REPORT

River Clun SAC

Nutrient Mitigation Solutions

Client: Shropshire Council

Reference: PC3212-RHD-ZZ-XX-RP-Z-0013

Status: Draft/02

Date: 20 December 2023

Royal HaskoningDHV
Enhancing Society Together

HASKONINGDHV UK LTD.

Westpoint
Peterborough Business Park
Lynch Wood
Peterborough
PE2 6FZ
United Kingdom
Water & Maritime

+44 1733 3344 55 **T**
info@uk.rhdhv.com **E**
royalhaskoningdhv.com **W**

Document title:	River Clun SAC
Subtitle:	Nutrient Mitigation Solutions
Reference:	PC3212-RHD-ZZ-XX-RP-Z-0013
Your reference	-
Status:	Draft/02
Date:	20 December 2023
Project name:	River Clun Nutrient Mitigation
Project number:	PC3212

Classification
Project related

Revision	Date	Description	Prepared	Checked	Approved
00	02.08.2023	Draft Version	JB	OB	ID
01	08.08.2023	Draft Version	JB & TM	OB	ID
00	14.11.2023	Final version	JB & TM	OB	ID

Royal HaskoningDHV

Table of Tables

Table of Figures

Abbreviations

Abbreviation	Description
ADAS	Agricultural Development and Advisory Service
AMP	Asset Management Planning
BNG	Biodiversity Net Gain
CIRIA	Construction Industry Research and Information Association
CJEU	Courts of Justice of the European Union
CSF	Catchment Sensitive Farming
CSS	Countryside Stewardship Scheme
CW	Constructed Wetlands
DEFRA	Department for Environment Food and Rural Affairs
Dutch-N	Dutch Nitrogen Joint Cases
EIA	Environmental Impact Assessment
ELMS	Environmental Land Management Scheme
GIS	Geographic Information System
HRA	Habitats Regulations Assessment
LPA	Local Planning Authority
NN	Nutrient Neutrality
P	Phosphate
PTPs	Package Treatment Plants
PTWs	Portable Treatment Works
SAC	Special Area of Conservation
SSSI	Site of Special Scientific Interest
SuDS	Sustainable Drainage Systems
TAL	Technically Achievable Limit
TP	Total Phosphorus
WFD	Water Framework Directive
WRC	Water Recycling Centre
WwTWs	Wastewater Treatment Works

Units of Measurement

Unit	Description
$g/m^2/yr$	Grams per metres squared per year
Kg	Kilogram
kg/yr	Kilograms per year
kg/ha/yr	Kilograms per hectare per year
kg TP/d	Kilogram of Phosphorus per day
kg TP/yr	Kilogram of Phosphorus per year
km	Kilometre
ha	Hectare
m	Metres
m^2	Metres Squared
m^3	Metres cubed
Ml/d	Megalitres per day
mg/l	Milligrams per litre
mg TP/l	Milligrams of Phosphorus per litre
SRP/ha/yr	Orthophosphate per hectare per year
t/ha	Tonnes per hectare
t/yr	Tonnes per year
TP/yr	Total Phosphate per year
TP/ha/yr	Total Phosphate per hectare per year
Yr	Year
%	Percentage
£	Pound Sterling
£/ha	Pound Sterling per hectare
£/kg	Pound Sterling per kilogram
£/yr	Pound Sterling per year
£/kg/yr	Pounds sterling per kilogram per year

1 Introduction

1.1 Nutrient neutrality and the Dutch Nitrogen Case

A joint legal case was brought to the Court of Justice of the European Union (CJEU) regarding authorisations for schemes with respect to agricultural activities on sites protected by the *Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and species* ('The Habitats Directive') and where nitrogen deposition levels already exceeded the critical load.

Following the Dutch Nitrogen Joint Cases (the 'Dutch-N') in the CJEU which ruled that where a European important site, i.e., , Special Areas of Conservation (SACs) and/ or Special Protection Areas (SPAs), is failing to achieve condition due to pollution, the potential for a new development to add to the nutrient load is "*necessarily limited*". Similarly, internationally important wetland sites which are designated as Ramsar sites have also been caught up in the judgement as under national policy they are afforded the same protection as SACs and SPAs. The Dutch-N has informed the way in which Regulation 63 of the Habitats Regulations 2017 should apply to pollution related incidents.

The Conservation of Habitats and Species (Amendment) (EU Exit) Regulations 2019 brought the Habitats Regulations 2017 into force from 1 January 2021. The Dutch-N ruling has resulted in greater scrutiny of proposed developments that are likely to increase nutrient loads to internationally important sites where a reason for unfavourable condition is an excess of a specific pollutant. The Dutch-N case applies to National Site Network sites which are already in an unfavourable condition due to high nutrient levels in combination with the importance of the designation.

The types of development that are impacted include:

- New residential units, student accommodation, care homes;
- Tourist attractions including campsites, glamping pods, and holiday lets;
- Commercial developments where overnight accommodation is provided;
- Agricultural development including additional barns, slurry stores; and
- Anaerobic Digesters.

In March 2022 Natural England published updated guidance on water quality and nutrient neutrality (NN) advice (NE785) which identified a further twenty protected sites that are adversely affected by nutrient pollution. The River Clun SAC was identified being in an 'unfavourable condition' due to the continued depletion of the freshwater pearl mussel (FPM) population as a result of declining water quality. As a result, Shropshire Council ('the Council') are not able to grant planning permission for new developments that provide overnight accommodation within the catchment of the River Clun SAC unless it can be clearly demonstrated that they will not have a detrimental impact in terms of nutrient loading to the designated protected area.

1.2 Purpose of this report

This report discusses potential solutions that could be used to offset increased nutrient loadings and allow development in the catchment of the River Clun SAC to proceed whilst remaining nutrient neutral. **Section 2** of this report provides an overview of the River Clun SAC and its contributing catchments. Housing projections to identify likely mitigation requirements required within the River Clun SAC catchment are also laid out in **Section 2**. Potential nutrient management solutions are described in **Section** 3, and **Section 4** provides a summary of the main findings of the report and recommendations for next steps.

Natural England has not reviewed this report; therefore, the report has not received agreement or endorsement from Natural England. Furthermore, a Habitats Regulations Assessment may be required to demonstrate NN for any new development proposals.

2 Background

Natural England specifies Conservation Objectives for ecologically protected habitats. These are referred to in the Habitats Regulations 2017 and provide a framework which informs the need for 'Habitats Regulations Assessments' (HRA).

2.1 River Clun SAC

The River Clun is approximately 46 km long with a total catchment area of approximately 27 km² (**Figure 2-1**). The River Clun SAC is characterised by inland water bodies (standing or running water: 33%), improved grassland (55%) and broad-leaved deciduous woodland (12%). The Clun SAC is designated under article 4(4) of the Directive (92/43/EEC) due to hosting the freshwater pearl mussel (*Margaritifera margaritifera*) and is also a component of the River Teme Site of Special Scientific Interest (SSSI).

The River Clun is a tributary of the River Teme, which is the second largest tributary of the River Severn, draining a hilly, predominantly rural catchment of Silurian and Devonian rocks. The site includes only the lower reaches of the river and extends upstream from the confluence with the Teme to Broadward Bridge near Marlow. This section of the river holds a population of the freshwater pearl mussel, one of the few lowland populations left in the UK. The freshwater pearl mussel larvae attach to the gills of salmon and trout before eventually detaching and settling in the riverbed gravels where they grow to adulthood.

A joint position statement from the Environment Agency, Natural England, Shropshire Council and Severn Trent Water states that whilst the favourable conservation targets recognise the unique environmental value of the River Clun SAC, there is also the need to recognise the value of the area as an important rural community. This means taking account of the requirement for new development to maintain and meet future community needs. The joint vision for the River Clun SAC is therefore for the whole catchment area to be restored to a functional unit where a nature recovery plan enables ecological and human needs to success fully interact, thereby balancing the needs of people, economy, and the environment.

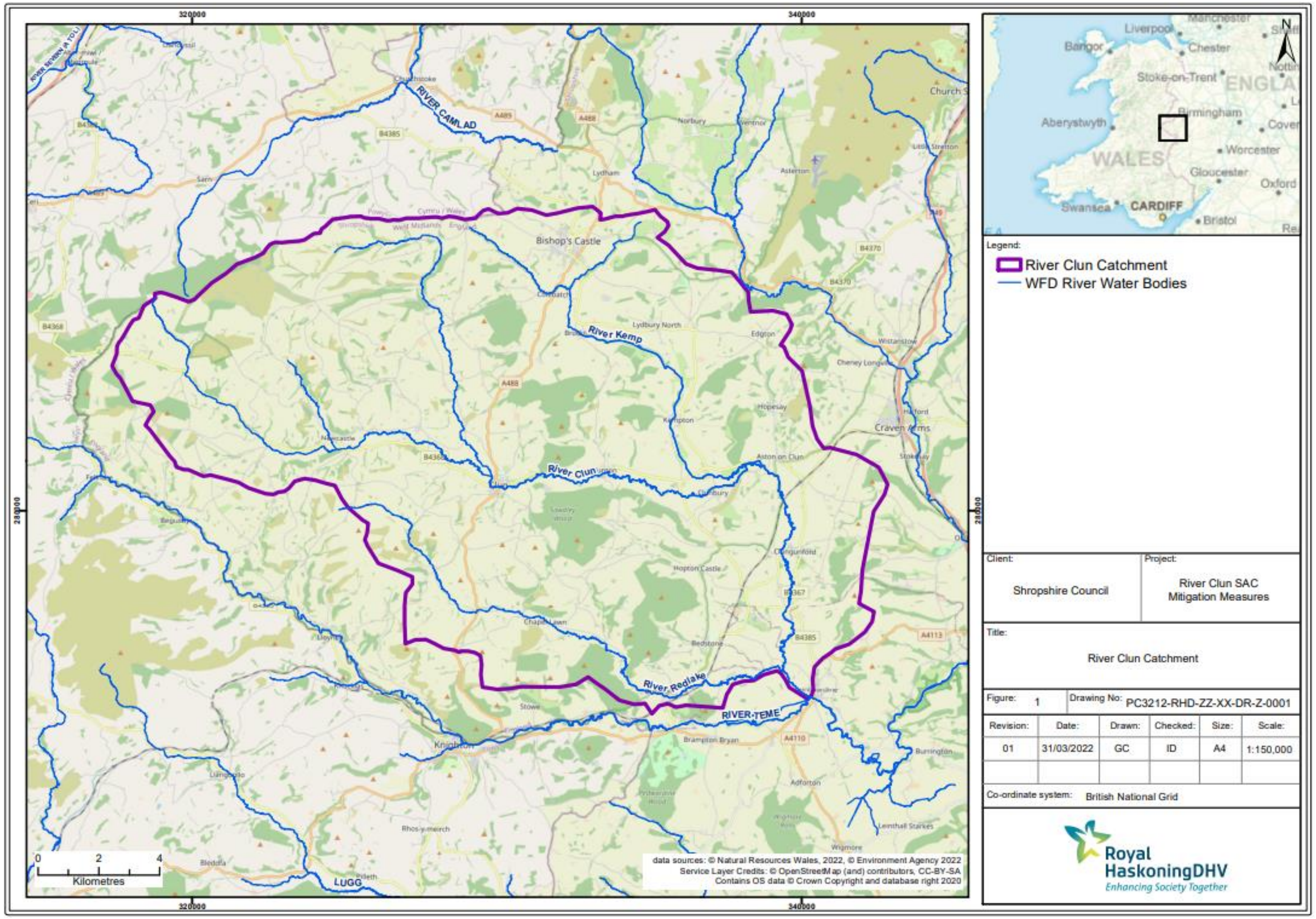


Figure 2-1: River Clun Catchment

2.2 The River Clun catchment

The Clun catchment drains the eastern slopes of the Cambrian Mountains, and the River Clun flows in a south easterly direction until it joins the River Teme at Leintwardine. The total catchment area is 27km^2, and includes three main sub-catchments, namely Folly Brook, River Kemp, and River Redlake. In terms of assessing water quality, the Clun catchment has been divided into eight water bodies by the Environment Agency as per the requirements of the Water Environment (Water Framework Directive) (England and Wales) Regulations 2017 (as amended) (**Figure 2-2**).

Note that there appear to be slight discrepancies between the River Clun catchment boundary as defined by the River Clun Strategic Liaison Group and the sub-catchment boundaries as defined by the WFD River Water Body Catchments. We have used the boundary defined by the River Clun Strategic Liaison Group for consistency through this report.

Key catchment physical descriptors relevant to phosphorus pollution include:

- Easily erodible soils. Most (35% of the catchment) is characterised by soils from the Barton series soil type, which has a large silt and fine sand content. This leads to capping during heavy rain and runoff then causes erosion on slopes. Risks greatest in spring before the crop cover is established and during summer storms which follow dry spells (Atkins, 2014).
- High catchment connectivity. The Clun catchment is highly connected to the surface drainage network, and a limited amount of land in the catchment is more than 1km from running water (Howells, 2011). The catchment is dominated by steep slopes and incised valleys. These provide numerous flow pathways and potential for expansion of the drainage network during wet periods.
- Land use. Land use is dominated by temporary grass (sown in last five years) and permanent pasture (over 5 years old). Cropping is dominated by wheat and barley, and livestock by fowl and sheep (**Table 2.1**).
- Land quality. Land in the west and south is generally Grade 4-5 (poor to very poor); land in northern, central and south eastern areas is typically Moderate to good (Grade 3) with very limited areas of Grade 2.

Table 2.1: Crop, land use and livestock types in the Clun catchment (Atkins, 2014)

Crop Type	Area (ha)
Wheat	1,366
Barley	1,396
Oats & rye	617
Maize	80
Potatoes	52
Oilseed rape	456
Stock feed crops	129
Land use	**Area (ha)**
Temporary grass (<5 years old)	1,795
Temporary grass (>5 years old)	13,461

Crop Type	Area (ha)
Rough grazing	250
Woodland	557
Livestock type	**Area (ha)**
Cattle	13,914
Sheep	159
Pig	119,282
Fowl	287,784

At a sub-catchment scale, the 2010 Defra agricultural census shows that:

- Arable land use is concentrated in the Kemp and Lower Clun sub-catchments.
- Cattle are spread throughout the catchment but are most concentrated in the Middle Clun.
- Sheep are most concentrated in the upper catchments (Upper Clun, Middle Clun, Folly Brook, River Unk).
- Fowl and poultry are restricted to the Lower Clun and Kemp – the density of animals in the Lower Clun is more than double that in the Kemp catchment.
- The Clun catchment was a pilot catchment for the Catchment Sensitive Farming (CSF) initiative which started in 2005. CSF can provide a good route for delivery of advice to farmers on general diffuse pollution and capital grants to help with implementation, However, the CSF programme was not set up to specifically deliver reductions in agricultural phosphorus pollution in water bodies and as such is only so far estimated to have resulted in a small percentage reduction in in-river nutrient concentrations (Atkins, 2014).

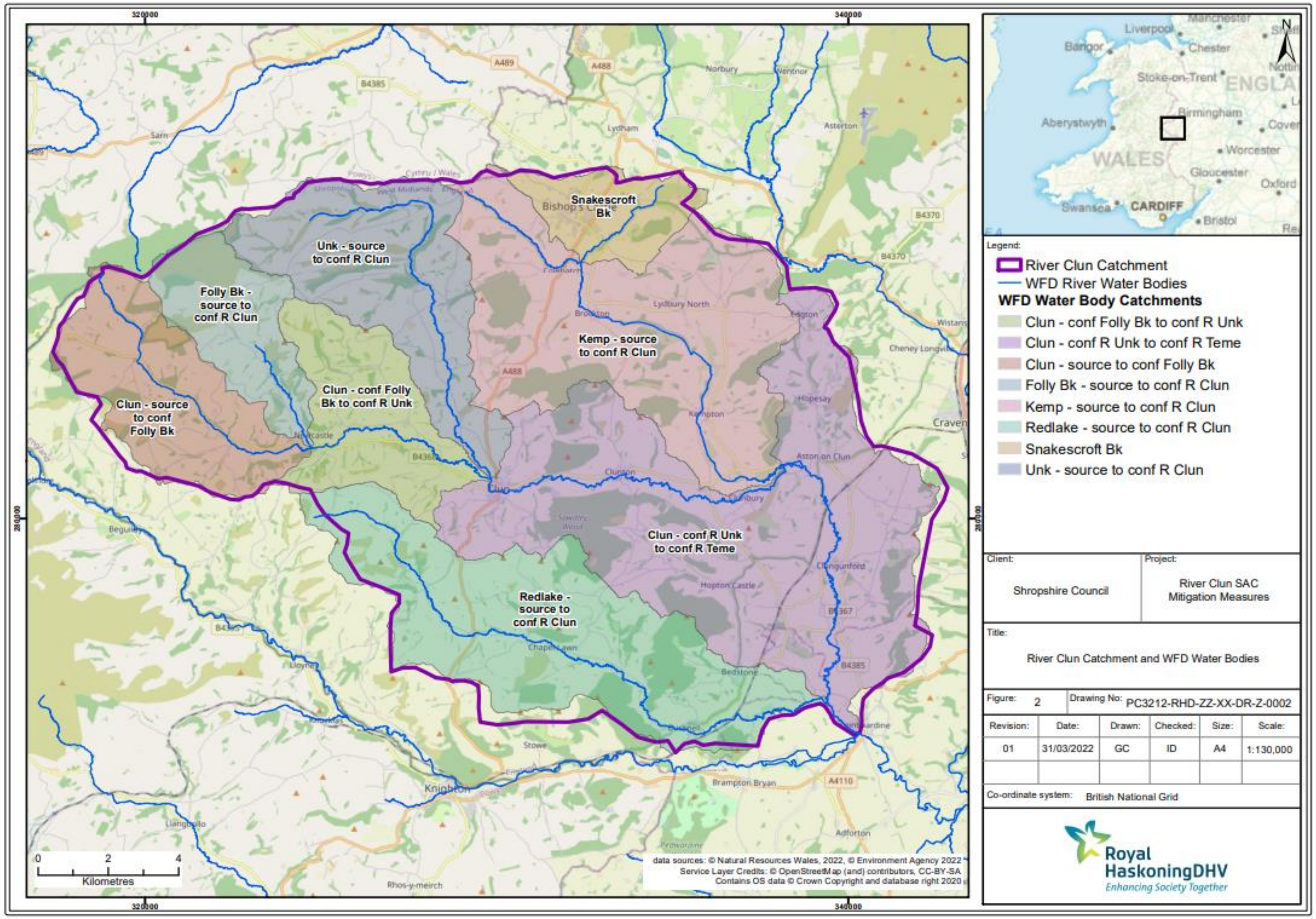


Figure 2-2: Water Framework Directive waterbodies within the River Clun catchment

2.3 The need for mitigation

The Clun catchment has a long-term records of phosphorus, nitrogen and suspended solids measured monthly at Leintwardine since 1995. As well as current WFD data, two key documents have been used to review water quality with respect to the Clun SAC:

- the Atkins (2014) Clun Nutrient Management Plan, and;
- the Natural England (2021) SAC water quality review.

Supplementary data reviewed includes an analysis of catchment population and STW permit limits. Water quality conservation targets (Natural England, 2021) for the Clun SAC are set at 0.01mg/l for orthophosphate. This target must be met as an annual average, a 3-year rolling mean and as a growing season mean (March to September inclusive).

One of the key drivers of water quality monitoring in the Clun SAC is freshwater pearl mussel (FPM) habitat. This species lives buried or partly buried in coarse sand and fine gravel and requires clean, oligotrophic, fast-flowing and unpolluted water. The phosphorus favourable condition target for FPM is expressed as mean annual Soluble Reactive Phosphorus (SRP); the Environment Agency uses orthophosphate to estimate dissolved and soluble phosphate levels in rivers. Data covering the last three years (2018-2020 inclusive) is shown in **Figure 2-3**.

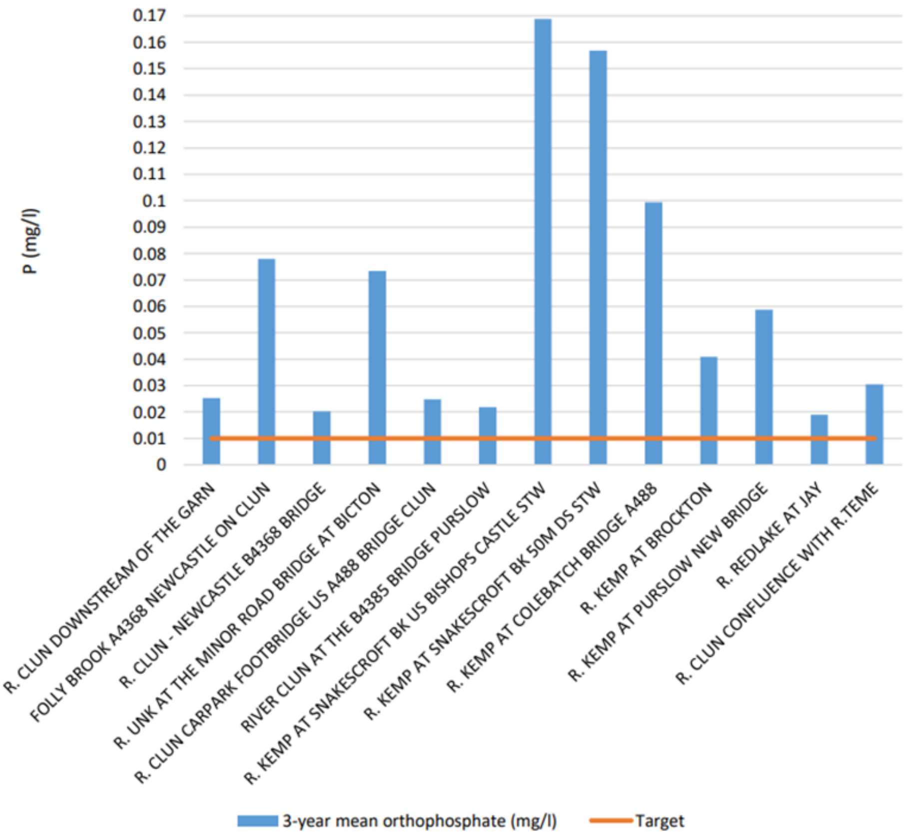


Figure 2-3: Three year mean orthophosphate values throughout the River Clun Catchment (upstream to downstream) (Natural England, 2021)

Key points identified through analysis of the Environment Agency's phosphate monitoring data include:

- Phosphate levels have declined as a result of AMP5 funded phosphate-stripping of the Bishops Castle STW (in 2007) and Bucknell STW (in 2010).
- Since 1990, application of fertilisers are reported to have declined by 67% on grassland and 51% on tillage land, while phosphate from manures is reported to have reduced by 20% between 1990 and 2012.
- Monitoring throughout the catchment shows a general downstream increase in mean annual phosphate levels. At locations downstream of Clun, phosphate levels were higher than those required for a functioning pearl mussel population. The highest concentrations were recorded in the River Kemp and in the Clun at Purslow.
- The latest 3-year mean orthophosphate (P) recorded within the SAC is 0.032mg/l, 320% of the site target of 0.01mg/l. Data suggests that the River Clun SAC is still far in excess of its nutrient targets, with little or no improvement since 2007 when a small reduction in phosphate occurred. Phosphate levels are consistently more than double the site target throughout the entire length of the River Clun (Natural England, 2021).

The nitrogen favourable condition target for freshwater pearl mussel is expressed as mean annual Total Oxidised Nitrogen (TON). Long-term TON data are shown in **Figure 2-4**. Although concentrations declined steadily between 1995 and 2012, as of the latter date they were still 2 – 3 times greater than the favourable condition target for freshwater pearl mussel.

The most recent Natural England data shows that the 3-year mean TON recorded within the SAC is 4 mg/l which is 267% of the site target of 1.5 mg/l.

Spatially, TON levels are above the favourable condition target throughout the Clun catchment. In the Folly Brook and Mid Clun sub-catchments concentrations are closest (1.65-1.82 mg/l) to the favourable condition target (1.5. mg/l) target (Atkins, 2014). Elsewhere, annual average TON levels are at least two times the favourable condition target and more than 5 times the target in the Kemp sub-catchment.

Recent Natural England data confirms this historical pattern as TON levels were found to fall below the SAC target in the upper reaches but exceeded it from the Middle Clun and then increase along the river's length to the SAC, where levels far exceed the target value.

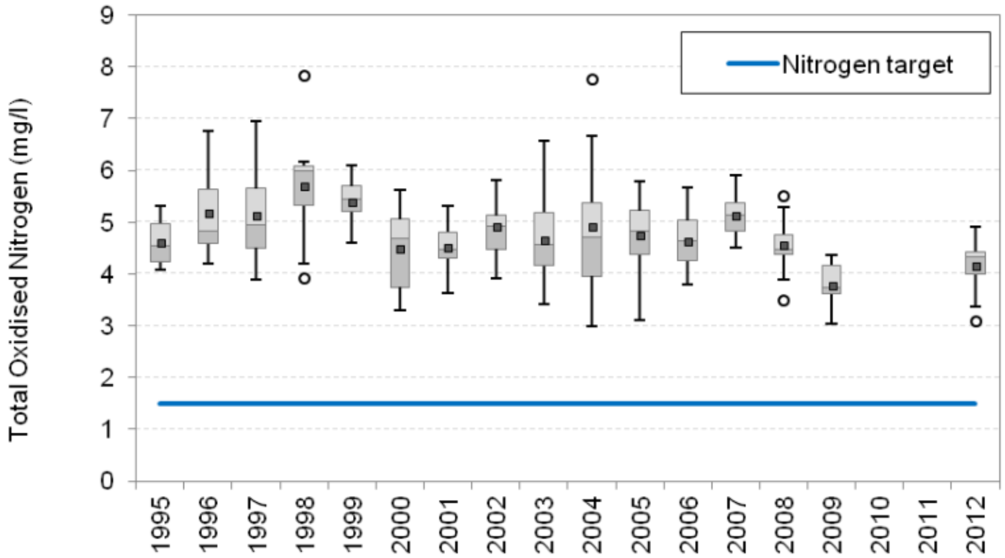


Figure 2-4: Mean annual nitrogen levels (TON) in the River Clun SAC at Leintwardine from 1995 to 2012. The boxes represent the inter-quartile range and the midline of the box the median. The black circles represent outliers. Whiskers represent the maximum and minimum values. The blue line is the long term favourable condition target (Atkins, 2014).

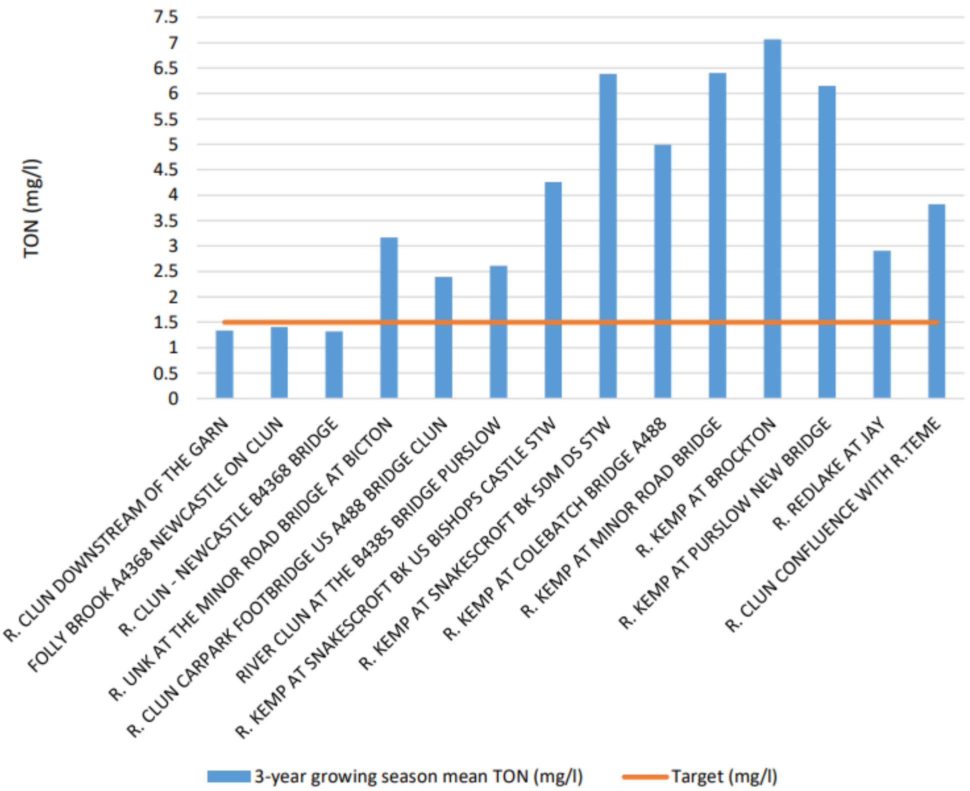


Figure 2-5: Three year mean TON values throughout the River Clun Catchment, upstream to downstream (Natural England, 2021).

