic exchange between sediments and overlying water, which may result in lower rates of P removal.

Engineered logjams will increase the connectivity of river channels with their floodplains and can result in localised increases in flooding onto floodplain areas. This approach will therefore require engagement with both landowners / land managers as well as NRW, in order to ensure that the increased localised flood risk is acceptable. Logjam schemes are thus likely to require some form of flood risk assessment. The potential implications of localised flooding on landowners / land managers mean that engagement with these stakeholders is essential.

Baseline surveys of the TP load within the section of river to be dammed will help to inform whether a potential logjam site will provide a significant quantity of P mitigation. Monitoring of a scheme once operational will be essential to quantify the amount of TP it is removing from a river system.

If the proposed location for a logjam is within the boundary of a designated site or its supporting habitat, considerations should be given as to whether the physical habitat alterations caused by a scheme will have adverse effects on the protected features of the site. Any adverse impacts on protected features of designated sites may cause issues for the feasibility of a scheme.

Consideration should also be given the primary P removal processes operational within an engineered logjam scheme. Owing to the temporary nature of sedimentation and sorption, these schemes are recommended be deployed as short-term mitigation measures for P. As such, these schemes can function as temporary bridging measures to unlock local development whilst a larger scale and more permanent scheme is put in place.

4.9.5 Long-term maintenance and monitoring requirements

The management and maintenance required to ensure an engineered log jam scheme remains safe and functional will mainly consist of regular checks of the dam and surrounding area. Although the specific maintenance required will be site-specific and depend on how a scheme is designed, management and maintenance should have regard for the following:

- Sediment scour issues: As channel bed scour is the leading cause for engineered log jam failure and can have a significant impact on the dam’s longevity, regular visual checks post construction are required to support early identification. This should be supported with a strong understanding of sediment dynamics within the system prior to installation. If issues with channel bed scour are identified, appropriate action must be taken to reduce the risk a dam being undermined and failing.
- Debris and sediment removal: As engineered log jams aim to slow the flow velocity of the river and not stop flow entirely, the dam should remain semi-permeable and leaky. Removing debris and sediment build up should take place routinely to ensure that these build-ups do not obstruct the flow of water entirely.
- Structural damage repair: Regular checks to assess the structural integrity of an engineered log jam should be carried out. If any structural damage is identified or if the structural integrity is compromised, repair works should be carried out.

A monitoring programme will be required to quantify the amount of TP removed by a logjam. Baseline monitoring of nutrient concentrations is recommended but is not essential – sampling upstream and downstream of a logjam after it is constructed should be sufficient to quantify the reduction in TP load caused by a scheme “before” implementation (i.e., upstream of the scheme) and after. Monitoring before the scheme has been deployed and at points along the length of river that is being dammed will provide an indication of the TP load that will enter the dammed length of channel directly, rather than just measuring the TP load that enters the dammed stretch of river from upstream. Operational monitoring should take flow measurements and TP water quality samples upstream and downstream of the dammed section of channel in order to quantify the influent and effluent load of TP to a logjam scheme. This monitoring regime will allow for the quantification of any TP load reduction caused by the logjam. Monitoring should initially be conducted at a minimum monthly frequency to capture seasonal variation. Monitoring programmes should be conducted for as long as required for the system to reach equilibrium, whereby the fluctuations in load reductions show steady patterns of change on repeating cycle, or simply stabilise around a long-term average. At this point it may be possible to change the monitoring frequency with an emphasis on identification of any adaptive management/maintenance that may be required if any negative changes/reduction TP removal patterns are identified.

4.10 TERRESTRIAL SEDIMENT TRAPS

4.10.1 Process of removal

The erosion of soils contributes to diffuse P pollution due to the desorption of soil-bound P from soils that are washed into rivers. Heavy rainfall and subsequent surface water runoff mobilises sediments, with a greater risk of soil erosions and sediment mobilisation in high-risk areas such as steep slopes, exposed soils, types of vegetation cover and hillslope connectivity with river channels (Vinten et al, 2017). Sediment traps immobilise sediment and sediment-bound P by trapping sediment on surface water runoff pathways. A sediment trap is placed in an area where surface water flow pathways are known to occur. Sediment accumulates in the traps and is left to stabilise or is removed, thus immobilising and removing a source of P pollution to rivers. The efficacy of a sediment trap is determined by measuring or estimating the volume of sediment that accumulates behind a trap over a given period of time and sampling soils to understand the P load within the trapped sediment.

4.10.2 Types of sediment traps

There are various types of sediment traps. Sediment fences (also known as a filter fence or silt fence) are temporary fences comprised of a permeable geotextile that is constructed downslope of a farm at a field boundary and at the location of known surface water runoff pathway. This blocks the flow pathway and water is forced through the permeable fence, slowing flow to cause sedimentation and essentially acting as a filter to trap sediment and the associated P load (Vinten et al, 2014). Sediment fences can be constructed cheaply and also moved to different locations once accumulated sediment has been removed. It is also possible to leave them in a location and allow them to become buried. They are typically used on arable farms and in construction sites. Earthen bunds and leaky dams are more permanent features that will have the same impact as a sediment fence but cannot be moved once they have been installed.

Detention ponds are depressions that are filled by surface water runoff during rainfall events, forming ephemeral wetland features. A detention pond will slow surface water runoff flows and drain slowly, allowing time for sediment to be trapped in the pond. Detention ponds are typically used as a SuDS feature, though they can also be deployed in the rural environment to intercept eroded soils. Urban detention ponds are typically more engineered than rural detention ponds in order to reduce the risk of localised flooding if the pond overtops. Rural detention ponds can utilise natural depressions by routing flow to these features.

4.10.3 Factors affecting efficacy

The performance of sediment fences is primarily controlled by their location. The location of the fence will dictate how much surface water runoff passes through the fence and thus how much sediment will be trapped by it. Therefore, best practice suggests locating these features on a surface water runoff pathway downslope of an agricultural field.

Detention ponds will reduce in effectiveness once they are full and flow moves continuously through the ponds without slowing sufficiently to support sediment deposition. Sediment accumulation will also affect the storage capacity of a pond, which can in turn affect the time taken for a pond to fill and subsequently reduce the potential for sediment deposition.

4.10.4 Practical considerations

The permeable geotextiles used for sediment fences can become blocked, which can cause water to back up behind a fence and then overtop it, resulting in a reduction in sediment deposition and P removal performance (Vinten et al, 2014). It may be necessary to periodically clean sediment fences to ensure they continue to allow water to pass through rather than over them. It is also important not to build fences in an area of high flow velocities as this could cause damage to the fence and impact P removal performance.

Rural detention ponds are typically designed with an outlet that allows water out when it is near ground level, rather than being positioned at the base of a pond, in order to avoid accumulated sediment blocking the outlet (Fiener et al, 2005).

For both sediment fences and detention ponds, an approach to estimating the quantity of TP removal the sediment trap can achieve will need to be developed if these solutions are to be deployed without needing prior monitoring to quantify their efficacy. It is likely that an estimate of TP removal could be derived by delineating the catchment area for a sediment trap and determining likely runoff rates for this catchment. Combining runoff rates with estimates of soil erosion potential and the probable TP load of soils within the trap's catchment area could provide an estimate of the amount of TP a sediment trap could remove. No established method has been found to derive an estimate of TP load removal by sediment traps and the required assessment would need to be carried out for each location where a trap could be deployed. Monitoring of sediment traps provides an alternative approach to determining their efficacy however, this would require deploying them without having an estimate of the quantum of TP mitigation they could deliver.

4.10.5 Long-term maintenance and monitoring requirements

The maintenance requirements for sediment fences are dependent on their use. If a sediment fence is being left to be buried, no maintenance will be required, provided there are no rips or breaks in the geotextile used. However, this would not prove nutrient neutrality in perpetuity. Therefore, to increase the longevity of nutrient retention, the sediment should be removed and disposed of correctly and in accordance with contaminated sediment regulation. Alternatively, a mobile sediment fence could be utilised that is moved once the captured sediment is stabilised.

Urban detention ponds require regular maintenance in a similar manner to SuDS wetland features (see Section 4.5 and 4.6). Rural detention ponds will require less maintenance than permanently inundated wetlands, though as is the case with sediment fences, they will fill with sediment if left unmaintained and thus will only provide a temporary mitigation solution. Visual monitoring of the detention pond is required to assess the sediment accumulation rates. Removal of sediment and safe disposal in a way that does not recirculate the removed TP within an affected river catchment can help to prolong the life of a detention pond. The outlet pipes in detention ponds may need regular unblocking or desilting.

Monitoring should be used to determine the amount of TP that is being removed by terrestrial sediment traps. Ideally monitoring will be carried out throughout the lifetime of a sediment trap as the amount of sediment being stored by these solutions will vary over time, depending on landcover, land management and weather conditions in the area of catchment that the sediment trap is receiving runoff from. The frequency of monitoring should be set by the frequency of runoff events that may deliver sediment to a trap. Alternatively, the amount of TP stored in a trap could be calculated when sediment is removed.

5. MAPPING POTENTIAL MITIGATION LOCATIONS

5.1 IDENTIFICATION OF WWTW TO TARGET FOR WETLAND CREATION

This section evaluates the WwTW wetland opportunities at the SAC catchment scale as opposed to the LPA scale. Planning mitigation at the hydrological catchment scale incorporates collaborative working which facilitates the identification of strategic measures that provide co-benefits to multiple LPAs through holistic management. Notwithstanding, it is recommended that each LPA leads the planning and management for a SAC catchment. The Afon Tywi is predominantly in the CCC administrative boundary, therefore it recommended that CCC leads on delivering mitigation in this SAC catchment. Ceredigion contains roughly 67% of Teifi compared to 23% for Carmarthenshire and 10% for Pembrokeshire. As such it is recommended that CeCC leads on the Afon Teifi. The CeCC boundary contains the largest proportion of the Wye catchment relative to the other LPAs. However, the majority of this catchment is in Herefordshire, therefore it is recommended that the West Wales steering group opens up communication with this English LPA. The Afon Cleddau is nearly entirely within Pembrokeshire and so it is recommended that PCC lead the management in this SAC catchment.

The WSM approach, described in Section 2.3.1.1, identified and ranked the WwTW within each SAC catchment based on the estimated TP load and the strategic position in the catchment. This approach does not provide a definitive hierarchy of WwTW to target, but it does provide an indication of the WwTW that has the most opportunity for maximising mitigation provided by a wetland scheme. The strategic position of the WwTW within the catchment is a crucial factor to consider when planning a strategic wetland - mitigation in the upper catchment is preferred as the water quality improvements provided propagate downstream, unlocking development throughout the catchment. However, a mitigation scheme upstream of a development does not necessarily provide nutrient mitigation as some developments may discharge to a tributary of the main SAC river that is also designated as a SAC. For example, the Afon Cleddau and the Afon Teifi SAC designations extend along the tributaries of the main rivers throughout the entire catchment. For example, if a theoretical development connected to Cribyn WwTW, which discharges to the Grannell, a designated tributary which confluences with the Teifi just upstream of Llanbyther, mitigation in the upper catchment would not necessarily improve the water quality of that river. Accordingly, the Afon Cleddau is split into the Eastern Cleddau and Western Cleddau for the purposes of this assessment.

Figure 5-1 shows the estimated TP loading from the WwTW in the affected catchments within Carmarthenshire, Pembrokeshire and Ceredigion based on the consented dry weather flow (DWF) limits. The consented DWF for a WwTW describes the maximum consented flow rate from a WwTW when it is not receiving combined foul and stormwater flows. It is the maximum amount of water a WwTW should discharge when it has not been raining (hence ‘dry weather flow’) and so the only water that should enter a works is raw sewage. Estimated TP loads for each WwTW were calculated by multiplying the DWF by the assumed non-permit limited WwTW TP concentration in the final effluent (8 mg/l[30]). The top 5 WwTW with the most mitigation opportunity within each SAC catchment are shown in the WwTW labels. The following subsections assess the highest ranking WwTW.

