REPORT

Norfolk Nutrient Guidance

Nutrient Mitigation Solutions

Client: Norfolk

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Abbreviations

Abbreviation	Description
ADAS	Agricultural Development and Advisory Service
AMP	Asset Management Planning
AWS	Anglian Water Services
BNG	Biodiversity Net Gain
CEMP	Construction and Environmental Management Plan
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
DWF	Dry Weather Flow
EIA	Environmental Impact Assessment
ELMS	Environmental Land Management Scheme
FRA	Flood Risk Assessment
FWS	Free Water Surface
GIS	Geographic Information System
HF	Horizontal Subsurface Flow
HRA	Habitats Regulations Assessment
ICW	Integrated Constructed Wetland
LPA	Local Planning Authority
LURB	The Levelling Up and Regeneration Bill
N	Nitrogen
NN	Nutrient Neutrality
NAVs	New Appointments and Variations
NFM	Natural Flood Management
NFS	New Farming Systems
NRT	Norfolk Rivers Trust
Ofwat	The Water Services Regulation Authority
P	Phosphorus
PE	Population Equivalent
PR	Price Review
PTP	Package Treatment Plants
RBD	River Basin District
RBMP	River Basement Management Plan

Abbreviation	Description
RPS	Regulatory Position Statement
RSuDS	Rural Sustainable Drainage Systems
SAC	Special Area of Conservation
ST	Septic Tanks
SPA	Special Protection Area
SRP	Orthophosphate
SSSI	Site of Special Scientific Interest
SuDS	Sustainable Drainage Systems
SWMP	Surface Water Management Plans
TAL	Technically Achievable Limit
TP	Total Phosphorus
TN	Total Nitrogen
VF	Vertical Subsurface Flow
WFD	Water Framework Directive
WRC	Water Recycling Centre

Glossary

Name	Description
Diffuse	The movement of ions or molecules from an area of higher concentration to an area of lower concentration
Point Pollution	Any single identifiable source of pollution from which pollutants are discharged, such as a pipe
ORIGINS™	Farmers from Kellogg's Origins Natural Heritage sites

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 TN/d	Kilogram of Nitrogen per day
kg TP/d	Kilogram of Phosphate per day
kg TN/yr	Kilogram of Nitrogen per year
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 TN/l	Milligrams of Nitrogen 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
t N/yr	Tonnes of Nitrogen per year
TN/yr	Total Nitrogen per year
TN/ha/yr	Total Nitrogen per hectare 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

Executive Summary

Introduction and purpose of this report

Following the Dutch Nitrogen Joint Cases (‘Dutch-N’) in the Court of Justice of the European Union, which ruled that where a European important site, i.e., Special Areas of Conservation and Special Protection Areas, 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 Special Areas of Conservation and Special Protection Areas. The Dutch-N case has informed the way in which Regulation 63 of the Conservation of Habitats and Species Regulations 2017 (as amended) (Habitats Regulations 2017) should apply to pollution related incidents and has resulted in greater scrutiny of proposed developments that are likely to increase nutrient loads to designated sites.

This report sets out suitable short, medium, and long-term mitigation options that could potentially be used to offset the additional nutrient load from a new development within the catchment of the River Wensum Special Areas of Conservation and/ or The Broads Special Areas of Conservation, including potential strategic options to manage nutrient inputs and allow further residential development to proceed.

Potential nutrient mitigation options

Following a detailed review of scientific literature and best practice guidance, a range of different nutrient management solutions have been identified. Following an initial screening exercise, in which the potential viability of solutions was evaluated, the following types of solutions were identified as potentially viable for use in the River Wensum and Broads catchment:

- Nature-based solutions: solutions that would be implemented within a catchment to reduce diffuse-source phosphate loadings.
- Drainage and wastewater-based interventions: solutions that apply to wastewater and drainage and will require targeted interventions (excluding nature-based and wetland solutions) or specific local policies to be implemented.

The following solutions are considered in this report:

- Short-term solutions: taking land out of agricultural use; cessation of fertiliser and manure application; riparian buffer strips; wet woodlands; cover crops; bringing forward planned wastewater improvements; sustainable drainage systems; portable treatment works; alternative wastewater providers; retrofitting more water efficient fittings; package treatment plants; and cesspools.
- Medium-term solutions: constructed wetlands; beaver reintroduction; farm management measures; retrofitting sustainable drainage systems in existing developments; use alternative wastewater treatment providers; and upgrade existing private sewage systems.
- Long-term solutions: broadland restoration; improve existing wastewater treatment infrastructure; improve existing wastewater distribution infrastructure, i.e., reduce leakage from foul sewer network; rectifying misconnections to combined systems; and incentivise disconnection from combined systems.

Housing Projections

To understand the mitigation required to meet the upcoming housing requirements, a review of local plan documents and housing projections was undertaken. The additional nutrient loading from the projected housing was calculated using the Norfolk Nutrient Budget Calculator (Royal HaskoningDHV, 2022). The outcome of the study determined 37,300 dwellings require mitigation until the end of the plan periods in 2038. This is equivalent to 4,760 kg/yr of phosphorus mitigation and 52,887 kg/yr of nitrogen mitigation.

Conclusions and next steps

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.
- 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, carbon offsetting and nitrogen mitigation.
- 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.
- A Mitigation Plan should be established which would set out the key solutions and timescales for expected delivery. This will allow for quantification of when and how many credits will be available.

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 EU Nature Law 'The Habitats Directive,' 1992 and where nitrogen (N) 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 following developments which 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 advice (NE785) which identified a further twenty protected sites that are adversely affected by nutrient pollution. As a result, Local Planning Authorities (LPAs) in Norfolk are not able to grant planning permission for new developments that provide overnight accommodation within the catchment of the River Wensum SAC and/ or The Broads SAC unless it can be clearly demonstrated that they will not have a detrimental impact in terms of nutrient loading to the designated protected areas.

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 catchments of the River Wensum and Broads SACs to proceed whilst remaining nutrient neutral. **Section 2** of this report provides an overview of the River Wensum and Broads SACs and their contributing catchments. It uses housing projections to identify likely mitigation requirements in each catchment and LPA area. 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 have reviewed this report and note that it has been prepared for several of the Norfolk Local Planning Authorities, and therefore, has not received agreement or endorsement from Natural England. Furthermore, a Habitats Regulations Assessment may be required to demonstrate nutrient neutrality.

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2 Background

2.1 Protected habitats in Norfolk

Norfolk has a number of European and Internationally important ecologically protected habitats, including the River Wensum SAC and The Broads SAC (**Figure 2.1**). Natural England provide 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).

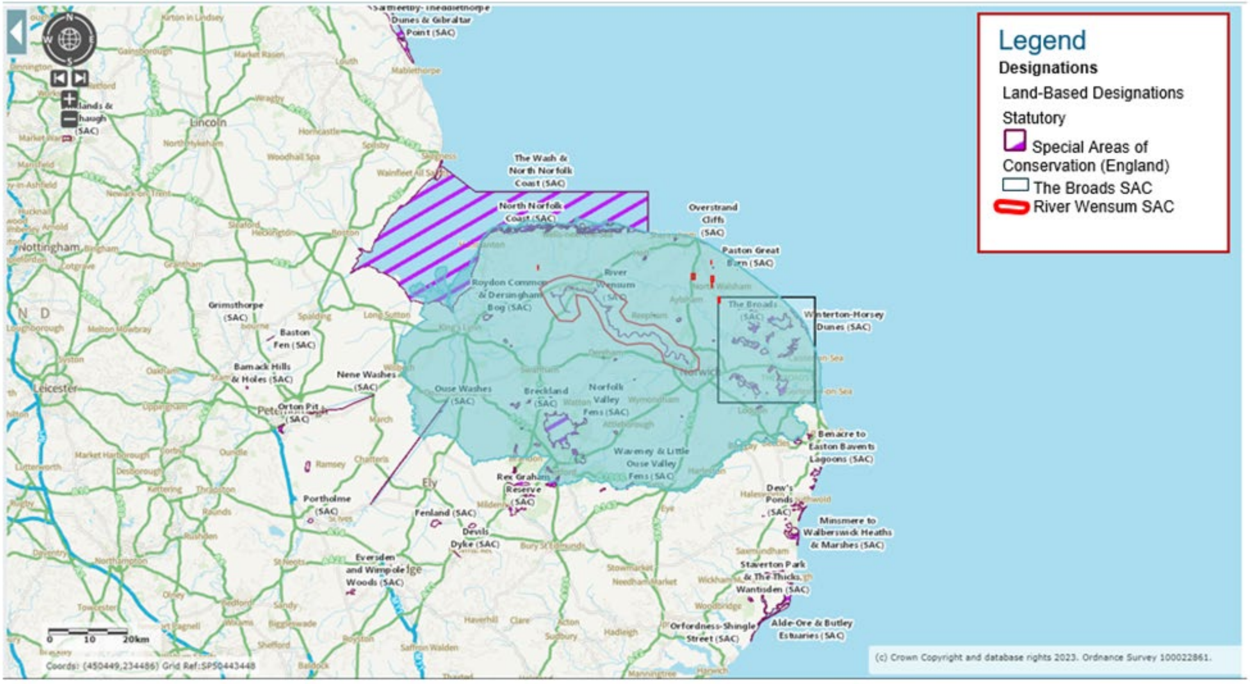

Figure 2.1 Map of Special Areas of Conservation in the study area Norfolk (source: Defra MagicMap, accessed March 2023)

2.1.1 River Wensum SAC

Natural England's (2019a) supplementary advice about the European Site Conservation Objectives relating to the River Wensum SAC (site code: UK0012647) summarises the habitat as a low gradient, groundwater dominated river. The upper reaches are fed by springs that rise from the chalk and by run-off from calcareous soils rich in plant nutrients. It is also designated as a Site of Special Scientific Interest (SSSI). The river supports an abundant and diverse invertebrate flora and fauna in a relatively natural corridor.

The River Wensum rises close to the village of Whissonsett in North Norfolk and flows for 73km, primarily in a south-easterly direction until it reaches its confluence with the River Yare in Whitlingham. The River Wensum has a catchment area of approximately 685km^2 (Natural England, 2015[1]). The catchment is primarily rural, with only a few urban areas such as Fakenham and Dereham. The river is recognised as being one of the best examples of a lowland calcareous river in the world due to the diversity of its internationally important flora and fauna.

The river flows over chalk, particularly in the upper reaches, and a complex sequence of superficial glacial drift deposits of sands and gravels which increase in thickness in the lower reaches. As the river is often separated from the chalk aquifer by these superficial glacial deposits, it does not exhibit some of the

1 River Wensum SSSI Diffuse Water Pollution Plan

characteristics of classic chalk rivers. However, the chalk and run-off from calcareous soils gives rise to beds of submerged and emergent vegetation characteristic of a chalk stream.

The landscape of the River Wensum catchment varies from areas of higher topography in the west (98 m Above Ordnance Datum (AOD) to areas of lower topography in the southeast (c. 2 mAOD) but is generally relatively flat. The catchment has relatively shallow slopes and the soil erosion risk is generally low across most of the catchment, expect for some areas of increased risk as a result of increased connectivity and steep slopes adjacent to watercourses. Water management and artificial drainage significantly affect the levels of water and flow in the catchment.

The once meandering river has been modified and managed historically and the channel has been straightened, dredged, diverted, impounded, and embanked. Some reaches have been subject to excessive silt ingress, and/ or lack natural riparian vegetation. A qualifying habitat, of Annex I of the (Conservation of Natural Habitats and of Wild Fauna and Flora) Habitats Directive (92/43/EEC), is water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation; rivers with floating vegetation often dominated by water-crowfoot.

The qualifying features with respect to the SAC designation are described as:

- S1016 Desmoulin`s whorl snail (*Vertigo moulinsiana*);
- S1092 White-clawed (or Atlantic stream) crayfish (*Austropotamobius pallipes*);
- S1096 Brook lamprey (*Lampetra planeri*); and
- S1163 Bullhead (*Cottus gobio*).

2.1.2 Broads SAC

Natural England's supplementary advice (2019b) about the European Site Conservation Objectives relating to The Broads SAC (site code UK0013577) summarises the habitat as an example of nutrient-rich lakes and contains 163 SSSIs. The study boundary contains eight Ramsar sites, 12 SACs, and nine SPAs, many of which overlap (**Figure 2.2**).

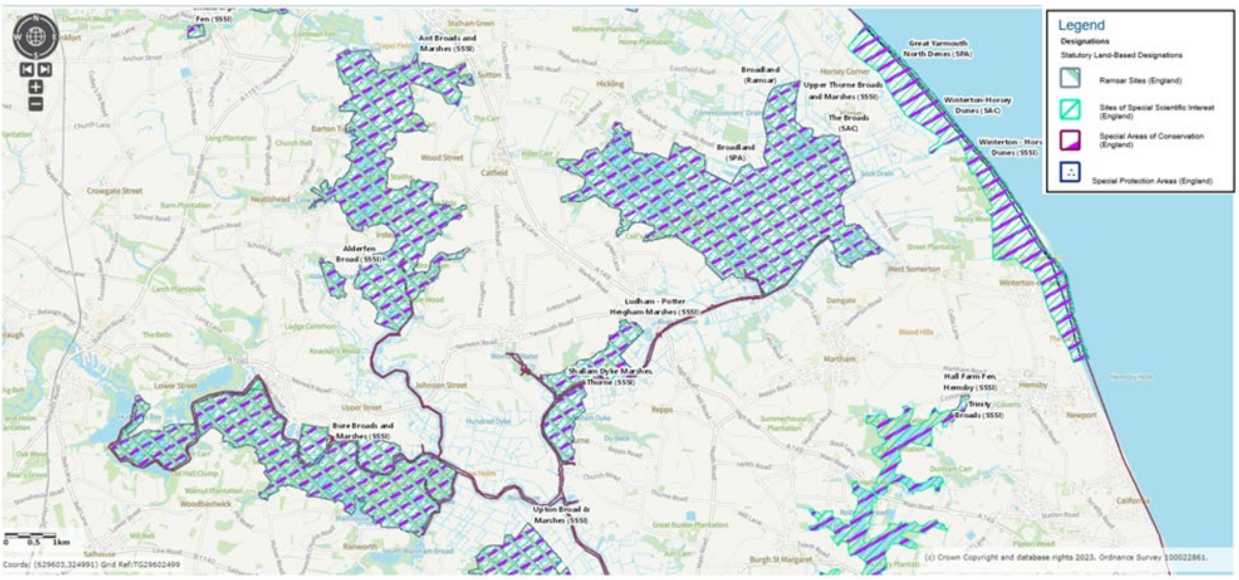

Figure 2.2 Map of the Norfolk area showing overlap of statutory designations

The Broads SAC designated under article 4(4) of the Directive (92/43/EEC) as it hosts the following SAC qualifying features listed in **Annex I**:

- H3140 Hard oligo-mesotrophic waters with benthic vegetation of *Chara spp.* (calcium-rich nutrient-poor lakes, lochs, and pools);
- H3150 Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition*-type vegetation (naturally nutrient-rich lakes or lochs which are often dominated by pondweed);
- H6410 Molinia meadows on calcareous, peat or clay-silt soil (*Molinion caeruleae*) (purple moor-grass meadows);
- H7140 Transition mires and quaking bogs (very wet mires often identified by an unstable 'quaking' surface);
- H7210 Calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae* (calcium-rich fen dominated by great fen sedge, e.g., saw sedge);
- H7230 Alkaline fens (calcium-rich spring water-fed fens); and
- H91E0 Alluvial woods with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae,* and *Salicion albae*) (alder woodland on floodplains).