Longer term (2014 onwards) trends in P and TON are generally static. There has been a general deterioration in P in the Folly Brook and River Unk sub-catchment. There have been potential improvements in TON at some locations, although confidence is low.

2.4 Projected mitigation requirements

2.4.1 Methods and assumptions

A review of the Draft Shropshire Local Plan (2016-2038) data and housing projections was undertaken to understand the mitigation required to meet the upcoming housing requirements. The additional nutrient loading from the projected housing was calculated using the River Clun Nutrient Budget Calculator ('the Calculator') (Royal HaskoningDHV, 2023). Worst-case scenarios were assumed to ensure the nutrient loading value is not understated. For example, conservative assumptions were taken on future permit limits and land use types.

The following assumptions were made:

- Local Planning Authorities (LPAs) are required by law to produce an annual report which demonstrates whether they have a deliverable supply of homes to meet their planned housing requirement over the next five years. Nutrient neutrality (NN) guidance has affected the ability of the Council to deliver housing and therefore demonstrate a five-year land supply. As such the delivery of housing is a key pressure, more so than other accommodation types, and is therefore the focus of this report;
- All new dwellings were assumed to be houses with an average occupancy of 2.33 persons per dwelling;
- It is assumed by Natural England that anyone living in the NN catchment also works and uses facilities in the catchment. Therefore, wastewater generated by commercial and industrial development is not considered, removing the potential for double counting of human wastewater arising from different planning uses;
- Other types of overnight accommodation, e.g., , campsites, holiday homes, hotels, etc., that do not fall under the same use class as dwellinghouses (Class C) are not considered, as there are no projections on the likelihood or number of these accommodation types being brought forward;
- The previous land use of the sites was derived from aerial imagery;
- Where the land use type was uncertain, it was assumed to be general arable which represents the dominant land use in the catchment;
- The proposed land use following development was assumed to be medium-density urban;
- The soil drainage type was derived from Soilscapes (Cranfield Soil and AgriFood Institute, 2018)[1] and the dominant soil type was found to be freely draining in the River Clun catchment;
- The Wastewater Treatment Works (WwTWs) that a proposed development will drain to was estimated using Geographic Information System (GIS) data on the existing catchment;
- The standard deviation of the measured average phosphorus discharge was derived and applied to treatment works. However, where there is a greater than 10% increase in population proposed, it was assumed these treatment works (i.e., Clun) operated at 90% of their permit.
- Where onsite treatment plants are to be used, default values of 5 mg/l Total Phosphorous (TP) and 25 mg/l Total Nitrogen (TN) were used. These represent the likely effluent concentration from a typical

[1] Soilscapes soil types viewer - Cranfield Environment Centre. Cranfield University (landis.org.uk)

Package Treatment Plant (PTP) but are still conservative estimates of what P-stripping PTPs can achieve;

- A 20% buffer was applied to the calculations in line with Natural England guidance on NN (Natural England, 2020); and,
- The catchment that a development will contribute the nutrient loading to was determined by the location of the water recycling centres (WRCs). Some developments will be located in one surface water catchment, but the wastewater (and majority of the nutrient contribution) will drain to a different catchment.

It was assumed that all development currently held up would require nutrient mitigation by the end of 2025. This assumption ensures that mitigation requirements reflect the realistic demand for mitigation. The calculations consider reductions in permit limits that will take effect at the end of the Asset Management Planning (AMP) 7 Cycle (December 2024).

Furthermore, proposed 2030 permit limit reductions were also included following the Department for Levelling Up, Housing and Communities announcement (18th November 2022). It was assumed that only WRCs with a current Population Equivalent (PE) of greater than 2,000 residents would be operating at Technically Achievable Limit (TAL) by 2030. The TAL for TP is 0.25 mg/l. It is assumed within the calculations that planned upgrades to WRCs will be implemented by 2030 at the latest, however information on the target dates and scale of these improvements is pending confirmation from the water company and Defra.

2.4.2 Housing budget projections

The projected housing growth was derived from the draft Local Plan and current planning applications. A total of 306 dwellings are projected to be constructed across approximately 12.9 ha of the catchment area. **Table 2.2** provides a breakdown of the number of dwellings and their status.

Table 2.2: Shropshire housing projections evidence base for the period 2022-2038

Location of Dwellings	No. of dwellings				
	Permissions (requiring mitigation)	Saved SAMDev Allocations	Draft Local Plan Allocations	Windfall	Total
Bishop’s Castle	18	40	0	35	93
Bucknell	0	70	20	8	98
Clun	1	60	20	8	89
Lydbury North	9	11	0	0	20
Abcot, Beckjay, Clungunford, Hopton Heath, Shelderton and Twitchen (Three Ashes)	4	0	0	0	4
Newcastle and Whitcott Keysett	0	0	0	0	0
Total	32	181	40	51	304

The following equation was used to calculate the nutrient loading requirements per development.

$$Nutrient\ loading = \left(\frac{D\ \times O\ \times W\ \times C}{1000000} \times 365.25\right) + \left(\left(A\ \times R_f\right) - \left(A\ \times\ R_c\right)\right) \times P$$

Where:

$nutrient\ loading$ (kg/yr), D = No. of dwellings, O = occupancy rate (persons/dwelling), W = water usage (l/person/day), C = effluent concentration (mg/l), A = surface area of site (m2), R_f = future land use runoff coefficient (kg/ha/yr), R_c = current land use runoff coefficient (kg/ha/yr) and P = Precautionary buffer.

Equation 1: Nutrient loading requirements per development

The expected excess P and N loading per year across the NN catchment area is provided in **Table 2.3** and **Table 2.4** and the total amount of P and N required to be mitigated per year is represented visually in **Figure 2-6** and **Figure 2-7**. This includes both temporary mitigation (required until planned upgrades at wastewater treatment works are completed) and permanent mitigation (required for the duration of the development).

The total mitigation required up to 2039 is 19.20 kg/yr TP, and 659.81 kg/yr TN. In the period 2023-2025, the total mitigation required is 1.94 kg/yr TP and 59.12 kg.yr TN. The TP and TN loading per year in 2025 is 1.76 kg/yr and 59.12 kg/year, and between 2026-2034 approximately 0.85 kg/yr and 33.40 kg/year requires mitigation. Between 2034-2038 1.48 kg/yr TP and 54.47 kg/year TN will need mitigation.

Further information on projected nutrient loadings from new housing is provided in **Appendix 1**.

Royal HaskoningDHV

Table 2.3: Total P loading and mitigation required across period 2023-2038

Mitigation type	Phosphorus loading over the Plan period (kg/yr)																
	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	Total
Permanent	1.94		1.76	0.85									1.48				**19.20**

Table 2.4: Total N loading and mitigation required across period 2023-2038

Mitigation type	Phosphorus loading over the Plan period (kg/yr)																
	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	Total
Permanent	59.12			33.40									54.47				**659.81**

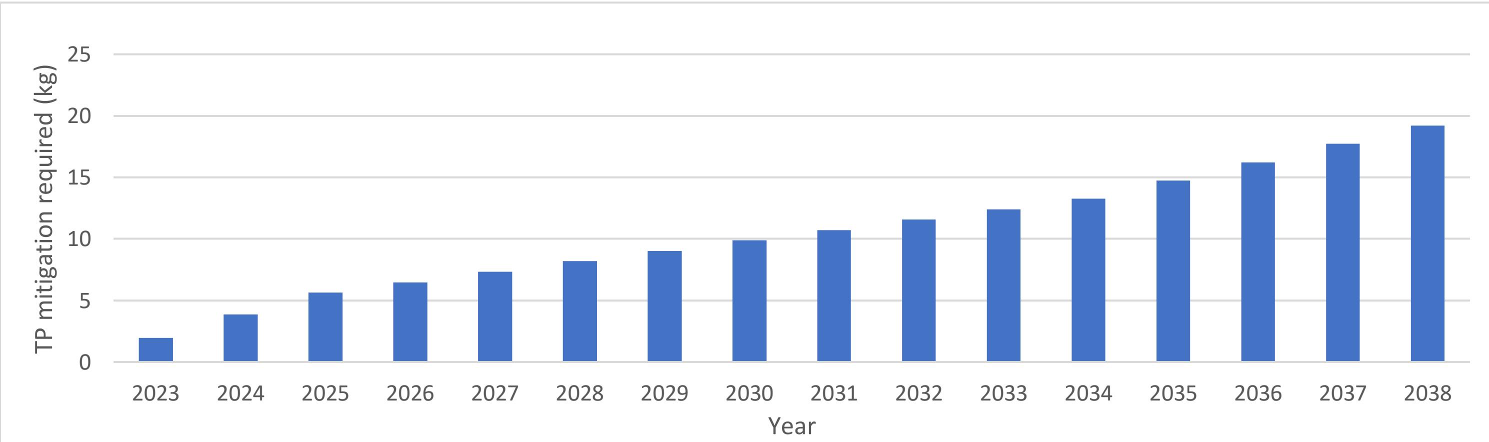


Figure 2-6: Amount of P mitigation that must be delivered by permanent solutions per year to successfully mitigate P produced by existing planning applications, allocated sites, and windfall sites

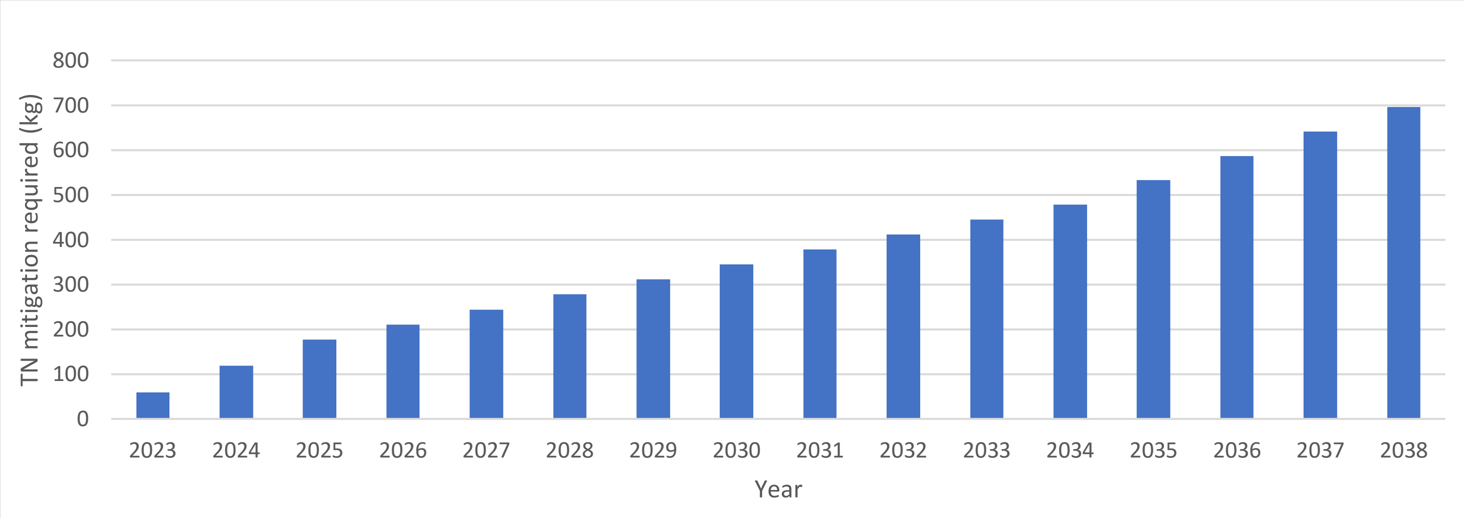


Figure 2-7: Amount of N mitigation that must be delivered by permanent solutions per year to successfully mitigation N produced by existing planning applications, allocated sites, and windfall sites

3 Potential nutrient management solutions

3.1 Types of nutrient management solution

This section outlines potential solutions that can be used to achieve nutrient mitigation for the purpose of allowing planning applications to proceed. Solutions where there is the potential to comply with Natural England's HRA tests (detailed below) were assessed further. The solutions have been classified into the four following categories:

- Nature-based solutions: solutions that aim to use natural processes (physical, chemical, and biological) to reduce diffuse- and point-sources of nutrients from within a catchment;
- Runoff management solutions: solutions that aim to reduce nutrient supply through the management of surface runoff and sediment supply (excluding nature-based solutions);
- Wastewater management solutions: solutions that aim to manage wastewater as a source of nutrients (excluding nature-based solutions); and
- Demand management solutions: solutions that aim to reduce nutrient loadings by reducing the production of wastewater at source, e.g., , reduced water usage of residential properties.

Some established solutions for nutrient management at a catchment-scale do not provide the certainty that is required for mitigating new developments and therefore have not been assessed. Examples of established solutions include:

- Methods adopted by Catchment Sensitive Farming (CSF) which is a government land management initiative (Natural England, 2022) that provides support such as:
  - farm advice; and
  - training and capital grants targeted at priority catchments to help reduce soil erosion and nutrient losses to water (air and soil).

The following section presents a brief overview of the potential short, medium, and long-term nutrient management solutions that are considered and describes how they are appraised (**Section 3.2**). This is followed by a more detailed description and appraisal of Nature-based Solutions, which this report focusses on (**Section 3.3**), Runoff Management Solutions (**Section 3.3.2**), Wastewater Management Solutions (**Section 3.3.3**) and Demand Management Solutions (**Section 3.3.4**).

3.2 Overview of potential nutrient management solutions

The potential nutrient management solutions that are considered are listed in **Table 3.1**. This overview table provides an indication of the timescales in which the solution could be delivered. A full description of each solution is provided in the subsequent sections of this report, as indicated by the cross references provided in **Table 3.1**. Natural England advice on mitigation principles which was issued to LPAs in March 2022 was used to assess the suitability of solutions and to facilitate the solutions in meeting the requirements of the Habitat Regulations.

Table 3.1: Potential nutrient management solutions

Type of Solution	Solution	Delivery Timescale	Further Information
Nature-based	Silt traps	Short-term	Section 3.3.1.1
	Riparian buffer strips	Short-term	Section 3.3.1.2
	Wet woodlands	Short-term	Section 3.3.1.3
	Constructed wetlands	Medium-term	Section 3.3.1.4
	Willow buffers	Short-term	Section 3.3.1.4
	Beetle banks	Short-term	Section 3.3.1.6
	Beaver reintroduction	Medium-term	Section 3.3.1.7
Run-off management	Taking land out of agricultural use	Short-term	Section 3.3.2.1
	Cessation of fertiliser and manure application	Short-term	Section 3.3.2.2
	Cover crops	Short-term	Section 3.3.2.3
	Installation of SuDS in new developments	Short-term	Section 3.3.2.4
	Retro-installation of SuDS in existing developments	Medium-term	Section 3.3.2.5
	Highway drainage improvements	Medium-term	Section 3.3.2.6
Wastewater management	Expedite planned improvements to treatment works	Short-term	Section 3.3.3.1
	Improvements to Clunbury treatment works	Medium-term	Section 3.3.3.2
	Moving Clunbury ST onto mains sewage	Long-term	Section 3.3.3.4
	Bishop’s Castle WwTW transfer scheme	Long-term	Section 3.3.3.6
	Installation of cesspools and capture outputs from private sewage systems	Short-term	Section 3.3.3.5
	Replacement of package treatment plants/ septic tanks	Short-term	Section 3.3.3.6
	Installation of portable treatment works	Short-term	Section 3.3.3.7
	Rectifying misconnections to combined systems	Long-term	Section 3.3.3.8
	Reduce leakage from foul sewer network	Long-term	Section 3.3.3.9
	Incentivise commercial water efficiency and treatment efficiency	Long-term	Section 3.3.3.10
Demand management	Retrofit water saving measures in existing properties (local authority, registered providers, public buildings)	Short-term	Section 3.3.4.1

3.2.1 Description of nutrient management solutions

The terminology used to describe the characteristics, performance and evidence base for each option in the subsequent sections is set out in **Table 3.2**.

Table 3.2: Description of nutrient management terminology

Descriptor	Definition
Description of solution	This section provides an overview of the nutrient management solution and the activities required for its implementation.
Delivery timescale	Delivery timescales are classified as follows:

Descriptor	Definition
	▪ Short: The solution could potentially be implemented in one year or less. Planning permission, policy changes and significant funding are not likely to be required, although it may be necessary to obtain third party consents and agreements. ▪ Medium: The solution could potentially be implemented over a period of one to five years. Planning permission, policy changes and/ or third-party funding are likely to be required, alongside other third-party consents and agreements. ▪ Long: It is likely to take more than five years to implement the solution. Environmental Impact Assessment (EIA), major policy changes and/ or significant funding are likely to be required, alongside other third-party consents and agreements.
Duration of operation	The longevity of the solution is classified as follows: ▪ Temporary: The solution is likely to remain in place for up to five years and could be secured through interim or temporary agreements with third parties. ▪ Impermanent: The solution is likely to remain in place for between five and 10 years, secured in agreement with third parties. ▪ Permanent: The solution is likely to remain in place for more than 10 years and could be secured in perpetuity through long term agreements with third parties.
Nutrient removal	This section provides a summary of the nutrient removal that the solution could potentially deliver.
Applicability	This section provides a high-level summary of the potential applicability of the solution in the catchment(s), including constraints posed by farm type, land use, etc.
Management and maintenance	This section describes the management and maintenance activities that are required to maintain the effectiveness of the solution.
Additional benefits	This section provides a description of any additional secondary benefits that could be delivered alongside the primary nutrient management aim of the solution.
Best available evidence	Sufficient reliable evidence which provides certainty that mitigation may be effective. It should be noted, with some types of mitigation there will be, (particularly with novel or complex mitigation), uncertainty as to the exact effectiveness the mitigation may deliver.
Wider environmental considerations	This section provides a description of any wider environmental constraints that could be associated with the solution. Potential unintended consequences are considered within this section.
Evidence of effectiveness	This section summarises any evidence available to demonstrate the effectiveness of the solution in managing nutrient supply.
Precautionary	The precautionary principle is an approach to ensure sufficient certainty via application of a precautionary an efficacy value based on the evidence can be applied, or provision of greater mitigation than required. For example, monitoring efficacy of a mitigation measure may provide evidence and therefore certainty which can be relied upon.
Securable in perpetuity	Natural England Nutrient Neutrality Principles guidance (Wood *et al.,* 2022) defines ‘in perpetuity’ timeframe between 80-125 years and ‘securable’ is defined as practical certainty that the mitigation measures will be implemented and in place at the relevant time. Mitigation measures which can be secured through legally binding obligations that are enforceable are understood to be securable in perpetuity. Likewise, a mitigation measure which can offer tax relief or a grant for example, although not legally enforceable, is considered to offer a degree of security.
Cost estimate	This section provides an outline estimate of the costs associated with implementing the solution. Costs are given over 80 years (the lifetime of the development) to allow for direct comparison with long-term solutions. Costs typically exclude administration and legal costs which are likely to apply to all solutions. Costs also exclude development of monitoring regimes to measure the effectiveness.

3.3 Potential nutrient management solutions

3.3.1 Nature-based solutions

3.3.1.1 Silt traps

Silt traps can be installed on farms to intercept sediment bound nutrients and prevent the nutrients from entering the surface drainage network. **Figure 3-1** shows an example of a silt trap in situ and **Table 3.3** provides an overview of silt traps as a solution.

Figure 3-1: Silt trap installed in a stream (Source: IRD Duhallow, 2015)

Table 3.3: Key considerations of silt traps

Descriptor	Definition
Description of solution	Silt traps can be installed on farms to catch sediment bound P & N. Silt traps are basins set upstream that capture sediments. Fine sediments to which nutrient are bound become physically immobilised, i.e., , deposited, behind a barrier due to a reduction in flow energy, decreasing the volume of sediment and therefore nutrients within the watercourse. As a result of its early removal, there is also a reduced potential for P to become soluble further downstream and detrimentally impact water quality. The benefits of silt traps for water quality are well established.
Delivery timescale	Silt traps require limited infrastructure and, depending upon their location, may not require any environmental permits. They can therefore be delivered as a short-term solution.
Duration of operation	Silt traps are predominantly considered an impermanent solution due to the need for maintenance to remain effective (see Management and Maintenance below). However, there is scope for this solution to be made permanent if landowners agree to maintain traps and replace them at the end of their lifecycle; approximately 30 years.
Nutrient removal	The nutrient removal rate of silt traps is dependent on site-specific variables such as location, soil type, rainfall, frequency of de-silting and is likely to differ between locations. Silt trap schemes should not be reliant upon water supply from one single upstream surface water source as this does not provide sufficient certainty of the long-term nutrient removal. TP removal potential: regularly reported between 25-75% for well designed and sited systems. TN removal potential: typically reported to be less than 25%.

Descriptor	Definition
	The Environment Agency (2012) Rural Sustainable Drainage Systems (RSuDS) guidance indicates that TP removal is regularly reported between 25-75% for well-designed and sited systems during design condition events.
Applicability	All farm typologies applicable, particularly farms which have a high risk of silt runoff.
Management and maintenance	Silt traps would need to be maintained periodically to remove accumulated fine sediments and ensure that they remain effective as sediment and nutrient traps. Fine sediments removed from the silt traps would need to be disposed of appropriately to prevent them becoming a new source of nutrients in the catchment.
Additional benefits	Silt traps are effective in improving the quality of water in the drainage network by reducing sediment supply to downstream watercourses. This can result in improved habitat quality for aquatic plants, invertebrates and fish.
Best available evidence	Although there is considerable evidence that supports the use of silt traps as effective measures to remove sediment from flowing water, e.g., , Environment Agency (2011), there is limited evidence of their effectiveness in removing nutrients.
Wider environmental considerations	Periodic removal of the sediment containing nutrients and any other chemicals which have collected requires consideration with particular respect to re-use or waste disposal in addition to any environmental considerations related to removal and transport.
Evidence of effectiveness	This solution is effective beyond reasonable scientific doubt. Although there is evidence to indicate effective sediment capture, the effectiveness can vary considerably under different conditions, poor design and poor management. As such, there is currently uncertainty regarding nutrient removal rate.
Precautionary	A precautionary approach can be taken with this method through assuming precautionary removal rates and the possible addition of precautionary buffers within the calculations.
Securable in perpetuity	Yes – management agreements will likely need to be put in place, especially where land is leased. Replacements will be required as the lifetime of the silt trap (approximately 30 years) is less than the developments.
Cost estimate	Capital costs are between £1,000-£4,000 with additional maintenance costs of £500 per annum.

3.3.1.2 Riparian buffer strips

Riparian buffer strips can be created around a watercourse to create separation between itself and an agricultural field. **Figure 3-2** shows an example riparian buffer strip, and **Table 3.4** provides an overview of them as a solution.

Figure 3-2: Aerial view of a riparian buffer strip (Source: Iowa State University Forestry Department, 2016)

Table 3.4: Key considerations of riparian buffer strips

Descriptor	Definition
Description of solution	Riparian buffer strips are zones of permanent grass and/ or woodland cover greater than 5 m wide that act as a separation barrier and filter between an agricultural field and a watercourse. They can also act as a filter between point sources of nutrients and the surface drainage network. Nutrient reductions are achieved through sedimentation of P-bound particles and uptake via vegetation. Vegetation within buffer strips increases surface roughness and reduces runoff rates, which in turn promotes infiltration (Hoffman *et al.,* 2009). Riparian buffer strips are typically located at field margins (less productive areas) and are, therefore, more likely to be adopted by farmers. This provides good certainty that the land use will be maintained and not revert back to agriculture. The upstream sources are important to maintaining the predicted removal rates from the buffer strips. If these sources are altered or removed, then the nutrient removal of the buffer could be adversely impacted. A minimal amount of monitoring will be required to confirm removal rates are consistent with the predicted rate. This is likely to comprise six months to yearly for approximately the first five years, then every 10 years for the lifetime of the scheme. Nutrient credits are earned by reducing nutrient outputs to below quota targets. The lower the nutrient output of a source, the greater number of quota targets are met, and credits earned. Therefore, should a riparian buffer strip outperforms its predicted design capacity, this will be identified by the monitoring process and allow the additional nutrient removal to be used as nutrient credits. Key considerations of riparian buffer strips include the following: • Where buffer strips are used as a long-term, in perpetuity solution, the long-term management of the adjacent fields presents a risk. Should the adjacent land be taken out of agricultural use or significant changes in agricultural practices, e.g., , conversion to solar or wind farm, this could reduce the P sources and subsequent removal potential.

Descriptor	Definition
	• Improper upkeep of buffer strip vegetation; fencing and excess silt could reduce the removal potential. • Should overland flow not be maintained, and flow becomes channelised, the buffer strip will not operate at optimum removal rates. Farmers may be unwilling to commit to 80-year agreements initially. Therefore, shorter agreements, e.g., , 20-30 years, may be necessary to establish this solution, with the ability to renew agreements.
Delivery timescale	Buffer strips do not require extensive infrastructure or investment, although fencing may be necessary where used in livestock farming. They do not require planning or environmental permits and can therefore be delivered in the short term.
Duration of operation	Buffer strips are likely to be operational over long timescales, depending upon landowner agreements. However, because they do not require any specific infrastructure, they are considered impermanent and subject to changes in farming practices.
Nutrient removal	P removal efficiency increases with buffer width, with 15-20 m buffers being the most effective (seen in **Figure 3-3**). Buffer strips composed of woody material can store a significant amount of P biomass (Fortier *et al*., 2015), and are more effective at trapping sediment than grasses (Hoffmann *et al*., 2009; Anguiar *et al*., 2015). Soil type may affect P removal efficiency, for example loam soils typically have lower P removal rates than silt soils when buffer strips consist of grass (Lee *et al*., 1998; Chaubey *et al*., 1995). TP removal potential: Median TP retention rates of 67% (Hoffmann *et al*., 2009). Site-specific factors also play a role in controlling nutrient reductions from riparian buffer strips and should be considered when considering the most appropriate location for buffer strip placement. For example, the orientation of the buffers and the adjacent agricultural activity are both important considerations. Typically, riparian buffers adjacent to agricultural land used for cropping will achieve the greatest real-world reduction rates due to the potential to remove a high degree of phosphorus bound sediment in the runoff. TN removal potential: There is considerable evidence within the scientific literature regarding the effectiveness of buffer strips as solutions for nitrogen removal. **Figure 3-4** shows the relationship between riparian buffer width and N removal for all studies. Assuming a conservative removal rate of 55% and a typical upstream land use (assumed to be arable), the TP and TN removal rates in the Clun catchment are expected to be 0.67 kg/ha/yr and 130.35 kg/ha/yr, respectively. The relatively modest P removal rates are due to the typically freely draining soils within the catchment. Increased removal rates could be achieved on land with more impeded drainage.
Applicability	Can be applied to all agricultural land and farm typologies where land is suitable for riparian buffers to be grown. Locations that are potentially suitable for the establishment of riparian buffer strips are shown in **Appendix 2**.
Management and maintenance	Maintenance is predominantly limited to cutting vegetation and the removal of accumulated sediment. Woodland buffers, particularly those containing willow, have less onerous maintenance requirements than grassland buffers. Where input flows are too great to promote infiltration, ponds could be added to remove sediment and would also need to be de-silted. Monitoring of management practices and water quality may be required following establishment to determine functionality.
Additional benefits	▪ Riverbank stabilisation ▪ Improved water quality ▪ Erosion reduction ▪ Habitat creation ▪ Improved amenity value ▪ Biodiversity Net Gain (BNG)

Descriptor	Definition
	▪ Carbon offsetting – potential for stacking ecosystem services credits carbon offsetting and BNG could provide an additional revenue stream, similar to the Countryside Stewardship payment scheme
Best available evidence	Riparian buffer strips are an established nature-based solution for pollution control within catchments and have been employed for multiple years.
Wider environmental considerations	Buffer strips may support sensitive species or communities and may need management to avoid damaging these. Fenced-off buffer strips may limit livestock access to a water source and wildlife throughways. Alternative water sources and fenced throughways may be required. Where groundworks are operating within a flood zone then it is important that the flood storage area is not reduced.
Evidence of effectiveness	This method is effective beyond reasonable scientific doubt.
Precautionary	Yes – a precautionary approach can be applied to this solution until and after site specific information becomes available.
Securable in perpetuity	Yes – management agreements may be needed where the solution is intended to provide medium/ long term solutions to ensure it does not revert to agricultural use and is maintained correctly. Conservation covenant agreements can be a mechanism for securing perpetuity.
Cost estimate	Typical annual costs are approximately £786/ha, with an approximate upfront cost of £183/ha (Farmscoper, 2023). This is fairly well constrained with annual Countryside Stewardship Grants that are paid at £440 - £512 ha/yr.