5.1.1 Afon Tywi

The WwTWs that rank the highest in the WSM approach are shown in Figure 5-1 and Table 5.1. Llandovery WwTW is the highest ranking and has the second highest estimated TP load in this catchment. The relative position of the WwTW in the catchment makes it a prime candidate site for further investigation into the feasibility of constructing a point source wetland. Ffairfach STW has the highest TP load, however the relatively low ranking (joint eighth) is due to the position of this WwTW in the catchment – any development upstream of this WwTW would not benefit from the mitigation provided. Llangadog STW (which ranks fifth), may also be a target for a wetland considering the high estimated TP load of 780 kg TP/year. Conversely, Cynghordy STW and Pumpsaint STW are ranked

[30] As used in the West Wales Nutrient Budget Calculator.

relatively high (third and fourth, respectively) due to the upper catchment location, though the estimated TP load is too low for both WwTW to warrant constructing a wetland.

Using the rate of removal for tertiary treatment of domestic wastewater of 46%, from Land et al. (2016) a wetland at Llandovery WwTW would remove 592 kg TP/year. It should be noted that these removal rates are high level estimates and the actual quantity of mitigation available from a wetland at each site will depend on many factors to do with wetland design and measured inflow characteristics. A well-designed wetland may be able to achieve significantly greater treatment efficiency than 46%[31]. However, these estimates are likely to be in the region of what a wetland could deliver at these sites and should provide a starting point from which further investigation of suitable wetland sites can be developed.

Assuming a dwelling outputs around 1 kg TP/year (a value that in reality is extremely variable and highly dependent on the occupancy rate, water usage and pre- and post-development land uses), a wetland at Llandovery could provide P mitigation for around 592 dwellings. The recent predictions of housing demand of 697 dwellings per annum, as stated in the forthcoming second LDP[11] suggest a treatment wetland at Llandovery could make a significant contribution to the mitigation requirement within Carmarthenshire. Furthermore, any further treatment of wastewater is likely to lower the concentration of P in the final effluent, in turn reducing the amount of mitigation required for dwellings that connect to an upgraded WwTW.

When selecting a potential location for a treatment wetland at a WwTW, a variety of datasets can be used to mask out areas where a wetland should not be created, such as on designated sites where the wetland would interfere with the site's conservation objectives. Appendix 2 contains a list of datasets that could be used to inform an assessment of site feasibility, with descriptions on how they can be used.

Ffairfach STW and Llandovery WwTW appear to have the highest number of planning applications that are constrained by P surrounding them. Although a development that is near a WwTW does not necessarily connect to that WwTW, a general assumption can be made that a site will connect to the closest WwTW. Implementing a WwTW at these works will not provide mitigation to connecting developments. However, it may lower the P concentrations in the final effluent, therefore lowering the mitigation requirement.

5.1.2 **Afon Teifi**

The WwTWs that rank the highest in the WSM approach are shown in Figure 5-1 and Table 5.2. The ranks suggest that Pontrhydfendigaid WwTW and Tregaron WwTW are the top two most suitable WwTW sites to target for nutrient mitigation. This is mainly due the catchment position and the relatively high estimated TP load. The DCWW Phosphorus Programme[21] aims to reduce the concentrations of P in the final effluent to 1.8 and 2 mg TP/l, respectively. Considering that the TP removal rate is positively correlated with the influent concentration (Land et al., 2016), Pontrhydfendigaid WwTW and Tregaron WwTW may not be the optimal targets for a wetland. As such, Llanbydder WwtW or Pencader STW (ranked 3rd and 4th, respectively), which are both in CCC, may be better targets. Furthermore, Figure 5-2 demonstrates that a wetland at Pencader may be more advantageous due to the amount of stalled development surrounding it, which may lower the mitigation requirement for any these developments.

Using the rate of removal for tertiary treatment of domestic wastewater of 46%, from Land et al. (2016) a wetland at Pontrhydfendigaid WwTW, Tregaron WwTW, and Llanbydder WwTW would remove 71, 175 and 428 kg TP/year, respectively. Again, it is important to consider that these are estimates and may not be indicative of the actual mitigation provided. Furthermore, a site feasibility assessment would need to be conducted to provide further clarification of the site's potential.

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[31] See: Constructed Wetland Hub, available here:
https://storymaps.arcgis.com/collections/6543a2f8de0348f683187ff268a79687?item=1, accessed on 14/04/23

5.1.3 Afon Cleddau

The WwTWs that rank the highest in the WSM approach are shown in Figure 5-1, Table 5.3, and Table 5.4. In the Western Cleddau, Letterston West STW and Wolfcastle STW appear to be the most suitable WwTW sites to target for nutrient mitigation (ranking first and second respectively). The TP loading is higher for Letterston West STW despite the lower concentration of TP in the final effluent (2.5 mg TP/l). Letterston West STW is likely to be the optimal target due to the higher load and the position in the catchment.

The Eastern Cleddau has a lack of WwTW with a high estimated TP load. Rosebuch WwTW discharges the highest TP load at an estimated 64 kg/year and it is positioned in a desirable position in the upper catchment. However, the TP load is likely to be too low to warrant implementing a wetland.

Using the rate of removal for tertiary treatment of domestic wastewater of 46%, from Land et al (2016), a wetland at Letterson West STW could remove 214 kg TP/year, respectively. It should be noted that these removal rates are high level estimates and the actual quantity of mitigation available from a wetland at each site will depend on many factors to do with wetland design and measured inflow characteristics.

Overlaying the proposed planning applications data (Figure 5-2) enables the identification of priority areas for nutrient mitigation schemes and facilitates strategic decision making. There is a cluster of developments planned in the south-east of Pembrokeshire. However, the WwTW which is near these developments has no dry weather flow permit and so the TP load cannot be estimated. An alternative WwTW that is near to these sites, Robeston Wathen Housing Act Works, contributes an estimated TP load of 13 kg/year meaning nutrient mitigation yields would be low. It is also positioned relatively low in the catchment area, so the benefits of the mitigation would be localised downstream. Therefore, it would not be strategic to use a point source wetland as a mitigation option in this area. Instead, it may be suitable to target alternative mitigation solutions, such as upgrading ageing private sewerage systems, retrofitting SuDS to urban areas, or implementing catchment-scale nature-based solutions such as riparian buffer strips.

5.1.4 Summary

The LPAs must carefully consider the most suitable method and location for nutrient mitigation within the SAC. They should consider the position within the catchment as this will influence the benefit to the water quality of the watercourse downstream of the mitigation. It is also important to consider the estimated TP load from the WwTW as the influent nutrient load to a wetland will directly influence the amount of nutrients which can be mitigated. For example, a treatment wetland would ideally be located at a WwTW with a high estimated TP load in the upper catchment (upstream of where the wastewater from the proposed development will eventually discharge). This approach aims to maximise the nutrient mitigation benefits because the water quality improvements will propagate downstream unlocking development along the SAC.

Table 5.1 The ten most highly ranked WwTW (low value = high rank) for a wetland in relation to nutrient load and catchment position in the Afon Tywi

Name	LPA	Coordinates (X Y)		Updated TP permit (mg/l)	Estimated TP load (kg/year)	Rank
Llandovery WwTW	CCC	276130	233180	5	1288	1
Talley WwTW	CCC	264050	231782	5	234	2
Cynghordy WwTW	CCC	280419	239810	5	40	3
Pumpsaint STW	CCC	265842	240569	8	48	4
Llangadog STW	CCC	269890	228140	5	780	5
Myddfai WwTW	CCC	277535	229762	5	51	6

Name	LPA	Coordinates (X Y)		Updated TP permit (mg/l)	Estimated TP load (kg/year)	Rank
Cilycwm WwTW	CCC	275450	239629	5	N/A	7
Farmers STW	CCC	264800	244550	8	50	8
Llansawel WwTW	CCC	262395	236140	5	104	9
Ffairfach STW	CCC	261590	221170	5	1547	10

Table 5.2 The ten most highly ranked WwTW (low value = high rank) for a wetland in relation to nutrient load and catchment position in the Afon Teifi

Name	LPA	Coordinates (X Y)		Updated TP permit (mg/l)	Estimated TP load (kg/year)	Rank
Pontrhydfendigaid WwTW	CeCC	272788	266741	1.8	157	1
Tregaron WwTW	CeCC	267261	259165	2	380	2
Llanybydder WwTW	CCC	251724	243265	2.5	930	3
Drefach/Velindre WwTW	CCC	235134	239797	5	1722	4
Llandewi Brefi WwTW	CeCC	265726	255184	1.5	79	5
Pencader STW	CCC	244600	236500	3.5	561	6
Cwrtnewydd STW	CeCC	249450	247100	5	374	7
Lampeter STW	CeCC	257630	247340	0.5	219	8
Llanfair Clydogau WwTW	CeCC	262206	251252	8	44	9
Llanfihangel-Ar-Arth STW	CeCC	245490	240120	5	103	10

Table 5.3 The five most highly ranked WwTW (low value = high rank) for a wetland in relation to nutrient load and catchment position in the Afon Cleddau (Eastern Cleddau)

Name	LPA	Coordinates (X Y)		Updated TP permit (mg/l)	Estimated TP load (kg/year)	Rank
Rosebush WwTW	PCC	207327	229192	8	64	1
Llanddewi Velfrey STW	PCC	214210	216830	1	34	2
Walton East STW	PCC	202300	223000	8	48	3
Maenclochog STW	PCC	207545	226879	1	22	4
Llys Y Fran WwTW	PCC	203886	224216	8	29	5

Table 5.3 The five most highly ranked WwTW (low value = high rank) for a wetland in relation to nutrient load and catchment position in the Afon Cleddau (Western Cleddau)

Name	LPA	Coordinates (X Y)		Updated TP permit (mg/l)	Estimated TP load (kg/year)	Rank
Letterston West STW	PCC	192900	229150	2.5	466	1
Wolfscastle STW	PCC	195800	226600	4.5	127	2
Puncheston WwTW	PCC	200974	229846	5	66	3
Mathry STW	PCC	188339	231395	1	55	4
Ambleston STW	PCC	200370	225240	5	56	5

5.2 ASSESSMENT OF LAND PARCELS ADJACENT TO WWTW WITH HIGH POTENTIAL FOR WETLAND

According to the analysis of the Consented discharge register, Llandovery WwTW, Tregaron WwTW, and Letterston West STW are the optimum WwTW to target for a treatment wetland in the CCC, CeCC and PCC administrative boundaries, respectively. These sites contribute 1288, 380 and 466 kg TP/year estimated using the dry weather flow permits of 705, 520 and 510 m^3/day, respectively. Llandovery and Letterston West both use biological filtration techniques to treat the wastewater whereas Tregaron uses high-rate biological processes. Considering none of these WwTW already use a wetland system as a form of secondary or tertiary treatment, all are potential locations for a wetland depending on the site constraints. Assuming a HLR of 2.3 cm per day, the loading at which Lin et al (2002) recorded high TP removal rates, a wetland receiving 705 m^3 would need to be 3.1 hectares. For a wetland receiving 510-520 m^3/day, it would need to be 2.2-2.3 hectares. Figure 5-3 shows field parcels adjacent to the WwTW that could serve as potential locations for a wetland. All field parcels shown comprise modified grassland are likely used for livestock grazing. The field parcel adjacent to Llandovery WwTW is 1.7 hectares. The high-level estimate of the area of wetland required to treat the permitted flow at this site suggests that this land parcel would not be suitable for the construction of a treatment wetland. Therefore, other land parcels further from the WwTW may not to be considered or another WwTW with a lower estimated TP load could be targeted, such as Llangadog STW. The field parcels adjacent to Tregaron WwTW and Llandovery West STW are 4.4 and 3.7 hectares, respectively. As such, these parcels may provide the area needed to treat the entirety of the permitted flow. However, further investigation of these sites would be needed that should consider:

- Detailed assessment of landcovers
- Topography, including slope and elevation
- Current land use/rights of way
- Utilities/infrastructure
- Flood risk
- Site drainage
- Habitats and species

Figure 5-1 A map showing the locations of WwTW with permitted flow limits in the administrative boundaries of CCC, PCC and CeCC.