The site hosts the following species listed in **Annex II**:

- S1016 Desmoulin's whorl snail (*Vertigo moulinsiana*);
- S1355 Otter, (*Lutra lutra*);
- S1903 Fen orchid, (*Liparis loeselii*); and
- S4056 Little ram's-horn whirlpool snail (*Anisus vorticulus*).

The Broads SAC catchment is low-lying with highest elevations typically found in the north and west of the catchment with a maximum elevation of around 100 mAOD. It is usually gently sloping with steeper slopes generally on the sides of the river valleys to the south and west. The underlying geology is chalk to the west and a mix of gravel, sand, and silt to the east.

This catchment is largely covered by superficial glacial deposits of sand, silt, and clay. There is considerable variability in soil type across the catchment, and even variations within adjacent fields. Although several major rivers flow through the area, the flat nature of the topography and the proximity of the sea and its tides means that flushing through is slow.

The Broads is fed by three major river catchments: the River Wensum, the River Bure and the River Yare, with The Broads catchment covering much of mid and east Norfolk, including the city of Norwich as well as the towns of Dereham, Wymondham, Aylsham, Fakenham, and Long Stratton.

2.1.3 Contributing catchments

The SSSI component site in the River Wensum SAC that is subject to nutrient neutrality guidance is the River Wensum SSSI. The SSSI component sites in The Broads SAC that are subject to nutrient neutrality guidance are:

- Bure Broads and Marshes;
- Ant Broads and Marshes;
- Upper Thurne Broad and Marshes;

- Trinity Broads; and
- Yare Broads and Marshes.

The Bure Broads and Marshes, Ant Broads, and Marshes, Upper Thurne Broads and Marshes and Trinity Broads and Marshes are located within the River Bure operational catchment. The Yare Broads and Marshes is within the River Yare catchment, while the upstream catchment also includes the entire River Wensum catchment, which has its confluence with the River Yare in Whitlingham.

The River Wensum, River Bure, and River Yare catchments (**Figure 2.3**) could supply nutrients into the River Wensum SAC and The Broads SAC. This is based on surface hydrological catchments, i.e., the natural drainage network, as defined by the Environment Agency as part of the Southeast River Basin Management Plan (RBMP). **Figure 2.3** also shows the component SSSI catchments of The Broads SAC that are located within the Bure catchment.

However, nutrient supply paths are complicated by the artificial wastewater catchments that intersect natural drainage patterns. This means that wastewater produced within a surface drainage catchment could potentially be collected, treated, and discharged outside of that catchment. Conversely, the opposite could also apply, with wastewater produced outside a surface drainage catchment being discharged inside that catchment.

The catchments (**Figure 2.3**) have therefore been refined to reflect the foul water catchments and the locations at which they discharge. The component SSSI sites in The Broads SAC are each subject to nutrient neutrality guidance and their catchments are treated independently of each other. Mitigation must be delivered within the same SSSI component catchment as the development.

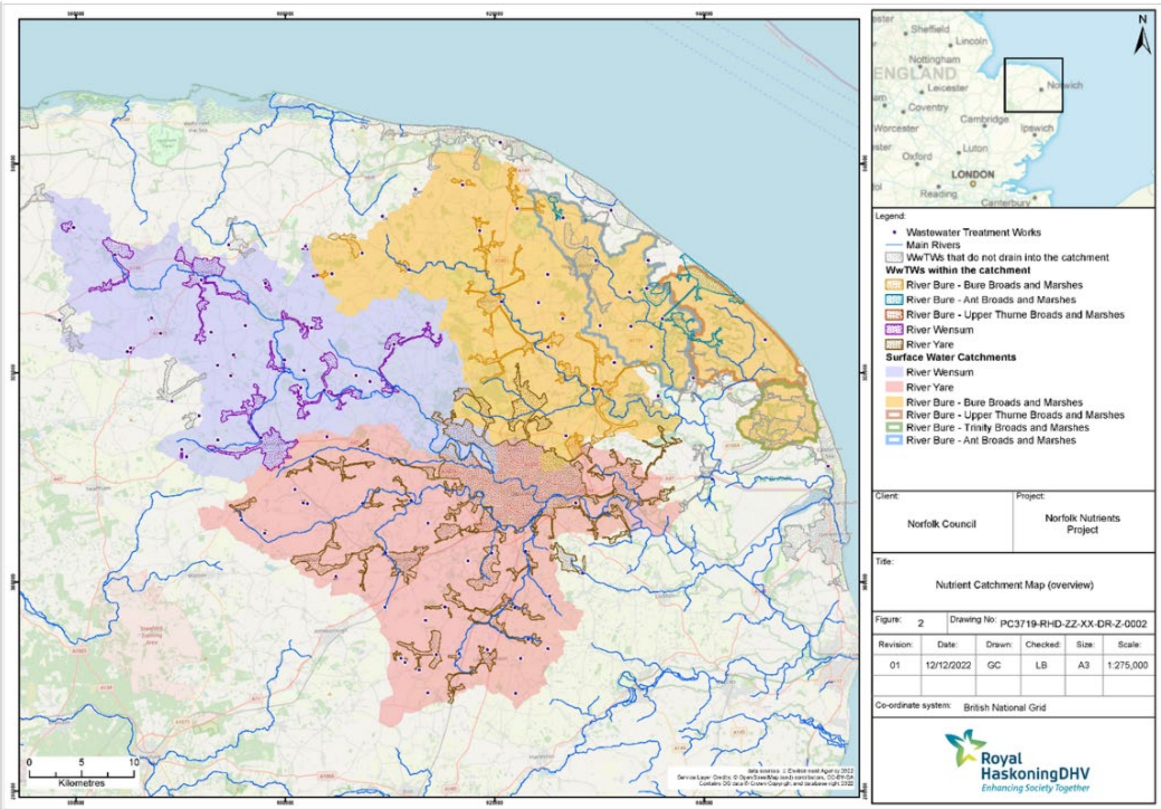

Figure 2.3 Norfolk nutrient catchment map

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The discharge location of wastewater is used to determine where a development will have the greatest impact on nutrient concentrations. A development site may be located in one surface water, i.e., Wensum, Yare or Bure, catchment but the wastewater discharge will be within a different surface water catchment. Mitigation should also be provided upstream of the component SAC site in The Broads SAC catchment and upstream of the point of impact, i.e., wastewater discharge, in the Wensum.

The Yare Broads and Marshes SSSI, a designated sites within The Broads SAC subject to nutrient neutrality requirements, is located downstream within the Yare catchment. Any mitigation upstream of the Yare Broads and Marshes SSSI can provide mitigation for the River Yare catchment, including within the River Wensum catchment. The River Wensum SSSI is only designated for phosphorus (P) neutrality. However, the Wensum is a tributary of the Yare catchment which is subject to both P and nitrogen (N) neutrality requirements. Therefore, any development in the Wensum catchment must provide P mitigation within the Wensum catchment and N mitigation within either the Wensum or Yare catchment.

2.2 Projected mitigation requirements

2.2.1 Methods and assumptions

A review of local plan data and housing projections supplied by the relevant LPA 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 Norfolk Nutrient Budget Calculator (Royal HaskoningDHV, 2022). 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:

- 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 rules have affected the ability of the Norfolk LPAs to deliver housing, and therefore demonstrate a five-year land supply. As such, the delivery of housing, rather than other accommodation types, is a key pressure and is therefore the focus of this report;
- All new dwellings were assumed to be houses with an average occupancy of 1.88 persons per dwelling;
- It is assumed by Natural England that anyone living in the nitrogen neutrality (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 across Norfolk;
- 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 one of the dominant land use types in the catchment and has a runoff coefficient close to the average of all the land uses;
- The proposed land use was assumed to be urban;

- The soil drainage type was derived from Soilscapes (Cranfield Soil and AgriFood Institute, 2018)[2] and the dominant soil of the area was chosen, e.g., for the Wensum impeded/ slightly impeded, and for the Bure, freely draining;
- The Water Recycling Centre (WRC) that a proposed development will drain to was estimated using Geographic Information System (GIS) data on the existing catchment;
- Where onsite treatment plants are to be used, default values of 5mg/l Total phosphorous (TP) and 25mg/l Total nitrogen (TN) were used. These represent the likely effluent concentration from a typical 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 nutrient neutrality (Natural England, 2020); and
- The catchment that a development will contribute the nutrient loading to was determined by the location of the WRC. 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.

The end dates of the Local Plans for the Norfolk LPAs do not align. In order to provide a standardised approach, the housing projections for Breckland, West Norfolk and The Broads Authority were calculated up to 2036 using Local Plan data and for the model it is assumed that house building will continue at the same rate up to 2038. The housing projections for North Norfolk, Broadland, South Norfolk, and Norwich were calculated up to the end of the Local Plan period in 2038.

The Great Yarmouth Local Plan covers the period up to 2030, however, no development is projected that lies within the catchments subject to nutrient neutrality guidance. It was assumed that the affected projected development will be evenly proportioned within each year up to and including 2038, with the exception of North Norfolk which was modelled in line with the housing trajectory. The dwellings currently held up due to nutrient neutrality are as follows:

- Breckland – 668;
- Broadland – 8,867;
- Broads Authority – 0;
- Great Yarmouth – 0.
- North Norfolk – 1,317;
- Norwich – 1,878;
- South Norfolk – 4,275; and
- West Norfolk – 0.

The Greater Norwich Local Plan housing figures included an element of windfall, i.e., sites not specifically allocated in the appropriate plan, therefore, windfall sites have been considered for Norwich City Council, South Norfolk and Broadland Council, and Broadland Council. Windfall sites have also been considered for Breckland and North Norfolk District Councils, so that the potential nutrient output of housing development has been accounted for in the majority of the county.

There is currently insufficient information available across Norfolk on tourism uses that do not require the construction of a dwelling to plan and account for tourism within nutrient calculations. This use has therefore

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

been omitted from the calculations presented in this report. The development currently held up was cross referenced against the development projected to come forwards in the various local plans.

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 April 2030 permit limit reductions were also included following the Department for Levelling Up, Housing and Communities announcement (18 November 2022[3]). 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 and TN is 0.25mg/l and 10mg/l, respectively. 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.

2.2.2 Projected housing growth per Local Planning Authority area

The projected growth was derived from the respective Local Plans and previous housing data for each district and is presented in **Table 2-1**. A total of 37,300 dwellings are projected to be constructed across the entire nutrient neutrality catchment. Of these 17,005 are presently on hold. Within **Table 2-1,** the figures in brackets represent the number of homes on hold in the planning system at the beginning of March 2023.

Table 2-1 Summary of the planned growth of dwellings on hold within the Nutrient Neutrality catchment in Norfolk

District	Dwellings (dwellings currently on hold)	Source
North Norfolk	3,753 (1,317)	North Norfolk Local Plan allocations + windfall
Breckland	3,903 (668)	Breckland Local Plan (2019) + Delayed applications provided by the LPA
West Norfolk	15 (0)	King's Lynn and West Norfolk Local Plan (2016)
Broads Authority	145 (0)	Local Plan for The Broads (2019)
Broadland	14,311 (8,867)	Greater Norwich Local Plan (under examination 2021 to 2023)
South Norfolk	7,258 (4,275)	Greater Norwich Local Plan (under examination 2021 to 2023)
Norwich	7,915 (1,878)	Greater Norwich Local Plan (under examination 2021 to 2023)
Total	**37,300 (17,005)**	**-**

The expected phosphate and nitrate loading per year for each Local Planning Authority is provided in **Table 2-2** and **Table 2-3**. These tables show the amount of additional mitigation that is required each year within the defined period. The cumulative total for 2023 to 2038 is provided in the 'Total' column.

[3] *Press release: Plans to level up and build new homes tabled in Parliament. Available: https://www.gov.uk/government/news/plans-to-level-up-and-build-new-homes-tabled-in-parliament.*

The total additional TP load based on the Local Plan is predicted to be 4,760 kg/yr. In 2023 the required mitigation is 895 kg/yr due to the number of dwellings currently delayed. Following the planned improvements to WRC by 2030, the TP loading per year will be approximately 136 - 139 kg/yr. Similarly, the additional TN load based on the Local Plan is predicted to be 52,887 kg/yr. In 2023 the required mitigation is 11,320 kg/yr. This is approximately 951-958 kg/yr required post 2030.