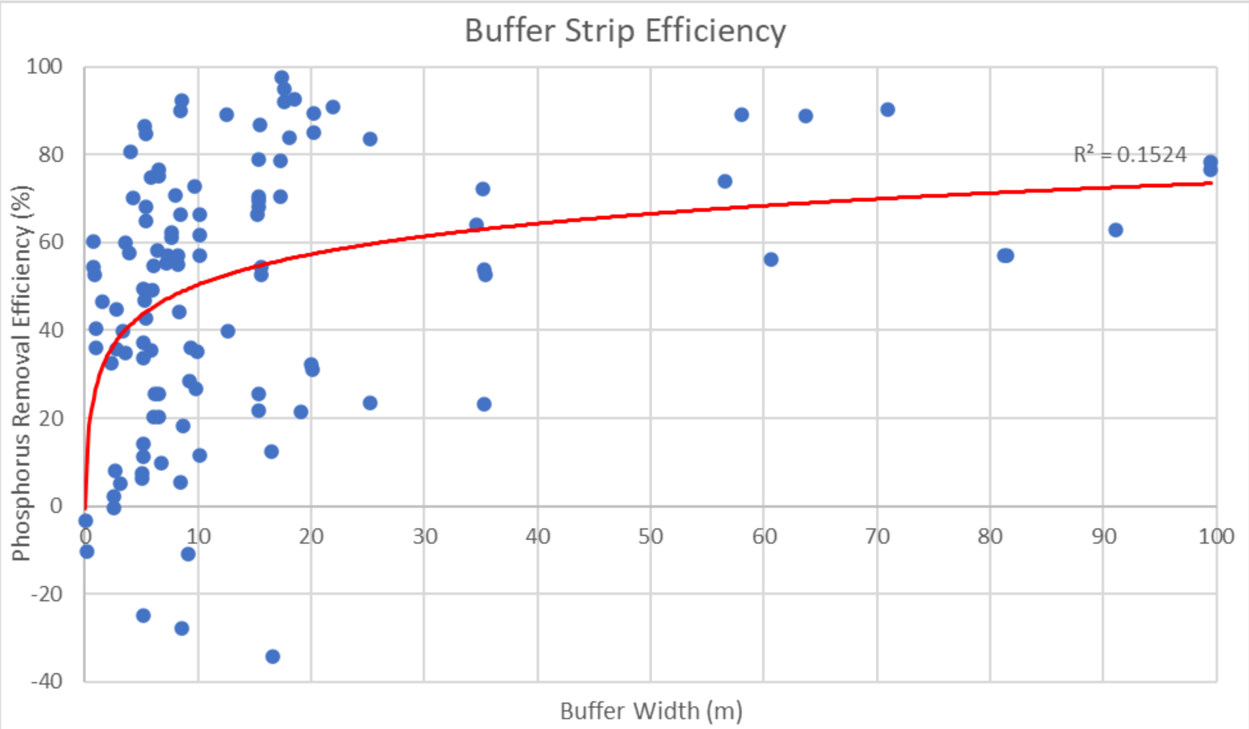


Figure 3-3: Buffer strip efficiency by width (edited from Tsai et al.*, 2016)*

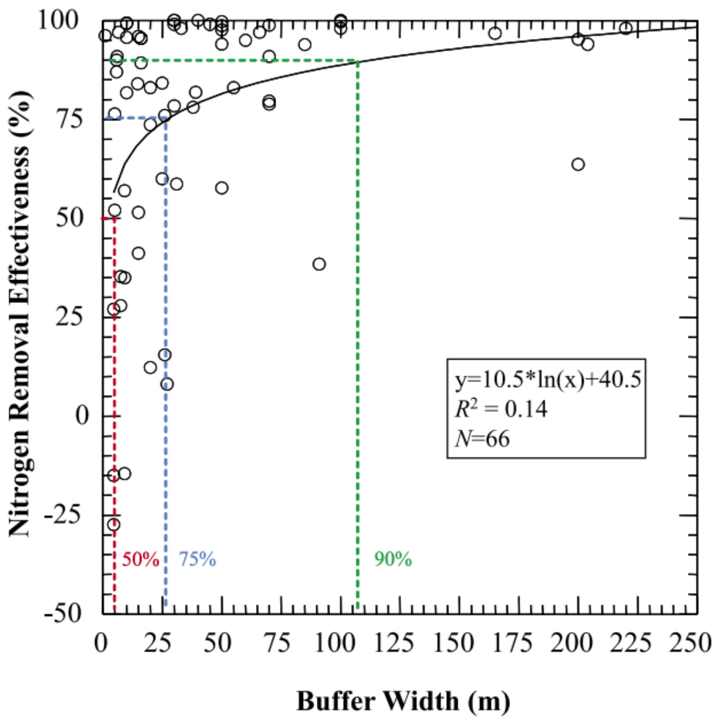


Figure 3-4: Relationship of N removal effectiveness and buffer width for all vegetation types (Mayer et al.*, 2005)*

3.3.1.3 Wet woodlands

Wet (floodplain) woodlands can be created or restored on river floodplains and remove nutrients from the watercourse by enhancing sediment deposition and nutrient uptake by plants. **Figure 3-5** shows a created area of wet woodland, and **Table 3.5** provides an overview of wet woodlands as a solution.

Figure 3-5: Area of wet woodland created in Salford in 2016. The project led to the attenuation of pollutants by biodegradation (Source: Natural Course, 2017)

Table 3.5: Key considerations of wet woodlands

Descriptor	Definition
Description of solution	Wet woodlands occur on soils that are permanently or seasonally wet. Wet woodlands increase hydraulic roughness, which slows flow velocities and allows sediment and particulate bound pollutants

Descriptor	Definition
	to fall out of suspension and enter storage on the floodplain, or in a designed wetland setting. Riparian woods reduce diffuse pollution by trapping fine sediment runoff generated by agricultural practices. Nutrient removal strategies involve either restoring existing floodplain woodland or creating new areas of planting. Natural Flood Management interventions can divert water out of the channel and into the floodplain wetland. Reversion of areas to floodplain woodland could deliver nutrient mitigation of land that is naturally wet, not only reducing the impact of runoff from the agricultural land, but also increasing the connectivity of the woodland. This would likely achieve greater nutrient reductions than purely the change of land use would predict.
Delivery timescale	Wet woodlands do not require extensive infrastructure, investment, planning or environmental permits, and can therefore be delivered in the short term. However, the relatively slow growth rate of trees means that it may take some time before they become fully effective.
Duration of operation	Wet woodlands are likely to be operational over long timescales, depending upon landowner agreements. Because of the long timescales required for them to become established, wet woodlands are considered to be permanent features.
Nutrient removal	TP removal potential: Uncertain – likely to be similar to riparian buffers (Median TP retention rates of 67%). Data on nutrient removal rates in wet woodlands is scarce. A study by Olde Venterink *et al.* (2006) analysed floodplain communities and their relative abilities to influence water quality through nutrient retention, though this does not consider key elements such as sediment trapping and associated standing water. Due to the lack of reliable literature, TP removal rates are assumed to have some similarities to riparian buffer strips. N removal rates are highly variable in wet woodlands, ranging from 12-80% of surface water N (Yates and Sheridan 1983; Brusch and Nilsson, 1993). Greater reductions can occur in the groundwater (Burns and Nguyen, 2002). **Table 3.6** presents examples of TN removal from wet woodlands (Mayer et al., 2005). The TP and TN removal rates in the Clun catchment are assumed to be the same as riparian buffer strips (**Section 3.3.1.2**)
Applicability	Wet woodlands can be created on riparian land holdings that are likely to be inundated regularly, e.g., within the functional floodplain and/ or Flood Zone 3, as defined by the Environment Agency. Locations that are potentially suitable for the establishment of wet woodlands are shown in **Appendix 2**.
Management and maintenance	Wet woodlands by their nature thrive on non-intervention and limited to no management. Light management includes: ▪ Coppicing some areas to create a more diverse woodland structure with some clearings; ▪ Allowing woodland edges to grade upwards from grass, through scrub, to woodland; ▪ Coppicing to provide wood fuel; ▪ Managing areas of willow and scrub to maintain some open areas and wet scrub; ▪ Controlling invasive species, e.g., , Himalayan balsam (*Impatiens glandulifera*).
Additional benefits	▪ Recreation ▪ Carbon sequestration ▪ Biodiversity conservation ▪ Air pollution reduction ▪ Flood risk reduction ▪ Short rotation coppice utilised as biofuel
Best available evidence	No – there is doubt over removal rates due to lack of research and data.

Descriptor	Definition
Wider environmental considerations	Once established, wet woodland could potentially support sensitive species and as such may need careful management to avoid adversely affecting these species. Care should be taken to ensure that the creation of wet woodlands does not contribute to the spreading of invasive species.
Evidence of effectiveness	There is limited scientific evidence to demonstrate with certainty that wet woodlands are effective at mitigating TP. As such, there is currently uncertainty regarding nutrient removal rate and monitoring is likely to be required.
Precautionary	Yes – a precautionary approach can be applied to this solution until and after site specific information becomes available.
Securable in perpetuity	Yes – it is anticipated that this solution will be suitable for the lifetime of the development. Land that is suited to wet woodland is very unlikely to revert to any other land use.
Cost estimate	Bare root stock suitable for tree planting programmes for typical wetland species are in the range of £2-£3 per tree, which may be reduced to <£1 if ordered in bulk from suppliers. Bulk order tree guards are a similar price. For broadleaved trees, planting density is recommended 1,600 to 2,500 trees per hectare (Creating Tomorrow's Forests, 2021). However, these figures are for general woodland creation, not floodplain wet woods where additional space may be needed for wetland landscaping, e.g., , pools and scrapes. Typical planting costs (trees + guard) may be ~£5,000 per ha. Grants of up to £10,000/ ha could be available through the government's England Woodland Creation Offer (Gov.uk, 2022) and nutrient mitigation credits may need to match this figure. Total costs: up to £10,000/ha.

Table 3.6: N removal from wet woodland buffers

Flow path	Buffer width (m)	TN removal (%)	Soil type	Source
Surface	-	81	Sand	Yates and Sheridan, 1983
Subsurface	31	59	Sand	Hanson *et al*., 1994
Subsurface	38	78	Sandy loam	Vellidis *et al*., 2003
Subsurface	14.6	84	Sandy mix	Simmons *et al*., 1992
Subsurface	5.8	87	Sandy mix	Simmons *et al*., 1992
Subsurface	5.8	90	Sandy mix	Simmons *et al*., 1992
Subsurface	6.6	97	Sandy mix	Simmons *et al*., 1992
Subsurface	30	100	Loamy mix	Pinay *et al*., 1993
Surface	20	12	Clay loam	Brusch and Nilsson, 1993
Surface	20	74	Peat/ sand	Brusch and Nilsson, 1993
Subsurface	5	76	Stony silt loam	Clausen *et al*., 2000
Subsurface	5	52	Stony silt loam	Clausen *et al*., 2000
Subsurface	1	96	Clay loam/ clay	Burns and Nguyen, 2002
Subsurface	200	95	Silt/ sand/ gravel	Fustec *et al*., 1991
Subsurface	40	100	Fine to coarse sand	Puckett *et al*., 2002

3.3.1.4 Constructed wetlands

Constructed wetlands (CWs) have been used for nutrient removal and water treatment since the 1950s for improving water quality from industrial and agricultural water sources (Vymazal, 2010). CWs are designed to facilitate natural processes that can remove nutrients from the influent water source(s) to a wetland (Vymazal, 2010). Key considerations of constructed wetlands are presented in **Table 3.7**.

Table 3.7: Key considerations of Constructed Wetlands

Descriptor	Definition
Description of solution	Nutrient removal occurs through natural process such as physical, biogeochemical, and biological. ICW have proven to be the most effective in removing nutrients and can deliver the greatest number of additional benefits compared with other wetland types (Harrington & McInnes, 2009).
Delivery timescale	CWs require engineering design and construction and may require planning permission, an environmental permit and an impounding licence. Depending on the watercourse, it is likely that a flood defence consent and a flood risk activity permit may also be needed. It is estimated that a CW scheme for nutrient removal will take between one to two years to complete
Duration of operation	With an appropriate management and maintenance plan, it is likely CWs will be able to provide nutrient mitigation in perpetuity
Nutrient removal	TP retention in wetlands occurs through physical processes such as soil/ sediment accretion, sediment adsorption, chemical precipitation, and burial of organic P (Vymazal, 2007). Biological processes include microbial and plant uptake convert P into forms that are available for biological uptake. It should be noted that P does not cycle to gaseous forms and thus is retained within wetlands, rather than being permanently removed. Various studies have shown that even with minimal intervention, CWs have maintained a high percentage removal efficiency for P (Cooper *et al.,* 2020). The removal of N in wetlands is largely a biogeochemical process whereby organic forms of N are sequentially converted to ammoniacal nitrogen, nitrite and nitrate, before being converted to di-nitrogen gas Dzakpasu *et al*., 2011). The conversion of N to gaseous forms results in the complete removal of N from the water within a wetland, providing in perpetuity mitigation of the N load removed by this mechanism. Land *et al.* (2016) concluded that CWs have median removal efficiencies for TN and TP of 37% (95% confidence interval of 29-44%) and 46% (95% confidence interval of 37-55%), respectively. This review also reported areal removal rates of 930 kg/ha/yr 12 kg/ha/yr for TN and TP, respectively. Nutrient removal rates are highly variable and should be derived following advice published in the Constructed Wetlands Framework.
Applicability	Intensively farmed catchments with likely sources of agricultural runoff would result in a large nutrient source and be suitable for deployment of agricultural wetlands. Locations that are potentially suitable for the establishment of wetlands are shown in **Appendix 3**.
Management and maintenance	Wetlands require periodic maintenance to remove sediment built up approximately every five to ten years. Vegetation will need to be replaced at a timescale appropriate to the lifecycle of the vegetation the wetland is planted with. Natural England's wetlands framework provides details of the aspects of a management and maintenance plan that will be needed for CW for nutrient removal (Johnson *et al*., 2022)
Additional benefits	A well designed and located ICW can provide: ▪ biodiversity improvements, ▪ water quantity and quality (additional to nutrients) management, ▪ flood hazard management, ▪ carbon offsetting, and ▪ amenity and landscape aesthetic benefits (Harrington & McInnes, 2009)
Best available evidence	No – monitoring will be required to determine nutrient removal. This is likely to comprise 1 year of post-establishment monitoring, followed by 2-3 years of ongoing monitoring to identify any overperformance.

Royal HaskoningDHV

Descriptor	Definition
Wider environmental considerations	Environmental considerations should include: ▪ Relatively flat topography ▪ Soils (including nutrient content), geology and hydrogeology ▪ Hydrology and flood risk ▪ Infrastructure ▪ Nature, landscape, and archaeological conservation
Evidence of effectiveness	There is a large body of literature that provides evidence of the effectiveness of CWs for nutrient removal, which is supported by the recently release of Natural England's wetlands framework which is expressly aimed at supporting the development of wetlands for nutrient mitigation
Precautionary	A feasibility assessment may show that a proposed wetland is not deliverable due to one or more of the environmental conditions not being met, i.e., , topography does not support a wetland draining under gravity and/ or flood risk
Securable in perpetuity	It is anticipated that this solution will be suitable for the lifetime of the development. Land that is suited to wetlands is very unlikely to revert to any other land use
Cost estimate	Cooper *et al.*, (2020): Capital costs for a 1.1 ha wetland reported as: ▪ Planning, design & management £15,000 ▪ Construction £161,000 ▪ Wetland planting £18,000 ▪ Total cost £194,000 Total cost of the scheme suggested to be £500,000, which is assumed to include maintenance and monitoring. Cooper *et al*., (2020): Capital costs for a 0.3 ha wetland reported as: ▪ Planning, design & management £1,305 ▪ Construction £21,712 ▪ Wetland planting £7,004 ▪ Total cost £30,021 Note that the land for this site was donated. A conservative assumption was made that wetland cost is £500,000 per hectare, including planning, consent, construction, maintenance and monitoring.

There are various types of CW, which are described in **Table 3.8**. However, Integrated Constructed Wetlands (ICW) can deliver the greatest number of additional benefits compared with other wetland types (Harrington & McInnes, 2009). In line with Natural England wetland framework (Johnson *et al.*, 2022), wetlands should be appropriately designed and maintained.

Land *et al.,* (2016) summarised the results of 93 studies of 203 wetlands predominantly treating agricultural sources of water. They concluded CWs have moderate removal efficiencies for TP at 46% (95% confidence interval of 37-55%).

A review of wetlands treating effluent from Water Recycling Centres (WRC) in Ireland concluded that ICWs performed best out of all types of CWs and where ICWs were well designed under rigorous guidance, they outperformed mechanical treatment for P (Hickey *et al*., 2018). This study showed a sustained 98% and 97% removal rate for ammonium and nitrate, respectively, with a total of 2802 kg NH3-N and 441 kg NO3-N removed by the wetland over two years, equating to a removal rate of 1621.5 kg N/yr. A follow up study assessing the performance of the Glaslough wetland for Total Phosphate (TP) removal after four-years of operation showed a TP removal efficiency of 93.5% (Dzakpasu *et al.*, 2015).

Well designed CWs that continue to receive high nutrient input loads can sustain high nutrient removal efficiencies. A study of 12 ICWs treating livestock wastewater found that these wetlands averaged soluble reactive phosphorus (SRP) removal efficiencies of > 80% over and eight-year period, with 11 of the 12 averaging removal efficiencies > 90%.

Recent studies have also been published for ICWs treating final effluent from two Anglian Water Services (AWS) WRCs in Norfolk, both of which are in Norfolk. In 2014, the Norfolk Rivers Trust (NRT) deployed an ICW to treat final effluent discharge from the Northrepps WRC. Analysis of monitoring data from the first 18 months of operation at this wetland reported high nutrient removal efficiencies, with TP concentrations reduced by 78%.

Table 3.8: Types of constructed wetland used for the treatment of polluted water sources (after Dotro et al.*, 2017; Hickey* et al.*, 2018)*

Type	Description
Horizontal Subsurface Flow (HF)	▪ Influent water flows horizontally through a sand- or gravel-based filter ▪ Water is kept below the wetlands surface ▪ Plants (emergent macrophytes[2]) grow in the filter media[3] and help to promote nutrient removal processes ▪ Filter media is mainly saturated, with anaerobic (oxygen-free) conditions dominating nutrient removal processes
Vertical Subsurface Flow (VF)	▪ Influent water is pumped intermittently onto a filter and percolates vertically through the filter ▪ Between pumping of water, air re-enters the filter and aerobic (oxygen-rich) conditions dominate ▪ Emergent macrophytes are grown at the surface of the wetland
Hybrid wetlands	▪ Combine HF and VF wetland types ▪ Most commonly a VF compartment is followed by an HF compartment
Free water surface (FWS)	▪ Resemble natural wetlands, with shallow water and emergent macrophytes ▪ FWS can either be engineered rectangular waterbodies or can be designed to fit in with landscape and termed ICWs ▪ Water is retained for longer in FWS (longer hydraulic residence time (HRT)) than in other types of wetlands

3.3.1.5 Willow buffers

Willow buffers consist of short-rotation willow coppice irrigated with wastewater from a development and removes a significant amount of nutrients from the wastewater before it enters the watercourse. **Table 3.9** provides an overview of willow buffers as a solution.

Table 3.9: Key considerations of willow buffers

Descriptor	Definition
Description of solution	Short-rotation willow coppice can be used to treat wastewater by providing vegetation filter strips irrigated with wastewater to remove nutrients from the wastewater, whilst producing woody biomass for energy purposes through a coppicing cycle (2-5 years, though commonly every 3 years). The irrigation system will not completely eliminate wastewater pollution as some wastewater by run off or percolate into groundwater. As a result, timing and irrigation rates must be considered.

[2] A plant that has adapted to live in an aquatic (water) environment, both freshwater and saltwater. The term macrophyte is used to distinguish them from algae and other microphytes.
[3] A type of filter that uses a bed of sand, peat of man-made materials such as tyres, foam, crushed glass, or geotextile membranes to filter water for drinking aquaculture or other purposes to improve water quality.

Descriptor	Definition
	Evapotranspirative willow systems have zero discharge and are an alternative to irrigated systems and are typically used to treat domestic wastewater from small settlements or individual households. All influent wastewater and precipitation are evapotranspired on an annual basis with proper design. They do not require skilled personnel for operation or maintenance.
Delivery timescale	Willow buffers are unlikely to require extensive infrastructure, planning permission or environmental permits, and can therefore be delivered in the short term. The rapid growth rate of willows means that a functional solution could be delivered more rapidly than a traditional wet woodland.
Duration of operation	Willow buffers could potentially be operational over long timescales. Because they need to be regularly managed to maintain effectiveness and trees need to be periodically replaced, willow buffers are considered impermanent features.
Nutrient removal	Short-rotation willow coppice filter strips achieve TP removal rates of 67-74% (Larsson *et al.*, 2003; Perttu, 1994), although initial reduction rates are often closer to 95%. Lachapelle *et al*., (2019) suggested a significant increase in available P in the soil, suggesting the soil can become saturated over time. For evapotranspirative willow systems, wastewater is constantly applied and stored as an elevated water level. P accumulation results in a P rich substrate which can be reused as fertiliser. More P is stored in the soil, roots, and leaves of the willows than in the woody biomass (Istenic and Bozic, 2021). The recommended TP application to prevent saturation of soils is 24 kg/ha/yr (Caslin *et al*., 2015), which is typically a lesser volume than that applied directly from domestic wastewater. This solution could be used as a form of secondary treatment after domestic PTPs. TP removal potential: 70% long-term. Although many species of willow have low N requirements, they often have a high uptake capacity. Previous research found a willow-soil system treating 200 kg TN/ha/yr (Kuzovkina and Quigley, 2005). Similarly, in a study by Mohsin *et al.* (2021), willow showed 41–60% TN and 32–50% TP removal when subjected to foul water irrigation. The results are in line with the findings of Holm and Heinsoo (2013), who reported willow take up of 58% TN and 70% of TP under the application of foul water. TN removal potential: variable, approx. 40-60%
Applicability	Willow buffers are applicable to the Clun catchment as the rural land which dominates the landscape allows this to be a feasible option.
Management and maintenance	Harvesting of willow would be required every three to five years and replanting every 20-25 years. This solution typically sees a 30% increase in biomass yield (Buonocore *et al*., 2012).
Additional benefits	There are additional benefits of improved water quality and a BNG due to improved habitat.
Best available evidence	No – monitoring will be required to determine nutrient removal.
Wider environmental considerations	The transport of biomass to energy production plants, and implications of waste disposal from the energy plant output must be considered as this may have adverse impacts on the wider environment.
Evidence of effectiveness	Though there is limited evidence to determine the efficacy of such a scheme, the solution is likely to be effective beyond reasonable scientific doubt. There is the potential for P saturation within soils and monitoring should be used to evidence the effectiveness.
Precautionary	Yes – a precautionary approach can be applied to this solution until and after site specific information becomes available.
Securable in perpetuity	Yes – it is anticipated that this solution will be suitable for the lifetime of the development, though the harvest cycle may lead to variance in uptake.
Cost estimate	The cost for establishment is typically £2,500/ha. Operational costs including ploughing and cultivation and are likely to £200 - £300/ha/yr. Potential returns vary hugely depending on many variables including price received for crop and drying requirements.

Descriptor	Definition
	Rising energy costs of oil and gas may provide greater future opportunities for willow chips as a fuel source.

3.3.1.6 Beetle banks

Beetle banks are densely grassed mound constructed on agricultural land to control runoff. **Figure 3-6** depicts an example beetle bank, and **Table 3.10** provides an overview of them as a solution.

Figure 3-6: Photograph of a beetle bank (Source: Walsh, 2016)

Table 3.10: Key considerations of beetle banks

Descriptor	Definition
Description of solution	A beetle bank is a densely grassed mound approximately 3m to 5m wide and a least 0.4 m high constructed on agricultural land to control runoff. Beetle banks can be planted across slopes or along natural drainage ways to minimise runoff and soil erosion. They present a similar scenario to a riparian buffer strip (**Section 3.3.1.2**). There is also unlikely to be a high uptake amongst farmers because they need to be positioned in more productive areas in the centre of fields rather than in the margins.
Delivery timescale	Beetle banks do not require extensive infrastructure, planning permission or environmental permits, and can therefore be delivered in the short term.
Duration of operation	Once installed and established beetle banks are anticipated to be a permanent feature.
Nutrient removal	Nutrient removal rates are unknown, but likely to be similar to Riparian Buffer strips. Calculations have not been undertaken to determine the level of nutrient removal. An assumption is made that nutrients are removed via both the removal of small areas of farmland which would ordinarily be subject to application of nutrient containing fertilisers, and the uptake of nutrients via the tussock grass on the bank.
Applicability	The agricultural nature of the catchment means this could offer plausible, although possibly small-scale, solutions. The location of beetle bank installation may be limited by parameters such as soil type, which should be suitable to form a free-draining raised bank.
Management and maintenance	The earth ridge size, measuring between 3m to 5m wide and at least 0.4m high, should be maintained. The grass should be cut several times in the first year to help it establish.

Descriptor	Definition
	Once a tussocky grass mixture has been established (1 year post construction) annual grass cutting should occur. This should take place after 1st August to protect nesting invertebrates and control woody growth and suckering species. The upper bank area should be dry and therefore constructed of free-draining soils to allow insects to hibernate securely.
Additional benefits	Beetle banks provide a BNG in the form of nesting and foraging habitats for pollinators, small mammals, some farmland birds and beneficial insects which feed on crop pests. To achieve wider environmental benefits beetle banks do not require the application of fertilisers, manured and/ or lime and pesticides (except herbicides used to weed-wipe or spot-treat control of injurious weeds, invasive non-natives, nettles or bracken). Beetle banks can help to slow down, reduce or stop soil erosion.
Best available evidence	As there have been no calculations to determine the level of nutrient removal, evidence cannot be drawn upon.
Wider environmental considerations	Earthworks and associated machinery fuel and transport must be considered as they may have detrimental environmental impacts. Grass cut during maintenance must be removed from the area to remove nutrients, likely incurring fuel and carbon usage. Best practice beetle bank construction is designed in order to achieve wider environmental benefits.
Evidence of effectiveness	Significant monitoring is likely to be required as there is a high level of uncertainty as to the P removal rates.
Precautionary	Not possible to determine at this stage.
Securable in perpetuity	There are many site-specific location parameters required to deliver a successful beetle bank scheme. There is a high level of uncertainty of success. Monitoring for Countryside Stewardship grant could act as a mechanism for securing obligations; however, this is not a firm legally binding enforceable agreement. Therefore, the scheme is not currently securable in perpetuity.
Cost estimate	Costs are assumed to be as provided for riparian buffer strips.

3.3.1.7 Beaver reintroduction

The Eurasian beaver (*Castor fiber*) was once common in UK riverscapes but has been largely extirpated across the UK and Europe. Beavers are recognised as ecosystem engineers and ‘keystone species’ that can have a disproportionate impact on the hydrology, geomorphology, water quality and aquatic ecology of rivers (**Figure 3-7**) (Brazier *et al.*, 2021). As such, there is now an increased interest in conservation strategies that include beaver reintroduction as part of wider river restoration and catchment management strategies.