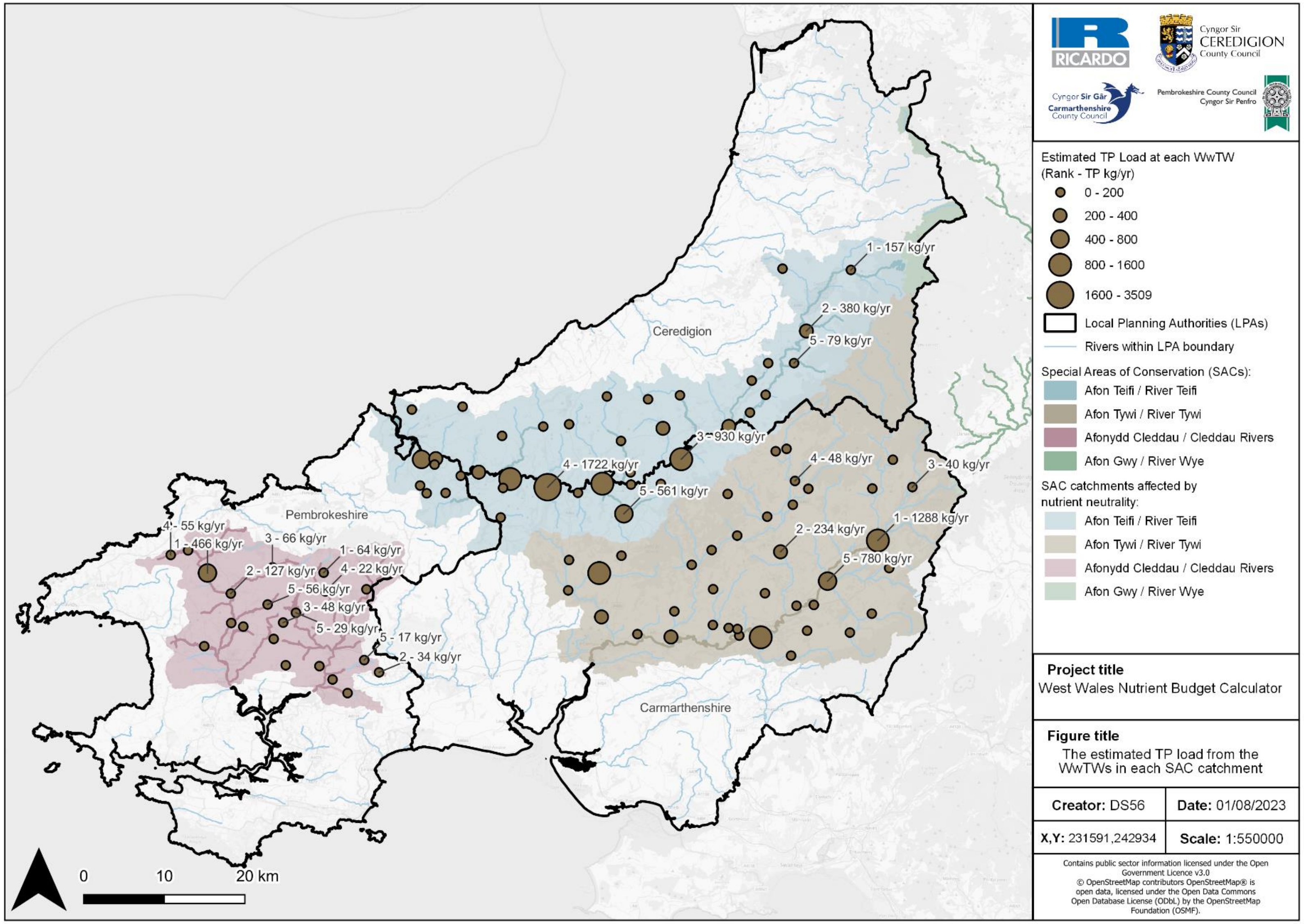


Figure 5-2 Map showing the locations of stalled developments, housing allocations, WwTW and the average agricultural export coefficient per WFD waterbody catchment

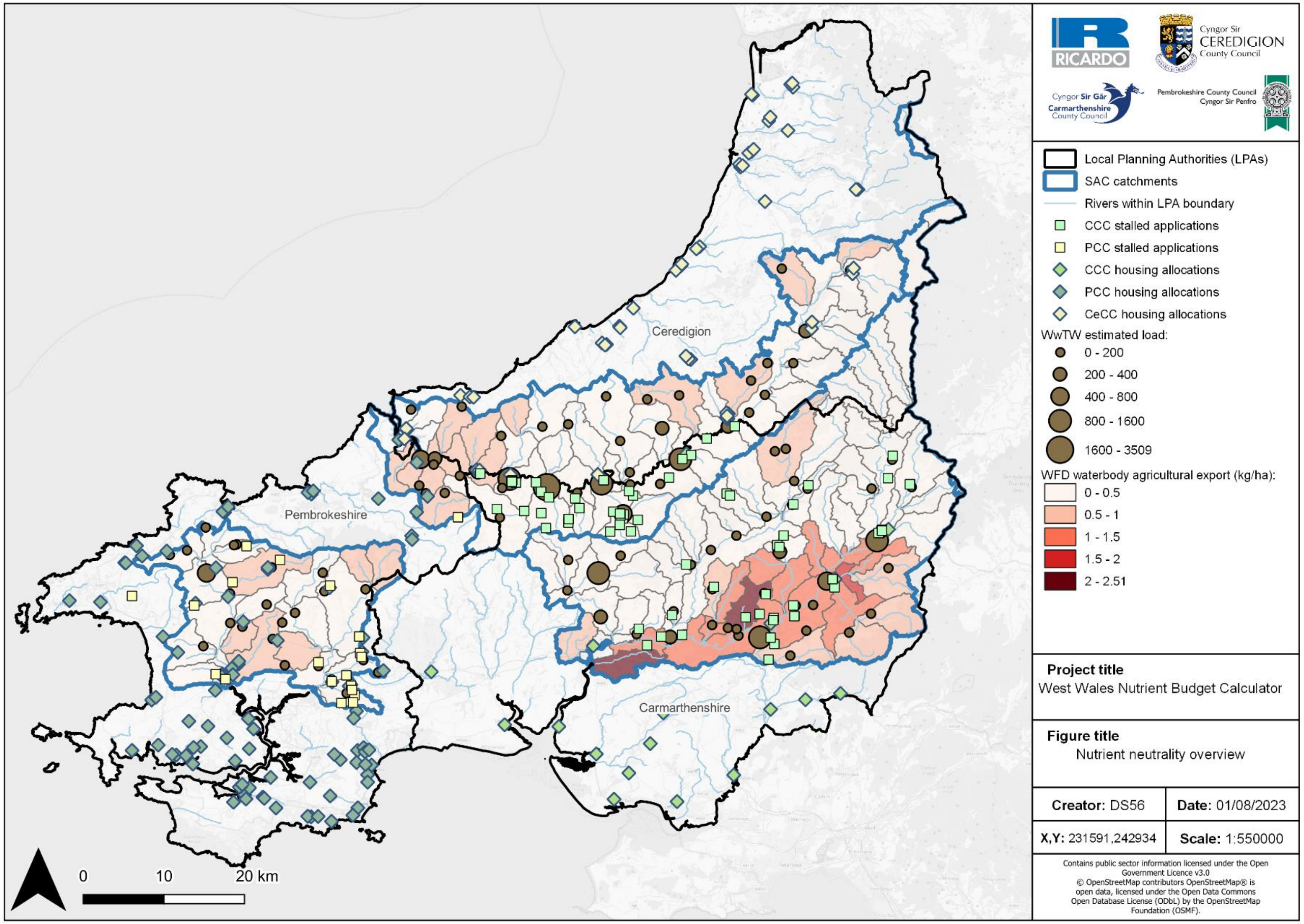
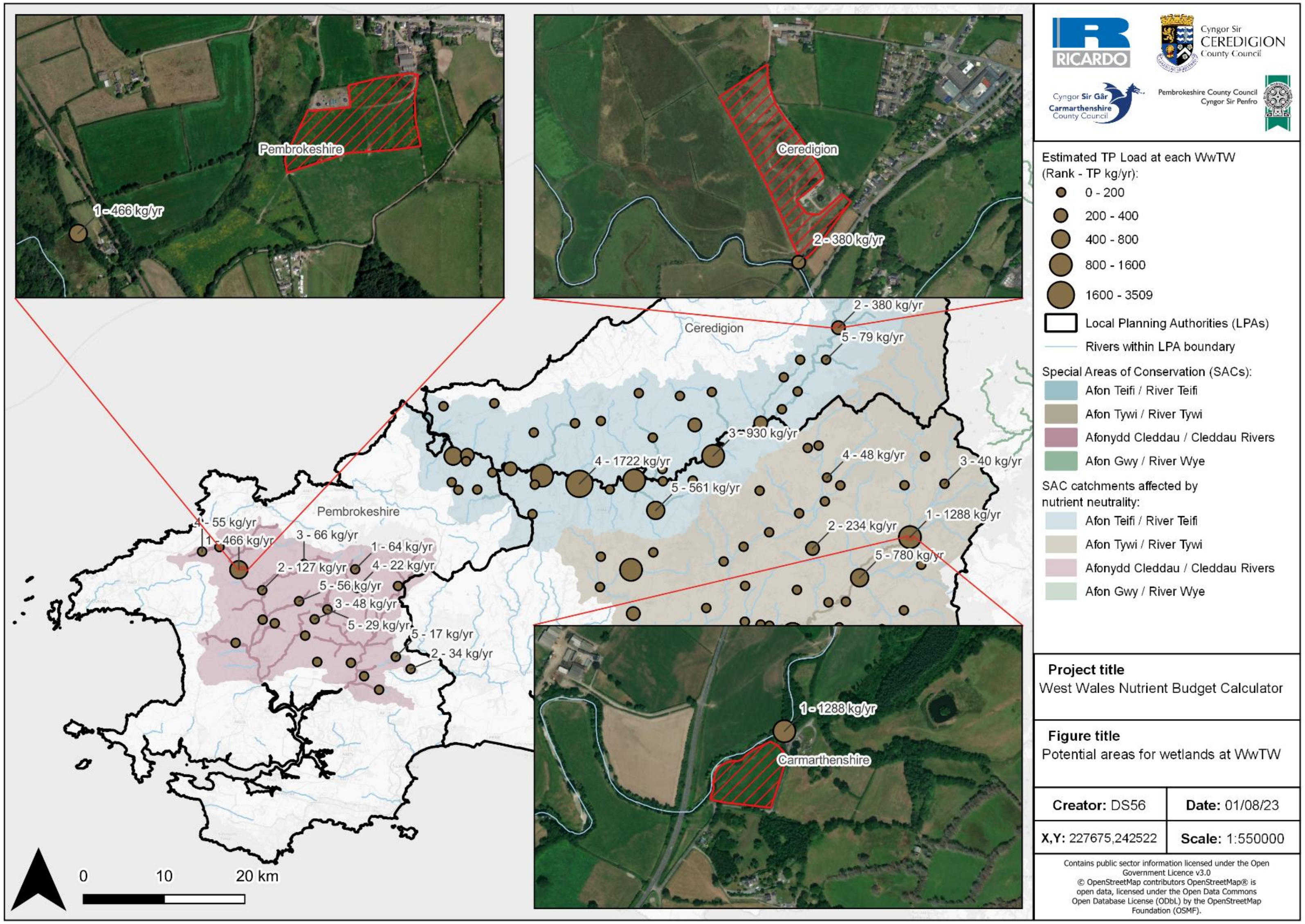


Figure 5-3 Field parcels adjacent to WwTW with high potential for a treatment wetland



5.3 TARGET AREAS FOR CATCHMENT-MANAGEMENT MITIGATION SOLUTIONS

Initially the catchment hotspots of agricultural diffuse pollution are presented. Next, the WFD waterbody catchments with the highest potential for catchment scale mitigation measures are presented. These catchments were ranked based on the position of the sub-catchment within the wider SAC catchment, the agricultural diffuse TP load and the total area of mitigation opportunities. The area of mitigation opportunities was calculated using two JBA WWNP (see Section 2.3.1.4) datasets that identify areas that may be suitable for the deployment of buffer strips (see Section 4.4) and sediment traps (see Section 4.9). Finally, a map showing the mitigation datasets in a key target catchment is presented. This is a high-level analysis, more detailed feasibility studies will be needed to inform actual locations for deployment of mitigation, however the following analysis provides an indication of how more detailed work could be targeted to specific locations to try and maximise the benefit from catchment management interventions to mitigate P from the agricultural sources.