Table 2-2 Total phosphorus loading per LPA

<table>
<tr><th rowspan="2">District</th><th colspan="17">Phosphorus loading per year (kg/yr)lt</th></tr>
<tr><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th><th>2029</th><th>2030</th><th>2031</th><th>2032</th><th>2033</th><th>2034</th><th>2035</th><th>2036</th><th>2037</th><th>2038</th><th>Total*</th></tr>
<tr><td>North Norfolk</td><td>69</td><td>72</td><td>71</td><td>24</td><td>33</td><td>32</td><td>23</td><td>14</td><td colspan="2">10</td><td>11</td><td>12</td><td>14</td><td>16</td><td colspan="2">10</td><td>433</td></tr>
<tr><td>Breckland</td><td colspan="3">132</td><td colspan="4">69</td><td colspan="9">63</td><td>1,235</td></tr>
<tr><td>West Norfolk</td><td colspan="16">0.1</td><td>1</td></tr>
<tr><td>Broads Authority</td><td colspan="7">1</td><td colspan="9">0.5</td><td>12</td></tr>
<tr><td>Broadland</td><td colspan="2">431</td><td>430</td><td colspan="4">39</td><td colspan="9">24</td><td>1,667</td></tr>
<tr><td>South Norfolk</td><td colspan="2">179</td><td>175</td><td colspan="4">41</td><td colspan="9">29</td><td>958</td></tr>
<tr><td>Norwich</td><td>82</td><td colspan="2">81</td><td colspan="4">32</td><td colspan="9">9</td><td>454</td></tr>
<tr><td>Great Yarmouth</td><td colspan="16">0</td><td>0</td></tr>
<tr><td>Total*</td><td>895</td><td>897</td><td>890</td><td>206</td><td>215</td><td>214</td><td>205</td><td>139</td><td>136</td><td>136</td><td>137</td><td>138</td><td>139</td><td>141</td><td>136</td><td>136</td><td>4,760</td></tr>
</table>

**The Totals may not directly equate to the total when the individual years are added up due to the differential caused by rounding. The Total column would be considered to be more accurate than adding the individual years up when looking at the total figures.*

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Table 2-3 Total nitrogen loading per LPA

<table>
<tr><th rowspan="2">District</th><th colspan="17">Nitrogen loading per year (kg/yr)</th></tr>
<tr><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th><th>2029</th><th>2030</th><th>2031</th><th>2032</th><th>2033</th><th>2034</th><th>2035</th><th>2036</th><th>2037</th><th>2038</th><th>Total*</th></tr>
<tr><td>North Norfolk</td><td>932</td><td>977</td><td>962</td><td>317</td><td>456</td><td>437</td><td>295</td><td>91</td><td colspan="8">84</td><td>5,139</td></tr>
<tr><td>Breckland</td><td colspan="3">665</td><td colspan="4">289</td><td colspan="9">156</td><td>4,554</td></tr>
<tr><td>West Norfolk</td><td colspan="16">1</td><td>20</td></tr>
<tr><td>Broads Authority</td><td colspan="7">18</td><td colspan="9">3</td><td>150</td></tr>
<tr><td>Broadland</td><td colspan="3">4,691</td><td colspan="4">765</td><td colspan="9">300</td><td>19,835</td></tr>
<tr><td>South Norfolk</td><td>2,692</td><td colspan="2">2,691</td><td colspan="4">236</td><td colspan="9">66</td><td>9,611</td></tr>
<tr><td>Norwich</td><td colspan="3">2,322</td><td colspan="4">887</td><td colspan="9">341</td><td>13,576</td></tr>
<tr><td>Great Yarmouth</td><td colspan="16">0</td><td>0</td></tr>
<tr><td>Total*</td><td>11,320</td><td>11,364</td><td>11,349</td><td>2,514</td><td>2,652</td><td>2,633</td><td>2,491</td><td>958</td><td>951</td><td>951</td><td>951</td><td>951</td><td>951</td><td>951</td><td>951</td><td>951</td><td>52,887</td></tr>
</table>

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Table 2-4 outlines the permanent and temporary mitigation required, per LPA, assuming permit limits are reduced to the TAL by 2030. **Figure 2.4** and **Figure 2.5** provide a visual representation of the permanent and temporary mitigation required. A total of 1,407 kg/yr of temporary TP mitigation is required up to 2030, which is approximately 30% of the total mitigation required. The temporary TN mitigation required is 31,178 kg/yr and approximately 60% of the total mitigation required.

Table 2-4 Mitigation required, per LPA, assuming permit limits are reduced to the TAL post 2030

District	Total TP mitigation*	Permanent TP mitigation	Temporary TP mitigation (up to 2030)	Total TN mitigation*	Permanent TN mitigation	Temporary TN mitigation (up to 2030)
North Norfolk	433	287	146	5,139	1,941	3,198
Breckland	1,235	1,175	60	4,554	3,234	1,320
West Norfolk	1	1	0	20	20	0
Broads Authority	12	8	4	150	49	101
Broadland	1667	1,068	599	19,836	6,421	13,415
South Norfolk	958	633	324	9611	3,008	6,603
Norwich	454	180	274	13,576	7,036	6,540
Great Yarmouth	0	0	0	0	0	0
Total	**4,760**	**3,353**	**1,407**	**52,887**	**21,709**	**31,178**

**The Total mitigation may be different to totalling the permanent and temporary mitigation columns due to the differentials in rounding.*

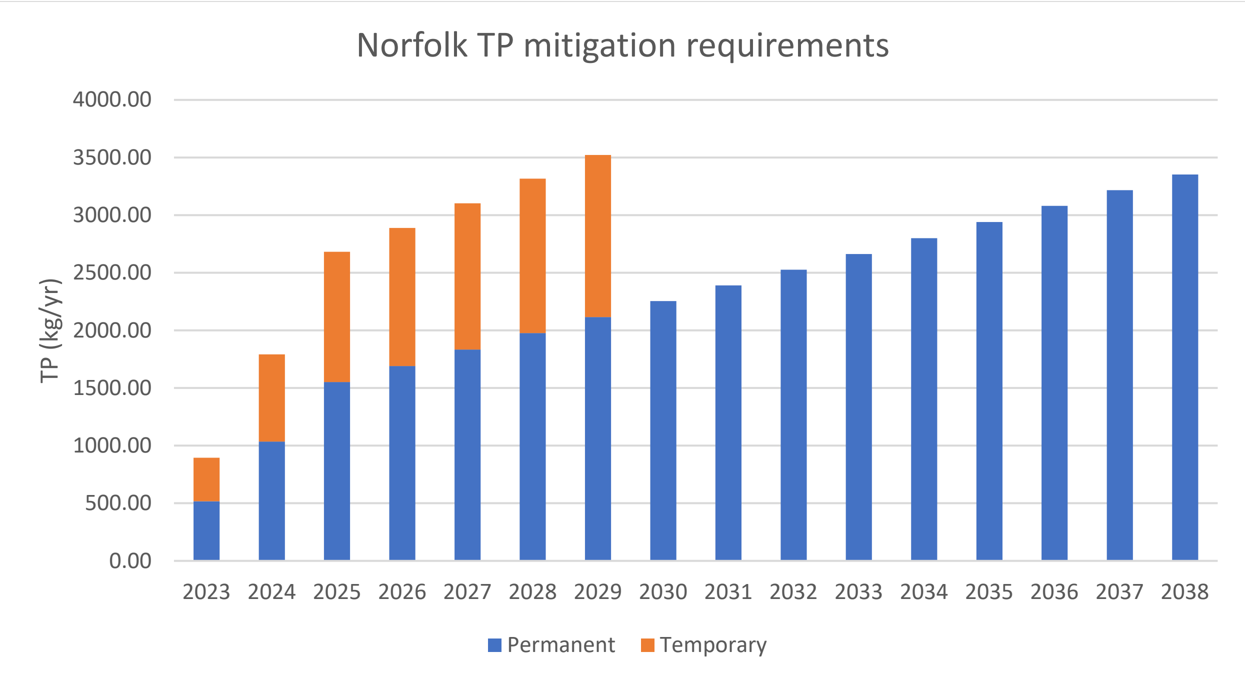

Figure 2.4 Mitigation requirements for TP

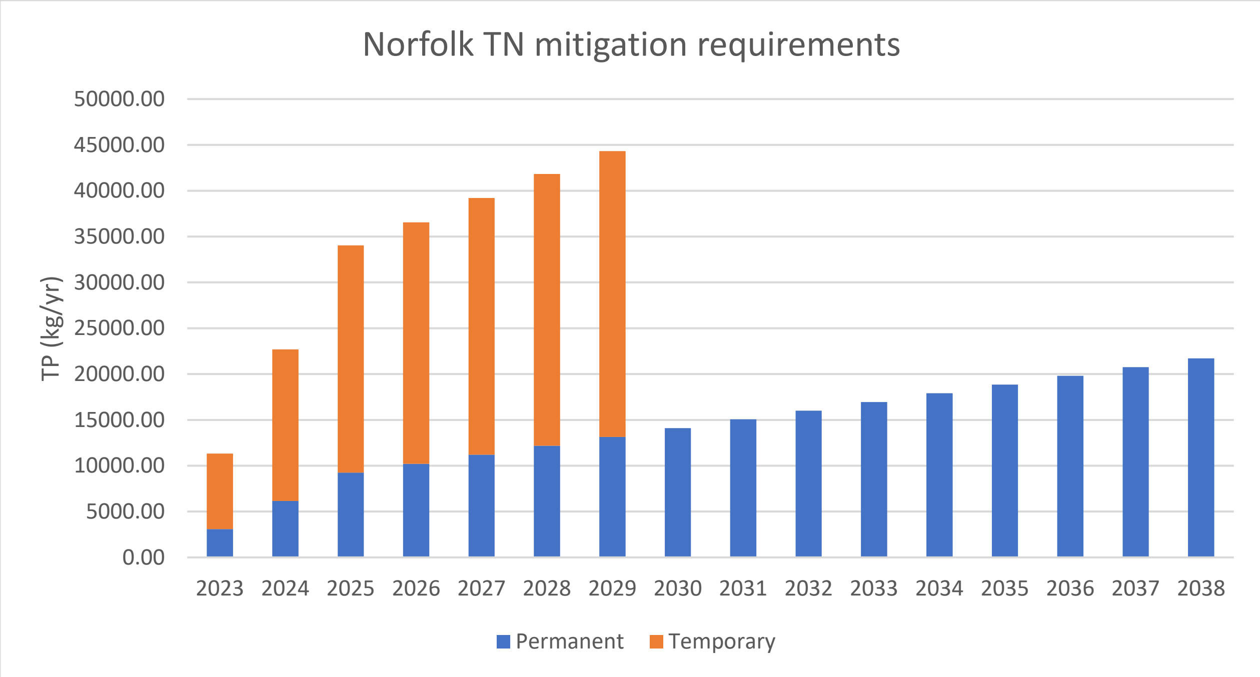

Figure 2.5 Mitigation requirements for TN

2.2.3 Projected housing growth per catchment

The projected nutrient loading from proposed developments has also been calculated for the Wensum, Yare and Bure catchments (**Table 2-5** and **Table 2-6**). The majority of the nutrient mitigation is required within the River Yare catchment. This is primarily due to the discharge locations of WRC within Norfolk, particularly Whitlingham treatment works which serves Norwich and the surrounding areas.

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Table 2-5 Phosphorus mitigation requirements per river catchment

<table>
<tr><th rowspan="2">District</th><th colspan="17">Phosphorus loading (kg/yr)</th></tr>
<tr><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th><th>2029</th><th>2030</th><th>2031</th><th>2032</th><th>2033</th><th>2034</th><th>2035</th><th>2036</th><th>2037</th><th>2038</th><th>Total*</th></tr>
<tr><td>Wensum</td><td colspan="3">65</td><td>21</td><td>27</td><td>25</td><td>18</td><td colspan="3">11</td><td>12</td><td>13</td><td>14</td><td>16</td><td colspan="2">11</td><td>396</td></tr>
<tr><td>Yare</td><td>754</td><td>753</td><td>749</td><td colspan="4">152</td><td colspan="9">102</td><td>3,787</td></tr>
<tr><td>Bure sub-catchment</td><td colspan="2">71</td><td>69</td><td colspan="2">29</td><td>30</td><td>32</td><td>25</td><td colspan="8">22</td><td>527</td></tr>
<tr><td>Ant sub-catchment</td><td>4</td><td>7</td><td>6</td><td>4</td><td colspan="2">6</td><td>3</td><td colspan="9">1</td><td>48</td></tr>
<tr><td>Thurne sub-catchment</td><td colspan="3">0.6</td><td colspan="13">0</td><td>2</td></tr>
<tr><td>Trinity sub-catchment</td><td colspan="16">0</td><td>0</td></tr>
<tr><td>Total*</td><td>895</td><td>897</td><td>890</td><td>206</td><td>215</td><td>214</td><td>205</td><td>139</td><td>136</td><td>136</td><td>136</td><td>138</td><td>139</td><td>141</td><td>136</td><td>136</td><td>4,760</td></tr>
</table>

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Table 2-6 Nitrogen mitigation requirements per river catchment

<table>
<tr><th rowspan="2">*District</th><th colspan="17">Nitrogen loading (kg/yr)</th></tr>
<tr><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th><th>2029</th><th>2030</th><th>2031</th><th>2032</th><th>2033</th><th>2034</th><th>2035</th><th>2036</th><th>2037</th><th>2038</th><th>Total*</th></tr>
<tr><td>Wensum</td><td colspan="3">1,086</td><td>271</td><td>375</td><td>341</td><td>219</td><td colspan="3">47</td><td colspan="4">46</td><td colspan="2">47</td><td>**4,885**</td></tr>
<tr><td>Yare</td><td>9,361</td><td colspan="2">9,360</td><td colspan="4">1,824</td><td colspan="9">688</td><td>**41,573**</td></tr>
<tr><td>Bure sub-catchment</td><td colspan="3">800</td><td colspan="2">348</td><td>364</td><td>395</td><td>210</td><td colspan="8">204</td><td>**5,695**</td></tr>
<tr><td>Ant sub-catchment</td><td>68</td><td>113</td><td>98</td><td>70</td><td colspan="2">104</td><td>53</td><td colspan="9">12</td><td>**719**</td></tr>
<tr><td>Thurne sub-catchment</td><td colspan="3">4</td><td colspan="13">0</td><td>**13**</td></tr>
<tr><td>Trinity sub-catchment</td><td colspan="16">0</td><td>**0**</td></tr>
<tr><td>**Total***</td><td>**11,320**</td><td>**11,364**</td><td>**11,349**</td><td>**2,514**</td><td>**2,652**</td><td>**2,633**</td><td>**2,491**</td><td>**956**</td><td colspan="8">**951**</td><td>**52,887**</td></tr>
</table>

**The Totals may not directly equate to the total when the individual years are added up due to the differential caused by rounding. The Total column would be considered to be more accurate than adding the individual years up when looking at the total figures.*

Table 2-7 outlines the permanent and temporary mitigation required, per river catchment, assuming permit limits are reduced to the TAL by 2030.

Table 2-7 Mitigation required, per river catchment, assuming permit limits are reduced to the TAL post 2030

District	Total TP mitigation*	Permanent TP mitigation	Temporary TP mitigation (up to 2030)	Total TN mitigation*	Permanent TN mitigation	Temporary TN mitigation (up to 2030)
Wensum	396	256	140	4,885	1,390	3,495
Yare	3,787	2,600	1,187	41,574	15,649	25,925
Bure sub-catchment	527	468	59	5,695	4,455	1,240
Ant sub-catchment	49	28	21	720	215	505
Thurne sub-catchment	2	0.9	0.8	13	0	13
Trinity sub-catchment	0	0	0	0	0	0
Total	**4,760**	**3,353**	**1,407**	**52,887**	**21,709**	**31,178**

**The Total mitigation may be different to totalling the permanent and temporary mitigation columns due to the differentials in rounding.*

The expected TP and TN loading per year for each LPA within the Wensum, Yare and Bure catchments are provided in **Table 2-8** and **Table 2-9**. The greatest TP mitigation is required in Breckland and Broadland. Despite Breckland having much lower development aspirations than Broadland, the lack of current and future P stripping at WRC results in large TP loads.