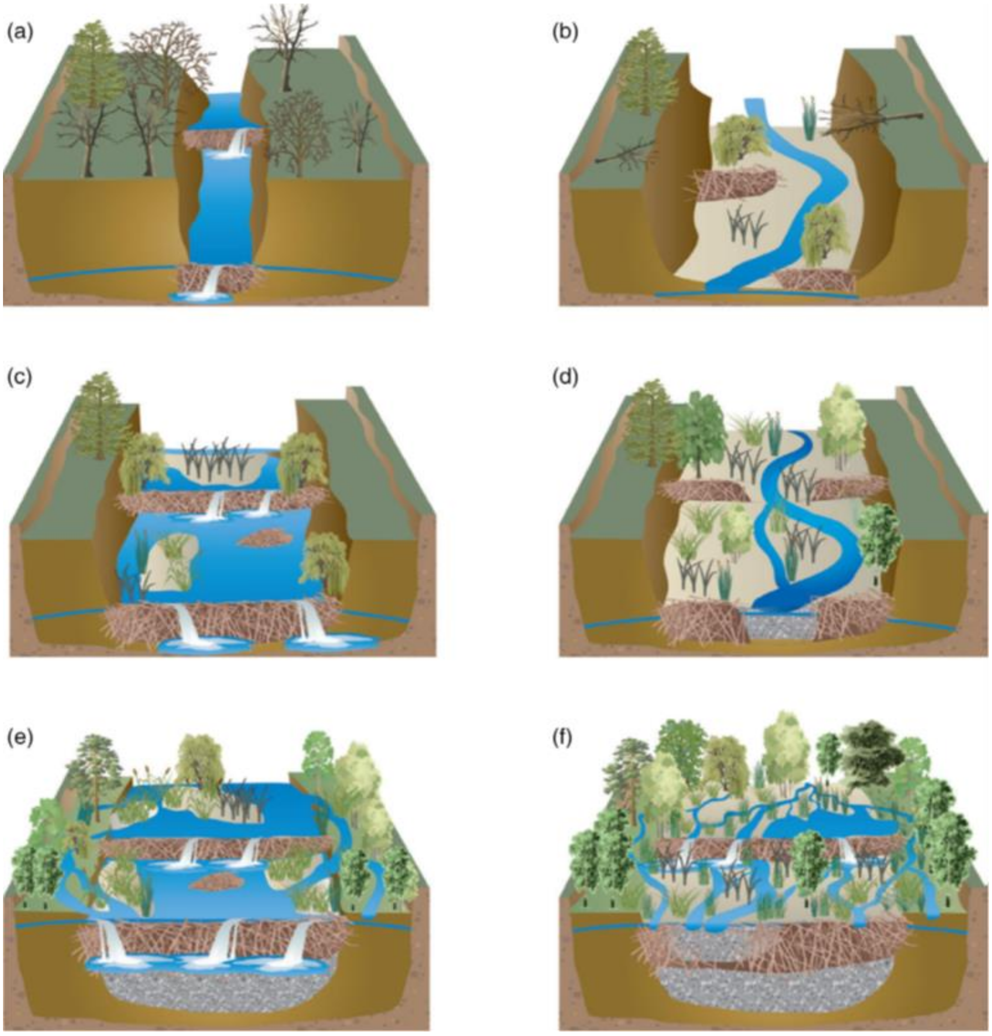


Figure 3-7: Conceptualisation of the geomorphic changes beaver damming can have on incised streams:

a) beavers dam an over-deep and straightened river channel;

b) channel widening and greater sediment mobilisation reconfigures the channel with vegetation establishment within new marginal channel areas;

c) a wider channel reduced high flow peaks, enabling more stable dams to be built;

d) vegetation establishment and sediment accumulation combined with small dam 'blowout' establishes a system of ponds;

e) process repeated with more dam building, channel widening resulting in an increase in water table height that reconnects the river to its floodplain;

f) further establishment of vegetation communities and sediment deposition results in a multi-thread channel with an increase in pond areas and areas of reduced flow that provide wetlands habitats. (Source: Brazier et al., 2021).

The damming of streams by beavers' results in the creation of ponds behind the dams that allow for increased sediment deposition. These ponds can facilitate a set of linked processes that together can remove or retain nutrients within the beaver pond complexes. Because the nutrient removal processes that are associated with beaver impacts on rivers require beavers to construct and maintain large dam and pond complexes, they cannot be relied upon to deliver nutrient removal in perpetuity.

Engineered logjams have the potential to support the same set of processes that remove nutrients as in beaver dam and pond complexes but are not supported by a large body of academic research for water quality impact as most research focusses on flood risk management. Because engineered logjams have a greater ability to be managed and maintained in the long-term, the sections below will consider them as an alternative practical solution to beaver reintroduction as a nutrient mitigation option.

Key considerations for beaver reintroduction are summarised in **Table 3.11**.

Table 3.11: Key considerations of beaver reintroduction

Descriptor	Definition
Description of solution	The Eurasian beaver was once common in UK and are recognised as ecosystem engineers and a 'keystone species' that can have a disproportionate impact on the hydrology, geomorphology, water quality and aquatic ecology of rivers. Their damming of streams results in the creation of ponds behind the dams, which can remove or retain N and P due to linked processes. As such, there is now an increased interest in conservation strategies that include beaver reintroduction as part of wider river restoration and catchment management strategies.
Delivery timescale	For beaver reintroduction schemes, likely between 4.5-6 years. Logjam schemes could be delivered in six to nine months
Duration of operation	Beaver reintroduction schemes are unlikely to last in perpetuity. Logjams with appropriate maintenance may provide long-term, in perpetuity nutrient mitigation
Nutrient removal	TP removal potential: Variable, with some studies reporting P sources from beaver ponds while UK and European studies reporting P removal efficiencies between 20%-80%. Most studies also report SRP and not TP. UK and European studies reporting P removal efficiencies between 4%-60%. TN removal potential: unknown within in the UK due to limited research; likely to be a lower removal rate than TP.
Applicability	N/A
Management and maintenance	Beaver reintroduction requires little management and maintenance. Logjams require maintenance to repair dams should they become damaged by high flows
Additional benefits	NFM, biodiversity and amenity benefits
Best available evidence	Yes, but evidence is more limited for UK applications
Wider environmental considerations	The following environmental considerations and assessments may be required for deploying beaver/ logjam schemes: • FRA – for flood risk; • WFD – for potential impacts on WFD status of a protected water body; • HRA – for potential impacts on Habitats Sites; and • Engagement with landowners and managers to tackle perception issues
Evidence of effectiveness	Yes, but only if assuming very precautionary estimates of N and P removal
Precautionary	Yes
Securable in perpetuity	Beaver reintroductions – no, engineered logjams – yes
Cost estimation	No reliable estimate for beaver reintroduction. Engineered logjams in the range of £5,000-25,000, not including land purchase if required.

Nutrient removal

Recent reviews of the impact of beavers on river systems presents contrasting evidence on the impact of beaver impacts on nutrient removal. In a meta-analysis of studies from across North America and Eurasia, Ecke *et al.*, (2017) suggest that beaver have a little impact on nutrient removal in streams.

Brazier *et al.*, (2021) detail how beaver impacts cause changes to hydrology and geomorphology that are linked to nutrient removal. They cite numerous studies that have provided evidence of nutrient removal in rivers because of beaver activities and discuss the concept of ‘beaver meadows’: an end state of beaver damming where infilling of beaver ponds by sediment and then progressive vegetation growth results in an altered landscape akin to that shown in **Figure 3-7**. Progression to beaver meadows is likely to result in more sustained nutrient removal.

The processes that retain nutrient within beaver dam and pond complexes are predominantly related to P deposition that is attached to sediments. Some adsorption of P to sediments occurs in beaver ponds due to exchange of surface water with subsurface flow pathways in pond sediments, however where subsurface flow pathways encounter anaerobic conditions, this can also result in the release of P that is bound to sediments and has been hypothesised as the reason for inconsistent results for SRP removal by beaver activities (Larsen *et al.*, 2021).

This review also suggests that the main process of N removal beaver dam and pond complexes is denitrification, however they also note the importance of sediment and organic matter deposition and the potential for the degradation of organic matter to release ammonia. Whilst various studies have reported ammonia releases from beaver ponds, it is thought that the denitrification rates seen in beaver ponds are sufficient for them to be used as N sinks.

Table 3.12 collates key information from relevant studies and highlights that each study recorded nutrient reductions resulting from beaver activities, with a wide range of reductions recorded across the different study sites.

Table 3.12: Results from studies of beaver impacts on phosphorous in rivers in the UK and Europe

Study	Location	Study length	Upstream to downstream Nutrient concentration reductions		Accounted for seasonality?
			N	P	
Puttock *et al.* (2017)	Devon, UK	1 year	35% TON reduction	80% PO4 reduction	Yes
Law *et al.* (2016)	Blairgowrie, Scotland	1 year	32% NO3 reduction	25% PO4 reduction	Yes
Smith *et al.* (2020)	Brandenburg, Germany	1 year	3.8% NO3 reduction	46% PO4 reduction and 13% TP reduction	Yes
Čiuldiene *et al.*, (2020)	Northwest Lithuania	< 1 year	60% TN reduction	20% TP reduction	No

Research has shown that beaver impacts on streams can result in the removal of nutrients, including in a UK context, but this removal is not always consistent and removal efficiencies may not be that high.

It is noted that there is very limited research on the impact of logjams on nutrient dynamics in rivers. However, if a series of logjams was designed that created a similar ponding effect to that created by beavers where they dam rivers, the same nutrient removal processes could potentially be created at similar removal efficiencies.

Engineered logjams can be deployed in a complex of dams in one go, which may help a logjam scheme to reach peak nutrient removal efficiency faster than a beaver reintroduction scheme. It is likely that a logjam scheme would take six to nine months to deliver, allowing for site assessments, surveys, design, land acquisition and deployment.

3.3.2 Runoff management systems

3.3.2.1 Taking land out of agricultural use

Taking land out of agricultural use involves replacing high nutrient exporting agricultural land with low nutrient exporting land. **Table 3.13** provides an overview of taking land out of agricultural use as a solution.

Table 3.13: Key considerations of taking land out of agricultural use

Descriptor	Definition
Description of solution	Land taken out of agricultural use is replaced with low exporting land such as semi-natural grassland, woodland, or energy crops, e.g., , willow or *Miscanthus*. Vegetation such as this actively uptakes nutrients and limits the impact of legacy P (build-up of P in soil caused by repeated applications of fertilizers and animal waste) and N. Reversion of previously agricultural land to a more natural state will eventually reduce P and N leaching to natural background rates. Woodland planting can accelerate the transition to background nutrient concentrations. Natural England suggest that woodland planting is a viable mitigation method that can be easily implemented. There is a minimum requirement for 20% canopy cover at maturity, which is equivalent to approximately 100 trees/ha. Maintenance of woodland is easy to verify and well established. Native tree species would be the preferred choice, although climate resilience may require the use of non-native species to account for long-term climate change effects. Though most P is sediment bound, it is worth noting energy crops (e.g., , *Miscanthus* and willow) are considered to have a higher soluble nutrient uptake than woodland. *Miscanthus* is also ideally suited to marginal land that provides a small value for generating income, as it can be grown for biofuel. However, energy crops provide a lower biodiversity benefit and would be unable to retrieve as much income through potential monetised biodiversity schemes as more natural planting would. Other measures to accelerate the transition to nutrient background levels include the ploughing of previously agricultural land, suggested by Sharpley (2003) and Dodd *et al*., (2014) to decrease nutrient concentrations by half and therefore reduce P surface runoff losses.
Delivery timescale	Taking agricultural land out of use can be implemented over short-term timescales. Identification of suitable land, willing landowners and agreeing terms are likely to be the most time-consuming tasks in the implementation process of this solution.
Duration of operation	This solution could potentially be implemented over a temporary, impermanent, and permanent timescale. ▪ Temporary: Land taken out of production but otherwise unchanged ▪ Impermanent: A longer-term reversion from agriculture ▪ Permanent: It could be maintained in perpetuity if the land use is changed so that it is used for non-agricultural purposes (i.e., , woodland, *Miscanthus* etc.)
Nutrient removal	The nutrient reduction calculations assume that farms will be operating according to best practice and not polluting. This will also ensure that mitigation schemes do not compromise the ability to deliver long term Water Framework Directive (WFD) targets. Average TP removal potential: 0.14 kg/ha/yr Average TN removal potential 26.39 kg/ha/yr The dominant land use is assumed to be mixed livestock. Nutrient removal rates for all land use types as provided in **Table 3.14**.

Descriptor	Definition
Applicability	Unlikely to be applicable to indoor pig or poultry farms - other methods of calculating nutrient removal.
Management and maintenance	For Miscanthus, fertiliser application is not needed to be added until it is established (after one to two years) and less needs to be applied than most farming practices. Harvesting needs to be completed every two to four years.
Additional benefits	▪ Energy crops can be used for coppice ▪ BNG potential ▪ Soil erosion which can lead to nutrient mobilisation is also likely to decrease with time as soil is stabilised by more continuous vegetation cover.
Best available evidence	This solution uses the best available scientific evidence. However, some doubt may remain over legacy P concentrations and may require further research or monitoring to gain a better understanding.
Wider environmental considerations	There is the potential for long term inflated agricultural land prices if this solution requires land to be out of agricultural use for more than one to two years.
Deliverability & Certainty	Certainty regarding cessation of arable farming can be easily secured and verified using aerial imagery and site visits. Where grazing land is taken out of use, in order for there to be an actual reduction in nutrient loads, then it is assumed that livestock numbers would also need to be decreased and the livestock/ hectare rate maintained. However, it is assumed that farms typically operate close to optimal stocking densities and livestock reductions would be needed to maintain this. Where this solution is used as a temporary measure, livestock can be temporarily located outside of the catchment. However, changes to grazing practices and stocking densities are more difficult to monitor and enforce in comparison to arable reversion to woodland or energy crops, and therefore provide a lower degree of certainty. Furthermore, consideration would need to be given where potentially polluting agricultural activity is moved to another location where the land parcel is smaller and could increase the pollution risk.
Evidence of effectiveness	Yes – beyond reasonable scientific doubt. Taking land out of agricultural use has an immediate impact on its P output, as the desisting of fertiliser application reduces surface water P levels following rainfall events. However, some legacy P will be maintained in the soil. The time taken for soils to reduce to agronomic targets and background concentrations varies depending on soil types and P concentrations (Dodd *et al*., 2012). A study by McCollum (1991) indicated that P levels may not be reduced to background concentrations for at least 17 years, based on fine sandy loamy soils in arable production in the United States. Much of the soil surrounding the Clun is loamy. Gatiboni *et al.,* (2021) found that the median time to reach agronomic targets was <1 year but could take as long as 11 years. However, the time taken to reach environmental targets purely by cessation of phosphorus fertiliser would be 26 – 55 years.
Precautionary	Yes – a precautionary approach can be applied to this solution until and after site specific information becomes available.
Securable in perpetuity	Yes – However, it is unlikely this solution would be used in the long term. Plantations may need to prove they can be in place for the lifetime of the development or offer a fallback option with an equivalent P removal.
Cost estimate	The average Farm Business Tenancy (FBT) rental price in the west midlands for farms in 2022 was £272/ha. The average purchase price in the west midlands for arable land is £24,375/ha and £18,750/ha for pasture land. Energy Crop Schemes that provide establishment grants for approved energy crops are available.

Table 3.14: Nutrient mitigation per land use type

Farm type	Clun Catchment	
	Phosphorus mitigation (Kg TP/ha/yr)	Nitrogen mitigation (Kg TNP/ha/yr)
Dairy	0.13	25.35
Lowland grazing	0.11	16.70
Mixed livestock	0.14	26.39
Poultry	0.32	306.17
Pig	0.16	64.10
Horticulture	0.10	19.50
Cereals	0.18	28.17
General arable	0.11	21.46
Allotment	0.11	21.46

3.3.2.2 Cessation of fertiliser and manure application

Where full land abandonment is not available, a change of farming practices or cessation of fertiliser application may be applicable. **Table 3.15** provides an overview of cessation of fertiliser and manure application as a solution.

Table 3.15: Key considerations of the cessation of fertiliser and manure application

Descriptor	Definition
Description of solution	A change of farming practices or cessation of fertiliser will have an immediate short-term impact by reducing the small amount of soluble P runoff lost following application, particularly during rainfall events. There will also be a longer-term impact on particulate P loss should the solution be implemented for consecutive years due to a reduction in soil P reserves. Particulate forms of P are typically lost through soil erosion when P is bound to soil. Legacy P could potentially be a source of fertiliser for use on crops and could decrease the dependence on external fertilisers. An alternative option to ceasing fertiliser application would be to apply the correct level of fertiliser, rather than applying a constant amount. However, the P removal is more variable, and the release of credits would only be available following soil sampling.
Delivery timescale	This solution does not require any investment in infrastructure, planning permission or environmental permits. It can therefore be implemented in very short timescales.
Duration of operation	This solution is envisaged as a temporary measure for use while longer-term solutions are developed and implemented. Prolonged cessation of fertiliser application may produce similar results as taking land out of agricultural use (**Section 3.3.2.1**).
Nutrient removal	Cessation of fertiliser allows land to continue to be farmed whilst still providing P reductions, with the loss of productivity from the lack of fertilisation balanced by income from nutrient mitigation. P levels can be reduced through cutting for silage without fertiliser which would prevent the application of approximately 30 kg/ha of P (Agriculture and Horticulture Development Board, 2022). Particulate P runoff reductions from the cessation of 100% of fertiliser application is estimated to be 50% (Newell Price *et al.*, 2011). White and Hammond (2009) found that particulate P accounts for 40% of the TP loss from improved grassland. However, on arable land particulate forms of phosphorus typically have more of an influence than on grassland areas, due to the lack of dense vegetation preventing particulate loss. Neal *et al.*, (2010) found that particulate P in agricultural and rural settings in the UK made up 50% TP. A conservative estimate of 25% removal of P was assumed. Nitrogen is much more soluble than phosphorus and there is likely to be a greater reduction in nitrogen runoff from the cessation of fertiliser. As such, it was assume that 75% removal of N is achieved.

Descriptor	Definition
	Nutrient mitigation rates (Kg/ha/yr) are provided in **Table 3.16.**
Applicability	This solution is applicable to all types of arable agriculture where natural or synthetic fertilisers are applied.
Management and maintenance	Monitoring will be required to ensure that estimated nutrient removal rates are achieved and validate that fertiliser/ manure application has ceased. This is likely to comprise initially of one to two visits per year, including an initial round of sampling to establish the baseline conditions.
Additional benefits	Land could be selected strategically to help buffer from other pollution sources, e.g., , suspended sediment.
Best available evidence	Yes – monitoring likely to be needed to confirm.
Wider environmental considerations	If the solution is widely implemented, then the reduced yield could result in food supply issues, but to a lesser degree than taking land out of agricultural use.
Evidence of effectiveness	Yes – beyond reasonable scientific doubt. The cessation of fertiliser and manure has an immediate impact on the land's P output, reducing surface water P levels following rainfall events. As with the taking land out of agricultural use solution, some legacy P will be maintained in the soil. McCollum (1991) indicated that P levels may not be reduced to background concentrations for at least 17 years.
Precautionary	Yes – a precautionary approach can be applied to this solution until and after site specific information becomes available.
Securable in perpetuity	No – likely to be utilised as a bridging solution. Cessation of fertiliser allows land to continue to be farmed whilst still providing P reductions, with the loss of productivity from the lack of fertilisation balanced by income from nutrient mitigation. This could be secured as a short-term bridging solution by planning conditions. Legal agreements to cease fertiliser application for a set area and duration will be required and spot checks undertaken to monitor farming practices and nutrient concentrations in runoff.
Cost estimate	Cessation of fertiliser application to arable land is estimated to have a 50% reduction in yield on the affected area. Similarly, cessation to grassland is assumed to have a reduction of 30% to an average yield of 8 t/ha (Newell Price *et al*., 2011). The actual costs per farm are likely to differ due to the variety of variables, such as fertilisation rates, soil types, crop types, etc. An estimated cost breakdown is provided in **Table 3.17**.

Table 3.16: Cessation of fertiliser mitigation rates

Farm type	Clun catchment	
	Phosphorus mitigation (Kg TP/ha/yr)	Nitrogen mitigation (Kg TN/ha/yr)
Dairy	0.03	19.01
Lowland grazing	0.03	12.53
Mixed livestock	0.04	19.79
Poultry	0.08	229.63
Pig	0.04	48.08
Horticulture	0.03	14.63
Cereals	0.05	21.13
General arable	0.03	16.10
Allotment	0.03	16.10

Table 3.17: Cessation of fertiliser/ manure cost estimation

Description	Cost (£/ha/yr)	
	Arable	Grassland
Saving in fertiliser	-100.82	-35.96
Reduced use of fertiliser spreaders	-6.65	-6.65
Reduced yield/ forage replacement	781.86	311.12
Soil testing	600	600
Total	**1,274.39**	**868.51**

3.3.2.3 Cover crops

Cover crops can be implemented on bare soils, particularly steeper slopes, to intercept and uptake nutrients present in surface water runoff before it reaches the watercourse. **Table 3.18** provides an overview of cover crops as a solution.

Table 3.18: Key considerations of cover crops

Descriptor	Definition
Description of solution	Surface runoff and erosion represents a principal mechanism for nutrient loss from many agricultural systems. The risk of runoff is primarily controlled by timing, rate and method or fertiliser or manure application, as well as post-application rainfall. Natural factors such as slope, surface roughness, infiltration capacity and magnitude of erosion also have a strong control. Bare soils are very prone to erosion and cover crops help maintain soil cover during the autumn and winter or any time of the year including drier months and cover crops can also be sown in springtime. They are especially useful to mitigate erosion on high-risk sloping land. Cover crops act to encourage infiltration and reduce overland flow velocity. They are best employed when land would otherwise be left bare during the crop rotation process. They are typically used either prior to main production cycle, e.g., , potatoes, sugar beet, or post-harvest, e.g., , cereals. Validation of cover crops can be achieved through satellite imagery, photographs, and drive by visits. Due to some uncertainty in removal values, soil sampling and monitoring may be required to establish the baseline and nutrient reduction.
Delivery timescale	This solution does not require any investment in infrastructure, planning permission or environmental permits. It can therefore be implemented in short timescales.
Duration of operation	This solution is envisaged as a long-term change in agricultural land management practices. However, in the absence of any significant infrastructure, long term investment, or mechanisms for binding agreements with landowners, it is considered to be impermanent.
Nutrient removal	Published P reduction rates are variable within the literature. Novotny and Olem (1994) suggest significant P removal rates of 30-50%, with others (Sharpley and Smith,1991) finding an average reduction of 77% across four studies. However, another investigation concluded that changes to P losses were not significant (Kleinman *et al.*, 2005). Similarly, Cooper *et al.* (2017) found that oilseed radish crops had no effect on P losses. TP and TN removal potential assumed to be ~30% despite uncertainty. TP removal rate: 0.04 kg/ha/yr TN removal rate: 7.92 kg/ha/yr Much greater amounts of N can be removed and make the solution much more viable. The N mitigation that can be achieved through the cessation of fertiliser application is likely to cost more than taking agricultural land out of use completely.

Descriptor	Definition
Applicability	This solution is applicable to all types of arable agriculture, particularly where fields are left bare and thus vulnerable to surface water runoff and erosion after the harvest of the main crop.
Management and maintenance	There will be annual maintenance requirements associated with preparation, planting, destruction, and cultivation of cover crops.
Additional benefits	▪ Reduced soil erosion ▪ Improved water quality ▪ BNG due to habitat creation and winter cover provides habitat for birds, mammals, and insects.
Best available evidence	No – Nutrient reduction estimates are highly variable and may require further research.
Wider environmental considerations	Implementation of this option is unlikely to be significantly constrained by wider environmental factors.
Evidence of effectiveness	Although there is scientific evidence to suggest that cover crops are effective in reducing the supply of P from agricultural land, estimates show considerable variation. There is therefore a degree of uncertainty associated with the effectiveness of this solution. It is expected that a conservative removal rate of 30% could be applied for cover crops. Monitoring would then be required to access 'credits' for removal rates above 30%.
Precautionary	Yes, conservative, precautionary estimated TP and TN removal rate of 30% is assumed.
Securable in perpetuity	This solution is securable in perpetuity through management agreements, particularly where land in leased.
Cost estimate	Annual maintenance costs estimated to be £150/ha/yr (AHDB, 2020)

3.3.2.4 Installation of SuDS in new developments

SuDS are efficient sediment traps that reduce the amount of runoff entering a watercourse. There are a variety of SuDS that can be installed with new developments, such as SuDS wetlands, swales and conveyance channels, filter strips and rain gardens. The different SuDS types are explored in **Table 3.19**, which provides an overview of installing SuDS in new developments as a solution.

Table 3.19: Key considerations of the installation of SuDS in new developments

Descriptor	Definition
Description of solution	The fundamental principles of SuDS are to slow flow and promote infiltration, allowing rainfall to enter the groundwater where it falls. SuDS that promote the infiltration of water and settlement of sediment will have the greatest benefit for nutrient, particularly P, removal. Similarly, SuDS that provide an environment for vegetation to uptake nutrients will achieve good removal rates. SuDS used in combination and that are linked in a treatment train, often culminating in a SuDS wetland, represent the most favourable scenario. Examples of different SuDS and their benefits are outlined below.
Delivery timescale	A requirement to implement SuDS as part of all new developments can be established in the short term.
Duration of operation	Once installed, SuDS are assumed to be permanent drainage and nutrient management solutions.
Nutrient removal	The CIRIA C808 (Bradley *et al.*, 2022) document; 'Using SuDS to reduce phosphorus in surface water runoff' works towards definitive recommendations for the use of SuDS for nutrient removal. The document sets out SuDS deployment via 'treatment trains' to achieve good practice nutrient removal which are expected to be set out at full planning applications stages. A precautionary reduction in the runoff rate of nutrients from new developments can be achieved for developments that secure the good practice SuDS set out in the document.

Royal HaskoningDHV

Descriptor	Definition
	The document summarises the relative performance of SuDS components for P capture and removal which is noted as highly variable. Where SuDS promote infiltration, it is assumed that 100% of the TP is removed. The TP removal from conveyed flows which are not infiltrated are presented in **Table 3.20**. The CIRIA C808 report only considers the impact of SuDS on phosphorus and not nitrogen. It is expected that a similar guidance document will be published in due course. However, until this guidance is available, The CIRIA SuDS guidance provides some indication of the possible nitrogen reductions achievable through SuDS.
Applicability	This solution is applicable to all new dwellings in the catchment and should be designed from an early stage. The size of the site will control the design and nutrient removal potential.
Management and maintenance	The long-term performance of SuDS would also need to be secured through maintenance agreements, e.g., , via Section 106 rather than planning conditions given the required duration of these commitments. There will be routine/ regular, occasional, and remedial maintenance (e.g., de-silting).
Additional benefits	▪ Improved water quality ▪ Reduced erosion ▪ Habitat creation/ BNG ▪ Improved amenity value
Best available evidence	Yes – P removal rates derived from CIRIA C808. N removal rates less confidence.
Wider environmental considerations	The use of SuDS in new developments is unlikely to be significantly constrained by wider environmental factors.
Evidence of effectiveness	There is currently limited evidence to demonstrate the efficiency of SuDS measures in the removal of nutrients from runoff. However, parallels could potentially be drawn with the evidence base for their effectiveness in attenuating flows and reducing sediment supply.
Precautionary	A precautionary approach can be adopted when implementing this solution.
Securable in perpetuity	Yes, though maintenance agreements (such as Section 106 agreement) may be required
Cost estimate	Costs are highly variable and site specific. Likely to be £20/m^2 – £40/m^2

Table 3.20: Performance of SuDS components for phosphorus capture and removal (Edited from CIRIA C808 (2022))

Relative performance	Swale	Detention basin	Retention basin	Pond	Floating wetland	Bioretention zone	Tree pit	Filter strip
Sediment capture capability	28%	28%	28%	38%	38% settled in pond	44%	44%	22%
Dissolved phosphorus capture/ removal	Nil	12%	50%	50%	Test results provided by manufacturer	Nil	Nil	Nil
TP removal	15.4%	20.8%	37.9%	43.4%	20.9%	24.2%	24.2%	12.1%

Relative performance	Filter drain	Willow beds	Permeable pavement	Vortex grit separator	Oil water separator	Stormwater filter	Granular treatment media	Rainwater and stormwater capture
Sediment capture capability	22%	100%	38%	28% based on 50% Total Suspended Solids (TSS) removal	28% based on 50% TSS removal	44% if sediment removal device included upstream	44% if sediment removal device included upstream	N/A
Dissolved phosphorus capture/ removal	Nil	100%	Nil	Nil	Nil	Up to 90% if the media selected specifically for P capture		N/A
TP removal	12.1%	100%	20.9%	15.4%	15.4%	64.7%	64.7%	N/A

3.3.2.5 Retrofitting SuDS in existing developments

Retrofitting SuDS into existing developments will provide efficient sediment traps and a reduction in the amount of runoff entering watercourses. **Table 3.21** presents the key considerations for the use of retrofitting SuDS for nutrient offsetting or reduction.