5.3.1 Catchment hotspots

Figure 5-4 and Figure 5-5 Figure 5-1 show the total agricultural diffuse export coefficients (kg/ha) and total TP load (tonnes) for each WFD waterbody catchment within the SAC catchments. Essentially, these are maps of the catchment hotspots. It is recommended that the WFD waterbody catchments with highest TP loading are targeted with catchment management solutions first. Figure 5-6 shows the source apportionment for each WFD waterbody to assist with catchment scale decision making.

Target catchments for catchment mitigation solutions shows 7 hectares of buffer in small bit – talk about the potential (50%) of total load in each WB.

5.3.2 Target catchments for the creation of diffuse TP mitigation measures

Figure 5-7 shows a map of the WFD waterbody catchments with the most opportunity for the creation of riparian buffer solutions. Figure 5-8 shows a map of the WFD waterbody catchments with the most opportunity for the implementation of runoff attenuation features. It is recommended that the WFD waterbody catchments with the highest ranking (lower value = higher rank) are targeted with catchment mitigation measures first. Figure 5-9 demonstrates the utility of the WWNP Riparian Woodland Potential and the WWNP Runoff Attenuation features datasets in a target catchment within the Eastern Cleddau.

The Runoff Attenuation Features Potential dataset estimates locations where it may be possible to temporarily store water during a 1 in 100-year rainfall event. The dataset contains information on the potential type of attenuation feature. For example, some features are described as 'Runoff Attenuation features', which are smaller features that could be targeted, and some are classed as 'Gully blocking', which are areas of run-off attenuation features on steeper ground, where leaky barriers may be more appropriate[32]. As such, the Runoff Attenuation Features Potential dataset could be used to locate areas to implement drainage ditch blocking solutions. Other mapped attenuation features could be used to identify potential locations for sediment fences and/or detention ponds. It is noted that the runoff attenuation features opportunity dataset will not provide the ability to estimate the P removal performance of these features and that monitoring will be needed in order to ascertain the efficacy of these solutions.

The WWNP Riparian Woodland Potential dataset maps area 50 metres either side of river waterbodies what would be suitable for riparian buffer creation. As explained in Section 4.4, a riparian buffer could be as narrow as 6 m metres to be effective and ideally would be between 20-30 m wide. As such, the Riparian Woodland Potential dataset is a very useful tool to identify these areas with potential for deploying riparian buffer strips.

The target catchment shown in Figure 5-9, the Eastern Cleddau – headwaters to confluence with the Wern, contributes an estimated 1.4 tonnes of TP. Assuming riparian buffers could capture all of the

[32] See: Working with natural processes mapping technical report, available here: https://www.gov.uk/flood-and-coastal-erosion-risk-management-research-reports/working-with-natural-processes-to-reduce-flood-risk, accessed on: 20/05/2022

surface runoff within this sub-catchment, and the buffer had a removal rate of 45% (halfway point between 10% recorded in Vanrobaeys et al, and 80% recorded in Peterjohn & Correll), the estimated 94 hectares of buffer opportunities (50m wide buffers) could remove 630 kg TP, or 6.7 kg TP/ha.

Without a full-scale feasibility exercise, it is difficult to accurately quantify the potential TP removal that these riparian buffers could provide. However, it is possible to demonstrate what information would need to be known in order to predict the TP removal for a riparian buffer scheme. In order to understand the TP loading to a riparian buffer and thus the potential TP removal from a buffer scheme, the following steps would need to be completed:

- Identify a Riparian buffer opportunity area
- Create a catchment boundary and identify flow pathways through topographical analysis. This can be completed through analysis of a Digital Terrain Model (DTM) in a GIS.
- Ensure flows pathways are routed through the riparian buffer opportunity area.
- Calculate the area of the catchment.
- Identify the landcovers, and their areal extents, within the catchment. This would include the soil types, the rainfall volume received and the farm type, if appropriate.
- Use the West Wales Nutrient Budget Calculator, or conduct field scale modelling / monitoring, to establish the TP export coefficients for the landcovers within the catchment.
- Multiply the export coefficients for each landcover type by the relevant export coefficient to calculate the total TP load entering the buffer.
- Apply a TP removal rate, based on sufficient evidence, to the total TP load in order to identify the amount of TP retained by the buffer.

5.4 TARGET AREAS FOR PRRIVATE SEWERAGE UPGRADES

Figure 5-10 shows the consented private sewerage systems, the permitted daily flow limits and the effective date of the consented discharge in the SAC catchments. Assuming a private sewerage system discharged 9.7 mg TP/l, the value used as the default concentration of TP in the final effluent from PTPs, and discharged 10 m^3/day of effluent, this would equate to 35.4 kg TP/year. If this hypothetical example was upgraded to a system that treated the final effluent to 1 mg TP/l, this change would effectively remove 31.8 kg TP/yr from the catchment. Should private sewerage upgrades be targeted, it is recommended that aging systems with high daily flow permits are targeted to maximise the mitigation provided.

Figure 5-4 Map showing the agricultural export coefficients of TP per WFD waterbody within the SAC catchments with nutrient pressures

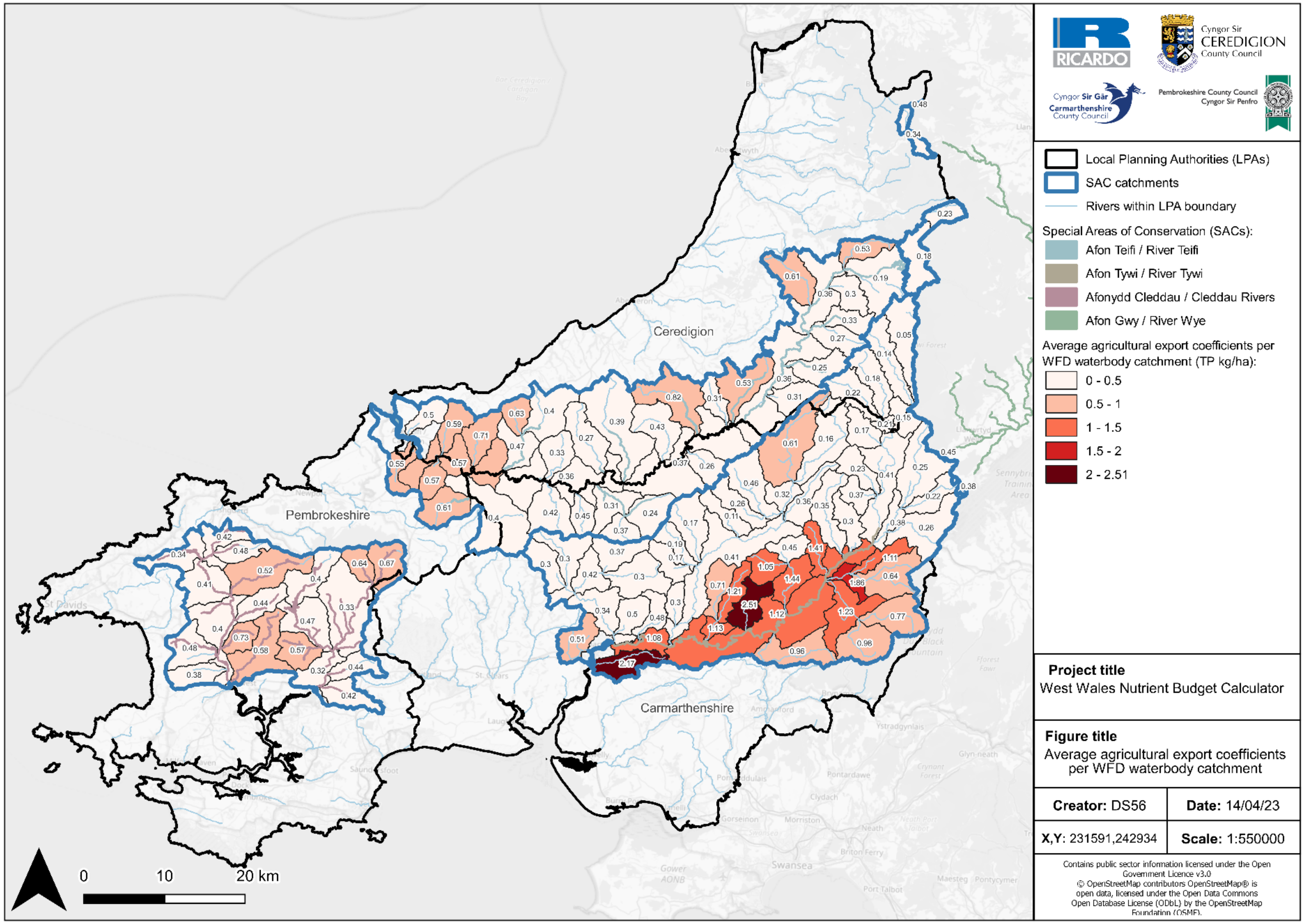


Figure 5-5 Map showing the annual agricultural TP load per WFD waterbody catchment

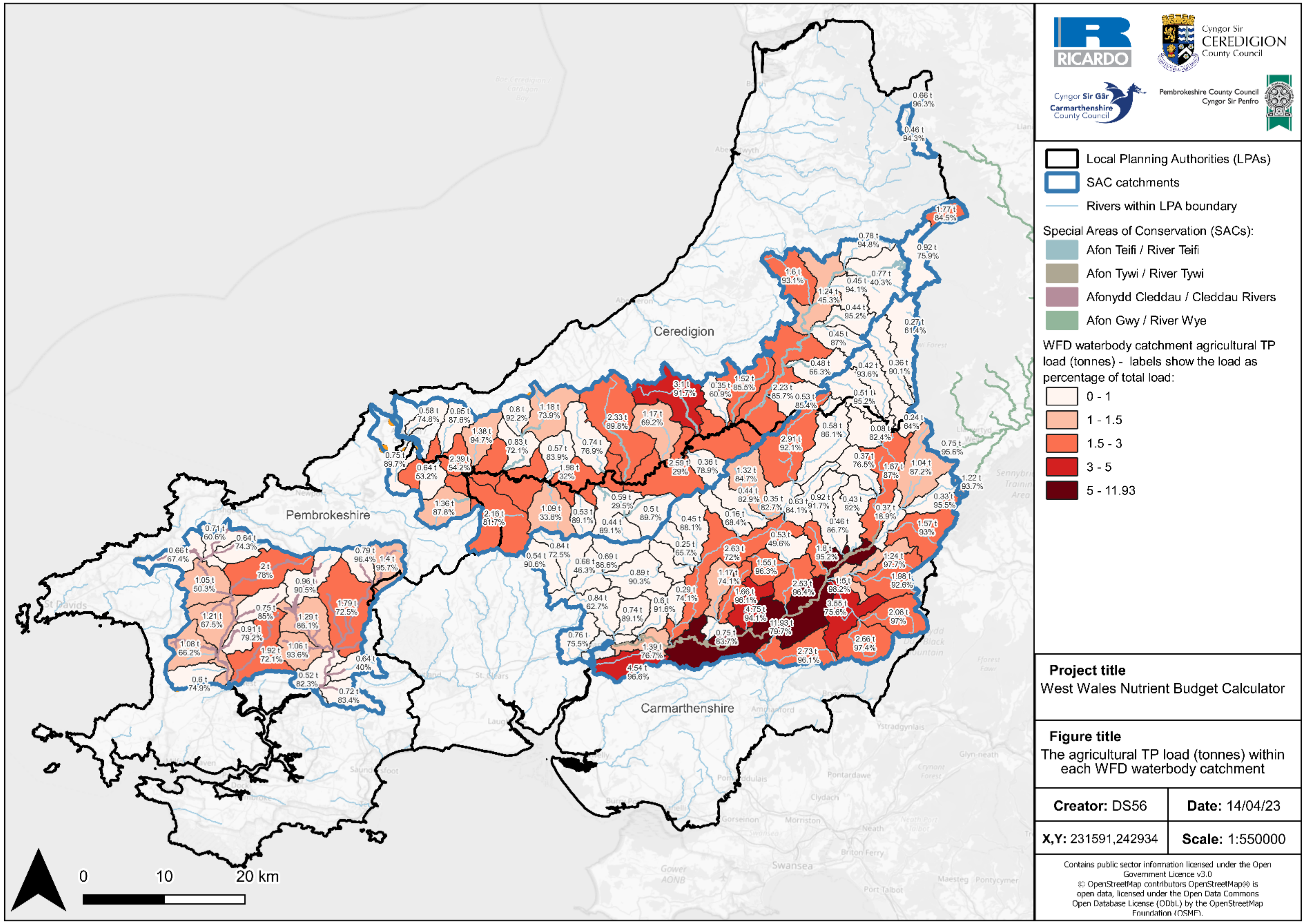


Figure 5-6 Map showing the source apportionment of TP per WFD waterbody catchment