For example, a significant proportion of the development proposed in Breckland will drain to Shipdham WRC, which currently serves a population of 1,946. This is below the 2,000 threshold for mandatory TAL in 2030, which would make a significant difference to the permanent TP loading in the district. The greatest TN mitigation requirements are in Norwich Broadland and Breckland. The modest proposed development within the nutrient neutrality catchments for West Norfolk and The Broads Authority results in low mitigation requirements.

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Table 2-8 Phosphorus mitigation requirement breakdown per river catchment for each LPA

District		Phosphorus loading (kg/yr)																
		2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	Total*
North Norfolk	Wensum	37			6	12	10	3	1			2	3	5	6	1		**164**
	Bure	27			15		16	18	11	8								**219**
	Ant	4	7	6	4	6		3	1									**48**
	Thurne	0.6			0													**2**
Breckland	Wensum	24			14				10									**215**
	Yare	108			55				53									**1,020**
West Norfolk	Wensum	0.1																**1**
Broads Authority	Bure	0.1							0									**1**
	Yare	1							0									**11**
Broadland	Wensum	4			0.3				**0.2**									16
	Yare	383			24				11									1,344
	Bure	43		42	15				13									307
South Norfolk	Yare	179		175	41				29									958
Norwich	Yare	82	81		32				9									**454**
Great Yarmouth	Trinity	**0**																**0**
Total*		**895**	**897**	**890**	**206**	**215**	**214**	**205**	**139**	**136**			**138**	**139**	**141**	**135**		**4,760**

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Table 2-9 Nitrogen mitigation requirement breakdown per river catchment for each LPA

<table>
<tr><th colspan="2" rowspan="2">District</th><th colspan="17">Nitrogen loading (kg/yr)</th></tr>
<tr><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th><th>2029</th><th>2030</th><th>2031</th><th>2032</th><th>2033</th><th>2034</th><th>2035</th><th>2036</th><th>2037</th><th>2038</th><th>Total*</th></tr>
<tr><td rowspan="4">North Norfolk</td><td>Wensum</td><td colspan="3">622</td><td>102</td><td colspan="2">206</td><td>171</td><td>50</td><td colspan="2">11</td><td colspan="4">10</td><td colspan="2">11</td><td>2,487</td></tr>
<tr><td>Bure</td><td colspan="4">238</td><td colspan="3">145</td><td>161</td><td>192</td><td>68</td><td colspan="6">62</td><td>1,919</td></tr>
<tr><td>Ant</td><td>68</td><td>113</td><td>98</td><td>70</td><td colspan="4">104</td><td>53</td><td colspan="7">12</td><td>719</td></tr>
<tr><td>Thurne</td><td colspan="4">4</td><td colspan="12">0</td><td>13</td></tr>
<tr><td rowspan="2">Breckland</td><td>Wensum</td><td colspan="4">347</td><td colspan="5">161</td><td colspan="7">31</td><td>1,967</td></tr>
<tr><td>Yare</td><td colspan="4">318</td><td colspan="5">128</td><td colspan="7">124</td><td>2,587</td></tr>
<tr><td>West Norfolk</td><td>Wensum</td><td colspan="16">1</td><td>20</td></tr>
<tr><td rowspan="2">Broads Authority</td><td>Bure</td><td colspan="9">3</td><td colspan="7">1</td><td>33</td></tr>
<tr><td>Yare</td><td colspan="9">14</td><td colspan="7">2</td><td>117</td></tr>
<tr><td rowspan="3">Broadland</td><td>Wensum</td><td colspan="4">116</td><td colspan="5">7</td><td colspan="7">4</td><td>411</td></tr>
<tr><td>Yare</td><td colspan="4">4,015</td><td colspan="5">559</td><td colspan="7">156</td><td>15,682</td></tr>
<tr><td>Bure</td><td colspan="4">559</td><td colspan="5">199</td><td colspan="7">140</td><td>3,743</td></tr>
<tr><td>South Norfolk</td><td>Yare</td><td colspan="4">2,692</td><td colspan="5">236</td><td colspan="7">66</td><td>9,611</td></tr>
<tr><td>Norwich</td><td>Yare</td><td colspan="4">2,322</td><td colspan="5">887</td><td colspan="7">341</td><td>13,576</td></tr>
<tr><td>Great Yarmouth</td><td>Trinity</td><td colspan="16">0</td><td>0</td></tr>
<tr><td colspan="2">Total*</td><td>11,320</td><td>11,364</td><td>11,349</td><td>2,514</td><td>2,652</td><td>2,633</td><td>2,491</td><td>958</td><td>951</td><td>951</td><td>951</td><td>951</td><td>951</td><td>951</td><td>951</td><td>951</td><td>52,887</td></tr>
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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 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.
    - training and capital grants targeted at priority catchments to help reduce soil erosion and nutrient losses to water (air and soil).
- Norfolk River Trust webpage summarises a study on the effect of tramline management (Cranfield, 2018) which indicates that wheels and tramlines are a pathway for soil and nutrients as surface run-off within arable land.
    - controlled traffic movements practice is described on the Soil Quality webpage as traffic control to confine soil compaction to smaller portions of a field, rather than random (uncontrolled) farm traffic patterns which create soil compaction across a wider field area.
    - controlled traffic movements can improve water infiltration and plant root growth.

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 (**Section 3.3**), Runoff Management Solutions (**Section 3.4**), Wastewater Management Solutions (**Section 3.5**) and Demand Management Solutions (**Section 3.6**).

3.2 Potential Nutrient Management Solutions

3.2.1 Overview

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	Solution	Delivery timescale	Further information
Nature-based solutions	Silt traps	Short-term	**Section 3.3.1**
	Riparian buffer strips	Short-term	**Section 3.3.2**
	Constructed wetlands	Medium-term	**Section 3.3.3**
	Wet woodlands	Short-term	**Section 3.3.4**
	Willow buffers	Short-term	**Section 3.3.5**
	Beetle banks	Short-term	**Section 3.3.6**
	Broadland restoration	Long-term	**Section 3.3.7**
	Beaver reintroduction	Medium-term	**Section 3.3.8**
Runoff management solutions	Taking land out of agricultural use	Short-term	**Section 3.4.1**
	Solar farms	Short-term	**Section 3.4.2**
	Cessation of Fertiliser and Manure Application	Short-term	**Section 3.4.3**
	Farm management measures	Medium-term	**Section 3.4.3**
	Cover crops	Short-term	**Section 3.4.5**
	Installing SuDS in new developments	Short-term	**Section 3.4.6**
	Retrofitting SuDS in existing developments	Medium-term	**Section 3.4.7**
Wastewater management solutions	Expedite planned improvements to treatment works	Short-term	**Section 3.5.1**
	Improve existing wastewater treatment infrastructure	Long-term	**Section 3.5.2**
	Improve existing wastewater distribution infrastructure (reduce leakage from foul sewer network)	Long-term	**Section 3.5.3**
	Install portable treatment works	Short-term	**Section 3.5.4**
	Rectifying misconnections to combined systems	Long-term	**Section 3.5.5**
	Incentivise disconnection from combined systems	Long-term	**Section 3.5.6**
	Use alternative wastewater treatment providers	Medium-term	**Section 3.5.7**
	Install package treatment plants	Short-term	**Section 3.5.8**
	Upgrade existing private sewage systems	Medium-term	**Section 3.5.9**
	Install cesspools and capture outputs from private sewage systems	Short-term	**Section 3.5.10**
Demand management solutions	Retrofit water saving measures in existing properties (local authority, registered providers, public buildings)	Short-term	**Section 3.6.1**
	Retrofit water saving measures in existing properties (private housing, commercial and industrial premises)	Short-term	**Section 3.6.2**
	Incentivise commercial water efficiency	Medium-term	**Section 3.6.3**

3.2.2 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 solutions

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: ■ 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. Removal rates of TP and TN are the same where TP and TN have not been distinguished between, and one figure/ estimate is presented.
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.

Descriptor	Definition
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.

3.2.3 Monitoring

Nutrient removal data, which in some circumstances can be used as baseline data, has been obtained from various literature sources (see references provided in **Section 5**) and other public domain data providers. The data compiled within this study is relevant to the catchments. At this stage of the project the mitigation measures are high level and have not been assigned to specific sites.

It is not possible to determine if site specific baseline data is available or in the absence of published data, a monitoring programme would be required. The nutrient removal values provided within the wastewater management solutions and demand management solutions are based on present outputs from WRCs and population data. The water company initiatives to reduce nutrient output from WRCs may change the baseline in the near future and the findings presented here may be outdated.

Cost estimates are included for some of the solutions, e.g., riparian buffer strips where costs have been easily derived from Farmscoper Version 5 (updated in January 2022) (Farmscoper Tool). The varying parameters of monitoring requirements according to the solution (or combination of solutions), site-specific detail and available relevant data mean it is not possible to provide costs for monitoring effectiveness, i.e., nutrient removal) for solutions at this stage.

However, as part of site selection for mitigation solutions it may be prudent to undertake site-specific baseline P and N soil and water measurements early on in the design and planning stage. Monitoring typically would require ‘wet weather’ sampling over at least one year in order to recognise seasonal difference and include laboratory analysis of at least total N and total P and in some circumstances nitrate (NO_3-N), nitrite (NO_2-N), ammonia-nitrogen (NH_3-N), dissolved P and orthophosphate (PO_4^{3-}) (SRP).

3.3 Nature-based solutions

3.3.1 Silt traps

3.3.1.1 Description of solution

Silt traps can be installed on farms to catch sediment bound phosphates that would be periodically cleaned. Silt traps are basins set upstream that capture sediments. Fine sediments to which phosphorus is bound become physically immobilised, i.e., deposited, behind a barrier due to a reduction in flow energy, decreasing the volume of sediment and therefore phosphorus within the watercourse.

As a result of its early removal, there is also a reduced potential for phosphorus to become soluble further downstream and detrimentally impact water quality. The benefits of silt traps for water quality are well established, i.e., they trap and retain sediment and nutrients, thereby improving water quality.

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Table 3-3 shows key considerations associated with silt traps. Examples of different types of silt traps are presented in **Figure 3.1**and **Figure 3.2**.

Table 3-3 Key considerations of silt traps

Key considerations	
Description of solution	Silt traps are basins set upstream that capture sediment bound phosphates, enabling them to be removed from the watercourse. As a result of its early removal, the potential for phosphorus to become soluble further downstream and detrimentally impact water quality is reduced
Delivery timescale	Short-term
Duration of operation	Impermanent
Nutrient removal	TP removal potential: 25-75% TN removal potential: <25%
Applicability	All farm typologies applicable
Management and maintenance	Regular de-silting will be required
Additional benefits	Water quality
Best available evidence	No, explained under Evidence of effectiveness
Wider environmental considerations	Sediment containing collected nutrients and chemicals, and its 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	This method is precautionary
Securable in perpetuity	Yes – management agreements will likely need to be put in place, especially where land in leased Replacements may be required if the lifetime is less than the developments
Cost estimation	Capital costs: £1,000 - £4,000 Maintenance costs: £500/yr

Figure 3.1 Silt trap installed in a stream (Source: IRD Duhallow, 2015)

Figure 3.2 Silt fencing installed on agricultural fields (Source: HY-TEX, 2022)

3.3.1.2 Nutrient removal

In general, data is available in relation to the silt capture rate, however, currently there is a large degree of uncertainty in relation to nutrient removal rate as it is dependent on multiple variables such as location, soil type, rainfall, frequency of de-silting and is likely to differ between locations. Quantitative nutrient data is required according to site-specific variables to seek optimal locations. Pilot trials should be undertaken to determine the design of silt traps, their installation and array type to optimise their usage.

Reducing sediment runoff should be a matter of farming good practice where there is a serious risk of fine-grained sediment pollution. Therefore, mitigation schemes should not promote soil erosion or be installed at locations where ongoing soil erosion is currently taking place because locations such as these should be managed in line with farming good practice. Furthermore, a silt trap scheme 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.

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. TN removal is typically reported to be less than 25%.

3.3.1.3 Delivery timescale

Silt traps require limited infrastructure and, depending upon their location, may not require any environmental permits. They can therefore be delivered in the short-term.

3.3.1.4 Duration of operation

Silt traps are considered to be an impermanent solution, provided that they are adequately maintained throughout their lifetime.

3.3.1.5 Applicability

This nature-based solution is applicable for all farm typologies, particularly farms which have a high risk of silt runoff.

3.3.1.6 Management and maintenance requirements

Maintenance costs are dependent on the loading rate and location of the silt traps, however undertaking periodic clearance every two to five years, the costs are likely to be in the order of £500 per year. Returning the silt to land as a replacement for fertiliser may lead to overall financial savings for farmers. There is a possibility that in the future this solution would also be covered as part of countryside stewardship agreements that could provide additional financial benefits.

3.3.1.7 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, particularly those that are sensitive to high turbidity or require coarse substrates for part of their life cycle.

3.3.1.8 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.

3.3.1.9 Evidence of effectiveness

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. The solution is likely to have some effectiveness in the removal of sediment-associated nutrients, it is less likely to be effective at removing nutrients transported in the dissolved phase.

The solution is therefore likely to be more effective in removing P than N, although there is a large uncertainty regarding its effectiveness. As such, monitoring and potentially pilot trials would be required to provide representative data which measures nutrient removal rate potential.

3.3.1.10 Deliverability and certainty

There is a large amount of uncertainty regarding removal rate. This is dependent upon a number of parameters which determine variable success, for example water flow rates and storm events.

3.3.1.11 Cost estimate

Capital costs are between £1,000-£4,000 with additional maintenance costs of £500 per annum. **Table 3-4** and **Table 3-5** provide an indication of the likely mitigation that could be delivered and associated costs in each sub-catchment. This assumes a silt trap removes 25% of the TP and TN load from one cereal field and the costs outlined above. This assumes that 100% of the flow is treated by a series of silt traps.

Table 3-4 Estimated TP mitigation and associated costs in each sub-catchment

Sub-catchment	Mitigation	Dwelling equivalent	Cost estimation (£/ha)	£/kg TP/yr for each year	£/dwelling for each year	£/kg TP/yr over 80 years	£/dwelling over 80 years
Wensum	0.18	3	500	2,740	186	219,178	14,868
Yare	0.09	1	500	5,882	399	470,588	31,923
Bure	0.02	0	500	33,333	2261	2,666,667	180,895

Table 3-5 Estimated TN mitigation and associated costs in each sub-catchment

Sub-catchment	Mitigation	Dwelling equivalent	Cost estimation (£/ha)	£/kg TN/yr for each year	£/dwelling for each year	£/kg TN/yr over 80 years	£/dwelling over 80 years
Wensum	5.94	3	500	84	159	6,737	12,694
Yare	4.81	3	500	104	196	8,320	15,678
Bure	6.44	3	500	78	146	6,214	11,708

3.3.1.12 Summary

The key considerations for silt traps are presented in **Table 3-3**.