Table 3.21: Retrofitting SuDS key considerations

Key considerations	
Description of solution	Retrofitting SuDS into existing developments will provide efficient sediment traps and a reduction in the amount of runoff entering watercourses. The fundamental principles of SuDS are to slow flow and promote infiltration, allowing rainfall to enter the groundwater where it falls.
Delivery Timescale	Medium-term
Duration of operation	Permanent
Nutrient removal	Highly variable and will likely need site specific calculations. The best SuDS for retrofitting are likely to include swales, bioretention areas, filter drains, tree pits and porous paving.
Management and maintenance	The long-term performance of SuDS would also need to be secured through maintenance agreements. Maintenance works would include desilting of swales, wetlands, and basins to maintain their efficiency. Vegetation management of buffers would be necessary to maintain the optimum roughness/ composition and sediment trapping efficiency.
Applicability	Location specific
Additional benefits	▪ Improved water quality ▪ Reduced erosion ▪ Habitat creation; and ▪ Improved amenity value
Best available evidence	No – Monitoring may be required to determine the efficacy of specific schemes
Wider environmental considerations	The use of SuDS in new developments is unlikely to be significantly constrained by wider environmental factors
Evidence of effectiveness	Yes - nutrient removal rates derived from CIRIA.
Precautionary	Yes
Securable in perpetuity	Yes – maintenance agreements may be required
Cost estimation	See **Table 3.19**.

3.3.2.6 Highway drainage improvements

Highways drainage represents a source of sediment-bound nutrients in the River Clun catchment. Measures to remove the sediment prior to it entering the water environment could potentially be used to mitigate future residential development. **Table 3.22** presents the key considerations of highways drainage improvements.

Table 3.22: Highway drainage improvements key considerations

Key considerations	
Description of solution	Highways drainage represents a source of sediment-bound nutrients and could be mitigated by installing measures (i.e., SuDS) to remove the sediment from road drainage prior to it entering the water environment.
Delivery Timescale	Medium-term

Royal HaskoningDHV

Key considerations	
Duration of operation	Permanent
Nutrient removal	The greatest nutrient removal rates can be achieved where catchments for the SuDS drain urban and arable land. Areas at high risk of sediment runoff are likely to contain high concentrations of nutrients. Depending on the area of land available to implement highway SuDS, a variety of solutions are available with a range of phosphate removal rates. Solutions and typical phosphate removal rates are shown in **Table 3.23**. Where phosphorus removal rates have been documented, typical values range from 25% for highway/ infield filter strips to 55% for in ditch wetlands. Phosphate removal efficiencies of well-designed SuDS acting as sediment traps are typically around 50%. Highway SuDS are also effective at capturing nitrogen and settling out suspended solids (60-90%) – the latter is particularly important for improving water quality for freshwater pearl mussels. The average catchment size of the highways drains assessed is 4.4ha. Assuming the land is in lowland grazing use on freely draining soils, the phosphorus loading would be 0.48kg/yr. Assuming a reduction efficiency of 50%, installing SuDS to highways could deliver on average 0.24kg/yr of phosphorus mitigation per drain. The equivalent nitrogen loading would be 73.48kg/yr. Assuming a reduction efficiency of 70%, installing SuDS to highways could deliver on average 51.44kg/yr of nitrogen mitigation per drain.
Management and maintenance	The long-term performance of SuDS would also need to be secured through maintenance agreements (e.g., Shropshire Council Highways team). Maintenance works would include desilting of swales, wetlands, and basins to maintain their efficiency. Vegetation management of buffers would be necessary to maintain the optimum roughness/ composition and sediment trapping efficiency.
Applicability	For larger SuDS schemes, such as detention ponds/ basins, sufficient space would be needed beside the highway (most likely on A roads). Many of the minor roads that cross the Clun catchment do not fall into this category, being both narrow in terms of road surface and verge width.
Additional benefits	▪ Suspended sediment removal ▪ Habitat creation ▪ Water quality
Best available evidence	Yes – However, monitoring may be able to determine improved efficacy of specific schemes
Wider environmental considerations	The use of SuDS in highway drains is unlikely to be significantly constrained by wider environmental factors
Evidence of effectiveness	Yes - nutrient removal rates derived from Natural England.
Precautionary	Yes
Securable in perpetuity	Yes – maintenance agreements may be required
Cost estimation	See **Table 3.23**.

Table 3.23: Highway SuDS methods, pollutant removal rates and highway retrofit applicability (after Natural England, 2013)

Solution	Capital costs	P removal (%)	N removal (%)	Suspended solids Removal (%)	Highway retrofit
Infiltration trench/ soak away	£55-65/m3 stored volume	45	80	80	✓
Sediment traps/ infiltration basin	£400-500 excavated sediment trap	50	-	90	✓

Solution	Capital costs	P removal (%)	N removal (%)	Suspended solids Removal (%)	Highway retrofit
Grass swales	£10-15/m3 for Swale area	-	-	-	Only wider highway corridors parallel to road
In-ditch wetlands	£5,000 for 30 m sedge wetland Widening of existing ditch to create in-ditch wetland digger and driver £300/ day	55	70	63	Only wider highway corridors parallel to road
Detention basin	Small basins typically £3,000	45	45	90	Only if sufficient space available beside the highway
Hedgerow/ hedgebank	New hedgebank establishment £800/15m (including filter drain) New hedge - Tree whips and guards £6/m	No data	No data	No data	The effectiveness of hedgerows could be increased by incorporating grass filter strips either on the field side or where there is space adjoining the highway.
Highway/ in field filter strips	£32/ha	25	25	85	On wider highway corridors parallel to road
Relocation of roadside gateways	£300-400	-	-	-	✓

3.3.3 Wastewater management solutions

3.3.3.1 Expedite planned improvements to treatment works

Bringing forward scheduled improvements to treatment works which are planned to be online by 2025 or 2030 will reduce the temporary mitigation burden. **Table 3.24** provides an overview of expediting planned improvements to treatment works as a solution.

Table 3.24: Key considerations of expediting planned improvements to treatment works

Descriptor	Definition
Description of solution	In many cases, water companies will complete infrastructure upgrades to WRCs in advance of AMP deadlines but would not operate at the future permit limit until required to do so to save on operational costs. Operating these WRCs at the permit limit in advance of original deadline reduces the amount of temporary mitigation that needs to be delivered. Agreements would need to be in place between the water company, environment agency and Ofwat. Bishop's Castle is scheduled to operate at a permit limit of 0.4mg/l by 2025.
Delivery timescale	The delivery timescales are dependent on the level of existing infrastructure in place and how quickly the effluent concentrations could reach the target concentration.

Descriptor	Definition
Duration of operation	This is a short-term intervention that would be operational between the agreed expedited date and the original planned improvement date.
Nutrient removal	Bringing forward the 2025 improvement would reduce the mitigation burden by 0.34 kg/yr for phosphorus until 2025. This solution would not deliver nitrogen mitigation.
Applicability	WRCs planned for upgrades in 2025 (i.e., Bishop's Castle) any treatment works subject to mandatory TAL requirements by 2030 (currently not expected to apply to any treatment works).
Management and maintenance	Nothing in addition to the regular maintenance and monitoring requirements fulfilled by the water company.
Additional benefits	This solution is unlikely to deliver any wider environmental benefits.
Best available evidence	This solution used the best available evidence.
Wider environmental considerations	Achieving low TP effluent concentrations may require extensive chemical dosing, which is typically imported, e.g., , from China, and may be associated with carbon dioxide emissions.
Evidence of effectiveness	The WRC upgrades will employ industry best practise in order to achieve the desired TP effluent concentrations. Mandatory monitoring of effluent quality can be used to verify the intended reductions have been achieved.
Precautionary	Precautionary measures can be implemented.
Securable in perpetuity	Yes - the schemes would go beyond what was originally planned.
Cost estimate	Severn Trent Water may be willing to bring forward these improvements following pressure from the Environment Agency. Alternatively, funding could be provided by developer contributions. Costs are uncertain and would need to be provided by Severn Trent Water. The likely costs associated with expediting improvements will be the operational and management costs, e.g., , phosphorus dosing and energy costs to operate to a lower permit limit.

3.3.3.2 Improvements to Clunbury treatment works

Improving the effluent concentration at wastewater treatment works within the catchment which are unpermitted. **Table 3.25** provides an overview of improving wastewater treatment works. Further details on the feasibility for Clunbury treatment for wetland creation is provided in **Appendix 4**.

Table 3.25: Key considerations of expediting planned improvements to treatment works

Descriptor	Definition
Description of solution	Much of the additional nutrient load from new residential development comes from the increase in wastewater production that results from the additional population occupying new developments. Raw sewage entering a municipal Wastewater treatment works is highly enriched in nutrients. Most WwTWs have primary and secondary treatment of wastewater, which uses settlement of sediments and biological removal processes to remove organic pollution and some dissolved nutrients (Rout *et al.*, 2021). However, secondary treatment does not remove a significant amount of nutrients from wastewater and tertiary treatment systems are needed to provide large reductions in nutrient concentration and load in the final treated effluent discharged by a WwTWs (Kang *et al.*, 2008). Tertiary treatment to remove nutrients at WRCs is often termed 'nutrient stripping.' Installation of nutrient stripping technologies at WRCs requires significant capital expenditure by the water company and as such, a relatively small number of WwTWs have tertiary treatment to remove nutrients. The Levelling Up and Regeneration Bill (LURB) is proposing a mandate for all WRCs that serve more than 2,000 people (> 2,000 PE) to be upgraded to TAL by 2030. TAL concentrations for nutrients in treated wastewater is 0.25 mg TP/L. Furthermore, some WwTWs will be required to improve their effluent concentration through the Water Industry National Environment Programme (WINEP). For N, nutrient stripping at WRCs predominantly relies on biological treatment technologies (Kang *et al.*, 2008; Rahimi *et al.*, 2020).

Descriptor	Definition
	Any WwTWs not requiring upgrades through the LURB and WINEP could deliver phosphorus mitigation. Clunbury treatment works has the potential to serve a Population Equivalent (PE) of 83. However, it is estimated that the actual figure connected to mains sewerage is 25-30, with 53-58 served by septic tanks/ package treatment plants. The treatment works does not have a phosphorus permit and is assumed to have an effluent concentration of 5mg/l. Installing additional treatment (likely to be a reed bed or constructed wetland) could achieve significant concentration reductions.
Delivery timescale	The delivery timescales are likely to be long-term due to the timescales associated with design, consenting, building and establishment of a constructed wetland.
Duration of operation	This solution is a permanent solution that would deliver mitigation in perpetuity.
Nutrient removal	Assuming a population of 27.5 people (i.e. those connected to mains sewerage), a wetland could deliver 6.08kg/yr of phosphorus mitigation and 32.45 kg/yr of nitrogen mitigation. The wetland removal potential is likely to be limited by the low flow volume as a result of the low population served. Assuming a population of 83 people, a wetland could deliver 16.94kg/yr of phosphorus mitigation and 97.94kg/yr of nitrogen mitigation. The increased population allows for a greater flow rate and subsequent increase in the wetland size.
Applicability	This solution only applies to Clunbury wastewater treatment works.
Management and maintenance	Management agreements and monitoring regime will need to be in place in order to provide certainty in perpetuity. See Section 3.3.1.4.
Additional benefits	Additional water quality benefits.
Best available evidence	This solution used the best available evidence.
Wider environmental considerations	No wider environmental considerations.
Evidence of effectiveness	The WRC upgrades will employ industry best practise in order to achieve the desired effluent concentrations. Monitoring of effluent quality can be used to verify the intended reductions have been achieved.
Precautionary	Precautionary measures can be implemented.
Securable in perpetuity	Yes - the schemes would go beyond what was originally planned.
Cost estimate	Costs are uncertain and would need to be provided by Severn Trent Water. An estimate of £500,000 per ha was assumed for this study. It is anticipated that nutrient credits would be used to pay for the implementation costs. However, upfront capital expenditure will need to be sourced until developer contributions can be accepted.

3.3.3.3 Moving Clunbury ST on to mains sewerage

Table 3.26 provides an overview of transferring private on-site treatment plants to mains sewerage.

Table 3.26: Key considerations of transferring private on-site treatment plants to mains sewerage

Descriptor	Definition
Description of solution	Clunbury treatment works has the potential to serve a Population Equivalent (PE) of 83. However, it is estimated that the actual figure connected to mains sewerage is 25-30, with 53-58 served by septic tanks. Connecting these properties from private sewerage onto the mains is likely to create nutrient mitigation.
Delivery timescale	The delivery timescales are likely to be long-term due to the timescales associated with design, consenting, building and establishment of a constructed wetland (required to achieve the greatest nutrient benefits).
Duration of operation	This solution is a permanent solution that would deliver mitigation in perpetuity.

Descriptor	Definition
Nutrient removal	Assuming that 55.5 PE are connected to septic tanks with a phosphorus effluent concentration of 11.6 mg/l and nitrogen effluent concentration of 96.3 mg/l (May and Woods, 2016), the existing loading is 30.57kg/yr for phosphorus and 253.78kg/yr for nitrogen. Connecting the entire 83 PE to mains (i.e., an additional 55.5 PE) under the existing permit limits will create a phosphorus saving of 17.39kg/yr and nitrogen saving of 187.90kg/yr. Where other STs are to be connected to the mains (e.g., Bishop's Castle), this could deliver 1.34kg/yr phosphorus mitigation per septic tank.
Applicability	This solution only applies to Clunbury wastewater treatment works. Similarly, the existing STs should **not** meet the small scale thresholds criteria[4] - however, given the close proximity to neighbouring septic tanks, this is likely to be the case.
Management and maintenance	Existing management and maintenance of the treatment works by the water company.
Additional benefits	Additional water quality benefits.
Best available evidence	This solution used the best available evidence.
Wider environmental considerations	No wider environmental considerations.
Evidence of effectiveness	The calculations employ catchment specific information and best available evidence on concentrations.
Precautionary	Precautionary measures can be implemented.
Securable in perpetuity	Yes - the schemes would go beyond what was originally planned.
Cost estimate	Costs are likely to vary considerably depending upon the number of units, the diameter and length of pipe, and the requirements for excavation required to achieve a new connection. Severn Trent Water's developer enquiries website (https://www.stwater.co.uk/building-and-developing/overview/new-site-developments/developer-enquiries/) includes a tool to allow developers to calculate cost estimates for new domestic connections to the existing sewer network. Connecting 23 properties (i.e., 55.5 PE) that currently use septic tanks to Clunbury treatment works is estimated to cost ~£245,000. This estimation factors in various costs including Severn Trent's application and infrastructure charges, traffic management charges, street works licence charges and the estimated cost of the connection works carried out by a contractor. A breakdown of the charges per dwelling are set out in Error! Reference source not found.. *Table 3.27 Breakdown of the costs to connect to Clunbury treatment works per dwelling*

Factor	Charge per dwelling
Application fee (assumes connection with 2 lengths of lateral drain or sewer (30 metres))	£840.16
Infrastructure charge	£329.57
Traffic management/ highway charges (assumes standard full road closure for 3 days where the speed limit is up to 40 mph and not exceeding 1 mile diversion)	£659.29
Street works licence	£450
Connection works cost	£8,400

4 *https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwj87OTE2ZmBAxVXh_0HHQh7AWUQFnoECBMQAQ&url=https%3A%2F%2Fpublications.naturalengland.org.uk%2Ffile%2F5133936477601792&usg=AOvVaw2D9cd73rQWzQz48uhPr8L8&opi=89978449*

Descriptor	Definition	
	Total	£10,479.02

Table 3.32 outlines the various options for implementation.

Table 32: Options for implementing ST transfer to mains sewer

Options	Description	Discussion
Option 1 – Local Authority mandatory connection	If a property drains to a septic tank, the local authority has powers to force owners to connect to the public sewerage network if the current arrangements pose an environmental hazard, and there is a public sewer located within one hundred feet (30.48 metres). This will usually be at the home owner's expense. Any new pipes laid as part of this process would not automatically be adopted by the water company, and would therefore be the property owner's responsibility to maintain. If the nearest public sewer is more than a hundred feet from a property and a drain runs into an adequate cesspool or septic tank, the Local Authority can't insist that a property is connect to the public sewer. However, Local Authorities can insist if they agree to pay for the additional costs of connection, including construction, maintenance and repairs. These costs could be funded through developer contributions. It may be possible in a small number of cases for the Local Authority environmental health department to order a septic tank to be converted to mains sewerage. This would only be possible where a septic tank represents a risk to health and is typically faulty/ not maintained properly. The Local Authority has the power to carry out the work and charge the homeowner.	Mandatory connections, particularly where a home is greater than one hundred feet from the sewer, can be mandated. However, there is a high level of financial risk associated with this, due to the liability for ongoing maintenance and repairs.
Option 2 – Voluntary connection	All water and sewerage companies have a duty to provide public sewers to make sure the area is effectively drained. Usually, homeowners have the right to connect the drain from their property to the public sewer – although they may have to pay for this. Developer contributions could be used to refund the landowners for any expenditure (+ potential incentives). Identification of willing homeowners could be achieved through letter drops and website call for site.	Voluntary connections would rely on goodwill (and potentially small incentives) and are therefore have a lesser degree of certainty. This is likely to require a more involved role from the Local Authority. However, financial liability is likely to be limited to connection and construction, excluding maintenance and repairs.

3.3.3.4 Bishop's Castle WwTW transfer scheme

Bishop's Castle treatment works currently discharges to a tributary of the River Kemp, to the southeast of the town. There is the potential to alter the effluent discharge location from here to the River Onny which is located approximately 4km to the east and not within the Clun catchment. This would remove nutrient from existing properties from the catchment, as well as future development proposed in the draft Local Plan. **Table 3.29** provides an overview of this as a solution.

Table 3.29: Key considerations of transferring Bishop's Castle WwTWs to the Onny catchment

Descriptor	Definition
Description of solution	Bishop's Castle treatment works currently discharges to a tributary of the River Kemp, to the southeast of the town. There is the potential to alter the effluent discharge location from here to the River Onny which is located approximately 4km to the east and not within the Clun catchment. This would require Defra approval and would not be deliverable until mid-2026. Initial engagement has confirmed that the

Descriptor	Definition
	project is technically feasible, and the receiving catchment has the capacity to accept the additional nutrient loading.
Delivery Timescale	The implementation of this solution will require the installation of new infrastructure and would require planning permission. The solution is assumed to be achievable in the long-term.
Duration of Operation	The solution is considered to be permanent.
Nutrient Removal	Bishop's Castle currently serves a population of 1,817. An assumptions has been made on the average water usage of 130 l/person/day[5] and an average phosphorus effluent concentration of 0.37 mg/l[6] and nitrogen concentration of 25 mg/l. The Bishop's Castle treatment works currently discharges approximately 31.92kg/yr of phosphorus and 2,156.89kg/yr of nitrogen. This will be removed from the catchment in perpetuity. Furthermore, any future development in Bishop's Castle would then not increase the wastewater loading to the river Clun. This would also reduce the mitigation required over the Shropshire Local Plan period by 6.24kg/yr for phosphorus and 209.03kg/yr for Nitrogen. As a result, the remining budget for the catchment would be 12.96kg/yr for phosphorus and 486.78kg/yr for nitrogen. A more precautionary assumption could be taken which assumes the treatment works would be operating at the Technically Achievable Limit (TAL), which accounts for potential future permit limit changes. TAL is 0.25mg/l for phosphorus and 10mg/l for nitrogen and it is assumed the treatment works would operate at 90% of the permit. Under these assumptions, the treatment works would remove 19.41kg/yr of phosphorus and 776.48kg/yr of nitrogen.
Applicability	This would apply to all existing properties and any proposed future developments.
Management and Maintenance	Existing management and maintenance of the treatment works would continue.
Additional Benefits	This is likely to deliver additional water quality benefits to the catchment.
Best Available Evidence	This mitigation solution is based on the best available evidence.
Wider Environmental Considerations	This solution involves moving the nutrient loads from one catchment to another, which would lead to increased nutrient concentrations in these river catchments.
Evidence of Effectiveness	This solution is reliant on treatment of wastewater at a dedicated WRC therefore it is assumed to be highly effective.
Precautionary	A precautionary approach can be taken with this method through assuming precautionary removal rates.
Securable in Perpetuity	Yes – the treatment works are assumed to be operational for the lifetime of the development.
Cost Estimate	Capital costs: approx. £3,000 - £6,000 Operational costs: £3,200 - £5,600 per year

[5] *Severn Trent Water average water usage for the catchment*
[6] *Measured data for 2020 – 2023 from Environment Agency water quality archive*

3.3.3.5 Installation of cesspools and capture outputs from private sewage systems

Cesspools and capture outputs from private sewerage systems offer the possibility of tankering waste from dwellings within the catchment to registered waste facilities outside of the catchment. **Table 3.34** provides an overview of installing cesspools and capture outputs from private sewage systems as a solution.

Table 3.34: Key considerations of installing cesspools and capture outputs from private sewage systems

Descriptor	Definition
Description of solution	Closed cesspool systems offer the possibility of tankering waste from dwellings within the catchment to registered waste facilities outside of the catchment. As a result, there would be no increase in wastewater loading to the River Clun SAC from developments that use this approach. There are some locations towards the edge of the catchment where the distance waste would be carried is minimal. There is some risk of overflow and leak causing nutrients to be released into the environment, however we assume compliance with the associated planning conditions, building regulations, and the Environment Agency's General Binding Rules.
Delivery Timescale	The implementation of this solution will require the installation of new infrastructure and would require planning permission. The solution is assumed to be achievable in the short-term.
Duration of Operation	Cesspools would require regular maintenance to maintain their effectiveness and are an impermanent solution that could be used until a permanent solution can be implemented.
Nutrient Removal	Nutrient removal rates will be dependent on the number of dwellings. The use of cesspools will temporarily remove the entire wastewater contribution from catchment. This could be coupled with a well-designed SuDS scheme which could remove TP and TN contributions from surface water runoff and therefore achieve nutrient neutrality.
Applicability	This option could potentially be applicable to new or existing developments that cannot currently be connected to the foul drainage network.
Management and Maintenance	Cesspools would need to be emptied regularly and the owner would be responsible to ensure they do not leak or overflow. Where a cesspool causes pollution, it would break the law and the Environment Agency could take legal action under the Water Resource Act 1991, which can carry a fine of up to £20,000 and three-months imprisonment. Similarly, the Environment Agency and Local Authority can enforce repairs or replacements of cesspools in poor condition.
Additional Benefits	There are no additional benefits associated with cesspools.
Best Available Evidence	This mitigation solution is based on the best available evidence.
Wider Environmental Considerations	Cesspools could cause a significant increase in carbon production. If water company infrastructure allows for mains connection in the future, water companies would be obliged to connect and wastewater would then be contributing to loads into the catchment, requiring further mitigation. This solution involves moving the nutrient loads from one catchment to another, which could lead to increased nutrient concentrations in these river catchments.
Evidence of Effectiveness	This solution is reliant on treatment of wastewater at a dedicated WRC therefore it is assumed to be highly effective.
Precautionary	A precautionary approach can be taken with this method through assuming precautionary removal rates and the possible addition of precautionary buffers within the calculations.
Securable in Perpetuity	Yes – management agreements will likely need to be put in place, especially where land is leased. Replacements may be required if the lifetime is less than the developments.

Descriptor	Definition
Cost Estimate	Capital costs: approx. £3,000 - £6,000 Operational costs: £3,200 - £5,600 per year

3.3.3.6 Replacement of package treatment plants and septic tanks

Older package treatment plants and septic tanks are typically poorly performing and often have high phosphorus effluent concentrations. Replacing these poorly performing onsite treatment plants with new treatment plants can provide significant nutrient mitigation. **Table 3.35** provides an overview of replacing onsite treatment plants as a solution, and **Table 3.32** provides approximate P removal rates for the main PTP manufacturers.

Table 3.35: Key considerations of installing PTPs

Descriptor	Definition
Description of solution	Correctly operated and well-maintained PTPs produce a higher quality effluent which may be able to be discharged to a soakaway, surface water or groundwater in some circumstances, as well as to drainage fields. Septic Tanks (STs) are an alternative type of basic onsite wastewater treatment along with PTPs. Alterations to existing PTPs and ST or installing new tanks to provide additional dosing could achieve significant nutrient reductions. Typically, older PTPs (especially those without P dosing) will be discharging effluent at a much higher concentration than new PTPs. An assumption is made that a default ST will have an effluent concentration of 11.6 mg/l TP. A default PTP will have an effluent concentration of 9.7 mg/l TP.
Delivery Timescale	PTPs typically take three months to deliver and set up; they can therefore be implemented over short timescales. An environmental permit is likely to be required for any discharges from the PTP.
Duration of Operation	PTPs are considered a permanent solution. It is assumed that the PTP would be replaced with a model that has at least the same P removal in the future.
Nutrient Removal	TP removal potential: Assuming a default ST is replaced with a new PTP with a TP effluent concentration of 2 mg/l, approximately 1.14kg/yr of phosphorus mitigation and 9.69kg/yr of nitrogen mitigation would be created. The replacement would have an estimated additional cost of approximately £15,000.
Applicability	PTPs could potentially be applicable to all residential developments that cannot currently be connected to the existing foul sewer network. Similarly, the existing STs should **not** meet the small scale thresholds criteria - however, given the close proximity to neighbouring septic tanks, this is likely to be the case.
Management and Maintenance	Some maintenance of the PTP would be required. Where additional P stripping is used, this should be applied in accordance with the design instructions.
Additional Benefits	This solution is unlikely to deliver any additional or wider environmental benefits.
Best Available Evidence	This solution uses the best available evidence from the available data.
Wider Environmental Considerations	The use of package treatment plants could potentially have implications for the local population, including visual impact, noise, and odour. Energy use may also be an important consideration.
Evidence of Effectiveness	The manufacturers of PTPs have undertaken detailed testing of their performance and can provide certainty regarding the level of nutrient removal that can be achieved (**Table 3.32**). An advice note jointly published by Somerset Authorities in consultation with Environment Agency and Natural England in September 2022 states that all new ST and PTPs must undergo independent third-party testing to

Descriptor	Definition
	meet British Standards (BS EN 12566) with certification setting out the mean concentration of the effluent from that system.
Precautionary	A precautionary approach can be taken with this method through assuming precautionary removal rates and the possible addition of precautionary buffers within the calculations.
Securable in Perpetuity	Yes – management agreements will likely need to be put in place, especially where land is leased. Replacements may be required if the lifetime is less than the developments. Natural England currently have reservations on the use of package treatment plants that require additional phosphorus dosing to be added by the landowner. However, treatment plants typically achieve the lowest effluent concentrations. Management agreements could be put in place to provide additional certainty regarding management of the PTPs but this will incur additional costs and administration. Alternatively, PTPs which do not require additional dosing could be selected (typical effluent concentration of 2mg/l) and would represent a much simpler option meet the requirements of the habitat regulations. A filter media could also be used to further reduce effluent concentrations and would not require as much management and maintenance as chemical dosing.
Cost Estimate	Capital expenses will depend on plant size. The upper range will be approximately £10,000 - £15,000 for purchasing and installation.

Table 3.32: Main PTP manufacturers P removal rates

System	Removal rate/ concentration	Source
Graf One2clean plus	95.1% / 1.6 mg/l	https://www.graf.info/fileadmin/media/Catalogue_Wastewater_Treatment_Solutions.pdf
Graf Klaro E Professional KL24plus	94.5% / 0.4 mg/l	https://www.graf.info/fileadmin/media/Catalogue_Wastewater_Treatment_Solutions.pdf
Kingspan Klargester BioDisc	2 mg/l	Klargester Biodisc Sewage Treatment System | Kingspan | Great Britain
WPL HIPAF	3 - 6 mg/l	WPL HiPAF® Sewage System - WPL | WCS EE Division (wplinternational.com)

3.3.3.7 Installation of Portable Treatment Works

Portable Treatment Works (PTWs) are typically used by water companies during upgrades and can be used as a secondary treatment system designed specifically for P removal. **Figure 3-8** provides an example of a PTW and **Table 3.37** provides an overview of installing PTWs as a solution.