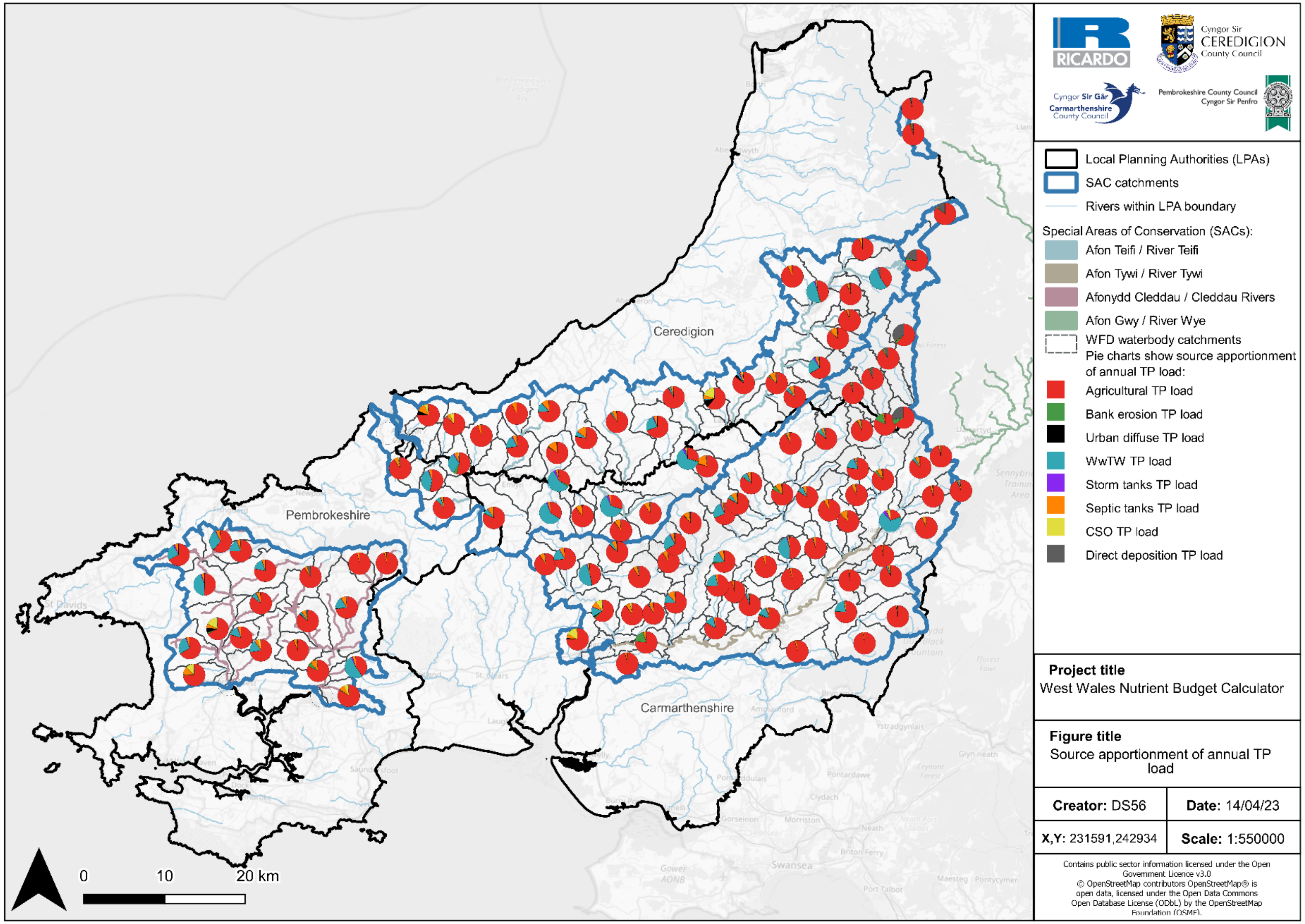


Figure 5-7 A map showing target catchments for riparian buffer creation using the WWNP Riparian Woodland Potential dataset

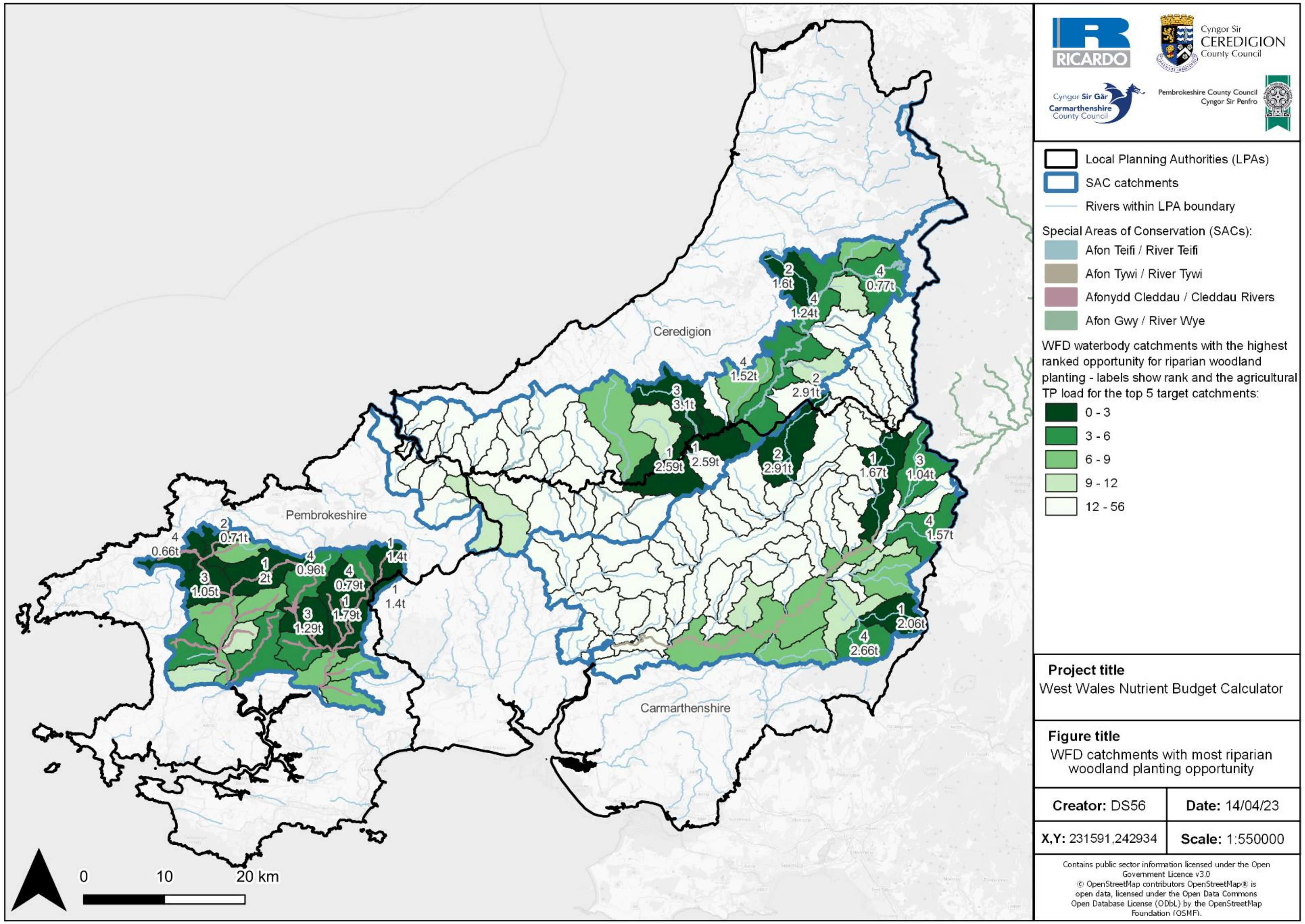


Figure 5-8 A map showing target catchments for runoff attenuation features using the WWNP Runoff attenuation features dataset

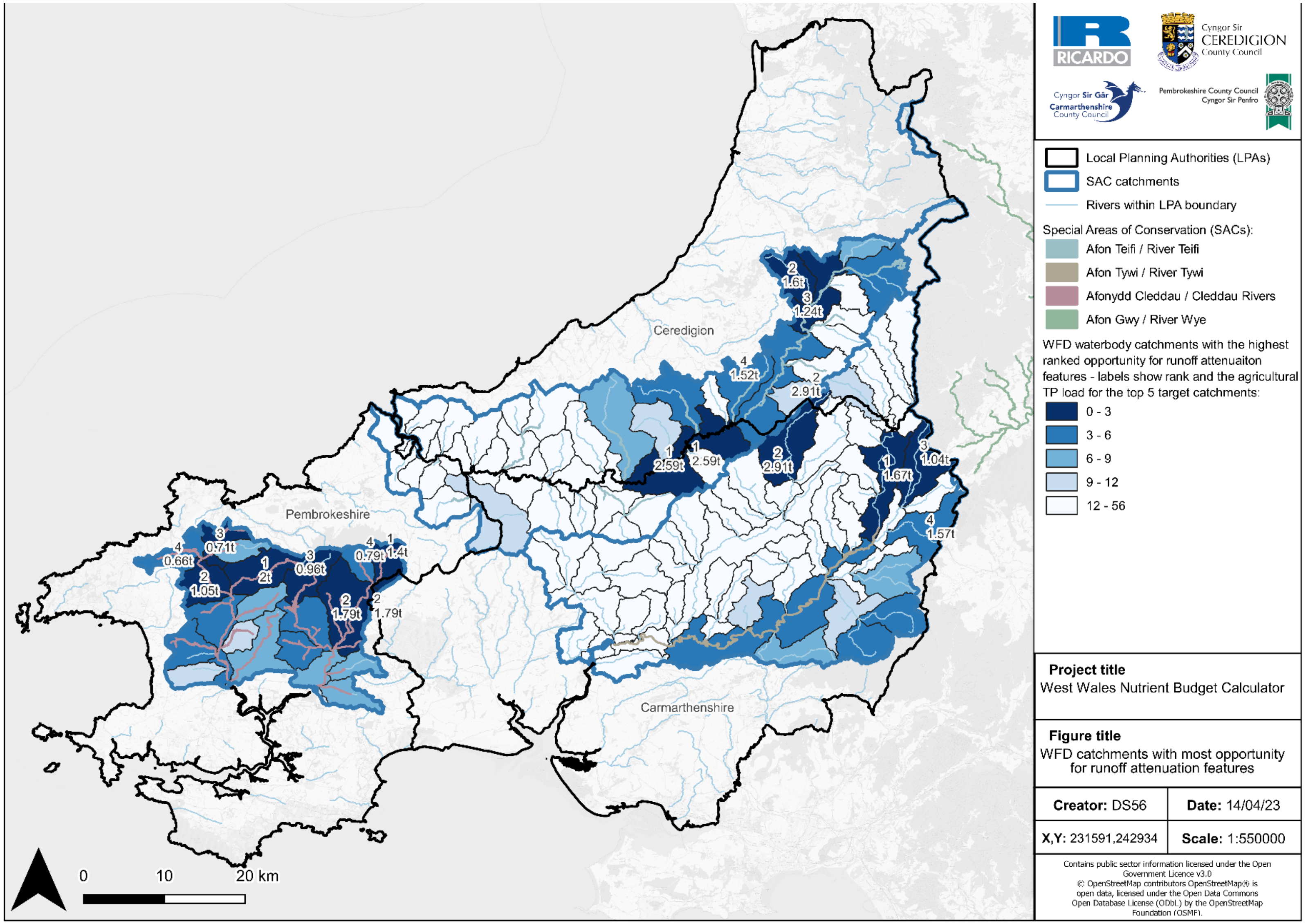


Figure 5-9 Potential locations of mitigation features within the Eastern Cleddau target catchment