3.3.2 Riparian buffer strips

3.3.2.1 Description of solution

Riparian buffer zones are strips greater than 5m wide composed of permanent grass and/ or woodland cover that act as a separation barrier between the 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 nutrient-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).

Figure 3.3 Aerial view of a riparian buffer strip (Source: Iowa State University Forestry Department, 2016).

3.3.2.2 Nutrient removal

Table 3-6 shows a summary of recent published research on P removal using buffer strips. Buffer strips composed of woody material as opposed to herbaceous material can store significant amounts of biomass phosphorus (Fortier *et al*., 2015), whilst woody buffers are more effective at trapping sediment than grasses (Hoffmann *et al*., 2009, Anguiar *et al*., 2015).

Woodland buffers, particularly those containing willow, also have less onerous maintenance requirements than grassland buffers. The phosphorus removal rate is greatest during the first few metres of the buffer strip. However, the highest total removal rates are typically only achieved in buffer strips 15m to 20m wide.

Vought *et al*., (1994) found that in grass buffer strips the phosphorus removal in the first 8m was 66%, and by 16m, 95% removal was achieved. To obtain maximum nutrient retention a buffer width of 10m to 20m is needed, alongside a density of vegetation (Vought *et al*., 1994). Wide buffer strips can also allow for the restoration of wetlands in wet lying areas and the creation of small scrapes alongside tree planting.

Table 3-6 outlines the P removal efficiency achieved by riparian buffer strips depending on their soil types and width (Zabronsky, 2016). **Figure 3.4** confirms that removal efficiency increases with buffer width and that buffer widths of 15m to 20m are most favourable. Beyond 20m the removal efficiency does not dramatically increase, and it may not be viable for the agricultural land take required.

Table 3-6 Riparian buffer effectiveness depending on buffer width and soil type (edited from Zabronsky (2016))

Study	Vegetation cover	Buffer width	Phosphorus removal efficiency (%)	Major soil type
Chaubey *et al*., 1995	Grass	3.1	39.6	Silt
	Grass	6.1	58.4	Silt
	Grass	9.2	74.0	Silt
	Grass	15.2	86.8	Silt
	Grass	21.4	91.2	Silt
Meals, 1996	Grass	Unknown	86	Clay
Lee *et al*., 1998	Grass	3	39.5	Loam
	Grass	3	35.2	Loam
	Grass	6	55.2	Loam
	Grass	6	49.4	Loam
Lim *et al*., 1998	Grass	6.1	76.1	Silt
	Grass	12.2	90.1	Silt
	Grass	18.3	93.6	Silt
Dillaha *et al*., 1989	Grass	9.1	79	Silt loam
	Grass	4.6	61	Silt loam

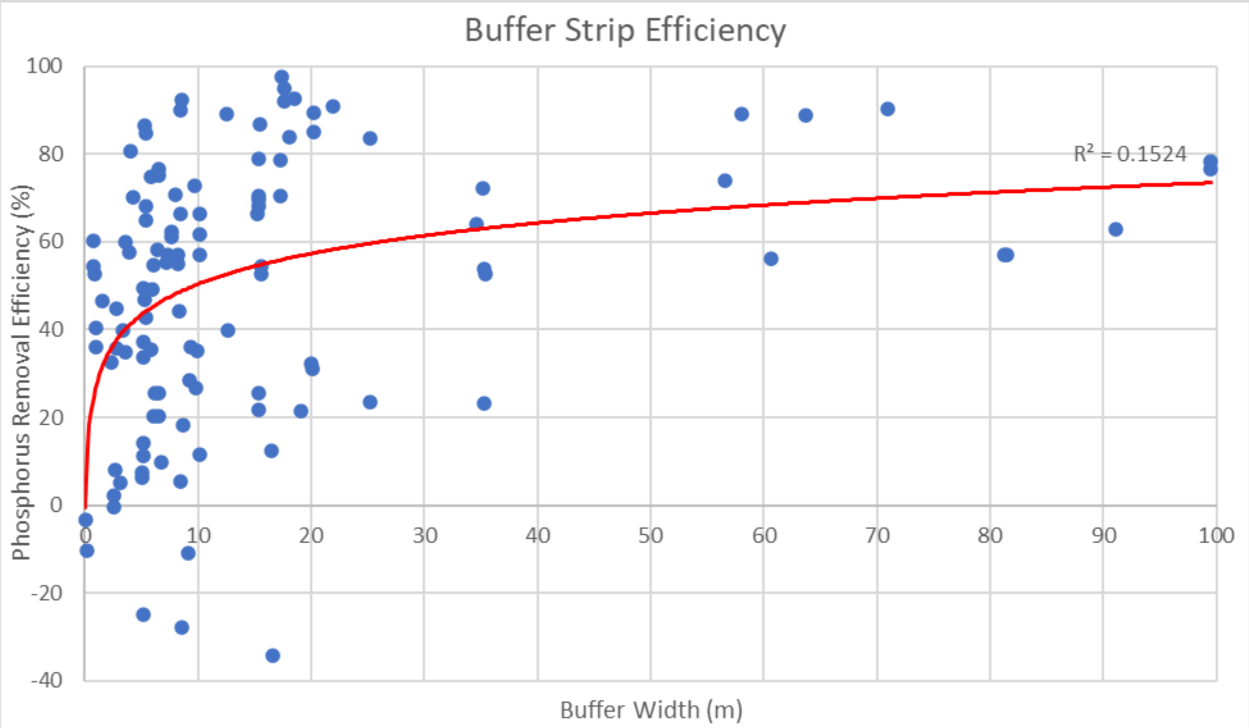

Figure 3.4 Buffer strip efficiency (Edited from Tsai et al., 2016)

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 phosphate bound sediment in the runoff.

There is considerable evidence within the scientific literature regarding the effectiveness of buffer strips as solutions for nitrogen removal. **Figure 3.5** shows the relationship between riparian buffer width and N removal for all studies.

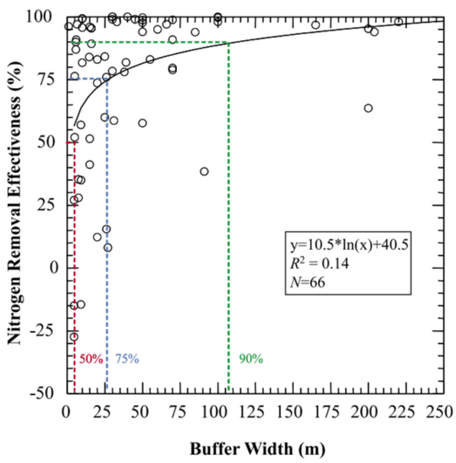

Figure 3.5 Relationship of nitrogen removal effectiveness and buffer width in for all vegetation types (From Mayer et al., 2005)

Lv & Wu (2021) found that beyond widths of 15m, N reductions within buffers did not substantially change. Assuming an optimum buffer width of 15m, **Figure 3.5** predicts an average removal rate approximately 65%. **Table 3-7** presents some of the typical removal rates observed within the literature. Mayer *et al.*, (2007) conducted a substantial review of riparian buffer strip literature with a variety of vegetation types and locations.

The results identified that N removal is positively correlated with the width of the buffer, but other factors affected the effectiveness. Their non-linear regression model indicated that TN removal efficiencies of all vegetation types (grass, forest, grass/ forest, wetland, forest/ wetland) of 50%, 75% and 90% would be achieved at widths of 3m, 28m and 112m. The results also indicated that grass and forest buffers were more effective than only grass buffers. **Table 3-8** suggests that a 20m grass/ forest buffer would achieve an average removal efficiency of 75%.

Table 3-7 Typical nitrogen removal rates

Study	Vegetation cover	Buffer width (m)	Nitrogen removal efficiency (%)	Major soil type
Mayer *et al.*, 2005	All	3	50	-
	All	28	75	-
	All	112	90	-
Lee *et al.*, 1998	Grass	3	28	Loam
	Grass	6	46	Loam
Lv & Wu, 2021	Poplar	15	65.1	-
	Poplar	30	65	-
	Poplar	40	66.	-
Dillaha *et al.*, 1989	Grass	9.1	73	Silt loam
	Grass	4.6	54	Silt loam

Table 3-8 Effectiveness of different types of buffer strip in removing TN (Edited from Mayer et al., 2005)

Buffer vegetation	Mean TN removal effectiveness (%)	Approximate buffer width by predicted effectiveness		
		50%	75%	90%
All vegetation types	74.2m	3m	28m	112m
Grass	53.3m	16m	47m	90m
Grass/ forest	80.5m	5m	20m	47m

3.3.2.3 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 any planning or environmental permits and can therefore be delivered in the short term.

3.3.2.4 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 to be impermanent and subject to changes in farming practices.

3.3.2.5 Applicability

This is applicable to the catchments as a proportion is located within agricultural land where riparian buffers could be grown.

3.3.2.6 Management and maintenance requirements

Riparian buffer zones need continued maintenance to ensure they achieve the desired loading rates – maintenance is mainly limited to cutting vegetation and removal of accumulated sediment. This is an important process to prevent the area from becoming a nutrient source rather than a sink. 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. Riparian buffer strips could be implemented as a short-term bridging solution or as a longer-term solution.

3.3.2.7 Additional benefits

Riparian buffer strips also have the added benefit of stabilising riverbanks and reducing erosion. This is achieved by dissipating energy in river flows and through stabilisation of soils by roots (Cooper *et al*., 1990). This will also lead to a reduction in particulate bound nutrients entering rivers, although quantification of the reduction is difficult to predict. Buffer strips also provide important habitats for wildlife.

3.3.2.8 Wider environmental considerations

The establishment of buffer strips will not require planning permission or any environmental permits. Buffer strips could potentially support sensitive species or ecological communities, and as such may need to be managed carefully to avoid damaging these communities. In addition, the establishment of fenced-off buffer strips may limit access to a water source by grazing livestock.

It may therefore be necessary to provide an alternative source and/ or defined drinking points. If there are important routes used by wildlife through the area of proposed buffer strips, a fenced path may be created as a throughway.

Furthermore, new woodland in parts of The Broads is not welcomed by the sailing community due to wind shadow. Therefore, consideration on the impact to such stakeholders would need to be considered during the screening of suitable locations. Additionally, the species of trees proposed for planting in these locations would need to be carefully considered, following the ‘right tree, right place, right reason’ mantra of the Forestry Commission (2020).

3.3.2.9 Evidence of effectiveness

Riparian buffer strips are an established nature-based solution for pollution control within catchments and have been employed for multiple years. **Section 3.3.2** provides literature evidence of the expected nutrient removal rates which are based of multiple examples in differing locations, soil types and vegetation types.

3.3.2.10 Deliverability and certainty

Riparian buffer strips are typically located at field margins and are, therefore, more likely to be adopted by farmers. Riparian buffer strips are likely to involve tree planting and fencing off from existing fields. This provides good certainty that the land use will be maintained and not revert back to agriculture.

Furthermore, riparian land is typically on the less productive margins of fields. Long-term management of the land as a riparian buffer can be secured through legal agreements to provide further certainty. 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 outperform its predicted design capacity, this will be identified by the monitoring process and allow the additional nutrient removal to be used as nutrient credits.

The monitoring will also identify if the maintenance of the buffer is ensuring nutrient removal is maintained. There are few consents which will be required for riparian buffer creation. Where groundworks are operating within a flood zone then it is important that the flood storage area is not reduced. 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 phosphorus sources and subsequent removal potential.
- 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.

Management agreements or a conservation covenant agreement could offer a route to securing this solution. A conservation covenant agreement is described as a private and voluntary agreement made between the landowner and responsible body and is legally binging executed as a deed and registered on the local land charges register. A conservation covenant agreement must offer benefit to the public in some way in addition to having a conservation purpose, although provision of public access does not need to be a feature of such an agreement.

Part of the agreement could include an obligation to make sure that money is available to cover maintenance costs. To be considered as meeting securable in perpetuity goal for landowners who have a freehold title or a leaseholder with >80 years remaining on the lease. The duration of a conservation covenant can be considered as indefinitely if a timescale is not expressly set out in the agreement.

A responsible body can be a public body or charity or private sector organisation where the main function relates to conservation or a Local Authority, and it is their responsibility to submit an annual return. DEFRA guidance for how to apply to become a responsible body should be available from early 2023.

3.3.2.11 Cost estimate

Costs were derived from Farmscoper Tool which is an industry good practise tool for assessing mitigation solutions. Typical costs for establishing new buffer strips are shown in **Table 3-9**.

Table 3-9 Summary buffer strip costs (from Farmscoper Tool)

Measure	Upfront costs (£/ ha)	Annual cost (£/ ha)
Loss of production	-	889
Seasonal cutting of buffer strip	-	200 (estimate made from £0.02/ m)
No crop management	-	-383
Establishment of buffer strip	163	40
Soil testing (for analytical laboratory cost only and exclusive of sample collection costs)	20	10 to 40 (cost varies between grassland and arable land and based on minimum of seven tests/ year)
Total	183	786

Additionally, **Table 3-9** outlines the rates received by farmers under the current Countryside Stewardship Grants.

Table 3-10 Annual Countryside Stewardship grants for riparian buffer strips

Option	Description	£/ha/yr	£/ha/80yr
SW11 Riparian Management Strip	Riparian buffer up to 12m in width. Prohibits application of fertiliser and pesticides and use of permanent fencing to exclude livestock	440	35,200
SW4 12 to 24m buffer on cultivated land	12 to 24m buffer strip excluding vehicles or stock and prohibiting fertiliser and pesticides	512	40,960

Where riparian buffer strips are already present within the catchment, through stewardship and environmental land management schemes, nutrient 'credits' cannot be achieved as this is likely to represent double counting. However, buffer strips under stewardship and environmental land management schemes are typically up to 10m in width whereas the optimum width for buffer strips for nutrient mitigation are 15-20m.

Therefore, riparian buffers for land management schemes could be extended to those for nutrient mitigation. A credit-based approach which utilises elements of the existing model could be established for new buffer strips. Riparian buffer strip grants are available under Mid-tier and Higher tier Countryside Stewardship Scheme (CSS).

These grants have a typical term of five years, after which point new grants can be applied or from 2024 the Environment Land Management Scheme (ELMS) will be in place. At the end of agreements, existing riparian buffers could be improved and extended for nutrient mitigation instead of payment schemes. This would reduce the need for significant areas of new riparian buffer strips.