Figure 3-8: Example of a portable containerised wastewater treatment works (Source: Vikaspumps.com)

Table 3.37: Key considerations of portable treatment works (PTWs)

Descriptor	Definition
Description of solution	PTWs can be used as short-term solutions whilst other mitigations options are designed and developed. Other examples of portable treatment works include portable vertical flow wetlands. The portable treatment works typically have a small footprint of < 0.2ha.
Delivery Timescale	PTWs typically take three months to deliver and set up; they can therefore be implemented over short timescales. They are typically built inside standard 20 ft shipping containers making them easy to install and move to another site (**Figure 3-8**). An Environmental Permit is likely to be required for any direct discharges from the PTWs.
Duration of Operation	This solution is envisaged to be a temporary solution that would be used until permanent solutions can be implemented. However, there is the potential for PTWs to be used over longer timescales as an impermanent solution, although costs may be proportionately high.
Nutrient Removal	Effluent to 0.5 mg/l phosphorus and 10mg/l phosphorus can be achieved. This can apply to all existing houses served by the WwTWs. This solution is most applicable to Clunbury treatment works. Installing a PTWs to an unpermitted WRC would achieve a temporary saving of 0.66kg/yr phosphorus and 1.19kg/yr nitrogen, for each property served.
Applicability	This solution is most likely to be applicable for use in a WwTWs alongside existing treatment equipment. It is most applicable to Clunbury treatment works and could be used while improvements are going through consent and design.
Management and Maintenance	Some maintenance on the system is required, equivalent to a few hours a week, likely to be carried out by staff from the rental company.
Additional Benefits	Potential for water quality improvements.
Best Available Evidence	A precautionary approach can be taken with this method through assuming precautionary removal rates and the possible addition of precautionary buffers within the calculations.
Wider Environmental Considerations	Potential implications such as including visual impact, noise, and odour on the local population. Energy use may also be an important consideration. Disposal of waste produced by the portable works may

Descriptor	Definition
	need to be removed and handled appropriately. There is the potential for the waste to be applied as a replacement to imported fertiliser.
Evidence of Effectiveness	The manufacturers of PTPs have undertaken detailed testing of their performance and are able to provide certainty regarding the level of nutrient removal that can be achieved.
Precautionary	A precautionary approach can be taken with this method through assuming precautionary removal rates and the possible addition of precautionary buffers within the calculations.
Securable in Perpetuity	Yes – management agreements will likely need to be put in place, especially where land is leased. Replacements may be required if the lifetime is less than the developments.
Cost Estimate	Capital costs £10,000 - £100,000 depending on size. Maintenance costs £1,000/yr - £5,000/yr.

3.3.3.8 Rectify misconnections to combined systems

Misconnections occur at a local property level when household wastewater is connected to a surface water drain instead of the local sewer network. When this occurs, there is the potential that the misconnections can cause pollution to the local environment and cause problems for bathing waters. The solution for this is to identify the misconnections and rectifying them, so that the household wastewater is connected to the local sewer network. Key considerations are summarised in **Table 3.38**.

Table 3.38: Key considerations of rectifying misconnections to combined systems.

Descriptor	Definition
Description of Solution	Misconnections occur at a local property level when household wastewater is connected to a surface water drain instead of the local sewer network. When this occurs, there is the potential that the misconnections can cause pollution to the local environment and cause problems for bathing waters. The solution for this is to identify the misconnections and rectifying them, so that the household wastewater is connected to the local sewer network. Correction of the misconnection is the duty of the property owner. The local water company will ensure the correction is performed satisfactorily. The Local Authority has power to enforce the owner rectifies the misconnection through Section 59 of the Building Act 1984. The following checks should be carried out to identify potential misconnections: ▪ Was the property built after the 1920s? ▪ Has there been changes to the original drainage? ▪ Has there been any extensions or alterations to the building? ▪ Are additional pipes connected to rainwater downpipes? and ▪ Is there an outside toilet or appliances in garages, sheds, or outbuildings? More intrusive tests can be carried out such as testing samples for bacteria, dye testing and CCTV surveys. Identifying misconnection is likely to be challenging and are often only discovered during maintenance/ building work. Misconnections are most common is densely populated areas, which homes that have been modified from their original character by extensions, en-suite bathrooms, separate washrooms and conversions. However, without pre-existing knowledge of the location of misconnections, this solution would likely be limited to a small number of properties each year that are identified or would require large-scale surveying of properties which would require significant time and investment and is unlikely to be cost-efficient.

Descriptor	Definition
Delivery Timescale	Rectifying a misconnection to a surface water drain can be established in the short term.
Duration of Operation	Once the misconnection has been remediated, it is assumed to be a permanent drainage and nutrient management solution.
Nutrient Removal	High levels of P and N concentrations are indicative of pollution from misconnected domestic appliances and is expected to be present in misconnection discharges. This occurs when the appliances are connected to the surface water drainage network and not the local sewage network. Examples of misconnections include washing machines and dishwashers which typically have a high P content. In order to quantify the nutrient saving from rectifying misconnections, assumptions would need to be made on concentrations of the appliances/ fitting that were misconnected. Wastewater volumes could be estimated using the Part G calculator[7]. It is unlikely that there will be many opportunities for monitoring misconnections to retrieve meaningful data on the nutrient reductions.
Applicability	This solution could be applied to existing domestic and commercial properties.
Management and Maintenance	None
Additional Benefits	The rectifying of misconnected surface water drainage networks will reduce the volume of pollutants entering the clean water system of the catchment.
Best Available Evidence	Yes – best practise values for volume and concentrations can be used.
Wider Environmental Considerations	The rectifying of misconnections is unlikely to be significantly constrained by wider environmental factors.
Evidence of Effectiveness	Yes – However, there is currently limited evidence to demonstrate the efficiency of rectifying misconnections to surface water drainage networks in the removal of nutrients from the catchment. Monitoring opportunities are likely to be limited. Therefore, generic concentrations would likely need to be applied with a conservative approach taken.
Precautionary	Yes – precautionary principles can be adopted.
Securable in Perpetuity	Yes - The rectifying of misconnections to surface water drainage networks are permanent features which will typically provide benefits for the lifetime of the development.
Cost Estimate	Variable - The costs may differ due to the secondary costs arising from the rectifying of the misconnection. Available comparisons between the variations in cost are limited.

3.3.3.9 Reduce leakage from the sewer network

Due to the age of water distribution networks in the UK, leakage from sewer and water mains are a potential source of nutrient pollution. Water leaks from water distribution networks follows subsurface flow pathways to either reach surface waters quite quickly as throughflow, or by flowing through superficial and deep aquifers to enter surface waters more slowly as baseflow. Nutrient enrichment of wastewater or drinking water in water distribution networks means leaks can create sources of nutrients to the designated site. Key considerations are summarised in **Table 3.39**.

Table 3.39: Key considerations of reducing leakage from the sewer network.

[7] *https://wrcpartgcalculator.co.uk/*

Descriptor	Definition
Description of Solution	Due to the age of water distribution networks in the UK, leakage from sewer and water mains are a potential source of nutrient pollution. Water leaks from water distribution networks follows subsurface flow pathways to either reach surface waters quite quickly as throughflow, or by flowing through superficial and deep aquifers to enter surface waters more slowly as baseflow. Nutrient enrichment of wastewater or drinking water in water distribution networks means leaks can create sources of P. Studies of nutrient pollution in groundwater often cite sewer and mains water networks as sources of P and N, with associated links to increased eutrophication risks in surface waters, e.g., , Holman et al., 2008; Stuart & Lapworth, 2016. It is also noted that although P can be strongly adsorbed to soils and sediments, research has shown that leaks of P-rich water from sewer and water mains can still contribute to elevated groundwater and surface water P concentrations (Ascott et al., 2016; Holman et al., 2008). Thus, fixing leaks from water distribution networks can reduce nutrient inputs to the environment and provide mitigation. Assistance from the water company will be required in order to identify leaking sewers and water mains and complete the necessary repairs.
Delivery Timescale	Medium-term - Given the technologies available for leakage detection and assuming there are no barriers to the availability of resources to carry out the infrastructure works, it is likely that leakage reductions projects could be completed within one year.
Duration of Operation	Impermanent/ Permanent Fixing pipe leaks as a nutrient mitigation measure will operate until a pipe is damaged again, which can occur over variable time that is hard to predict. Modern pipe materials for water mains are suggested to last for 62-113 years[8]. New sewer pipes have been suggested to have a lifespan of over 100 years[9]. This indicates that based on pipe materials, fixing sewer leaks should provide nutrient mitigation in perpetuity (i.e., 80 years) but fixing water mains may not. Agreements with the water company may be required to ensure future repairs are carried out if necessary.
Nutrient Removal	Previous studies have indicated that the scale of nutrient loading to the environment from sewer and water mains leaks is significant. Ascott et al., (2018) estimated national N loading from water mains of 3,620 t N/yr and loading from sewer leaks of 4,060 t N/yr. A study in Nottingham suggested that leaking water mains could cause loading of 7.7 kg N/ha/yr, with leaking sewers resulting in loading of 2.7 kg N/ha/yr (Wakida & Lerner, 2005). Studies of P loading from leaking water mains highlight that drinking water is dosed with P to reduce risks of lead leaching from old water mains and thus drinking water has P concentrations that tend to range from 0.5mg P/l to 1.5mg P/l, which is notably higher than most of the P standards for designated sites (Gooddy et al., 2015). A study of the P loading that might result from leaking water mains may be as high as 1,200t P/yr at a national scale. The model suggests P loading is concentrated in urban areas (where pipe density is greatest) and the majority of the P load (69%) is likely to be t surface water. There is a lack of available studies on the scale of P loading from sewer leaks, however Holman et al., (2008) cite concentrations of 9 to 15mg P/L in raw sewage, meaning every 100m^3 of leakage reduction from sewers will reduce P loading by around 1kg.
Applicability	Wastewater and drinking Water mains
Management and Maintenance	Pressure management and monitoring for pipe defects could be used to help detect and rectify problems that may result in fixed pipes bursting again. This may help increase certainty of the solution.
Additional Benefits	Reduction in abstraction for water supply (only applies to fixing leaks in water mains) and reductions in water pollution, e.g., , from microbiological pollutants
Best Available Evidence	Yes – the amount of water saved and expected concentrations can be used

[8] *https://ukwir.org/long-term-aging-of-polyethylene-*

[9] *https://piperehabspecialists.com/how-long-do-sewer-pipes-last/ and https://www.drainmasterohio.com/how-long-do-sewer-lines-last/*

Descriptor	Definition
Wider Environmental Considerations	Street works may require a street works permit. Consideration should be given to minimising traffic disruption due to street works Construction work should consider wider environmental impacts. A CEMP may be needed to support leakage reduction works and reduce risks
Evidence of Effectiveness	Yes - There is a body of evidence that shows the potential impact that leakage from sewers and water mains can have on nutrient pollution to the environment. However, there is the potential for a range of removal efficiencies for P on subsurface flows, which is primarily controlled by the types of soil and sediment (Penn et al., 2017). Proposals for mitigation schemes using leakage reductions should provide a consideration of the reduction in the P load that is leaked from pipes before it reaches a receiving waterbody and should factor this reduction into the calculations of the efficacy of the scheme.
Precautionary	Yes, assuming allowance for attenuation of P on subsurface flow pathways
Securable in Perpetuity	Yes, assuming robust maintenance and management plans
Cost Estimate	~£1 million to reduce 365 kg P/yr from leaking water main, assuming no attenuation of P on subsurface flow pathways. No costs identified for fixing sewer leaks.

3.3.3.10 Incentivise commercial water efficiency and treatment installation

Operators of a consent to discharge trade effluent would install treatment facilities ahead of discharge to the sewerage network. The installation of which would be enforced via the consent provided by the water company. Key considerations are summarised in **Table 3.40**.

Table 3.40: Key considerations of incentivising commercial water efficiency.

Descriptor	Definition
Description of Solution	A water company is the regulator of trade effluent discharge licence consents into the foul sewer network and the Environment Agency regulates effluent discharge into the surface water catchment (and groundwater). Operators of a consent to discharge trade effluent would install treatment facilities ahead of discharge to the sewerage network the installation of which would be enforced via the consent provided by the water company. For reasons of commercial confidentiality and/ or competition law it is considered necessary that this option would be led by a party other than the local sewerage undertaker (water company).
Delivery Timescale	Long-term
Duration of Operation	Permanent – This would require the installation of a permanent treatment facility on site.
Nutrient Removal	The nutrient removal calculations have not been undertaken and this option would require specific discharge output detail to develop an understanding of the plausible removal potential. However, the concept of this option is considered to remove nutrient from the catchment at a point upstream of the WRC and upstream of the point of discharge to surface water (or groundwater).
Applicability	The incentivisation of water efficiency is applicable to businesses which discharge into the catchment either via WRCs, which are regulated by the Water Industry Act 1991 as amended, and the Environmental Permitting Regulations 2016 as amended, and direct to surface water or groundwater, as regulated by the Environment Permitting Regulations 2016 as amended.

Descriptor	Definition
Management and Maintenance	The treatment facilities will require regular management and maintenance to maintain effective operation. Waste removal of solids in the form of 'filter cake' or similar is anticipated. Regulators of a discharge consent would review monitoring data for compliance and undertake site inspections.
Additional Benefits	Other potentially harmful substances within the discharge could also be captured via on site treatment facilities.
Best Available Evidence	Industry best practise methods and site-specific data can be used when determining the site specific nutrient removal.
Wider Environmental Considerations	Construction work to install on-site treatment facilities, and operation of a treatment facility, could potentially present wider environmental implications, for example: ▪ potential loss of habitat for new developments on greenfield sites ▪ potential for pollution resulting from construction activities if good environmental management practices are not adopted, e.g., , secondary containment for oil and chemical storage.
Evidence of Effectiveness	The treatment processes installed will be effectiveness beyond reasonable scientific doubt.
Precautionary	Yes – precautionary principles can be adopted when calculating the nutrient removal.
Securable in Perpetuity	Yes
Cost Estimate	Costs are unknown and will be very site specific.

3.3.4 Demand management solutions

3.3.4.1 Retrofit water saving measures in existing properties (Local Authority, Registered Providers, public buildings)

When water saving measures are retrofitted into existing properties (such as buildings that belong to Local Authority (LA), Registered Providers, and Public Buildings), the water usage saved from the retrofitted properties will be replaced by the additional water demand from new dwellings. Key considerations are summarised in **Table 3.41**.

Table 3.41: Key considerations of retrofitting water saving measures (LA, Registered Providers, and Public Buildings)

Descriptor	Definition
Description of Solution	When retrofitting water saving appliances the volume of water entering the treatment works will stay the same and providing the treatment works operates to a permit limit, the effluent discharge concentration remains the same. There is a greater potential for reducing P loading associated with older rather than more recently constructed dwellings. This solution is only applicable to existing dwellings where an organisation has control over fittings and any upgrade works. Requirement G2 and Regulations 36 and 37 of the Building Regulations (2015) introduce a minimum water efficiency standard for new dwellings of no more than 125 l/person/day. The UK Government also introduced an optional requirement of 110 l/person/day for new dwellings (excluding properties owned by Local Authorities and Registered Providers), which Local Planning Authorities must adhere to in future Local Plans. As a result, these two figures were used as targets when retrofitting water efficient appliances and fittings. This solution is not applicable to WwTWs without a permit limit.

Descriptor	Definition
Delivery Timescale	Short-term
Duration of Operation	Permanent – The fittings will be in place for the lifetime of the development and any replacements required will be to the same efficiency or better.
Nutrient Removal	Wastewater achievable reductions of 40 litre/person/day. Approximately three existing dwellings will need to be retrofitted for every one new dwelling.
Applicability	Applicable to Housing and buildings owned by Local Authorities or Registered Providers
Management and Maintenance	Replacement parts of the same or better efficiency must be used. Monitoring compliance checks required
Additional Benefits	Sustainability Water resources Reduced water bills for residents and/ or organisations
Best Available Evidence	Yes – UK government published calculator would be used for calculating water usage for appliances
Wider Environmental Considerations	This option may reduce water use in the south of England, an area of the UK, which is under water stress, saving water as a valuable resource.
Evidence of Effectiveness	Yes - UK government published calculator would be used for calculating water usage for appliances
Precautionary	Yes – precautionary assumptions can be applied to the water saving calculations.
Securable in Perpetuity	Yes – Where a Local Authority or Registered Provider have ownership and control of dwellings that are due to be retrofitted with more water efficient fittings. Registered providers may need to evidence water savings through water bills pre and post improvements. Where a scheme is proposed by private housing, commercial and industrial premises then this solution is unlikely to have sufficient certainty in perpetuity. In these cases, there is a greater risk that replacement fittings would not meet the required water efficiency.
Cost Estimate	£4,000 per new dwelling for a full retrofit (taps, toilets, showers, bath).

4 Recommended nutrient management solutions

4.1 Summary of potential solutions

Table 4.1 and **Table 4.2** provide an overview of the required land/ units and associated costs required for the implementation of some of the mitigation solutions outlined in **Section 3**. Riparian buffer strips and constructed wetlands offer the greatest nutrient removal for the cost required. Replacing existing private sewer systems also provide a cost effective and implementable mitigation option. Cover cropping represents an efficient temporary solution when compared to other temporary solutions such as taking agricultural land out of use.

Table 4.1: P mitigation and cost budget summary of deliverable solutions

Solution	Total area/ units required	Suitable area/ units within the catchment (ha)	Area/ units required as % of suitable land (%)	Estimated cost (£)	£/kg/yr	£/dwelling
Silt traps	549 ha	19,602 (4,096 Arable, 15,506 Livestock)	2.80%	£21,942,000	£1,143,000	£71,706
Riparian buffer strips	29 ha	3,659	0.79%	£1,807,000	£94,000	£5,905
Constructed wetlands	1.6 ha	198	0.80%	£791,000	£41,000	£2,584
Taking agricultural land out of use	160 ha	19,602	0.82%	£3,000,000	£156,000	£9,803
Cessation of fertiliser	549 ha	19,602	2.80%	£55,925,000	£2,913,000	£182,762
Cover crops	457 ha	19,602	2.33%	£5,485,000	£286,000	£17,926
Upgrade existing private sewer systems	17 units	456[10]	3.68%	£252,000	£13,000	£823
Connecting private sewer systems to the mains	14 units	456	3.14%	£1,321,000	£69,000	£4,317

Table 4.2: N mitigation and cost budget summary of deliverable solutions

Solution	Total area/ units required	Suitable area/ units within the catchment (ha)	Area/ units required as % of suitable land (%)	Estimated cost (£)	£/kg/yr	£/dwelling
Silt traps	105 ha	19,602 (4,096 Arable, 15,506 Livestock)	0.54%	£4,219,000	£220,000	£322
Riparian buffer strips	5.3 ha	3,659	0.15%	£336,000	£17,500	£26
Constructed wetlands	0.7 ha	198	0.38%	£374,000	£19,500	£29
Taking agricultural land out of use	30 ha	19,602	0.15%	£558,000	£29,000	£43
Cessation of fertiliser	105 ha	19,602	0.54%	£10,752,000	£560,000	£820

[10] *River Clun SAC Nutrient Management Plan (2014)*

Solution	Total area/ units required	Suitable area/ units within the catchment (ha)	Area/ units required as % of suitable land (%)	Estimated cost (£)	£/kg/yr	£/dwelling
Cover crops	88 ha	19,602	0.45%	£1,055,000	£55,000	£80
Upgrade existing private sewer systems	72 units	456	15.75%	£1,077,000	£56,000	£82
Connecting private sewer systems to the mains	82 units	456	17.96%	£1,155,000	£60,000	£88

Table 4.3 summarises potential nature-based solutions for the River Clun SAC and **Table 4.4** summarises potential wastewater management solutions.

Table 4.3: Potential nature-based management solutions summary

Solution	Delivery timescale	Duration of operation	Estimated P removal potential	Estimated N removal potential	Management/ maintenance requirements	Additional benefits	Best available evidence	Evidence of effectiveness?	Precautionary	Securable in perpetuity?	Approximate cost estimate	Further information
Silt traps	Short-term	Impermanent	25-75%	<25%	Regular de-silting	Water quality	No	Yes	Yes	Yes	Capital costs £1,000-£4,000 Maintenance costs £500/yr	Section 3.3.1.1
Riparian buffer strips	Short-term	Impermanent	55%	55%	Vegetation cutting/ management	Riverbank stabilisation Water quality Erosion reduction Habitat creation Amenity value BNG Carbon offset	Yes	Yes	Yes	Yes	Capital costs £183/ha Maintenance costs £786/ha	Section 3.3.1.2
Wet woodlands	Short-term	Permanent	Uncertain 55% assumed as riparian buffer strips	Uncertain 55% assumed as riparian buffer strips	Minimal to none	Recreation carbon sequestration Biodiversity conservation Air pollution reduction Flood risk reduction Biofuel	No	Yes	Yes	Yes	£10,000/ha Maintenance costs N/A as minimal	Section 3.3.1.3
Constructed wetlands	Medium-term	Permanent	Variable. Assumed to be 12kg/ha/yr	Variable. Assumed to be 930kg/ha/yr	Periodic maintenance to vegetation and de-silting	Biodiversity improvement Water quality and quantity Flood hazard management Carbon offsetting Amenity	No	Yes – if following Constructed Wetlands Framework	Yes – if following Constructed Wetlands Framework	Yes – if following Constructed Wetlands Framework	Approximately £300,000/ha	Section 3.3.1.4
Willow buffers	Short-term	Impermanent	70%	40-60%	Harvest every 3-5 years Replant every 20-25 years	Water quality BNG	No	Yes	Yes	Yes	Capital costs £2,500/ha Maintenance costs £200 - £300/ha/yr	Section 3.3.1.5
Beetle banks	Short-term	Permanent	Unknown and possibly similar to riparian buffer strips	Unknown and possibly similar to riparian buffer strips	Regular cutting	BNG Soil erosion reduction	No	No	Not known at this stage	No	Unknown – possibly similar to riparian buffer strips	Section 3.3.1.6
Beaver reintroduction	Medium-term	Beaver – impermanent Logjams - permanent	Variable – 20-80%.	Likely to be a lower removal rate than TP	Beaver – little maintenance Logjams – repair if damaged	Flood management Biodiversity Amenity	Yes	Yes	Yes	Beaver – no Logjams - Yes	Beaver – no reliable estimate Logjams - £5,000 - £25,000	Section 3.3.1.7
Taking land out of agricultural use	Short-term	Temporary Impermanent Permanent	0.14 kg/ha/yr	26.39 kg/ha/yr	Harvest every 2-4 years	Energy crop BNG Soil erosion reduction	Yes	Yes	Yes	Yes	£217/ha rental	Section 3.3.2.1

Solution	Delivery timescale	Duration of operation	Estimated P removal potential	Estimated N removal potential	Management/ maintenance requirements	Additional benefits	Best available evidence	Evidence of effectiveness?	Precautionary	Securable in perpetuity?	Approximate cost estimate	Further information
Cessation of fertiliser/ manure application	Short-term	Temporary	0.03 kg/ha/yr	12.53 kg/yr	None	Suspended sediment buffer via strategic land selection	Yes	Yes	Yes	No	£1,274.37/ha/yr	Section 3.3.2.2
Cover crops	Short-term	Impermanent	0.04 kg/yr	7.92 kg/yr	Regular maintenance with preparation, planting, destruction, and cultivation of cover crops	Soil erosion reduction Water quality BNG	No	No	Yes	Yes	£150/ha/yr	Section 3.3.2.3
Installation of SuDS in new developments	Short-term	Permanent	20-48%	Variable	Regular maintenance including de-silting	Soil erosion reduction Water quality Habitat creation Improved amenity value	Yes	Yes	Yes	Yes	Unknown and variable according to bespoke design at any particular site	Section 3.3.2.4
Retro-installation of SuDS in existing developments	medium-term	Permanent	20-48%	Variable	Regular maintenance including de-silting	Soil erosion reduction Water quality Habitat creation Improved amenity value	Yes	Yes	Yes	Yes	Unknown and variable according to bespoke design at any particular site	Section 3.3.2.5

Table 4.4: Summary of wastewater management solutions summary

Solution	Delivery timescale	Duration of operation	Estimated P removal potential	Estimated N removal potential	Management / maintenance requirements	Additional benefits	Best available evidence	Evidence of effectiveness?	Precautionary	Securable in perpetuity?	Approximate cost estimate	Further information
Expedite planned improvements to treatment works	Short-term	Temporary	0.56kg/yr for each year	None	Nothing in addition to the usual water company maintenance	None	Yes	Yes	Yes	No	Unknown and bespoke to any specific scheme undertaken by Severn Trent Water	Section 3.3.3.1
Improvements to Clunbury wastewater treatment works	Medium-term	Permanent	6.08 – 16.94kg/yr	32.45 – 97.94kg/yr	Nothing in addition to the usual water company maintenance	None	Yes	Yes	Yes	Yes	Unknown and bespoke to any specific scheme undertaken by Severn Trent Water	Section 3.3.3.2
Moving Clunbury ST on to mains sewerage	Long-term	Permanent	10.86kg/yr	155.25kg/yr	Nothing in addition to the usual water company maintenance	Water quality	Yes	Yes	Yes	Yes	Unknown and bespoke to any specific scheme undertaken by Severn Trent Water	Section 3.3.3.3
Bishop's Castle WwTWs transfer scheme	Long-term	Permanent	31.93kg/yr	2,156.89kg/yr	Nothing in addition to the usual water company maintenance	Water quality	Yes	Yes	Yes	Yes	Unknown and bespoke to any specific scheme undertaken by Severn Trent Water	Section 3.3.3.4
Installation of cesspools and capture outputs from private sewage systems	Short-term	Impermanent	100% temporarily	100% temporarily	Regular emptying and inspection	None	Yes	Yes	Yes	Yes	Capital costs: £3,000 to £6,000 Operational costs: £3,200 to £5,600 per year	Section 3.3.3.5
Replacement of package treatment plants / septic tanks	Short-term	Permanent	1.14kg/yr	9,69kg/yr	Regular maintenance	None	Yes	Yes	Yes	Yes	Capital costs: bespoke to plant size, up to £10,000 - £15,000 Maintenance costs of £400 to £600 per year.	Section 3.3.3.6
Installation of portable treatment works	Short-term	Temporary	0.66kg/yr	1.19kg/yr	Regular maintenance	Water quality	Yes	Yes	Yes	Yes	Capital costs £10,000 to £100,000 (depending on size) Maintenance costs £1,000 to £5,000 per year.	Section 3.3.3.7
Rectifying misconnections to combined systems	Long-term	Permanent	Highly variable and will likely need specific calculations for TP	Highly variable and will likely need specific calculations for TN	Correction of the misconnection is the duty of the property owner. The local water company will ensure the correction is performed satisfactorily.	None	No	No	No	Yes	Varies	Section 3.3.3.8

Solution	Delivery timescale	Duration of operation	Estimated P removal potential	Estimated N removal potential	Management / maintenance requirements	Additional benefits	Best available evidence	Evidence of effectiveness?	Precautionary	Securable in perpetuity?	Approximate cost estimate	Further information
Reduce leakage from foul sewer network	Long-term	Permanent	365 kg/yr and 4,380 kg P/yr from reducing 1 Ml/d of leakage from drinking water and sewer mains, respectively.	Leaking water mains could cause loading of 7.7 kg N/ha/yr, leaking sewers may cause loading of 2.7 kg N/ha/yr,	Pressure management and monitoring for pipe defects should be used to help detect and rectify problems that may result in fixed pipes bursting again. This may help increase duration timescale.	Reduction in abstraction for water supply (only applies to fixing leaks in water mains) and reductions in water pollution, e.g., from microbiological pollutants.	Yes	Yes	Yes	Yes	~£1,000,000 to reduce 365 kg P/yr and 1898 kg N/yr from leaking water main, assuming no attenuation of N and P on subsurface flow pathways. No costs found for fixing sewer leaks.	Section 3.3.3.9
Incentivise commercial water efficiency and treatment	Long-term	Permanent	Unknown	Unknown	Operation of the treatment facility and associated waste disposal works	Water quality	No	Not possible to determine at this stage	Not possible to determine at this stage	Yes	unknown	Section 3.3.3.10
Retrofit water saving measures in existing properties (local authority, registered providers, public buildings)	Short-term	Permanent	Approximately 40 l/person/day removal.	Approximately 40 l/person/day removal.	Maintenance and compliance monitoring	Sustainability Water resources	Yes	Yes	Yes	Yes	£4,000 full retrofit	Section 3.3.4.1

Royal HaskoningDHV

4.2 Solutions for restoration and mitigation

4.2.1 Restoring the River Clun SAC

The River Clun SAC, which lies at the lowest reach of the River Clun, is currently in an 'unfavourable declining' condition due to the continued depletion of the freshwater pearl mussel population. Freshwater pearl mussels are particularly susceptible to adverse impacts from elevated levels of suspended solids and the direct impacts from siltation. This sediment primarily originates from agriculture, urban run-off, highway drainage and scoured river banks (APEM, 2015). Freshwater pearl mussels are sensitive to changes in water quality, including phosphorus and nitrogen. River flow affects a range of habitat factors of critical importance to freshwater pearl mussel, including current velocity, water depth, wetted area, substrate quality, dissolved oxygen levels and water temperature.