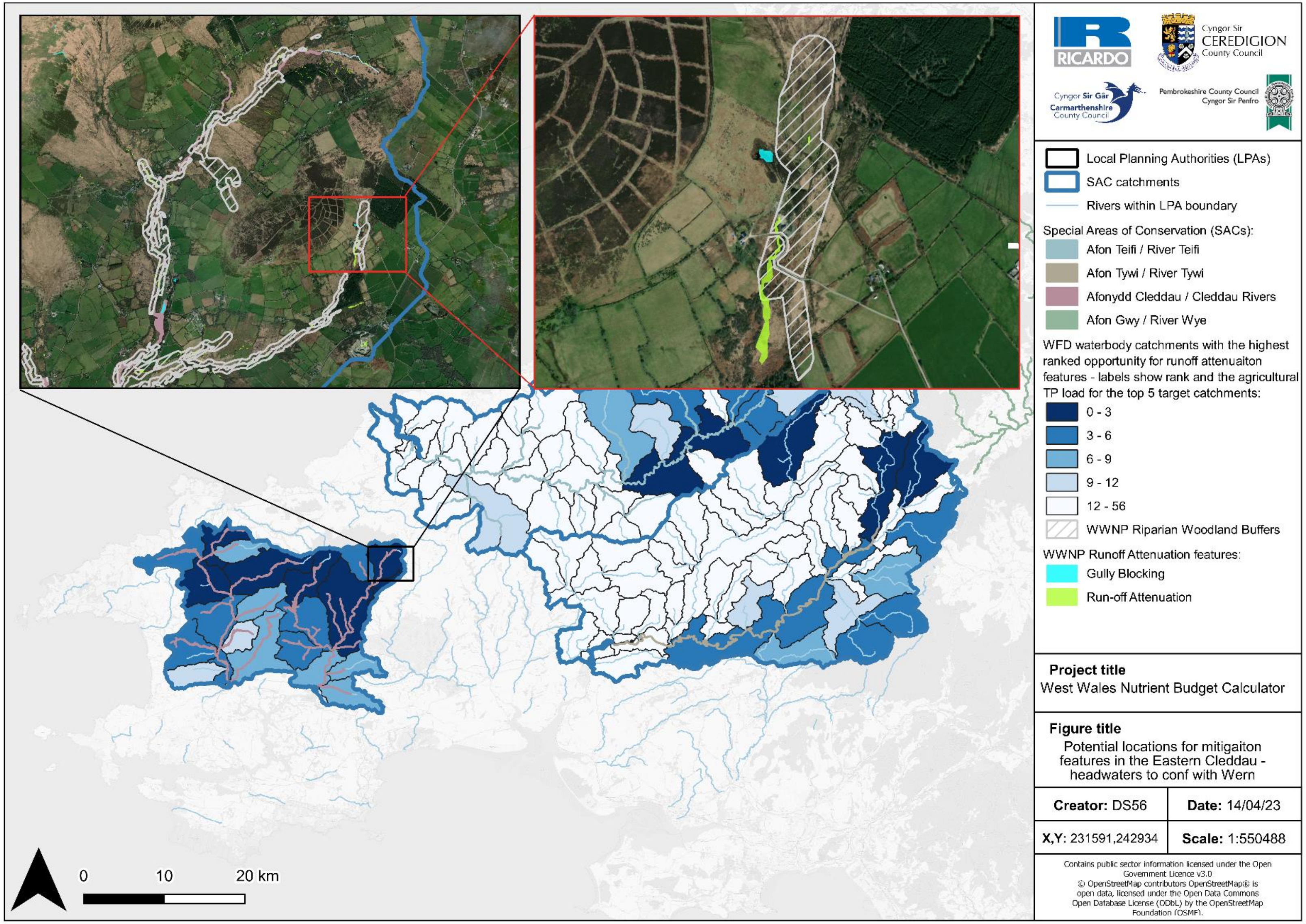
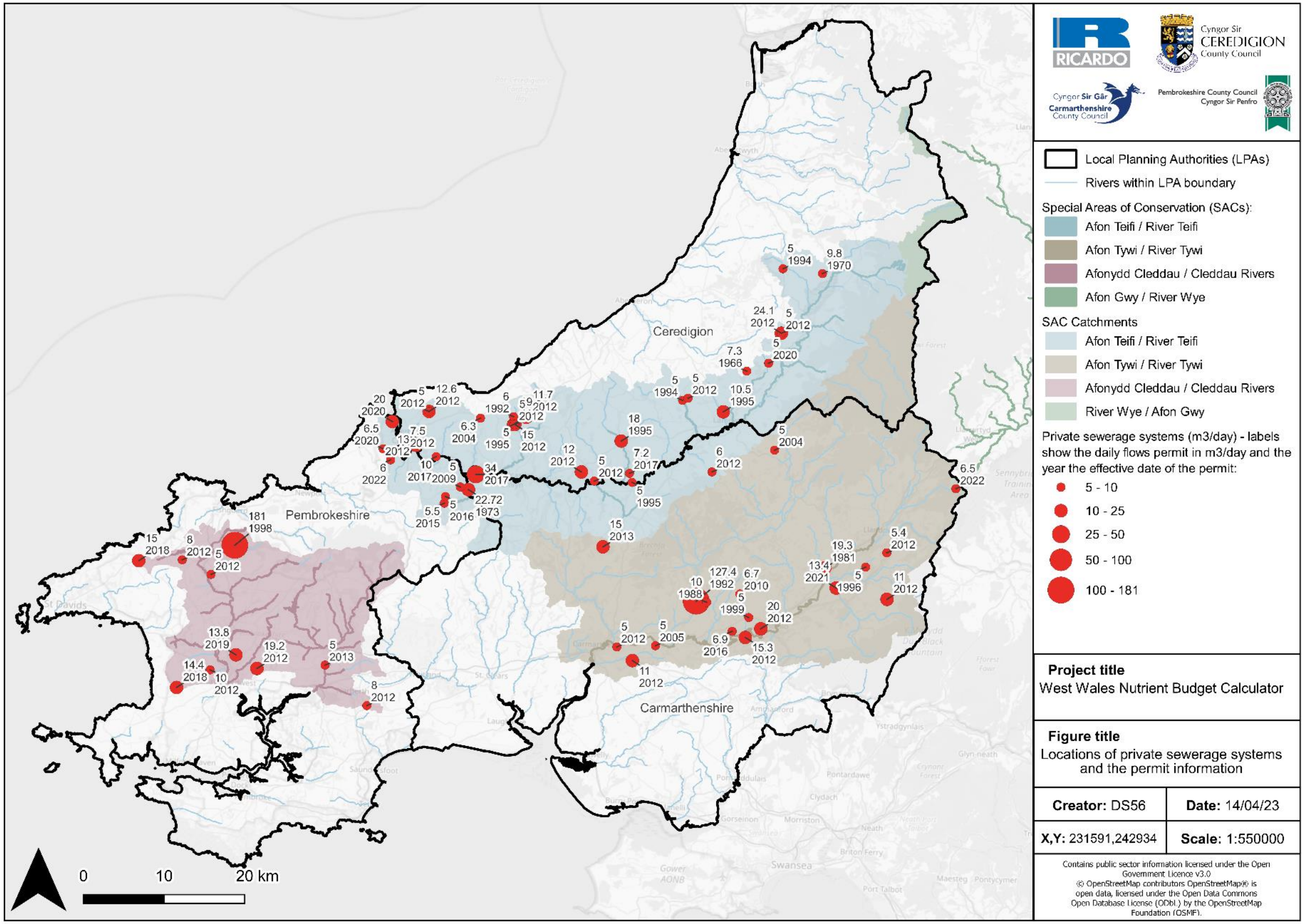


Figure 5-10 Locations of private sewerage systems with daily flow permitted limits



6. GENERIC FRAMEWORK FOR MITIGATION OPTION PROPOSALS

Deployment of any of the mitigation solutions detailed in Sections 3 and 4 will require a supporting mitigation proposal that will provide information on feasibility and supporting technical assessments and/or plans detailing how the quantity of P mitigation will be determined. This section describes some key area that should be covered in a mitigation proposal. The list detailed below is not an exhaustive checklist, but should provide a guide on the kinds of information that will be submitted with a good mitigation proposal. A proposal should aim to include as much information as possible on every point in the list, regardless of the mitigation solution being implemented. Appendix 2 provides a list of key datasets that can be used to assist with formulating a proposal.

Design objectives:

- A proposal for a mitigation solution should have clearly defined objectives. Objectives should aim to state a realistic reduction in TP that a mitigation solution can achieve, based on the best available evidence. Where a TP mitigation solution cannot estimate a reduction in TP loading before it has been implemented, it should state the requirement for monitoring to establish TP load reductions.
- The target P source for reduction should be clearly defined. Any variation in the TP load to the mitigation solution should be estimated and considered. All other sources of TP should be outlined if known.
- Any additional benefits that a solution is aiming to achieve should be detailed.
- The long-term performance of the solution should be described, as well as any potential variability in this performance.

Feasibility assessment:

- List the factors that could affect TP removal performance and might impact getting the proposal approved.
- Common factors related to mitigation deployment site that might impact feasibility include:
    - Topography
    - Soil characteristics (type, grain size, hydraulic conductivity, soil nutrients)
    - Source Protection Zone locations
    - Geology and hydrogeology
    - Groundwater vulnerability
    - Proximity to Flood Zone 2 and 3
    - Proximity to designated sites
    - Location of priority habitats
    - Location of historic monuments and archaeological sites
    - Proximity to strategic land allocation areas
    - Proximity to key infrastructure
    - Previous land use

Design overview:

- The design overview should provide a high-level conceptualisation of the mitigation solution.
- The design overview should recognise the potential for further iterations of a design to incorporate feedback from stakeholders and new evidence.

- The framework for how TP loading to a solution and TP load reductions will be calculated should be clearly set out.
- The design overview should reference any requirements for management and maintenance of a mitigation solution to maintain TP removal functions.

Detailed design of the solution:

- Detailed design should include any features and design elements that are fundamental to the functionality of the solution.
- The design should include the specific information about a solution, such as dimensions, vegetation planting plans, flow rates into and out of a solution and other details that describe how the solution will be built / developed.
- The detailed design should make an explicit link between how a solution's design will promote the processes that remove P.
- Where possible, the detailed design should be used to show how a solution will result in a quantified reduction in P loading.

Implementation of the solution:

- A construction / deployment plan for the solution should be provided.
- This plan should show the key steps required for the delivery of a solution so that it will achieve any stated TP removal performance.
- This plan should also clearly state any required delivery partners and their role in the implementation of a solution.

Monitoring strategy

- A monitoring plan should be provided. This should include information on:
    - The group responsible for monitoring the solution
    - The monitoring period
    - The sampling strategy
    - Baseline monitoring (prior to implementation of a solution)
    - Operational monitoring (post-implementation)
    - Monitoring methods
    - Reporting plan, including how monitoring will be linked to maintenance requirements.

Management and maintenance plan:

- A management and maintenance plan should include:
    - The maintenance requirements to ensure P removal functionality for the lifetime of a solution.
    - The maintenance actions that need to be implemented if functionality reduces.
    - The group responsible for completing these actions.
    - How maintenance will be financed over the lifetime of a solution.
    - How maintenance actions will be logged and reported to a responsible body, if required.

7. DELIVERY PARTNERS

Successful delivery of the mitigation measures described above will require the engagement of a range of partners from different stakeholder groups. Figure 7-1 provides an overview of stakeholder groups that are likely to be engaged in the delivery of each mitigation option. The 3 councils along with the Nutrient Management Board (NMB) for the SAC river catchments within the areas will be involved with the delivery of all P mitigation solutions in the county. NRW will also have a role as the statutory consultee on HRAs to approve mitigation proposals. Developers will be involved in all types of mitigation provision as the end users of the mitigation provided by different solutions. As such, these stakeholders have been placed centrally and linked to all mitigation solutions in Figure 7-1 and will be referred to below as the "central stakeholders". It is also noted that the 3 councils, as the Competent Authorities, will ultimately be responsible for signing off on any kind of mitigation scheme that will support an HRA AA of P neutrality. The stakeholder groups linked to each of the mitigation options in Figure 7-1 may have the roles detailed below for each mitigation option or set of options.