3.3.2.12 Mitigation potential

Table 3-11 and **Table 3-12** provide an indication of the likely mitigation that could be delivered and associated costs in each sub-catchment. This assumes a 1ha buffer strip that is adjacent to a cereal farm and the costs outlined in **Table 3-9**.

Table 3-11 Estimated TP mitigation and associated costs in each sub-catchment

Sub-catchment	Mitigation (kg/ha/yr)	Dwelling equivalent	Cost estimation (£/ha)	£/kg TP/yr for each year	£/dwelling for each year	£/kg TP/yr over 80 years	£/dwelling over 80 years
Wensum	4.4	64	786	181	12	14,452	982
Yare	2	30	786	388	26	31,028	2,107
Bure	0.36	5	786	2,198	149	175,815	11,928

Table 3-12 Estimated TN mitigation and associated costs in each sub-catchment

Sub-catchment	Mitigation (kg/ha/yr)	Dwelling equivalent	Cost estimation (£/ha)	£/kg TN/yr for each year	£/dwelling for each year	£/kg TN/yr over 80 years	£/dwelling over 80 years
Wensum	167.3	89	786	5	9	382	710
Yare	135.5	72	786	6	11	470	877
Bure	152.6	81	786	5	10	418	778

3.3.2.13 Summary

Key considerations are summarised in **Table 3-13**.

Table 3-13 Riparian buffer strips key considerations

Key considerations	
Description of solution	Riparian buffer strips are zones of permanent grass and/ or woodland cover that act as a separation barrier and filter between an agricultural field and a watercourse. Nutrient reductions are achieved through sedimentation of nutrient-bound particles and uptake via vegetation, which also increases surface roughness and reduces runoff rates
Delivery timescale	Short-term
Duration of operation	Impermanent
Nutrient removal	TP removal potential: Median TP retention rates of 67% (Hoffmann *et al.*, 2009) TN removal potential: 65% removal for a 15m buffer (Mayer *et al.*, 2005)
Applicability	All farm typologies applicable
Management and maintenance	Cutting/ vegetation removal
Additional benefits	■ Stabilised riverbanks ■ Water quality ■ Reduced erosion ■ Habitat creation ■ Improved amenity value ■ Biodiversity net gain (BNG) ■ 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	Yes
Evidence of effectiveness	This method is effective beyond reasonable scientific doubt
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's access to a water source and wildlife throughways. Alternative water sources and fenced throughways may be required

Key considerations	
	New woodland in parts of the Broads may affect the sailing community. The impact on stakeholders must be considered during the screening of suitable locations and tree species
Precautionary	Yes
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 back to agricultural use and is maintained correctly Conservation covenant agreement can be a mechanism for securing perpetuity
Cost estimation[4]	Typical costs are £786/ha. This is fairly well constrained with annual Countryside Stewardship Grants that are paid at £440 - £512 ha/yr A conservation covenant agreement can be used to secure income and funding for conservation activities Costs per dwelling are provided in **Table 3-73** and **Table 3-74**.

3.3.3 Constructed wetlands

3.3.3.1 Description of solution

Constructed wetlands (CW) have been used for nutrient removal and water treatment since the 1950s, with a proliferation of applications in the 1980s and 1990s in North America and Europe 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). There are various types of CW, which are described in **Table 3-14.**

It should be noted that whilst previous research studied the nutrient removal potential of all the types of the wetland detailed in **Table 3-14**, this report has focussed more on the Integrated Constructed Wetland (ICW) type as it can deliver the greatest number of additional benefits compared with other wetland types (Harrington & McInnes, 2009).

Table 3-14 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[5]) grow in the filter media[6] 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

[4] Environment Agency. 2015. Cost estimation for land use and run-off – summary of evidence (Report –SC080039/R12). (https://assets.publishing.service.gov.uk/media/6034eefdd3bf7f264e517436/Cost_estimation_for_land_use_and_run-off.pdf)
[5] 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.
[6] 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.

Type	Description
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

3.3.3.2 Nutrient removal

Nutrient removal in wetlands occurs through a suite of natural processes. These processes are physical, biogeochemical, and biological. The removal of N in wetlands is largely a biogeochemical process. Organic forms of N are sequentially converted to ammoniacal nitrogen (ammonification), nitrite and nitrate (nitrification), before being converted to di-nitrogen gas (denitrification; Dzakpasu *et al*., 2011).

Incomplete denitrification can also result in the release of nitrogen dioxide (a greenhouse gas). 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. Ammonia volatilization and anammox are also processes active in wetlands that convert N to gaseous forms (Dzakpasu *et al*., 2011), resulting in permanent removal from a wetland.

Physical processes of N retention in wetlands include ammonia sorption to sediments and the burial of organic forms of N, while biological retention occurs through N fixation by plants and the assimilation of N in plant tissues (Dzakpasu *et al*., 2011). P 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, while the biogeochemical cycling of P between organic and inorganic forms, termed mineralization, converts P into forms that are available for biological uptake.

It should be noted that unlike N, P does not cycle to gaseous forms and thus is retained within wetlands, rather than being permanently removed. There is large body of research on the efficacy of wetlands for nutrient removal. It should be noted that in the context of Nutrient Neutrality, studies are most valuable where they report reductions in N and P from wetlands in terms of nutrient load removed (in units of mass per year). However, some studies are reported here that only include the efficacy of wetlands in terms the reduction in N and P concentrations between the influent water source and the effluent from the wetland.

In a recent and seminal review of wetlands for nutrient removal, Land *et al*., (2016) summarised the results from 93 studies of 203 wetlands. These wetlands were in various countries, though the majority were in North America and Europe. The wetlands were predominantly treating agricultural sources of water, with wetlands for secondary or tertiary treatment of wastewater being the second most common type in the review.

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 removal rates of 930 kg/ha/yr 12 kg/ha/yr for TN and TP, respectively. As environmental variables such as temperature and precipitation can have a large impact on nutrient removal processes, it is useful to consider examples of wetlands preferably from the UK and Ireland.

A review of wetlands treating effluent from WRCs in Ireland compared the concentrations of TN and TP in the effluent from 44 CWs and compared this with effluent concentrations from mechanical WRCs (Hickey *et al*., 2018). This analysis showed that ICWs performed best out of all types of CWs and where ICWs were designed in line with more rigorous guidance, they also outperformed mechanical treatment in a WRC for both TP and TN.

A systematic review of on-farm wetlands, comprising both HF and FWS types, for agricultural pollution management in the UK and Ireland also concluded that these wetlands can be very effective for nutrient removal (Newman *et al*., 2015). This review reported mean SRP reductions of 58.3 ± 40.7% and load removal rates of up to 1,393 kg SRP/ha/yr, though most were markedly lower. Studies of TP removal were more limited but mean reductions of 81.7 ± 22.7% were reported, with load removal rates of the order of 1-2kg TP/ha/yr.

Ammonia and TN removal efficiencies of 98% and 83%, respectively for on-farm ICWs. Nitrate removal was considerably more variable, with an average removal efficiency of -58% for ICWs, suggesting that many of the studied ICWs were actually sources of nitrate. Analysis of this nitrate source behaviour of on-farm ICWs suggested that this was seen where nitrate inputs to a wetland were very low (≤1 kg/ha/yr), such that a small increase in nitrate concentration or load between the inlet and outlet of a wetland resulted in large negative percentage efficiencies (Newman *et al*., 2015).

A study of two ICWs treating sewage effluent in Ireland reported this behaviour for one wetland system, where the ICW was a source of nitrate when the influent to the wetland was at low nitrate concentrations and then switched to a nitrate sink when the influent concentrations increased (Kayranli *et al*., 2010). The potential for wetlands to switch from sinks to source of nutrients means that questions are often raised in the literature as to the long-term efficacy of wetlands for nutrient removal. Land *et al.,* (2016) reported that some studies show CWs retaining good performance for periods of 10+ years, while some show declines in nutrient removal performance over time.

While some studies have raised concerns over the long-term efficacy of CWs for nutrient removal, 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 SRP removal efficiencies of > 80% over and eight-year period, with 11 of the 12 averaging removal efficiencies > 90%. An intensive monitoring campaign of an ICW designed to treat raw sewage from the village of Glaslough, Ireland, has also shown sustained N removal over a two-year study (Dzakpasu *et al*., 2011).

This study showed a sustained 98% and 97% removal rate for ammonium and nitrate, respectively, with a total of 2,802 kg NH3-N and 441 kg NO_3-N removed by the wetland over two years, equating to a removal rate of 1,621.5 kg N/yr. As this study only accounted for ammonium and nitrate, the TN removal rate for this ICW may be higher, though it is noted that nitrite and organic N tend to be smaller components of TN in sewage.

A follow up study assessing the performance of the Glaslough wetland for TP removal after four-years of operation showed a TP removal efficiency of 93.5% (Dzakpasu *et al*., 2015). The wetland received a TP mass loading of 16.4 ± 0.96 g/m^2/yr, with an effluent TP load of 1.4 ± 0.39 g/m^2/yr. Scaling this mass removal rate by the wetland area of 3.25ha equates to an average TP removal of 453.75 kg TP/yr.

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 but outside of the Broads and Wensum catchments. In 2014, the Norfolk Rivers Trust (NRT) deployed an ICW to treat final effluent discharge from the Northrepps WRC[7]. Analysis of monitoring data from the first 18 months of operation at this wetland reported high nutrient

[7] *Norfolk Rivers Trust | Frogshall: Creating an Integrated Constructed Wetland (ICW). (n.d.). Retrieved December 30, 2022, from https://norfolkriverstrust.org/projet/upper-mun-restoration-frogshall-wetland-project/*

removal efficiencies, with TP concentrations reduced by 78%, SRP reduced by 80%, and total oxidisable nitrogen and nitrate reduced by 65% each (van Biervliet *et al*., 2020).

Following the success of the Northrepps WRC scheme, AWS and NRT have developed another ICW scheme at the Ingoldisthorpe WRC which was built in 2017 (Cooper *et al*., 2020). Six-month sampling campaigns at the Northrepps WRC and Ingoldisthorpe WRC ICWs in 2019 provided an assessment of the performance of each wetland in terms of nutrient load reductions (Cooper *et al*., 2020). This study reported load reductions for nitrate and phosphate at Ingoldisthorpe WRC and Frogshall WRC of 2,239 kg NO_3-N/yr and 153kg PO_4-P/yr, and 1,976kg NO_3-N/yr and 292kg PO_4-P/yr, respectively.

It was noted that the Frogshall WRC ICW appears to still be providing a considerable amount of N and P removal after five years of operation and with minimal maintenance. It was also observed that the Frogshall ICW received nearly half the inflow volume as the Ingoldisthorpe ICW and yet recorded nearly double the amount of P removal and only 12% less N removal. This is due to the phosphate and nitrate concentrations of the inflow from each WRC, which averaged 2.04 mg/l and 28.4 mg/l, respectively, at Ingoldisthorpe and 8.65 mg/l and 60.7 mg/l, respectively, at Frogshall (Cooper *et al*., 2020), highlighting the relative benefit that can be achieved by siting a CW in locations where the inflow source has high concentrations of N and P.

There is a strong evidence base highlighting the potential for CWs to provide nutrient mitigation for N and P. Furthermore, where wetlands have been well designed and receive consistent sources of higher concentration effluent, the evidence suggest that high rates of nutrient removal can be sustained over long time periods. Owing to the strength of the evidence supporting CWs as nutrient mitigation solutions, Natural England, with the Rivers Trust and Constructed Wetlands Association, have recently published a framework describing the key information that should be included in proposals for CWs to deliver nutrient removal (Johnson *et al*., 2022).

3.3.3.3 Delivery timescale

CWs require engineering design and construction, which in turn may require planning permission and an Impoundment Licence. Depending on data availability to inform the design, a monitoring campaign may also be required. It is likely that the following permits and consents will be required to deploy a CW scheme:

- Flood defence consents (varies depending on main river or ordinary watercourse);
- Flood Risk Activity Permit;
- Environmental Permit; and
- Impoundment License.

A recent Environment Agency Regulatory Position Statement (RPS) has eased the environmental permitting requirements for CWs treating effluent from WRCs[8]. The Environment Agency will no longer take enforcement action against operators of CWs designed specifically for nutrient removal who do not hold an environmental permit for the wetland, providing the operator of the wetland complies with the RPS and informs the Environment Agency that they are using the RPS. Compliance with the RPS has the following broad requirements:

- Wetlands should be appropriately designed and maintained, in line with the Natural England wetland framework (Johnson *et al*., 2022);
- Proposals should show that the wetland will protect surface water and groundwater from pollution;

[8] *Environment Agency. (n.d.). Using wetlands to improve treated effluent discharge: RPS 260 - GOV.UK. Retrieved December 30, 2022, from https://www.gov.uk/government/publications/using-wetlands-to-improve-treated-effluent-discharge-rps-260/using-wetlands-to-improve-treated-effluent-discharge-rps-260*

- Proposal should show that the wetland will not have an any adverse effects on conservation sites;
- Wetlands require monthly monitoring of the influent and effluent to the wetland for a suite of water quality parameters;
- Proposal should include a decommissioning plan for the wetland, in line with the Natural England wetland framework (Johnson *et al*., 2022); and
- Wetland operators must keep records showing how they have complied with the RPS.

Due to various design, planning/ permitting and construction requirements, it is estimated that a CW scheme for nutrient removal will take between one to two years to complete. The first P treatment wetlands for Nutrient Neutrality in England, deployed by Herefordshire Council, has recently gone online and took around two years to complete, including six months of monitoring and dealing with issues related to environmental permitting. The RPS will help to reduce some of the time required for permitting a CW treating effluent from a WRC.

Wetlands treating agricultural runoff are likely to be the least complex in terms of both design and planning/ permitting and thus are likely to be the fastest to deliver. CWs treating water abstracted from rivers and streams (online CWs) are likely to the slowest to deliver as they will require assessments and licencing related to the river abstraction, as well as detailed flood risk assessments (FRA) due to their location next to a watercourse.

3.3.3.4 Duration of operation

As stated above (**Section 3.3.3.2**), there are few studies of CWs that have assessed their nutrient removal capacity for more than 10 years. However, there are various studies that have shown that even with minimal intervention, CWs have maintained a high percentage removal efficiency for N and P, e.g., Cooper *et al*., 2020. Continual functioning of the processes that remove N and P from CWs can also be promoted through wetland maintenance.

Thus, it seems likely that with an appropriate management and maintenance plan, CWs will be able to provide nutrient mitigation in perpetuity. The potential risks associated with reductions in the efficacy of a wetland over time can be managed through the design process by taking precautionary estimates of the amount of mitigation a wetland will deliver.