Adult pearl mussels require enough water to cover them and a velocity at bed level that permits adequate filter feeding, while the substrate needs sufficient interstitial velocity to allow oxygen exchange in the areas where juveniles are living. In times of high rainfall, larger and more powerful flows with more energy will erode and transport river sediments and affect mussel substrate as well as causing the direct loss of mussels that are washed out of the river. Conversely, during dry periods there is little capacity for the landscape to retain water and release it slowly over time, maintaining adequate flows to sustain the ecology of the river, including the freshwater pearl mussel.

A range of nutrient management techniques can be used in the river catchment, and these are mainly aimed at slowing runoff and trapping sediment-bound pollutants. Wastewater management and demand management solutions provide an opportunity to deliver mitigation in typically medium-scale timescales. These solutions typically have greater certainty than runoff and nature-based nutrient management solutions and issues with land purchase/ rental may be possible to avoid.

Natural England held a workshop with specialist stakeholders to identify which restoration measures would stabilise/ improve the condition of the River Clun and to rank these based on which would have the biggest impact on restoring the SAC. The outcome was a prioritised list of 12 restoration actions that would have a significant positive impact on the SAC. The prioritised restoration actions are outlined in **Table 4.5**.

Table 4.5: River Clun prioritised restoration actions (Natural England, 2023)

Restoration group	Restoration measures	Comments
Upland restoration	• Peat restoration • Upland habitat restoration (e.g., heathland)	• Prioritised in the Upper Clun and Folly Brook catchments
Riparian corridor restoration	• Functioning riparian corridor • Ravine woodland • Slow the flow	• Clun and all tributaries
Wider Agricultural landscape	• Drain blocking and slow the flow • Arable reversion • Livestock de-intensification • Increase infiltration • Reduce fertiliser/ liming • Conifer management • Buffers/ ecotones to habitats	• Prioritised in uplands and slopes • Arable reversion in Unk • Kemp catchment at risk from dairy farming
Transport infrastructure	• De-link highway drainage • Constructed wetlands	-
Water companies	• Water company CSOs	-

Restoration group	Restoration measures	Comments
In channel restoration	• River crossing and tracks • Remove in channel man made obstructions • De-canalisation in lower reaches	-
FWPM restoration strategy	• Development of strategy	-

4.2.2 Restoration versus mitigation

It is important to acknowledge that the nutrient management solutions described in **Section 3** of this report could potentially be used to remediate the effects of existing nutrient pressures on the River Clun SAC (and therefore be delivered by Natural England and partner organisations) as well as to mitigate the effects of proposed new developments in the catchment (and therefore be delivered by developers and the local authority).

As part of ongoing discussions in the River Clun Strategic Liaison Group, Natural England has suggested that up to 95% of the land in the River Clun catchment is likely to be needed for restoration measures. Natural England consider that provision of mitigation to offset the effects of new developments should not prevent the ability to deliver the restoration measures required to address existing pressures. The restoration actions are focussing on delivering measures to improve the structure and function of the supporting habitat. This includes nitrogen and phosphorus concentrations, but also the impact of sediment, organic pollution, flow regime and in-channel morphology. Restoring the designated site to favourable condition will require significant landscape changes.

It is likely that a portfolio of solutions will be required in order to provide nutrient mitigation. Riparian buffer strip creation, wetland creation, taking land out of agricultural use and cover cropping represent the most effective and cost-efficient measures for delivering nutrient mitigation. The area needed for riparian buffer strips or constructed wetlands to deliver the required mitigation is less than 1% of the total area suitable for the development of each solution. Wastewater management solutions such as improvements to Clunbury WwTWs, Bishop's Castle transfer scheme, moving on-site wastewater treatment plants in Clunbury on to the mains and replacing existing septic tanks are also likely to deliver significant nutrient mitigation (particularly phosphorus mitigation). . Less than 5% of the total existing on-site wastewater treatment plants in the catchment would need to be replaced with more efficient PTPs or connected to the mains sewerage. Connecting the existing 23 on site treatment plants at Clunbury to the mains sewerage system would deliver all of the phosphorus mitigation plus an excess of 6.77kg/yr phosphorus mitigation (i.e. from 9 properties, given that only 14 are required). However, this solution would not deliver all the required nitrogen mitigation, with a shortfall of 577kg/yr.

A portfolio approach is important as this will give increased certainty of removal, is more robust and adaptable to change and will allow for greater efficiency in terms of land take. Wastewater solutions are typically more efficient at delivering phosphorus mitigation, whereas nature-based and runoff management solutions deliver more nitrogen mitigation. Where a solution delivers an excess of one nutrient (e.g., more nitrogen than phosphorus) and this is not needed for mitigation, this would be delivering restoration.

It is also understood that Natural England considers that mitigation for development should comprise those measures which are the hardest to secure and implement for restoration and would provide the most marginal benefits for the 'restore' objective. Some of the schemes outlined in **Section 3** are under the control of the Council (e.g., Highways drainage improvements and installation/ retrofitting SuDS). These solutions are unlikely to be brough forward without the additional driver (and funding) provided by the need for nutrient mitigation. This is also likely to be the case for wastewater management solutions, which are likely to require support from Severn Trent Water and additional funding (provided by developer contributions for nutrient mitigation credits). Several of the nutrient management options outlined in **Section 3** are particularly suited for use as mitigation rather than restoration measures because they are within the regulatory control of Shropshire Council. These include SuDS measures (**Sections 3.3.2.4** and **3.3.2.5**), measures to reduce inputs from septic tanks (**Sections 3.3.3.5** and **3.3.3.6**), and measures to reduce water usage in public buildings and housing controlled by Registered Providers (**Section 3.3.4.1**). Also, the small area of total catchment required to construct wetlands (**Section 3.3.1.4** and **4.1**) means that they could potentially be developed with support from the local authority. It is envisaged that these are the solutions which will need to be relied upon should NE object to solutions included in their prioritised actions (e.g., riparian buffer strip, agricultural landscape). This will leave Natural England free to focus on the delivery of catchment-scale nature-based and runoff management solutions through the Environmental Land Management mechanisms (e.g., Sustainable Farming Incentive, Local Nature Recovery and Landscape Recovery schemes) that they administer.

Many of the schemes suitable for nutrient mitigation will deliver additional benefits. These are likely to include wider water quality benefits, habitat creation, reduction in sediment runoff and flood risk benefits. Many of the nature-based and runoff management solutions will also deliver restoration of the structure/ function of the supporting habitat (e.g., sediment runoff, restoring hydrology and slowing the flow). Whilst the nutrient benefits of these schemes would be used for mitigation, the additional benefits would actively support the restoration objectives in the catchment.

Freshwater pearl mussel populations are often associated with areas of shade, normally created by overhanging, herbaceous vegetation, scrub and bank-side trees, with little or no bank erosion. Shade keeps water temperatures down during the summer months and inhibits the growth of filamentous algae which can interfere with mussel feeding. Furthermore, the additional riparian cover will stabilise banks and limit erosion, preventing the re-suspension of sediment during high rainfall and significantly decreasing the overall silt load in the river. Therefore, the development of riparian buffer strips for nutrient mitigation in the Clun catchment will directly improve the supporting habitat.

The implementation of in-river structures such as engineered log jams, silt traps, leaky woody dams, and ponds/ scrapes will not only promote the fallout of sediment-bound nutrients, but will also actively slow down flood water which might otherwise cause scouring or actively wash out adult mussels from the river, which can be a significant cause of loss.

In order to provide nutrient mitigation that is compliant with the habitat regulations, the schemes must adopt a precautionary principle. As such, it is likely that a conservative estimate would be taken on the likely nutrient removal prior to implementation. In many cases the actual nutrient removal rate would be confirmed through post implementation monitoring. Therefore, it is possible through the delivery of these schemes to deliver both mitigation and restoration. Mitigation would be assigned to the conservative removal rates prior to implementation and any additional nutrient removal achieved through post -implementation monitoring could be assigned for restoration.

One of the prioritised restoration actions for the Clun catchment is the development of a freshwater pearl mussel restoration strategy. It is envisaged that the findings of this report could be used in the development of this strategy.

4.3 Next steps to deliver nutrient mitigation

The following sets out the next steps required to develop the solutions presented within this report to functioning nutrient mitigation solutions:

- Identification of the preferred solutions to be delivered and the likely costs, timescales, and delivery mechanisms. The creation of a mitigation plan to formulate developer contributions. This will allow for quantification of when and how many credits will be available.
- A database or spreadsheet-based tracking tool to register and record the nutrient loading for each development and through what schemes this will be mitigated.
- A tracking tool could also be expanded to track 'credits' achieved through mitigation schemes that can be used for biodiversity net gain and carbon offsetting.
- Standardised legal agreements could be drawn up and used as a basis in future mitigation schemes. Conservation covenants are one option that should be explored.

5 References

Anguiar Jr., T., Rasera, K., Parron, L., Brito, A., and Ferreira, M. (2015). Nutrient removal effectiveness by riparian buffer zones in rural temperate watersheds: The impact of no-till crops practices. Agricultural Water Management, 129, p. 74-80.

Ardent. (2023) Donnington Veterinary Hospital, Ref. 2104391-03, Nutrient Neutrality Technical Note, 2 March 2023

Brusch, W. and Nilsson, B. (1993) Nitrate transformation and water movement in a wetland area. In: Hillbricht-Ilkowska, A. and Pieczynska, E. (ed.) Nutrient dynamics and retention in land/water ecotones of lowalnde, temperate lakes and rivers. Developments in Hydrobiology vol. 82, Springer Dordrecht, 103-111.

Buonocore, E., Granzese, P., and Ulgiati, S. (2012). Assessing the environmental performance and sustainability of bioenergy production in Sweden: A life cycle assessment perspective. Energy, Fuel and Energy Abstracts, 37 (1), P. 69-78.

Caslin, B., Finnan, J., Johnston, C., McCracken, A., and Walsh, L. (2015). Short Rotation Coppice Willow Best Practice Guide; Teagasc Agriculture and Food Development Authority: Carlow, Ireland; AFBI Agri-Food and Bioscience Institute: Belfast, Northern Ireland, UK, ISBN 1841705683.

Chauby, I., Edwards, D. R., Daniel, T. C., Moore Jr, P. A., and Nichols, D. J. (1995). Effectiveness of vegetative filter strips in controlling losses of surface-applied poultry litter constituents. ASABE. 38(6): 1687-1692.

Cooper, R.J., Hama-Aziz, Z., Hiscock, K.M., Lovett, A.A., Dugdale, S.J., Sünnenberg, G., Noble, L., Beamish, J. and Hovesen, P. (2017). Assessing the farm-scale impacts of cover crops and non-inversion tillage regimes on nutrient losses from an arable catchment. Agriculture, Ecosystems & Environment, [online] 237, pp.181–193. doi:10.1016/j.agee.2016.12.034.

Cranfield Soil and AgriFood Institute and NIAB CUF Agronomy Centre (2018). Effect of tramline management and irrigation method on runoff, April 2018. Available at: https://norfolkriverstrust.org/wp-content/uploads/2018/07/Cranfield_CUF_Tramline-Management-and-Runoff-Report_FINAL-3-1.pdf.

Creating Tomorrow's Forests (2021). Creating Woodland – How to Plant Trees. 2021 (https://creatingtomorrowsforests.co.uk/blogs/news/creating-woodland-how-to-plant-trees#:~:text=The%20density%20of%20trees%20varies,1500%20to%206000%20for%20beech).

Dodd, R., McDowell, R., and Condron, L. (2014). Is tillage an effective method to decrease phosphorus loss from phosphorus enriched pastoral soils? Soil Tillage Res. 135:1–8

Dodd, R., McDowell, R., Condron, L., (2012). Predicting the changes in environmentally and agronomically significant phosphorus forms following the cessation of phosphorus fertilizer applications to grassland. Soil Use and Management, p. 135-147.

Fortier, J., Truax, B., Gagnon, D., and Lambert, F. (2015). Biomass carbon, nitrogen and phosphorus stocks in hybrid poplar buffers, herbaceous buffers and natural woodlots in the riparian zone on agricultural land. Journal of Environmental Management: 154, 333-345.

Harrington, R., & McInnes, R. (2009). Integrated Constructed Wetlands (ICW) for livestock wastewater management. *Bioresource Technology*, *100*(22), 5498–5505. https://doi.org/10.1016/j.biortech.2009.06.007

Hoffmann, C., Kjaergaard, C., Uusi-Kamppa, J., Hansen, H. and Kronvang, B. (2009). Phosphorous Retention in Riparian Buffers: Review of Their Efficiency: 38, 1942-1955.

Istenic, D. and Bozic, G. (2021). Short-Rotation Willows as a Wastewater Treatment Plant: Biomass Production and the Fate of Macronutrients and Metals. Forests, 12, 554.

Kleinmann, P., Salon, P., Sharpley, A., and Saporito, L. (2005). Effect of cover crops established at time of Lachapelle-T, X., Labrecque, M., Comeau, Y. (2019). Treatment and valorization of a primary municipal wastewater by a short rotation willow coppice vegetation filter. Ecol. Eng. 130, 32–44.

Lachapelle-T, X., Labrecque, M., and Comeau, Y. (2019). Treatment and valorization of a primary municipal wastewater by a short rotation willow coppice vegetation filter. Ecol. Eng. 130, 32–44.

Larsson, S., Cuingnet, C., Clause, P., Jacobsson, P., Aronsson, P., Perttu, K., Rosenqvist, H., Dawson, M., Wilson, F., Backlund, A., Mavrogianopoulus, G., Riddel-Black, D., Carlander, A., Stenstrom, T., and Hasselgren, K. (2003). Short-rotation Willow Biomass Plantations Irrigated and Fertilised with Wastewater. Danish Environmental Protection Agency, Sustainable Urban Renewal and Wastewater Treatment, No. 37.

Lee, K-H., Isenhard, T. M., Schultz, R. C., and Mickelson, S. K. (1998). Nutrient and sediment removal by switchgrass and cool-season grass filter strips in Central Iowa, USA. Agroforestry systems. 44, pp. 121-132.

Lucke, T., Mohamed, M., and Tindale, N. (2014). Pollutant Removal and Hydraulic Reduction Performance of Field Grassed Swales during Runoff Simulation Experiments. Water, 6, p.1887-1904.

Mayer, P.M., Reynolds, S.K., Canfield, T.J. and McCutchen, M.D. (2005). Riparian buffer width, vegetative cover, and nitrogen removal effectiveness: A review of current science and regulations. United States Environmental Protection Agency, Cincinnati, Ohio, USA.

Natural England (2020). Advice on Nutrient Neutrality for New Development in the Stour Catchment in Relation to Stodmarsh Designated Sites – For Local Planning Authorities. Final Version Report.

Natural England (2022). Catchment Sensitive Farming: advice for farmers and land managers guidance, from natural England, Department for Environment, Food and Rural Affairs and Environment Agency, last updated 18 October 2022. Available at: https://www.gov.uk/guidance/catchment-sensitive-farming-reduce-agricultural-water-pollution.

Novotny, V. & Olem, H. (1994). Water quality: prevention, identification and management of diffuse pollution. Van Nostrand Reinhold, New York.

Olde Venterink, H., Vermaat, J.E., Pronk, M., Wiegman, F., Van Der Lee, G.E., van den Hoorn, M.W., Higler, L.W.G. and Verhoeven, J.T. (2006). Importance of sediment deposition and denitrification for nutrient retention in floodplain wetlands. Applied Vegetation Science, 9(2), pp.163-174.

Perttu, K. (1994). Biomass Production and Nutrient Removal from Municipal Wastes Using Willow Vegetation Filters. J. Sustain. For, 1, 57–70.

Sharpley, A. (2003). Soil mixing to decrease surface stratification of phosphorus in manured soils. J. Environ. Qual.

Sharpley, A. & Smith, S. (1991). Effects of cover crops on surface water quality. In: Cover crops for clean water. W.L. Hargrove (ed.) Soil and Water Conservation Society, Ankeny, Iowa. P. 41-49.

Tsai, Y., H. Zabronsky, B. Beckage, A. Zia and C. Koliba. (2016). A Review of Phosphorus Retention in Riparian Buffers: An Application of Random Effects Meta- and Multiple Regression Analyses. J. Environ. Qual. 1-29.

Wood, A., Wake, H., and McKendrick-Smith, K. (2022). Natural England Technical Information Note TIN186: Nutrient Neutrality Principles, August 2022.

Yates, P. and Sheridan, J.M. (1983) Estimating the effectiveness of vegetated floodplains / wetlands as nitrate-nitrite and orthophosphorus filters. *Agriculture, Ecosystems and Environment* **9**, 303-314.

Appendix 1
Nutrient contribution from new housing

APPENDIX

River Clun SAC Solutions Report

Appendix 1: Nutrient contribution from new housing

Client: Shropshire Council

Reference: PC3212-RHD-XX-XX-RP-Z-0006

Status: Final/0

Date: 20 December 2023

HASKONINGDHV UK LTD.

Telecom House
125-135 Preston Road
Brighton
BN1 6AF
United Kingdom
Water & Maritime

+44 (0)1444 458551 **T**
info@uk.rhdhv.com **E**
royalhaskoningdhv.com **W**

Document title:	River Clun SAC Solutions Report
Subtitle:	Appendix 1: Nutrient contribution from new housing
Reference:	PC3212-RHD-XX-XX-RP-Z-0006
Your reference	
Status:	Final/0
Date:	20 December 2023
Project name:	River Clun SAC Addendum
Project number:	PC3212
Author(s):	OB

Drafted by:	OB
Checked by:	OB
Date:	20/12/2023
Approved by:	ID
Date:	20/12/2023

Classification
Project related

Table of Contents

Table of Tables

Royal HaskoningDHV

1 Introduction

The purpose of this report is to outline the percentage contribution of nutrients that can be attributed to new housing compared to the overall nutrients' levels in the river Clun. In order to present this, the baseline nutrient contribution is first established, followed by the estimated future load following completion of the proposed housing. **Section 2** and **Section 3** present the phosphorus and nitrogen contributions, respectively.

2 Phosphorus Contribution

The relative contribution from different phosphorus sources in the River Clun catchment has been developed using the following sources:

- Source Apportionment GIS (SAGIS) model for the catchment – checked against observed flow and concentrations;
- River Clun Nutrient Management Plan (Atkins, 2014); and
- Monitored data supplied by Severn Trent Water.

The following sources are considered:

- Livestock;
- Arable;
- Wastewater treatment works;
- Onsite wastewater treatment plants;
- Urban runoff; and
- Combined Sewer Overflows (CSOs).

2.1 Baseline Source apportionment

2.1.1 Livestock farms

The estimated loading from Livestock was derived from the River Clun Nutrient Management Plan (Atkins, 2014). This plan outlines the numbers of livestock by type based on Defra livestock data (2010), and applies a standard export coefficient (kg/head/yr) for each livestock type (White and Hammond, 2006) (**Table 1**).

Table 1: *Phosphorus contribution from livestock (Edited from Atkins, 2014)*

Livestock type	Numbers of livestock	TP export coefficient (kg/head/yr)	Phosphate/TP ratio	Phosphate load (kg/yr)
Sheep	119.282	0.023	0.50	1372
Cattle	13,914	0.096	0.56	748
Poultry	800,000	0.003	0.35	840
Pigs	159	0.072	0.55	6
			Total	**2,966**

2.1.2 Arable farms

The phosphate contribution from different arable crops was based on catchment data provided by Defra (2010) and export coefficients proposed by White and Hammond (2006) (**Table 2**)

Table 2: *Phosphate contribution from arable farms (Edited from Atkins, 2014)*

Crop type	Extent (ha)	TP export coefficient (kg/ha/yr)	phosphate/TP ratio	P load (kg/yr)
Wheat	1366	0.6	0.35	287
Barley	1396	0.6	0.35	293
Oats & Rye	617	0.6	0.35	130
Maize	80	0.6	0.35	17
Potatoes	52	0.6	0.45	14
Oilseed rape	456	0.6	0.35	96
Fodder crops	129	0.6	0.45	35
			Total	**871**

2.1.3 Wastewater treatment works

The Contribution from sewage treatment works was calculated using measured flow data and phosphorus concentrations for each treatment works within the catchment (**Table 3**). For the purpose of the assessment, it was assumed that the measured TP at the treatment works is consistent with the phosphate contributions.

Table 3: *Phosphorus contribution from wastewater treatment works*

WwTWs	Mean flow (m^3/day)*	Mean concentration (mg/l)^	Phosphate load (kg/yr)
Bishop's Castle	608	0.37	82
Clun	160	0.13	8
Lydbury North	143	0.14	7
Bucknell	273	0.14	14
Newcastle on Clun	34	0.55	7
Aston on Clun	42	0.15	2
Clunbury	9	5	16
		Total	**137**

* Mean flow derived from Atkins, 2014, ^ Measured flow data from 2020-2023, Clunbury assumed to operate at average unpermitted concentration (provided by Severn Trent Water).

2.1.4 Onsite wastewater treatment plants

There are assumed to be an existing 456 onsite wastewater treatment plants in the River Clun catchment (Atkins, 2014). Assuming these are septic tanks with an average discharge concentration of 11.6 mg/l

(Natural England, 2022), and an average flow rate of 130 l/person/day (Severn Trent Water, 2022), the contribution is assumed to be **251 kg/yr.**

2.1.5 Urban

SAGIS source apportionment data indicates than urban sources are likely to contribute 1% of the overall phosphate load.

2.1.6 CSOs

SAGIS source apportionment data indicates than urban sources are likely to contribute 1% of the overall phosphate load.

2.1.7 Summary

Table 4 presents the various phosphate sources and the relative contribution of each.

Table 4: *Relative contribution from phosphate sources*

Source	Phosphate load (kg/yr)	% Contribution
Livestock	2,966	68.8%
Arable	871	20.2%
Wastewater treatment works	137	3.2%
Onsite wastewater treatment plants	251	5.8%
Urban	42	1.0%
CSOs	42	1.0%
Total	**4,309**	-

The baseline total phosphate load (4,309 kg/yr) correlates well with the in-river concentrations observed in the Clun Catchment. The River Clun at Leintwardine is 340,416 m^3/day, and assuming a mean phosphate concentration of 0.035 mg/l, the total Phosphate load for the catchment is 4,225 kg/yr (Atkins, 2014). This suggests the baseline loading estimate loads provide an accurate representation of the relative contribution from each source.

2.2 Future Loading

The proposed development, without nutrient mitigation offsetting, will increase phosphate loading at wastewater treatment works and onsite wastewater treatment plants. **Table 5** outlines the phosphate wastewater contribution post development, assuming a conservative occupancy rate of 2.33 persons per dwelling (River Clun SAC Nutrient Calculator Report, 2023).

Table 5: *Phosphorus contribution from wastewater treatment works*

WwTWs	Mean flow (m^3/day)*	Additional flow (m^3/day)	Post-development flow (m^3/day)	Mean concentration (mg/l)^	Phosphate load (kg/yr)
Bishop's Castle	608	11.28	634	0.51	118
Clun	160	10.68	185	0.16	11

WwTWs	Mean flow (m^3/day)*	Additional flow (m^3/day)	Post-development flow (m^3/day)	Mean concentration (mg/l)^	Phosphate load (kg/yr)
Lydbury North	143	2.4	149	0.16	9
Bucknell	273	11.76	300	0.17	19
Newcastle on Clun	34	0	34	0.67	8
Aston on Clun	42	0	42	0.16	2
Clunbury	9	0	9	5	16
				Total	**184**

* New development assumed have an occupancy of 2.33 persons/dwelling, water usage of 120 l/person/day and current P concentrations are assumed to remain constant.

Table 6 presents the assumed load and relative contribution post development.

Table 6: *Relative contribution from phosphate sources*

Source	Phosphate load (kg/yr)	% Contribution
Livestock	2,966	68.0%
Arable	871	20.0%
Wastewater treatment works	184	4.2%
Onsite wastewater treatment plants	251	5.8%
Urban	42	1.0%
CSOs	42	1.0%
Total	**4,360**	-

As a result of the proposed development, the contribution from wastewater would increase from 3.2% to 4.2%. The additional load from onsite wastewater treatment plants, urban runoff and CSOs is negligible. As such, new housing would account for 1% of the total phosphate contribution in the River Clun.

3 Nitrogen Contribution

The relative contribution from different nitrogen sources in the River Clun catchment has been developed using the following sources:

- Source Apportionment GIS (SAGIS) model for the catchment – checked against observed flow and concentrations;
- River Clun Nutrient Management Plan (Atkins, 2014); and
- Monitored data supplied by Severn Trent Water.

The following sources are considered:

- Diffuse agriculture
- Atmospheric
- Wastewater treatment works
- Onsite wastewater treatment plants

3.1 Baseline Source apportionment

3.1.1 Diffuse Agriculture

Diffuse agricultural contribution of **656,401 kg TN/yr** is presented in Atkins (2014) which relies on National Environment and Agricultural Pollution Nitrate (NEAP-N) dataset (Lord and Anthony, 2000). NEAP-N is a national scale tool for predicting concentration of nitrate in leachate from agricultural land for every 1km² in England and Wales and underpins Defra nitrate policy. It is also a key component of the Environment Agency method for defining Nitrate Vulnerable Zones (NVZs).

3.1.2 Atmospheric

Atmospheric contributions are estimated to be **43,562 kg TN/yr** (Atkins, 2014). This assumed an export coefficient of 1.6 kg/ha/yr and a catchment area of 27,226ha.

3.1.3 Wastewater treatment works

The Contribution from sewage treatment works was calculated using measured flow data and generic nitrogen concentrations for each treatment works within the catchment (**Table 7**).

Table 7: *Nitrogen contribution from wastewater treatment works*

WwTWs	Mean flow (m^3/day)	Mean concentration (mg/l)*	Nitrogen load (kg/yr)
Bishop's Castle	608	25	552
Clun	160	25	161
Lydbury North	143	25	106
Bucknell	273	25	293
Newcastle on Clun	34	25	310
Aston on Clun	42	25	384
Clunbury	9	25	82
		Total	**11,588**

* 25 mg/l represents the average value used by the Environment Agency for wastewater treatment works without a permitted nitrogen effluent limit.

3.1.4 Onsite wastewater treatment plants

There are assumed to be an existing 456 onsite wastewater treatment plants in the River Clun catchment (Atkins, 2014). Assuming these are septic tanks with an average discharge concentration of 96.3 mg/l (Natural England, 2022), and an average flow rate of 130 l/person/day (Severn Trent Water, 2022), the contribution is assumed to be **2,085 kg/yr.**

3.1.5 Summary

Table 8 presents the various nitrogen sources and the relative contribution of each.

Table 8: *Relative contribution from nitrogen sources (Edited from Atkins, 2014)*

Source	Nitrogen load (kg/yr)	% Contribution

Diffuse agriculture	656,401	92.0%
Atmospheric	43,562	6.1%
Wastewater treatment works	11,588	1.6%
Onsite wastewater treatment plants	2,085	0.3%
Total	**713,245**	-

3.2 Future Loading

The proposed development, without nutrient mitigation offsetting, will increase nitrogen loading at wastewater treatment works and onsite wastewater treatment plants. **Table 9** outlines the nitrogen wastewater contribution post development, assuming a conservative occupancy rate of 2.33 persons per dwelling (River Clun SAC Nutrient Calculator Report, 2023).

Table 9: *Nitrogen contribution from wastewater treatment works*

WwTWs	Mean flow (m^3/day)*	Additional flow (m^3/day)	Post-development flow (m^3/day)	Mean concentration (mg/l)^	Nitrogen load (kg/yr)
Bishop's Castle	608	11.28	634	25	5,792
Clun	160	10.68	185	25	1,688
Lydbury North	143	2.4	149	25	1,357
Bucknell	273	11.76	300	25	2,743
Newcastle on Clun	34	0	34	25	310
Aston on Clun	42	0	42	25	384
Clunbury	9	0	9	25	82
				Total	**12,356**

* New development assumed have an occupancy rate of 2.33 persons/dwelling, water usage of 120 l/person/day and N concentrations are assumed to remain constant.

Table 10 presents the assumed load and relative contribution post development.