Private sewerage drainage fields

- Unlikely to require other stakeholder engagement than the central stakeholders as the solutions will be managed by property owners.
- These solutions will have technical specifications that will detail how the design of the system will result in a quantified reduction in TP loading, which may be sufficient for a dwelling or dwellings to achieve P neutrality.
- Whilst it is the Competent Authority who will ultimately sign off on the HRA AA that will be supported by the technical specification for a private sewerage drainage field, NRW are also likely to be involved in the sign off process as the statutory consultee for European sites.

Buffer strips, river restoration, engineered logjams

- Both national parks and farmers / landowners / land managers may have a role in determining where these solutions can be deployed.
- Farmers and land managers are likely to need consultation on any impacts these solutions may have on present land uses.
- River restoration and engineered logjams may result in greater local floodplain connectivity, which may result in areas where localised flooding becomes more common, with associated impacts on land use that will impact farmers and land managers.
- There may be a requirement to purchase land from landowners to deploy these solutions. Buffer strips will require an area of land to be given up for the buffer. River restoration schemes may require some land to be given up if the scheme is going to result in changes to river form that will alter areas of riverbank, but not all schemes will require land use to be changed.
- Mitigation proposals for these schemes will require supporting technical information that will detail the reduction in TP a scheme will provide.
- Early engagement with NRW on these proposals will be beneficial and help to ensure proposals and the supporting technical information are sufficiently robust in their approach to quantifying and delivering TP reductions.
- As detailed above, for river restoration and engineered logjams it is likely that a scheme will need to be monitored to evidence the reductions in TP it will deliver. The results of the monitoring and thus the TP reductions provided by one of these schemes are likely to require ratification by NRW.
- For buffer strips, it is likely that engagement with NRW will be needed to agree the percentage reduction in TP a scheme can deliver. As detailed above, we suggest a precautionary value of *x*% has support based on the literature and this can be used as a starting point for engagement with NRW.
- Rivers trusts and wildlife trusts may have a dual role in both provisioning these mitigation solutions and the long-term maintenance and management.

- The NMB should be consulted to consider the location of these schemes and how this might interact with other P reduction schemes.

Agricultural land use change, drainage ditch blocking, sediment traps

- Both national parks and farmers / landowners / land managers may have a role determining where these solutions can be deployed.
- Farmers and land managers are likely to need consultation on any impacts these solutions may have on present land uses.
- Sediment traps and drainage ditch blocking may both cause a loss of areas of land that could be used for farming and thus would need to have agreement with farmers that they will be maintained.
- Mitigation proposals for these schemes will require supporting technical information that will detail the reduction in TP a scheme will provide.
- Early engagement with NRW on these proposals will be beneficial and help to ensure proposals and the supporting technical information are sufficiently robust in their approach to quantifying and delivering TP reductions.
- As detailed above, for drainage ditch blocking it is likely that a scheme will need to be monitored to evidence the reductions in TP it will deliver. The results of the monitoring and thus the TP reductions provided by one of these schemes are likely to require ratification by NRW.
- Sediment traps and agricultural land use change schemes are likely to be able to have their potential TP reduction benefit quantified before deployment. NRW will require engagement on the supporting technical information to show scale of TP reduction that can be achieved by these proposals.
- Wildlife trusts may have a dual role in both provisioning these mitigation solutions and the long-term maintenance and management.
- The NMB should be consulted to consider the location of these schemes and how this might interact with other P reduction schemes.

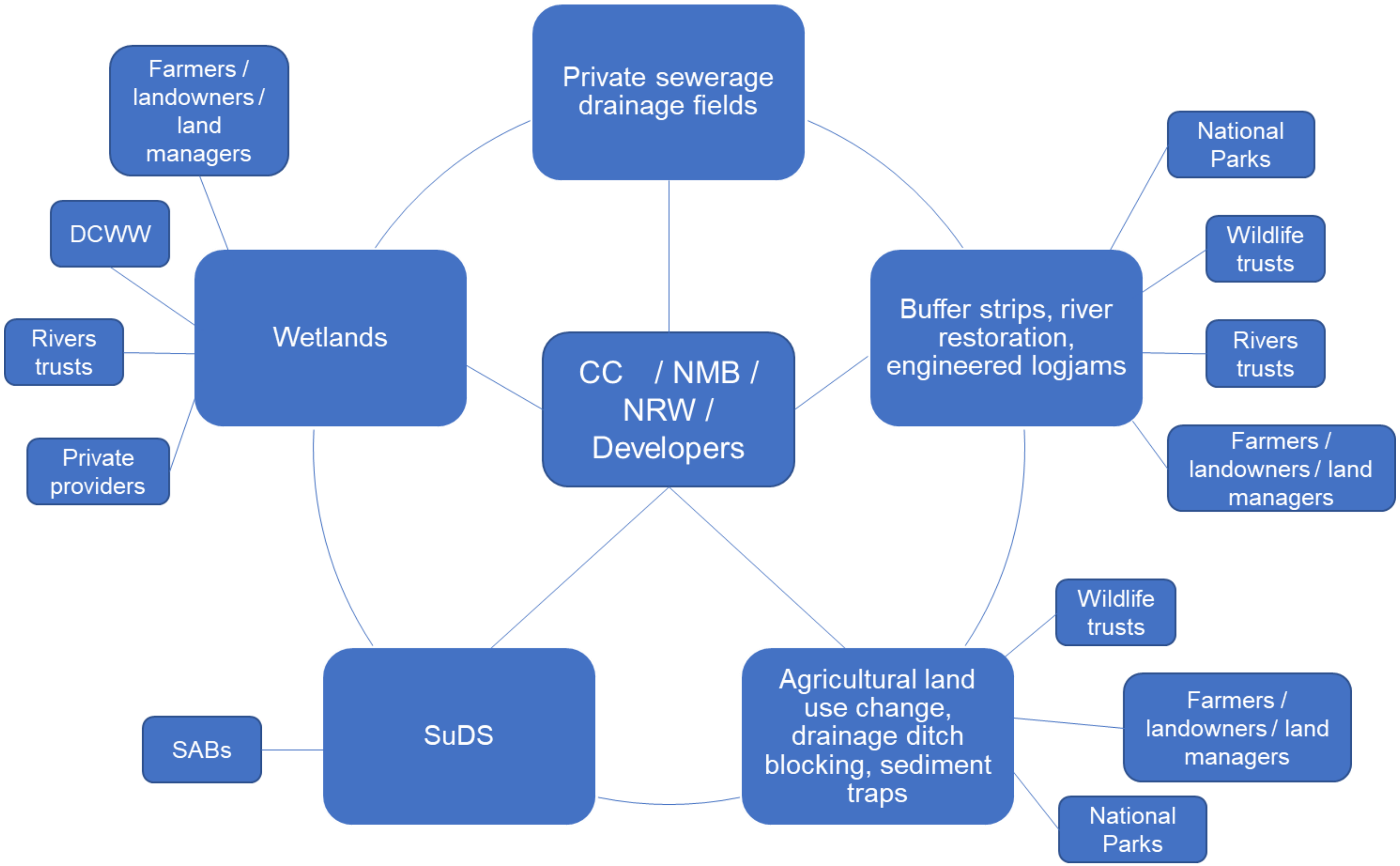
SuDS

- A technical report detailing the SuDS design and how this design will result in a quantified amount of TP reduction will need to be provided to the Competent Authority and NRW.
- SuDS Approving Bodies (SABs) will be involved in the approval and adoption of SuDS schemes.

Wetlands

- Likely to be deployed on agricultural land, requiring engagement with farmers / landowners / land managers.
- WwTWs are a key source of water to supply treatment wetlands, requiring engagement with DCWW.
- NRW will require consultation on the design of a wetland to ensure they are confident that the wetland will deliver stated TP mitigation benefits.
- The Competent Authority and the NMB may have a role in determining strategic locations where wetlands should be deployed, in order to serve the largest amount of development.
- Rivers trusts may play a role both in the design and commissioning process and/or the long-term management and maintenance of a wetland.
- Private providers of wetlands schemes may choose to develop schemes to sell P credits to developers.

Figure 7-1: Diagram showing the likely stakeholders who will need to be engaged for each type of mitigation option, noting that some mitigation options are likely to require engagement with similar stakeholder groups. N.b. CC = County Council, NMB = Nutrient Management Board, NRW = Natural Resources Wales, DCWW = Dwr Cymru Welsh Water, SABs = SuDS Approving Body.



8. SUMMARY

This technical review has detailed a set of mitigation options that may be appropriate for mitigating P in the three West Wales councils. The review has sought to provide guidance on how these mitigation solutions could be deployed in order to provide TP offsetting and support sustainable house building within the county. An initial longlist of mitigation options was selected based on previous reviews of mitigation options. From this longlist, a shortlist of options was developed based on an analysis of whether a mitigation option has the evidence-base required to show that it will be able to provide P mitigation beyond reasonable scientific doubt and/or whether the option is viable for deployment. This shortlist includes options which have an evidence-base that is sufficient to provide confidence that an option will deliver P mitigation, but where monitoring may be required to quantify the amount of TP mitigation the option can provide.

Each shortlisted option has been reviewed to provide detail on the processes within each option that remove or immobilise P within the environment. These processes were categorised as P removal by sedimentation, P removal by chemical sorption to sediment and P removal by plant uptake. Different combinations of these processes are active in each of the shortlisted mitigation options, with different processes active in different types of the shortlisted options. Various factors affect the efficacy of these processes within each mitigation option and these should be considered in proposals for a given mitigation option to maximise the potential P removal that an option can deliver. Different practical considerations and long-term maintenance and monitoring are required for each mitigation option. These practical considerations as well as maintenance and monitoring plans should be included in mitigation proposals and will help to secure the P removal potential of a scheme. Monitoring plans should be developed as part of the mitigation outline design process. Monitoring design should be developed relative to need to support most effective maintenance and to demonstrate nutrient mitigation success. As such monitoring timelines will be dependent on a range of factors including, for example, current knowledge base, scale, location and design. Deployment of P mitigation schemes will need to be supported by a proposal detailing the design of a scheme. If it is possible to predict the amount of TP a scheme will remove before it is deployed, the design will provide details of how this predicted TP removal has been calculated. Alternatively, for options where quantifying the reduction of TP will require monitoring, a mitigation proposal should include design details that include what monitoring will be required to evidence the TP reductions delivered by a scheme.

Wetlands, drainage fields and SuDS can be designed in such a way that the TP removal potential of these options can be predicted before they are deployed. A detailed design for each of these solutions should provide the relevant supporting information, data and calculations that can quantify the scale of TP removal each option can achieve. Prediction of the TP removal an option can receive should embed enough precaution to allow for the option to underachieve without causing a risk that developments relying on a scheme will not have sufficient mitigation available. Where suitably precautionary estimates of mitigation potential are made for wetlands, drainage fields and SuDS, monitoring the performance of scheme may provide the opportunity to release additional mitigation if the option is found to be performing better than predicted.

Agricultural land use change involving woodland planting or rewilding can evidence TP reductions from this option easily as the removal of agricultural P sources can be readily quantified using agricultural TP export coefficients. However, due to the relatively low amount of P that comes from average agricultural land uses relative to the cost of agricultural land, rewilding and woodland planting schemes are likely to be a very costly way of generating P mitigation. Conversion of farming systems to agroforestry provides an approach to generating P mitigation from agricultural land that means that farmers can continue to generate income from agricultural production while managing farms in a way that reduces P pollution. The evidence to support the scale of P reduction from agroforestry is relatively limited and may not be sufficient to provide accurate predictions of the amount of P mitigation that these schemes can deliver. Monitoring an agroforestry scheme may be required to determine the scale of P reductions it can achieve.

Buffer strips, drainage ditch blocking and terrestrial sediment traps all provide P mitigation solutions that can be deployed within the agricultural landscape to retain diffuse P pollution. These solutions could also be deployed in urban areas, but fewer studies of their application in urban environments have been found. The theory supporting the potential of these mitigation to remove P is robust, however it is likely that monitoring of these schemes will be required to provide a robust quantification of the scale of P mitigation a solution can deliver. Buffer strips have the most evidence of their TP reduction potential and it may be possible to provide a precautionary estimate of their efficacy through a well-reasoned and well evidenced design process.