3.3.3.5 Applicability

The Norfolk Broads and Wensum catchments are intensively farmed and thus there are likely to be sources of agricultural runoff that would be suitable for deployment of agricultural wetlands. Agricultural wetlands should ideally be sited in locations of intensive agriculture that are more likely to result in a large nutrient source to the wetland, which in turn will increase the mitigation potential of the wetland. There are also many WRCs in the affected catchment areas what could be potential sites for CWs treating WRC sewage effluent.

AWS have also previously supported CW creation at their Northrepps and Ingoldisthorpe WRCs and have announced an ambitious programme of wetland creation (AWS, 2022). NRT are also a motivated rivers trust with the in-house experience to push forward wetland projects and have previously done so in partnership with AWS. As such, the Broads and Wensum catchments are likely to be ideal areas for the development of CW schemes at WRCs, assuming suitable land can be found around WRC sites.

CWs treating WRC sewage effluent would have the greatest removal rates when treating effluent which is not discharging at low effluent concentrations, e.g., <0.5mg/l.

3.3.3.6 Management and maintenance requirements

Wetlands require periodic maintenance to remove sediment build up, e.g., approximately every five to ten years, and to replace vegetation at timescale appropriate to the lifecycle of the vegetation that the wetland is planted with. Removing sediment and dead vegetation should help to reduce the risk of wetlands switching from a nutrient sink to a nutrient source. 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).

A management and maintenance plan will need to cover silt management, vegetation management, maintenance of hydraulic structures, and bed and bank maintenance. CWs are subject to cycles of uptake and release of nutrient. Monitoring will be required to understand how a maintenance regime can be tailored over time to achieve optimal nutrient removal.

This process of adaptive management should enable a CW to maintain effective nutrient removal in perpetuity (Johnson *et al*., 2022). Compliance with Natural England's wetland framework and the Environment Agency's RPS for CWs will require a mix of visual and water quality monitoring, both of which can be used to inform an adaptive management programme.

3.3.3.7 Additional benefits

As stated above (**Section 3.3.3.1**), the ICW wetland type can deliver the largest number of 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). Other types of wetlands detailed in **Table 3-14** can generally provide a subset of these additional benefits.

3.3.3.8 Wider environmental considerations

Natural England's wetland framework (Johnson *et al*., 2022) provides a detailed description the requirements of a feasibility assessment that will form part of a CW proposal. The feasibility criteria are a range of wider environmental considerations and readers should refer to the wetland framework for full details. The environmental considerations can be summarised under the following main areas:

- Topography;
- Soils (including nutrient content), geology and hydrogeology;
- Hydrology and flood risk;
- Infrastructure; and
- Nature, landscape, and archaeological conservation.

CWs are best suited to an environment where the topography is relatively flat, where there is sufficient clay-rich soil to form a natural liner on-site, where the CW will avoid significant and regular flooding and where existing constraints do not prevent an obstacle to land use change. Some of these wider environmental considerations may be pivotal to the nutrient removal delivered by a wetland. For example, Land *et al*., (2016) reported that wetlands deployed on soils that have high P content were most likely to be sources of P to the environment.

3.3.3.9 Evidence of effectiveness

As detailed above (**Section 3.3.3.2**), 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. It is key that wetlands are designed well, following the principles laid out in the Natural England framework, to provide more confidence of effectiveness for nutrient removal.

3.3.3.10 Deliverability and certainty

The Natural England wetland framework provides a detailed, six stage process that will underpin the delivery of a CW 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 CW 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 CW.
5. Implementation – a plan will be required for how a CW will be deployed and managed.
6. Monitoring and evaluation – a plan will be required detailing the monitoring programme for the CW and how this will be used to evaluate wetland performance and inform adaptive management.

It should be noted that the feasibility assessment may show that a potential wetland site is not deliverable, e.g., if flood risk is too high or topography does not support a wetland draining under gravity. The design, implementation and monitoring and evaluation stages will provide the certainty that a wetland will deliver the estimated amount of nutrient mitigation. The P treatment wetland being deployed at Luston WRC by Herefordshire Council was designed with a precautionary estimate of the amount of P that will be removed by the wetland.

A further 20% of the P removal estimated through the wetland design process is not being used for P mitigation to support development to provide betterment for the River Wye and Lugg SAC. This approach will aid the delivery of the wetland with the required certainty. Dzakpasu *et al*., (2015) provide a good example of how wetland design can impact nutrient removal, reporting reduced TP and SRP removal when the inflow rate to a wetland in Ireland increased above a threshold due to precipitation and ice melt.

This highlights the need to account for factors in wetland design that may impact the efficacy of nutrient removal processes. The wetland framework is designed to assess the certainty of wetland schemes and release a percentage of the predicted removal as credits prior to monitoring. Nutrient credits can only be claimed where the source is controlled, inflow rates are predictable, incoming concentrations are well understood, water levels are controlled, and hydraulic retention time can be defined.

This typically applies to wetlands that have a well-defined source such as those receiving foul water or other wetlands where the best practice was applied, and the wetlands designed to receive water in a controlled way. Where the hydrology is more dynamic and control is more challenging, e.g., farm wetlands, SuDS wetlands, then the nutrient credits cannot be claimed without monitoring.

3.3.3.11 Cost estimate

Costs for wetland schemes can vary significantly but tend to increase broadly in line with the size of the wetland. Some examples of costs from case study projects are provided in **Table 3-15.**

Table 3-15 Example costs for ICW schemes. All these examples are for ICWs treating WRC effluent

Source	Costs
Cooper *et al*.,(2020) and CaBA, (n.d.) – Ingoldisthorpe ICW	Capital costs for a 1.1ha 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) – Frogshall ICW	Capital costs for a 0.3ha 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
Herefordshire Council (2022) – Luston ICW	Reported that construction could cost up to £495,000, with £100,000 allowed in this sum for contingency. This is for a 3ha wetland. This project will have also incurred additional costs for planning, design, planting, management, maintenance, and monitoring. Note that the literature does not typically provide maintenance costs.

An analysis of the cost-effectiveness of CWs for treating agricultural nutrient pollution in Sweden has highlighted that the most cost-effective CWs were sited in locations where they received the highest input of N and P (Djodjic *et al*., 2022). Wetlands sited in areas of low N and P sources had to be significantly larger to deliver a similar amount of N and P removal than those treating high N and P sources, thus increasing the cost per kg of N and P mitigation. This highlights the importance choosing suitable locations for wetland deployment.

3.3.3.12 Mitigation potential

Table 3-16 outlines the cost benefit for building a 1ha CW, assuming a conservative removal rate of 12kg TP/ha/yr and 930kg TN/ha/yr and a conservative cost estimate of £500,000/ha.

Table 3-16 Mitigation potential for CWs

Nutrient	Mitigation (kg/yr)	Dwelling equivalent	Cost estimation (£)	£/kg/yr over 80 years	£/dwelling over 80 years
TP	12	177	£500,000	£41,667	£2,826
TN	930	494	£500,000	£538	£1,013

3.3.3.13 Summary

Key considerations for constructed wetlands are summarised in **Table 3-17**.

Table 3-17 Constructed wetlands key considerations

Key considerations	
Description of solution	CWs are designed to facilitate natural processes that can remove nutrients from the influent water source(s) to a wetland. The types of CW are Horizontal Subsurface Flow, Vertical Subsurface Flow, Hybrid wetlands, and FWS, detailed in **Table 3-14**. The Integrated Constructed Wetland type can deliver the greatest number of additional benefits compared with other wetland types.
Delivery timescale	One to two years (Medium term)
Duration of operation	80+ years, assuming continued maintenance and management (Long term)

Key considerations	
Nutrient removal	TP removal potential: Median removal rate of 46% (Land *et al.*, 2016), however rates of > 90% often reported TN removal potential: Median removal rate of 37% (Land *et al.*, 2016), however rates of > 90% often reported
Applicability	All farm typologies applicable
Management and maintenance	Silt removal, vegetation removal, maintenance of hydraulic structures, and bed and bank maintenance
Additional benefits	Biodiversity improvements, water quantity and quality (additional to nutrients) management, flood hazard management, carbon offsetting, and amenity and landscape aesthetic benefits
Best available evidence	Yes
Wider environmental considerations	The environmental considerations can be summarised under the following main areas: ■ Topography; ■ Soils (including nutrient content), geology and hydrogeology; ■ Hydrology and flood risk; ■ Infrastructure; and ■ Nature, landscape, and archaeological conservation. Natural England's wetland framework (Johnson *et al.*, 2022) provides a detailed description the requirements of a feasibility assessment that will form part of a CW proposal
Evidence of effectiveness	This solution is effective beyond reasonable scientific doubt
Precautionary	Yes
Securable in perpetuity	Yes – management and maintenance plans will be needed to show that the wetland will continue to deliver nutrient removal in perpetuity
Cost estimation	Varies significantly depending on wetland size – costs for a wetland providing a strategic mitigation option are likely to be between £250,000-£750,000

3.3.4 Wet woodlands

3.3.4.1 Description of solution

Wet (floodplain) woodlands occur on soils that are permanently or seasonally wet, either because of flooding, or because of the landforms and soil type. They are found on river floodplains, in peaty hollows and at the margins of fens, bogs and mires (Woodland Trust, 2022). Nutrient removal strategies utilising wet woodlands involve working with either restoring existing floodplain woodland or creating new areas of planting (**Figure 3.6**).

Natural Flood Management (NFM) interventions can also be used to divert water out of the channel and into the floodplain wetland (**Figure 3.7**) to enhance sediment and nutrient deposition. The role of wet woodlands in water quality management is to increase hydraulic roughness, which slows flow velocities and allows sediment and particulate bound pollutants 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 (Cooper *et al.*, 2021).

Figure 3.6 Area of wet woodland created in Salford in 2016. The project led to the attenuation of pollutants by biodegradation (Natural Course, 2017)

Figure 3.7 Traditional NFM structures, such as leaky barriers, can be used to enhance channel-floodplain connectivity to encourage nutrient deposition

Reversion of areas to floodplain woodland could deliver nutrient mitigation of land which is naturally wet. This would not only reduce the impact of runoff from the agricultural land but would also increase the connectivity of the woodland, which would likely achieve greater nutrient reductions than purely the change of land use would predict. Similar gains (for managing diffuse pollution and flood risk) can be expected from extending fingers of riparian woodland into upstream source areas and intermittent flow/ run-off pathways, although few data are available to quantify impacts at a catchment scale (Nisbett *et al*., 2011).

In the UK, the most suitable trees for creating wet woodlands are native species best suited to boggy ground. For the main canopy this includes alder (*Alnus glutinosa*), crack willow (*Salix fragilis*), white willow (*Salix alba*), and downy birch (*Betula pubescens*). Understory species may typically include grey willow (*Salix cinerea*), osier (*Salix viminalis*) and a range of grasses, e.g., purple moor grass (*Molinia caerulea*) (Woodland Trust, 2022). It is uncertain how these species cycle and potentially uptake floodplain nutrients.

3.3.4.2 Nutrient removal

Data on nutrient removal rates in wet woodlands are scarce. Olde Venterink (2006) analysed various floodplain communities in terms of their relative abilities to influence water quality through nutrient retention and denitrification. The results showed that productivity and nutrient uptake were high in reedbeds, intermediate in agricultural grasslands, ponds, and semi-natural grasslands, and very low in woodlands (only understorey).

Furthermore, rehabilitation of agricultural grasslands into ponds or reedbeds is likely to be more beneficial for downstream water quality than into woodlands or semi-natural grasslands. Note that this study refers to woodland, not wet woodland, so comparisons are uncertain and do not necessarily reflect UK soils or climate. This study does not consider more effective sediment trapping in wet woodlands 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 3-18** presents examples of TN removal from wet woodlands (Mayer *et al*., 2005).

Table 3-18 Nitrogen 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

3.3.4.3 Delivery timescale

Wet woodlands do not require extensive infrastructure or investment. They do not require any 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.

3.3.4.4 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.

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3.3.4.5 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.

3.3.4.6 Management and maintenance requirements

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*).

3.3.4.7 Additional benefits

Wet woodland creation, or expansion of existing riparian woodland, has several co-benefits, such as: carbon sequestration, flow regulation and flood risk management, biodiversity conservation, landscape and amenity, air pollution reduction and reduced flood risk (Nisbett *et al*., 2011). One of the major potential benefits of using woodland to improve water quality is the opportunity to supplement farm income by utilising short rotation coppice for biofuel (Mackenzie and McIlwraith, 2013).

3.3.4.8 Wider environmental considerations

Planting wet woodland will not require planning permission or any environmental permits. Once established, wet woodland could potentially support sensitive species and as such may need to be managed carefully 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.

New woodland in parts of the Broads may not be welcomed by the sailing community due to wind shadow. Therefore, consideration on the impact to such stakeholders would need to be considered during the screening of suitable locations. The species of trees proposed in these locations would need to be carefully considered, following the 'right tree, right place, right reason' mantra of the Forestry Commission (2020).

3.3.4.9 Evidence of effectiveness

There is limited scientific evidence to demonstrate with certainty that wet woodlands are effective at mitigating TP. Evidence summarised in **Table 3-13** demonstrates that although wet woodlands can be effective in the removal of TN, removal rates vary considerably (possibly reflecting local conditions).

3.3.4.10 Deliverability and certainty

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.

3.3.4.11 Cost estimate

Bare root stock suitable for tree planting programmes for typical wetland species are in the range of £2-£3 per tree. Typically, bulk orders from suppliers reduce these unit costs to less than £1. Bulk order tree guards are a similar price. For broadleaved trees, planting density is recommended 1,600 to 2,500 trees per hectare respectively (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.

3.3.4.12 Summary

Table 3-19 presents a range of considerations for using wet woodlands for nutrient offsetting.

Table 3-19 Wet woodlands key considerations

Key considerations	
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 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
Delivery timescale	Short-term
Duration of operation	Permanent
Nutrient removal	TP removal potential: Uncertain – likely to be similar to riparian buffers TN removal potential: Uncertain – 12-80%
Applicability	Riparian land holdings (within flood zone 3)
Management and maintenance	Minimal – some coppicing to encourage understory growth; removal on invasive species, e.g., Himalayan balsam
Additional benefits	■ Recreation ■ carbon sequestration ■ Biodiversity conservation ■ Air pollution reduction ■ Flood risk reduction ■ Biofuel
Wider environmental considerations	Once established, wet woodland could support sensitive species and as such may need management. Potential contribution to the spreading of invasive species must be considered New woodland in parts of the Broads may affect the sailing community. The impact on stakeholders must be considered during the screening of suitable locations and tree species
Best available evidence	No – there is doubt over removal rates (lack of research and data)
Evidence of effectiveness	Yes - although there is evidence to indicate effectiveness, the effectiveness can vary considerably under different conditions. As such, there is currently uncertainty regarding nutrient removal rate and monitoring is likely to be required.
Precautionary	Yes
Securable in perpetuity	Yes – land suited to wet woodland is very unlikely to revert to any other land use
Cost estimation	Up to £10,000/ hectare

3.3.5 Willow buffers

3.3.5.1 Description of solution

Short-rotation willow coppice can be used to treat wastewater whilst producing woody biomass for energy purposes. The solutions can be used to treat domestic and industrial wastewater. The solutions comprise vegetation filter strips of short-rotation willow coppice irrigated with wastewater.