Table 10: *Relative contribution from nitrogen sources (Edited from Atkins, 2014)*

Source	Nitrogen load (kg/yr)	% Contribution
Diffuse agriculture	656,401	91.0%
Atmospheric	43,562	6.0%
Wastewater treatment works	11,917	1.7%
Onsite wastewater treatment plants	2,085	0.3%
Total	**713,575**	-

As a result of the proposed development, the contribution from wastewater would increase from 1.6% to 1.7%. The additional load from onsite wastewater treatment plants is negligible. As such, new housing would account for 0.1% of the total nitrogen contribution in the River Clun. Diffuse agriculture would still be the overriding contributor of nitrogen into the River Clun catchment.

4 Conclusions

The following conclusions can be made:

- Phosphate contributions in to the River Clun catchment are predominantly from livestock (68.8%) and arable (20.2%) sources, with wastewater treatment works only contributing 3.2%.
- Assuming the proposed development would not be mitigated, this would be attributable to 1% of the total phosphate loading to the River Clun catchment.
- Nitrogen contributions are overwhelmingly from diffuse agriculture.
- The proposed development would be attributable to 0.1% of the total nitrogen loading to the River Clun catchment.

5 References

Atkins (2014). River Clun SAC Nutrient Management Plan

Defra Project WQ0106 (Module 3). Unpublished report for Defra (March 2010).

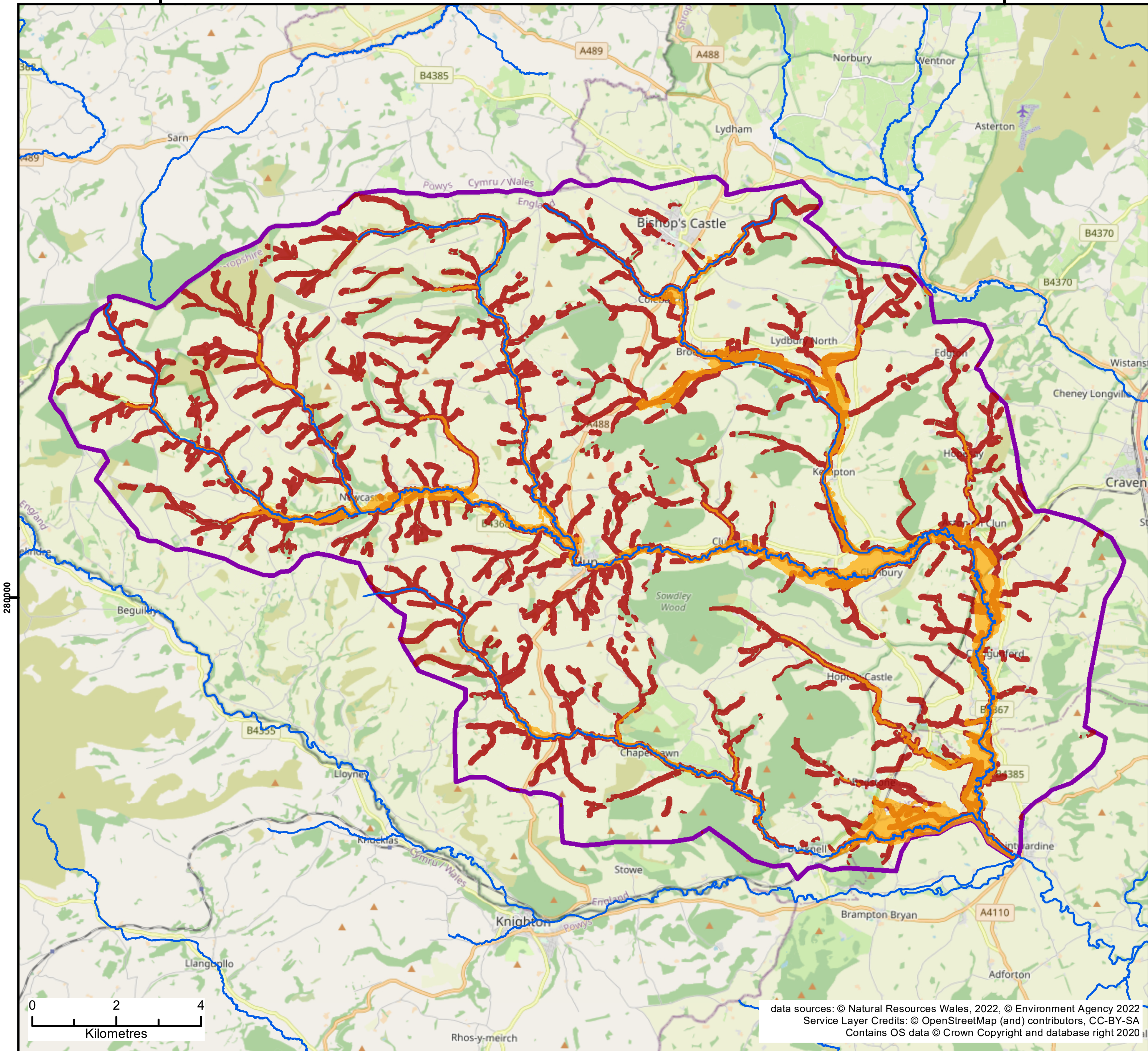
Gooday, R. D. and Anthony, S. (2010). Mitigation Method-Centric Framework for Evaluating Cost Effectiveness.

Lord, E., Anthony, S. (2000). MAGPIE: a modelling framework for evaluating nitrate losses at national and catchment scales. Soil Use Manag. 16, 167–174.

Natural England (2022) Nutrient Neutrality Generic Methodology (NECR459)

White, P. J. and Hammond, J. P. (2006). Updating the estimate of the sources of phosphorus in UK rivers.

Appendix 2
Potential locations for riparian buffer strips & wet woodland development



Legend:

- River Clun Catchment
- WFD River Water Bodies
- Riparian Woodland
- Floodplain Woodland

Client:	Project:
Shropshire Council	River Clun SAC Mitigation Measures

Title:

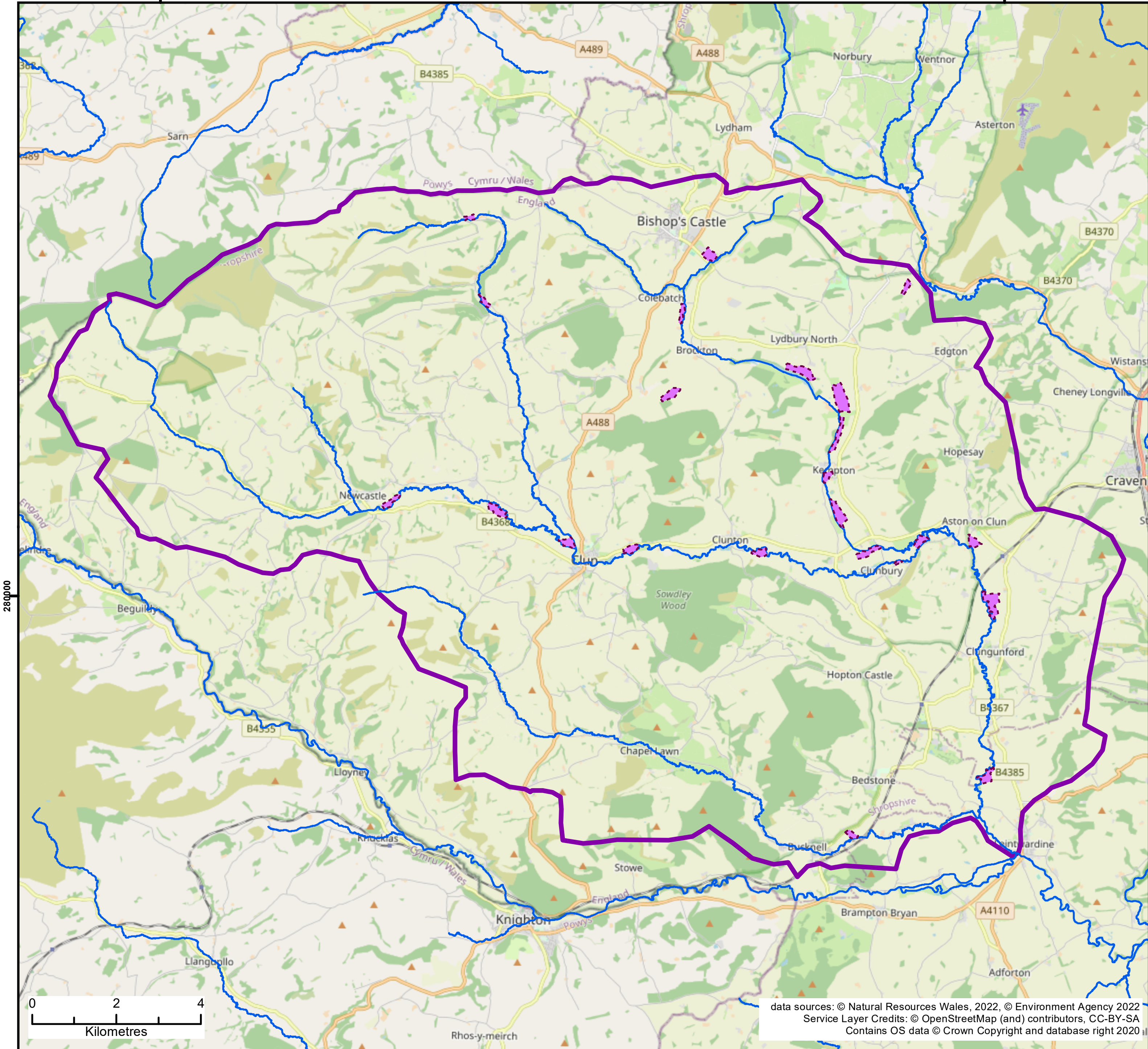
Potentially suitable locations for the establishment of riparian buffer strips & wet woodlands

Figure:	3	Drawing No:	PC3212-RHD-ZZ-XX-DR-Z-0003		
Revision:	Date:	Drawn:	Checked:	Size:	Scale:
01	20/11/2022	GC	ID	A4	1:130,000

Co-ordinate system: British National Grid

Royal HaskoningDHV
Enhancing Society Together

Appendix 3
Potential locations for constructed wetland development



Legend:

- River Clun Catchment
- WFD River Water Bodies
- Clun Wetlands

Client:	Project:
Shropshire Council	River Clun SAC Mitigation Measures

Title:

Potentially suitable locations for the establishment of constructed wetlands

Figure: 4 | Drawing No: PC3212-RHD-ZZ-XX-DR-Z-0004

Revision:	Date:	Drawn:	Checked:	Size:	Scale:
01	20/11/2023	GC	ID	A4	1:130,000

Co-ordinate system: British National Grid

Royal HaskoningDHV
Enhancing Society Together

Appendix 4
Clunbury constructed wetland feasibility study

APPENDIX

River Clun SAC Solutions Report

Appendix 4: Clunbury constructed wetland feasibility study

Client: Shropshire Council

Reference: PC4144-100-100-RHD-XX-ZZ-RP-Z-0004

Status: Final/002

Date: 7 December 2023

Royal HaskoningDHV
Enhancing Society Together

HASKONINGDHV UK LTD.

Telecom House
125-135 Preston Road
Brighton
BN1 6AF
Water & Maritime
Trade register number: 56515154

+44 (0)1444 458551 **T**
info@uk.rhdhv.com **E**
royalhaskoningdhv.com **W**

Document title:	River Clun SAC Solutions Report
Subtitle:	Appendix 4: Clunbury constructed wetland feasibility study
Reference:	PC4144-100-100-RHD-XX-ZZ-RP-Z-0004
Status:	002/Final
Date:	7 December 2023
Project name:	River Clun Nutrient Mitigation
Project number:	PC4144-100-100
Author(s):	VP
Drafted by:	OB
Checked by:	OB
Date:	07/12/2023
Approved by:	ID
Date:	07/12/2023

Classification	Final
Project related	

Royal HaskoningDHV

Table of Contents

Table of Tables

Table of Figures

1 Introduction

Shropshire Council are exploring various options for creating phosphorus mitigation which can be used to offset future housing developments in the catchment of the River Clun. This required an assessment of the suitability and nutrient removal potential of wetland adjacent to Clunbury wastewater treatment works (**Figure 1**).

Figure 1: *Area that was assessed for wetland creation*

1.1 Purpose of this report

This report discusses a potential wetland solution that could be used to offset increased nutrient loadings and allow new development to proceed whilst remaining nutrient neutral. **Section 2** of this report provides an overview of the environmental constraints on site. The wetland potential is described in **Section 3**, and **Section 4** provides a summary of the main findings of the report.

2 Screening environmental constraints

An evaluation of the suitability of sites was made possible by screening for environmental constraints across the entire site. This section describes the findings of the screening exercise.

2.1 Methodology

Current designations on-site were assessed using Magic.defra.gov.uk that included various layers containing the most significant environmental information to consider when undertaking an initial high-level assessment. The layers included:

- Listed buildings
- Scheduled monuments
- Biosphere Reserves
- The England Coast Path Route
- National trails
- Public rights of way
- Agricultural land classification
- Ancient woodland
- County parks
- Environmental stewardship schemes
- Local nature reserves
- International designated sites

The site were also assessed for the presence of overhead cables. On-site community activities were also assessed.

2.1.1 Environmental constraints

2.1.1.1 Listed buildings

The land parcel was assessed for the presence of listed buildings using DEFRA Magic. No Listed Buildings were found within the Site boundary. The nearest Listed Building is 28.4 metres from the top left corner of the site using DEFRA magic.

2.1.1.2 Scheduled monuments

The land parcel was assessed for the presence of Scheduled Monuments using DEFRA Magic. No Scheduled Monuments were found within the Site boundary. The nearest Scheduled Monument is 28.4 metres from the northwest corner of the site boundary.

2.1.1.3 Biosphere reserves

The land parcel was assessed for the presence of Biosphere Reserves using DEFRA Magic. No Biosphere Reserves were found within the Site boundary.

2.1.1.4 National trails

The land parcel was assessed for the presence of National Trails using DEFRA Magic. No National Trails were found within the Site boundary.

2.1.1.5 Public Rights of Way

The land parcel was assessed for the presence of Public Rights of Way using Shropshire Outdoor Recreation Map. No public footpath was identified within the site boundary. A public footpath is located along the western boundary of the site.

2.1.1.6 Agricultural land classification

The parcel land was assessed for Agricultural Land Classifications using DEFRA Magic. The site is primarily classified as ALC Grade 2; however parts of the site boundary are within ALC Grade 3 and 4.

2.1.1.7 Ancient woodland

The land parcel was assessed for the presence of Ancient Woodland using DEFRA Magic. No Ancient Woodland was identified within the site boundary. The nearest Ancient woodland is 914 metres north of the site.

2.1.1.8 Country parks

The land parcel was assessed for the presence of Country Parks using DEFRA Magic. No Country Parks were found within the Site boundary.

2.1.1.9 Environmental stewardship schemes

The land parcel was assessed for the presence of Environmental Stewardship Schemes (ESS) and Countryside Stewardship Schemes (CSS) using Natural England. The site is within an ESS, the West Midlands Area Team having an Entry Level plus Higher Level Stewardship (agreement started March 2013). The site boundary was not within any Countryside Stewardship Schemes.

2.1.1.10 Local nature reserves

The land parcel was assessed for the presence of Local Nature Reserves using DEFRA Magic. No Local Nature Reserves were found within the Site boundary. The nearest local nature reserve is 15,131 meters away.

2.1.1.11 Designated sites

The land parcel was assessed for the presence of International and National designated sites using DEFRA Magic. No designated site were found in the site boundary. Coston Farm Quarries SSSI Site of Special Scientific Interest) is 1,393 meters away.

2.1.2 Summary

A summary of the environmental constraints are presented in **Table 2-1**.

Table 2-1: *Summary of environmental constraints*

Environmental constraint	Findings
Listed buildings	None identified on site.
Scheduled monuments	None identified on site.
Biosphere reserves	None identified on site.
The England coast path route	None identified on site.
National trails	None identified on site.
PRoW	PRoW along south western boundary.
ALC	ALC Grade 2 Primarily, with parts of the site within Grade 3 and 4.
Ancient Woodland	None identified on site.
Country parks	None identified on site.
ESS & CSS	Within an ESS, the West Midlands Area Team having an Entry Level plus Higher Level Stewardship. The site boundary was not within any Countryside Stewardship Schemes.
Local nature reserves	None identified on site.
International designated sites	None identified on site.

3 Constructed wetland feasibility assessment

3.1 Key considerations

The key considerations of constructed wetlands are presented **Table 3-1**.

***Table 3-1:** Constructed wetlands key considerations*

Key considerations	
Description	Constructed wetlands use natural processes to remove nutrients from influent water sources. They resemble natural wetlands, with shallow water and emergent macrophytes and can be designed to fit in with the landscape.
Delivery timescales	Constructed wetlands require design and construction, which in turn will require planning permission and environmental permitting. The following permits and consents are likely to be required: • Flood defence consents (varies depending on main river or ordinary watercourse); • Flood risk activity permit; • Environmental permits and licences; and • Impoundment license should more than 20 cubic metres be impounded per day. Due to various design, planning / permitting and construction requirements, it is estimated that a constructed wetland scheme for nutrient removal will take between 1 - 2 years to complete.
Duration timescales	With appropriate management and a maintenance plan, constructed wetlands will provide nutrient mitigation in perpetuity.
Nutrient removal	P removal occurs through physical processes such as sediment accumulation and burial of organic P and biological processes such as plant uptake. There is large body of research on the efficacy of constructed wetlands for nutrient removal. The actual nutrient removal from a constructed wetland is heavily dependent on multiple site-specific parameters (e.g. wetland size, incoming concentration, hydraulic retention time). Therefore, the actual nutrient removal must be calculated using site-specific information during the outline design stage. For the purposes of this assessment a generic removal rate was applied and derived from Land et al. (2016), which summarised the results from 93 studies of 203 constructed wetlands. The constructed wetlands were predominantly treating agricultural sources of water, with constructed wetlands for secondary or tertiary treatment of wastewater being the second most common type in the review. Land et al. (2016) concluded that constructed wetlands have median removal efficiencies for Total Phosphorus (TP) of 46% (95% confidence interval of 37-55%), respectively. This review also reported areal removal rates of 12 kg TP/ha/yr.
Management and maintenance	Constructed wetlands require periodic maintenance to remove sediment build up (approximately every 5 – 10 years) and to replace vegetation at timescale appropriate to the lifecycle of the vegetation that the constructed wetland is planted with. Removing sediment and dead vegetation should help to reduce the risk of constructed wetlands switching from a nutrient sink to a nutrient source. Natural England's constructed wetlands framework provides details of the aspects of a management and maintenance plan that will be needed for constructed wetlands for nutrient removal (Johnson et al., 2022). A management and maintenance plan will need to cover silt management,

Key considerations	
	vegetation management, maintenance of hydraulic structures, and bed and bank maintenance. Compliance with Natural England's constructed wetland framework and the Environment Agency's RPS for constructed wetlands will require a mix of visual and water quality monitoring, both of which can be used to inform an adaptive management programme.
Additional benefits	A well designed and located constructed wetland can provide biodiversity improvements, water quantity and quality (additional to nutrients) management, flood hazard management, carbon offsetting, and amenity and landscape aesthetic benefits (Harrington & McInnes, 2009).
Deliverability and certainty	The Natural England wetland framework provides a detailed, six stage process that will underpin the delivery of a constructed wetland for nutrient removal with the required certainty. Readers should refer to the framework for full details of each stage, which are as follows: 1. Design objectives – detailing what a constructed wetlands is designed to deliver, which in the context of Nutrient Neutrality will be nutrient removal. 2. Feasibility – an assessment of numerous environmental and regulatory considerations. 3. Design process – an iterative process that marries design objectives with constraints to arrive at the initial estimate of what a wetland can deliver. 4. Detailed design – which will produce an engineering specification for construction of a constructed wetland. 5. Implementation – a plan will be required for how a constructed wetlands will be deployed and managed. 6. Monitoring and evaluation – a plan will be required detailing the monitoring programme for the constructed wetland and how this will be used to evaluate wetland performance and inform adaptive management.
Cost	Approximately £500,000 per hectare, which includes planning, design, permitting, construction, planting, maintenance, monitoring. Additional costs could be accrued from land purchase and contingency.

3.2 Hydrology and land drainage

The River Clun runs west to east along the northern boundary of the site. Clunbury wastewater treatment works is located in the centre of the site and discharges to the watercourse along the southern boundary.

3.3 Flood risk

The site is primarily located in Flood Zone 1. The proposed works should not increase fluvial flood risk elsewhere locally or further downstream by the removal of existing floodplain storage capacity. The proposed constructed wetland is likely to require a Flood Risk Assessment (FRA) in order to achieve planning permission.

3.4 Wetland screening

The field is approximately 1.8ha in size and is currently used for grazing.

Royal HaskoningDHV

3.4.1 Screening

A site screening was undertaken to identify any current site designations that could prevent land use change and to assess the suitability of the land for wetland creation. The details of this screening are presented in **Table 3-2**.

Table 3-2: *Field 1 suitability screening*

Parameter	Description
Topography	• The site is relatively flat with a gentle slope towards the north (i.e. towards the River Clun).
Soils	• The soils on site are typically loamy and clayey floodplain soils with naturally high groundwater. Drainage is natural and fertility is moderate. • Small portion of the site is a loamy soil, which is free draining and low fertility.
Geology and hydrogeology	• Mudstone, siltstone and sandstone bedrock. • Secondary B aquifer.
Hydrology and drainage	• Clay soils lead to higher surface runoff as there's less infiltration so runoff flows into the river Chun. If it does infiltrate, drainage is slow.
Flood risk	• The site is primarily located in Flood Zone 1. • Groundwater and reservoir flooding is very unlikely and low risk.
Protected sites and species	• The Priority Habitat Inventory includes part of the sites as Good quality semi-improved grassland (non-priority). • Common priority species could potentially include Curlew (*Numenius arquata*) and Lapwing (*Vanellus vanellus*).
Land use	• Majority of the site is used for livestock grazing.
Archaeology and heritage	• No scheduled monuments or listed buildings on site.
Right of way	• Public footpath is located adjacent to the western boundary of the site.
Birdstrike	• No airfields within or around site.
Unexploded ordnance	• Low risk.
Services and infrastructure	• No overhead cables identified on site.
Designations	• The River Clun SAC is located downstream of the site.

3.4.2 Suitability for wetland creation

The topography of the field has a gentle slope from southwest to northeast. This will assist with creating a hydraulic head for wetland flow fed through gravity for the eastern part of the site. The west part of the site is likely to require earthworks. The wetland would likely be supplied via the existing Clunbury wastewater treatment works.

3.4.3 Quantification of nutrient removal

The P-K-C* approach Kadlec and Wallace (2009) has been utilised for calculating nutrient reductions and estimating the required wetland area. This method has been used to calculate the potential effluent quality at each of the sites based on the following equation:

$$\frac{C_o - C^*}{C_i - C^*} = \frac{1}{(1 + \frac{k}{Pq})^P}$$

Where C_o = outlet concentration (mg/l), C_i = inlet concentration (mg/l), C^* = background concentration (mg/l), k = first order removal constant (m/d), P = number of cells in system and q = hydraulic loading rate (m/d).

The hydraulic loading rate (q) (m/d) is calculated by dividing the inflow rate (m^3/d) by the wetland surface area (m^2):

$$\mathrm{q} = \frac{\text{Inflow rate}}{\text{Wetland surface area}}$$

Clunbury currently serves a population equivalent of 25-30 currently (assumed to be 27.5). The wetland will therefore have a current inflow rate of approximately 3.58m^3/day. Assuming the population equivalent is increased to 83, the inflow rate would be 10.79m^3/day.

Default values used in the calculations are provided in **Table 3-3**.

Table 3-3: *Default values used in nutrient removal calculations*

Parameter	TP value	TN value	Source
C_i (mg/l)	5	25	Severn Trent Water and Natural England 2022
C^* (mg/l)	0.002	0.15	Kadlec and Wallace, 2009
k (m/yr)	0.03	12.6	Kadlec and Wallace, 2009
Average depth	0.4m		Wu et al., 2015

The number of cells (P) and wetland surface area were retrieved from outline designs of each site.

The number of new dwellings that will be mitigated assumes that the development will drain to Bishop's Castle WwTWs, post TAL. Therefore, this value only provides a guide on the likely number of new dwellings, which could either increase or decrease depending on the effluent concentration of the receiving treatment works.

An average value of £1,000,000/ha for the entire wetland cost was assumed. This accounts for outline design, detailed design, consenting, construction, monitoring and maintenance for the lifetime of the wetland, land purchase/rent and contingency. This value was derived from recent examples of constructed wetlands in the UK (e.g. Ingoldisthorpe, Frogshall, Luston)[1].

The field would accommodate up to approximately 0.5ha of wetland. However, due to the relatively small flow that would supply the wetland, the actual wetland size is likely to be 0.1-0.2ha.

[1] *Cooper et al., 2020*

This has the potential to remove approximately **16.94 kg TP/yr** and **97.94 kg TN/yr**. **Table 3-4** summarises the results of the nutrient removal calculations.

Table 3-4: *Summary of nutrient removal calculations*

Parameter	Phosphorus mitigation	Nitrogen mitigation
C_o (mg/l)	0.70	0.15
Removal amount ($C_i - C_o$) (mg/l)	4.30	24.85
Removal amount (kg/yr)	16.94	97.94
Removal rate (kg/ha/yr)	169.40	979.35
Cost (£mil)	£1,000,000	
£/kg/yr	£59,034	£10,211

4 Summary

Constructed wetlands offer the greatest potential for nutrient removal and low costs per kg/yr of nutrient mitigation. The site is suitable for wetland creation and would receive a consistent and high concentration source. Additional flow could be supplied via an existing stream. The wetland has the potential to remove 16.94 kg/yr of TP and 97.94 kg/yr TN. A further feasibility study and outline design is required to fully understand the suitability of the site and refine the nutrient reduction calculations.

References

Cooper, R. J., Hawkins, E., Locke, J., Thomas, T., & Tosney, J. (2020). Assessing the environmental and economic efficacy of two integrated constructed wetlands at mitigating eutrophication risk from sewage effluent. Water and Environment Journal, 34(4), 669–678. https://doi.org/10.1111/wej.12605

Cranfield Soil and AgriFood Institute. Soilscapes. Available at Soilscapes soil types viewer - National Soil Resources Institute. Cranfield University (landis.org.uk). [Accessed February 2023].

Department for Environment Food and Rural Affairs (2023). MAGIC Map.

Harrington, R., & McInnes, R. (2009). Integrated Constructed Wetlands (ICW) for livestock wastewater management. Bioresource Technology, 100(22), 5498–5505. https://doi.org/10.1016/j.biortech.2009.06.007

Johnson, D., Mcinnes, R., Simpson, M., Rose, G., Roberts, D., Sweaney, G., & Mcilwraith, C. (2022). Framework Approach for Responding to Wetland Mitigation Proposals Natural England Final River Ecosystem Services Project Manager Final.

Land, M., Granéli, W., Grimvall, A., Hoffmann, C. C., Mitsch, W. J., Tonderski, K. S., & Verhoeven, J. T. A. (2016). How effective are created or restored freshwater wetlands for nitrogen and phosphorus removal? A systematic review. In Environmental Evidence (Vol. 5, Issue 1). BioMed Central Ltd. https://doi.org/10.1186/s13750-016-0060-0

Ricardo Energy and Environment on behalf of Natural England (2022) Nutrient Budget Calculator Guidance Document v1.

UK Centre for Ecology and Hydrology (2023) Flood Estimation Handbook.

Royal HaskoningDHV is an independent, international engineering and project management consultancy with over 140 years of experience. Our professionals deliver services in the fields of aviation, buildings, energy, industry, infrastructure, maritime, mining, transport, urban and rural development and water.

Backed by expertise and experience of 6,000 colleagues across the world, we work for public and private clients in over 140 countries. We understand the local context and deliver appropriate local solutions.

We focus on delivering added value for our clients while at the same time addressing the challenges that societies are facing. These include the growing world population and the consequences for towns and cities; the demand for clean drinking water, water security and water safety; pressures on traffic and transport; resource availability and demand for energy and waste issues facing industry.

We aim to minimise our impact on the environment by leading by example in our projects, our own business operations and by the role we see in “giving back” to society. By showing leadership in sustainable development and innovation, together with our clients, we are working to become part of the solution to a more sustainable society now and into the future.

Our head office is in the Netherlands, other principal offices are in the United Kingdom, South Africa and Indonesia. We also have established offices in Thailand, India and the Americas; and we have a long standing presence in Africa and the Middle East.

euroCompliance certification ISO 37001

euroCompliance certification ISO 37301

royalhaskoningdhv.com

Royal HaskoningDHV

Enhancing Society Together