River channel re-naturalisation is likely to result in P reduction benefits but will require monitoring to determine the scale of P reductions they can achieve. This approach can also have range of ancillary benefits, such as NFM, carbon sequestration and biodiversity improvements that could support their deployment as P mitigation schemes that will deliver significant co-benefits. Engineered logjams can have similar benefits however, are suggested as short-term mitigation measures due to the temporary nature of the primary P removal processes and the potential for remobilisation under flood conditions.

This report has also provided outputs from a GIS exercise that demonstrated the utility of using open-source datasets to aid decision making on mitigation strategies and where mitigation can be targeted across the West Welsh councils. The WwTW have been identified that are likely to contribute a high TP load to the three council’s SAC rivers. In Carmarthenshire, Pembrokeshire and Ceredigion it is recommended that a catchment-wide mitigation strategy should target these WwTW initially due to the potential reductions that a well-designed treatment wetland could provide and thus ability for these sites to provide a predictable quantity of strategic mitigation that can help to unblock development. The GIS exercise also highlighted how a freely available dataset can be used to target locations where catchment management-based mitigation solutions such as riparian buffers, terrestrial sediment traps and drainage ditch blocking could be deployed.

Finally, an outline for a general framework to support mitigation proposals was elaborated that highlights the kind of details a mitigation proposal should include in order to evidence that a mitigation solution will deliver quantifiable reductions in P pollution. This framework includes considerations on how to determine the feasibility of a mitigation option and recommendations on how option design can be used to increase certainty that an option will deliver P mitigation. Part of a successful mitigation proposal will be required the identification of any delivery partners. Suggestions of the likely partners required for engagement in the delivery of each option were detailed. The LPAs in this area of West Wales, the NMB, NRW and developers are likely to be involved in the delivery of all mitigation options. Specific mitigation options are likely to have distinct stakeholder groups that may need engagement to support delivery of an option. These groups may include landowners / land managers where an option will require land use change. Engagement with DCWW for the deployment of treatment wetland schemes. And engagement with Environmental NGOs who may be able to support both the deployment and long-term management of various different types of mitigation solution.

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Front page image credits:

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APPENDICES

Appendix 1 Longlist of mitigation solutions

The long list of mitigation options is provided in the table below.

Mitigation Solution	Included?	Justification
Private sewerage with drainage fields	Yes	They are appropriate for small developments and sewerage systems can provide technical documentation evidencing TP removal / concentration of the final effluent.
Private sewerage upgrades	Yes	There are many ageing private sewerage systems within the three counties that could be upgraded.
SuDS	Yes	These are a legal requirement. They can be designed to achieve relatively high certainty of a known TP removal rate.
Wetlands	Yes	They are nature-based solutions that can be designed to achieve relatively high certainty of a known TP removal rate.
Buffer strips	Yes	
Agricultural land use change / short rotation coppice / agroforestry	Yes	
River restoration	Yes	They have a lot of theoretical evidence for TP removal, albeit with difficulty to quantify specific TP removal rate without conducting monitoring work. They are part of wider catalogue of catchment management practices.
Sediment Traps	Yes	
Drainage Ditch Blocking	Yes	
Engineered logjams	Yes	
Taking fish farms out of production	No	One fish farm within affected catchments.
Water efficiency measures	No	It is very difficult to predict or measure the impact of water efficiency measures in sewer catchments for WwTWs without a TP permit. Maintenance of water efficiency measures is hard to secure in perpetuity.
Reducing the intensity of agricultural production	No	It is difficult to predict or measure the impact of TP reductions. Significant lag times due to legacy P stores. Difficult to secure and measure in perpetuity.
Transporting excess phosphorous from dairy farms to arable farms	No	
Regulatory controls on agricultural phosphorus	No	
Reduce leakage from the foul sewage network	No	Quantifying the potential reduction in TP loading that these options will deliver is very difficult.
Reduce leakage from potable water supply	No	

<table>
<tr><th>Mitigation Solution</th><th>Included?</th><th>Justification</th></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Increased treatment of effluent</td><td>No</td><td>This is outside of the control of the LPA and the developer and would have to be delivered by Dwr Cymru Welsh Water. The Asset Management Planning cycle and regulations on water companies that limit their ability to receive direct payments for upgrades at WwTWs limits the ability to deploy these solutions. This solution also contains a lot embodied carbon and thus is not aligned with the water sector’s Net Zero strategies.</td></tr>
<tr><td>Diverting surface water flows away from the sewage network</td><td>No</td><td rowspan="2">There are only three works with TP permits in affected areas and this will only reduce TP loading in sewer catchments where WwTWs have TP permits. Furthermore, it is extremely difficult to quantify the TP load mitigated due to the complexity of wastewater treatment processes.</td></tr>
<tr><td>Addressing misconnections</td><td>No</td></tr>
</table>

Appendix 2 Useful opensource datasets

This section lists some datasets that could be useful to help locate mitigation solutions and cover the key themes in the generic framework for mitigation option proposals.

Datasets that can be used to locate mitigation features:

Name: WWNP Runoff Attenuation Features 1% AEP
Link: http://lle.gov.wales/catalogue/item/WWNPRunoffAttenuationFeatures1/?lang=en
Description: locations of high flow accumulation across the land surface or in smaller channels, where it may be possible to temporarily store water and attenuate flooding during high flows. For the 1 in 100-year event. This could be used for locating wetlands, sediment traps, drainage blocking areas etc.

Name: WWNP Runoff Attenuation Features 3.3% AEP
Link: https://datamap.gov.wales/layers/inspire-nrw:NRW_WWWP_RUNOFF_ANTEN_3PC
Description: locations of high flow accumulation across the land surface or in smaller channels, where it may be possible to temporarily store water and attenuate flooding during high flows. For the 1 in 100 year event. This could be used for locating wetlands, sediment traps, drainage blocking areas etc.

Name: WWNP Riparian Woodland Potential
Link: https://datamap.gov.wales/layers/inspire-nrw:NRW_WWNP_RIPERIAN_WOODLAND_POTENTIAL
Description: locations where tree planting may be possible on smaller floodplains close to flow pathways. This could be used for locating areas of riparian buffer creation.

Name: WWNP Floodplain Woodland Planting Potential
Link: https://lle.gov.wales/catalogue/item/WWNPFloodplainWoodlandPlantingPotentialWales/?lang=en
Description: locations where tree planting on the floodplain may be possible that are not wooded. This could be used for locating areas of buffer creation or areas to target agricultural land use change.

Name: WWNP Wider Catchment Woodland Potential
Link: https://datamap.gov.wales/layers/inspire-nrw:NRW_WWNP_WIDER_CATCHMENT_POTENTIAL
Description: locations where there are slowly permeable soils, where scrub and tree planting may be most effective to increase infiltration and hydrological losses. This could be used for locating areas of buffer creation or areas to target agricultural land use change.

Name: WWNP Floodplain Reconnection Potential
Link:https://datamap.gov.wales/layers/inspire-nrw:NRW_WWNP_FLOODPLAIN_RECONECTION_POTENTIAL
Description: dataset shows the locations where it may be possible to reconnect a watercourse and its natural floodplain, especially during high flows. The dataset targets areas of currently poor connectivity. This can be used to locate potential areas for wetlands receiving stream flow.

General landcover information for assessing site suitability:

Name: Soilscapes
Link: http://www.landis.org.uk/soilscapes/
Description: An online map of soil types in the UK.

Name: Landmap Landscape Habitats
Link: http://lle.gov.wales/catalogue/item/LandmapLandscapeHabitats/?lang=en
Description: Geographic dataset showing habitat landscape classification for Wales.

Name: OS Open Zoomstack
Link: https://www.ordnancesurvey.co.uk/business-government/products/open-zoomstack
Description: UK landcover spatial data (roads, surface water, greenspace, buildings)

Name: WFD Groundwater bodies Cycle 2
Link: http://lle.gov.wales/catalogue/item/WaterFrameworkDirectiveWFDGroundwaterBodiesCycle2/?lang=en
Description: Groundwater spatial data. This can be used for ascertaining the groundwater vulnerability to pollution.

Name: WFD River Waterbody Catchments Cycle 2
Link:
https://lle.gov.wales/catalogue/item/WaterFrameworkDirectiveRiverCatchmentWaterbodiesCycle2/?lang=en
Description: Geospatial data showing the hydrological catchments of rivers, streams and canals

Name: CORINE landcover
Link: https://land.copernicus.eu/pan-european/corine-land-cover/clc2018?tab=download
Description: UK landcover spatial data.

Name: British Geological Survey (BGS) Geology 625k
Link: https://www.bgs.ac.uk/datasets/bgs-geology/
Description: UK geology spatial data.

Name: Flood Map for Planning Flood Zones 2 and 3
Link: https://datamap.gov.wales/layergroups/inspire-nrw:FloodMapforPlanningFloodZones2and3
Description: Flood map spatial data.

Datasets that may affect the feasibility of a mitigation solution:

Name: Ancient Woodland Inventory 2021
Link: https://datamap.gov.wales/layers/inspire-nrw:NRW_ANCIENT_WOODLAND_INVENTORY_2021

Description: Spatial data showing the locations of Ancient Woodlands.

Name: Peatlands of Wales
Link: https://datamap.gov.wales/layers/geonode:peatlands_of_wales_scg8
Description: Spatial data showing the location of peatlands.

Name: Source Protection Zone (SPZ) (Zone 1)
Link: https://datamap.gov.wales/layers/inspire-nrw:NRW_Source_Protection_Zones
Description: Spatial data showing the locations of SPZ

Name: WOM21 Priority Habitat - High Sensitivity
Link: https://datamap.gov.wales/layers/geonode:gwc21_priority_habitat_high_sensitivity
Description: Spatial data showing semi-natural habitats which are listed as priority habitats under Section 7 of the Environment Act.

Name: Geological Conservation Review (GCR) Site Boundaries
Link: https://datamap.gov.wales/layers/inspire-nrw:NRW_GCR_SITES
Description: Spatial data showing the site boundaries for all Geological Conservation Review

Name: National Inventory of Woodland and Trees
Link: https://datamap.gov.wales/layers/inspire-nrw:NRW_NIWT
Description: Spatial data showing woodland areas.

Name: National Nature Reserves (NNR)
Link: https://datamap.gov.wales/layers/inspire-nrw:NRW_NNR
Description: Spatial data showing NNR in Wales.

Name: National Trails
Link: https://datamap.gov.wales/layers/inspire-nrw:NRW_NATIONAL_TRAIL
Description: Spatial data showing national trails.

Name: National Parks
Link: https://datamap.gov.wales/layers/inspire-nrw:NRW_NATIONAL_PARK
Description: Spatial data showing the locations of National Parks.

Name: Open Access - Registered Common Land
Link: https://datamap.gov.wales/layers/inspire-nrw:NRW_COMMON_LAND_2014

Description: Spatial data showing locations of public access land.

Name: Open Access - Other Statutory Access Land
Link: https://datamap.gov.wales/layers/inspire-nrw:NRW_OTHER_STATUTORY_LAND_2014
Description: This spatial dataset contains all Common Land with a higher right of access.

Name: Ramsar Wetlands of international importance
Link: https://datamap.gov.wales/layers/inspire-nrw:NRW_RAMSAR
Description: Spatial data showing the locations of Ramsar designated wetlands

Name: Regionally Important Geological and Geomorphological Sites (RIGS)
Link: https://datamap.gov.wales/layers/inspire-nrw:NRW_RIG_SITES
Description: Spatial information showing RIGS.

Name: Scheduled Monuments
Link: https://datamap.gov.wales/layers/inspire-wg:Cadw_SAM
Description: Spatial data showing archaeological sites of national importance.

Name: Sites of Special Scientific Interest (SSSI)
Link: https://datamap.gov.wales/layers/inspire-nrw:NRW_SSSI
Description: Spatial data showing locations SSSIs.

Name: Special Areas of Conservation (SAC)
Link: https://datamap.gov.wales/layers/inspire-nrw:NRW_SAC
Description: This spatial dataset shows the locations of SACs..

Name: Special Areas of Conservation (SPA)
Link: https://datamap.gov.wales/layers/inspire-nrw:NRW_SPA
Description: This spatial dataset shows the locations of SPAs/

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