The willow is harvested on a two-to-five-year cycle, although most commonly every three 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.

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. When designed properly, all influent wastewater and precipitation are evapotranspired on an annual basis. They provide efficient wastewater treatment and do not require skilled personnel for operation and maintenance.

3.3.5.2 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 phosphate in the soil, suggesting the soil can become saturated over time. In the case of evapotranspirative willow systems, wastewater is constantly applied and stored as an elevated water level.

P accumulation is expected and results in a P rich substrate which can be reused as fertiliser. Initial studies suggest that TP stored in woody biomass is between 31 – 45% of the influent, whereas TP stored in soil, roots and leaves is between 55 – 69% (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 lower than what is applied directly from domestic wastewater. This solution could be used as a form of secondary treatment after domestic PTPs.

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.

3.3.5.3 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.

3.3.5.4 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 to be impermanent features.

3.3.5.5 Applicability

Willow buffers are applicable to the catchments as the rural land which dominates the landscape allows this to be a feasible option. Further detail can be sought to the location of biomass energy plants to better determine how relevant this could be, however initial indications suggest that biomass energy plants are operational within Norfolk.

3.3.5.6 Management and maintenance requirements

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).

3.3.5.7 Additional benefits

There are additional benefits of improved water quality and a gain in biodiversity due to improved habitat.

3.3.5.8 Wider environmental considerations

Transport of biomass to energy production plants should be considered and implications of waste disposal from the energy plant output.

3.3.5.9 Evidence of effectiveness

There is the potential for phosphate saturation within soils and limited evidence to determine the efficacy of such a scheme.

3.3.5.10 Deliverability and certainty

A level of uncertainty is associated with the success of planting and growth. The harvest cycle may lead to variance in uptake. It is likely that a phase of 'trial and error' with respect the successful growth of particular willow species.

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

3.3.5.12 Summary

Table 3-20 presents the key considerations for the use of willow buffers for nutrient reduction and/ or offsetting.

Table 3-20 Willow buffers key considerations

Key considerations	
Description of solution	Short-rotation willow coppice can be used to treat wastewater by comprising vegetation filter strips irrigated with wastewater, whilst producing woody biomass for energy purposes through a coppicing cycle. Timing and irrigation rates must be considered for this method 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
Delivery timescale	Short term
Duration of operation	Impermanent
Nutrient removal	TP removal potential: 70% long-term TN removal potential: 41–60% TN
Applicability	All farm typologies applicable
Management and maintenance	Harvesting every two to three years
Additional benefits	Water quality Biodiversity
Best available evidence	No – monitoring will be required to determine nutrient removal
Wider environmental considerations	Transport of biomass to energy production plants and implications of waste disposal from the energy plant output
Evidence of effectiveness	The solution is effective beyond reasonable scientific doubt. There is the potential for phosphate saturation within soils

Key considerations	
Precautionary	Yes
Securable in perpetuity	Yes
Cost estimation	Capital costs: £2,500/ha, operational costs £200 - £300/ha/yr

3.3.6 Beetle banks

3.3.6.1 Description of solution

A beetle bank is a densely grassed mound approximately 3m to 5m wide and a least 0.4m high constructed on agricultural land to control runoff. They can be planted across long or steep slopes or along natural drainage ways to minimise runoff and soil erosion. Beetle banks present a similar scenario to a riparian buffer (**Section 3.3.2**)

3.3.6.2 Nutrient removal

Calculations have not been undertaken to determine the level of nutrient removal. An assumption is made the 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. Nutrient removal rates are likely to be similar to Riparian Buffer strips.

3.3.6.3 Delivery timescale

Beetle banks do not require extensive infrastructure, planning permission or environmental permits, and can therefore be delivered in the short term.

3.3.6.4 Duration of operation

Once installed and established they are anticipated to be a permanent feature.

3.3.6.5 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.

3.3.6.6 Management and maintenance requirements

Best practice beetle bank construction is designed in order to achieve wider environmental benefits. The earth ridge size, measuring between 3m to 5m wide and at least 0.4m high, should be maintained and once a tussocky grass mixture has been established after the first year of construction, following grass cutting several times in the first year to help grass establish. Annual grass cutting to be undertaken 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.

3.3.6.7 Additional benefits

Beetle banks provide increased biodiversity in the form of nesting and foraging habitats for pollinators, small mammals, some farmland birds, and beneficial insects which feed on crop pests. In order to achieve wider environmental benefits beetle banks do not require, and indeed the Countryside Stewardship grant funding prohibits application of fertilisers, manured and/ or lime and pesticides (excepting 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 or stop soil erosion.

3.3.6.8 Wider environmental considerations

Earthworks and associated machinery fuel and transport requirements will be required. Grass cut from the annual maintenance would need to be removed from the beetle bank area to remove nutrients, which has transport costs in terms of fuel and carbon to be considered.

3.3.6.9 Evidence of effectiveness

Significant monitoring is likely to be required and there is a high level of uncertainty. 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.

3.3.6.10 Deliverability and certainty

There are many site-specific location parameters required to deliver a successful beetle bank scheme, in addition to maintenance (of size structure of the beetle bank and grass cutting activities) and monitoring. 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.

3.3.6.11 Cost estimate

There is government incentive scheme via a Countryside Stewardship Grant which could be used to supplement the cost for this option if the selected site is on current arable or temporary grassland. In order to take advantage of a government grant scheme, declarations are required to confirm the prohibited activities, e.g., fertiliser and pesticide application, have not been applied on the beetle bank and record evidence to demonstrate delivery of the scheme.

3.3.6.12 Summary

Significant monitoring is likely to be required and there is a high level of uncertainty. There is also unlikely to be a high uptake amongst farmers because the location recommendations advise that beetle banks should be positioned in open landscape in larger fields, which is possibly the more productive areas in the centre of fields rather than in the non-productive margins. **Table 3-21** presents the key considerations for the use of beetle banks for nutrient reduction and/ or offsetting.

Table 3-21 Beetle banks key considerations

Key considerations	
Description of solution	A beetle bank is a densely grassed mound approximately 3m to 5m wide and a least 0.4m high constructed on agricultural land to control runoff. They can be planted across slopes or along natural drainage ways to minimise runoff and soil erosion. Beetle banks present a similar scenario to a riparian buffer strip.
Delivery timescale	Short-term
Duration of operation	Permanent
Nutrient removal	Unknown at this stage
Applicability	All farm typologies applicable
Management and maintenance	Annual grass cutting
Additional benefits	Biodiversity net gain potential Soil erosion
Best available evidence	No
Wider environmental considerations	Earthworks and associated machinery fuel and transport. Grass cut during maintenance must be removed from the area to remove nutrients, likely incurring fuel and carbon usage.
Evidence of effectiveness	Not possible to determine at this stage

Key considerations	
Precautionary	Not possible to determine at this stage
Securable in perpetuity	No
Cost estimation	Costs are assumed to be as provided for Riparian buffer strips (**Section 3.3.2**)

3.3.7 Restoration of The Broads

3.3.7.1 Description of solution

The Broads restoration aims to recreate clear water with healthy aquatic plant growth, which provides a habitat for wildlife (Broads Authority, 2022). The present situation is that high nutrient levels encourage algae to grow, which leads to cloudy water in the lakes and rivers. The population of water flea (D*aphnia*), which eats the algae and helps prevent cloudy water conditions developing, is negatively impacted by high concentrations of fish that eat the fleas.

As a nutrient solution, restoring the quality of The Broads watercourses presents an opportunity for a significant amount of phosphorus to be removed. As a large proportion of phosphorus is sediment bound, the restoration of clear water will involve reducing and removing sediment-bound phosphorus from the watercourses, positively impacting nutrient levels across the district.

Key areas for intervention in terms of environmental restoration include:

- Suction dredging – removing nutrient-rich mud from the bottom of rivers and lakes;
- Biomanipulation – removing the fish which eat water fleas, giving the water fleas a chance to graze algae and clear the water; and
- Educating users of the water environment about the importance of reducing nutrient inputs into the watercourses, e.g., eliminating or reducing the direct discharge of grey water from toilets including those installed on boats.

The existing Broads restoration programme is delivered through the Lake Restoration Strategy (Broads Authority, 2008), which has three ecological principles:

- To achieve low nutrients, minimal contaminants and native wildlife;
- To capture and deliver sufficient freshwater flow; and
- To connect a diverse landscape of habitats and create protective buffers along river corridors.

These principles support:

- The development of resilience of habitats and species to adapt to climate change or invasive species;
- Protection and enhancement of biodiversity across the wetland and adjacent habitats; and
- Delivery of ecosystem services.

Solutions identified by the Lake Restoration Strategy Action Plan are outlined. To date, two restoration solutions have been used:

- Sediment removal; and
- Biomanipulation.

These solutions have been used on Barton Broad, which is fed by the River Ant. Although improvements in water quality began in the 1970s through the reduction of sewage point sources, nutrients remained locked in lake bed sediments. From the mid-1990s, suction dredging was employed at Barton Broad to remove this nutrient rich sediment.

Over six years, 305,000m^3 of sediment was removed from the broad and transferred to settlement tanks. Dredging removed 50 tonnes of phosphorus from the sediment in Barton Broad, which is equivalent to ~20 years of phosphorus inputs from the River Ant catchment. Experiments showed a 50% decrease in phosphorus release from the sediment after dredging. Dredging has contributed towards lower phosphorus levels and fewer algae in the water.

Biomanipulation is a standard restoration technique in shallow freshwater lakes suffering from eutrophication. Biomanipulation often involves removing fish species that eat zooplankton, e.g., roach and bream, and stocking with piscivores (carnivorous) fish, such as pike and perch (Søndergaard *et al*., 2007). These measures reduce the number of fish-eating zooplankton. In shallow lakes without aquatic plants, fish that eat zooplankton often predominate, reducing the number of zooplankton that might otherwise suppress algal growth (Broads Authority, undated).

Biomanipulations resulting in increased abundances of daphnia and macrophytes were most likely to achieve stable clear water states and maintain improved water quality (Søndergaard *et al*., 2007). Intense grazing on phytoplankton by Daphnia leads to greater water clarity, which in turn allows macrophytes to become the dominant primary producers, whereas phytoplankton is suppressed (Kasprzak *et al*., 2002). Removing fish from Barton Broad proved difficult as a wide channel must remain open for navigation.

Fish were removed from enclosures, which were separated from the main lake by fish curtains. Biomanipulation resulted in lower fish numbers, and zooplankton began to thrive and significantly reduced the algae population inside the enclosures, creating clear water. However, when fish got into the enclosures, clear water was lost rapidly. Where the water remained clear, submerged plants grew, while there was almost total absence of submerged plants throughout the other areas of the broad.

3.3.7.2 Nutrient removal

Experiments showed a 50% decrease in phosphorus release from sediment following dredging. The work at Barton Broad did not measure nitrogen removal, but it is likely the direct removal of sediment would contribute significantly to reduced nitrogen levels.

3.3.7.3 Delivery timescale

Delivery timescales for effective broadland restoration are tied to the amount of funding available. The Lake Restoration Strategy sets out timescales for sediment removal and biomanipulation based on different investment scenarios from 2008/9 onwards. With annual investment of £500,000 or £250,000, £100,000 or £10,000 for sediment removal, full restoration would take nine, 18, 36 or 60 years. For biomanipulation and the same investment, restoration would take four, seven, 15 or 71 years. These figures are based on projections made in 2008 and may no longer be accurate.

3.3.7.4 Duration of operation

Measurable improvements in water quality through sediment removal and biomanipulation can be achieved in relatively short periods. However, scaling up from trial enclosures across The Broads lakes, and maintaining improved water quality over long timescale would require investment over decades (as described above).

3.3.7.5 Applicability

Sediment removal and biomanipulation are standard techniques for restoring shallow freshwater lakes with high nutrient levels. Both methods have been trialled and proved successful in Barton Broad. Further research is required to establish a framework for scaling up across all broadland lakes.

3.3.7.6 Management and maintenance requirements

Both methods require ongoing maintenance, and long-term research of restored lakes in Denmark and the Netherlands (Søndergaard *et al*., 2007) has shown that lasting benefits can be difficult to achieve. In terms of sediment removal, this will need to be repeated if external loadings from wider catchment areas remain high.

Also, in Barton Broad, surficial phosphorus concentrations quickly returned to pre-dredged levels as disturbed sediment resettled. It may be necessary to repeatedly dredge to remove nutrient rich material. Research has also show that for biomanipulation, long-term effects (> 8–10 years) are less obvious and a return to turbid conditions is often seen unless fish removal is repeated Søndergaard *et al*., 2007).

3.3.7.7 Additional benefits

Additional benefits from this solution include the improvement of water quality which will contribute to achieving Water Framework Directive (WFD) targets and increasing water depth for to allow easier navigation.

3.3.7.8 Wider environmental considerations

Dredging at Barton Broad increased water depth and made navigation easier. However, suspended material in shallow waters, such as Barton Broad, is highly influenced by wind and boats (Broads Authority, undated). This means that dredging and greater ease of navigation could have impacts on suspended sediment levels in the water column.

Wave energy from boating also contributes to bank erosion, loss of reed swamps and increased sediment yield to lakes. Work at Barton Broad also highlighted the importance of reducing scrub encroachment and shading effect at lake margins, where reed swamps grow. An actively growing reed swamp margin provides valuable habitat for invertebrates such as dragonfly larvae and snails, refuges for daphnia, and spawning sites for fish, as well as helping to resist erosion.

3.3.7.9 Evidence of effectiveness

A summary of detailed, long-term studies of biomanipulation in Danish lakes (Søndergaard *et al*., 2007) concluded that long-term effects (>10 years) of lake restoration seem unlikely. Kasprzak *et al*., (2007) suggest the reasons for the relatively short-term effects remain uncertain, but the need to reduce the external loading further, as well as the internal loading capacity are probably important factors. This means that lake-specific interventions, such as biomanipulation and sediment removal, would need to be implemented alongside catchment wide initiatives to tackle diffuse and point sources of nutrient pollution, i.e., external loadings to The Broads.

For example, although dredging in Barton Broad removed 50 tonnes of phosphorus, ongoing high external P loads from diffuse catchment-wide sources would quickly undo any improvements. Søndergaard *et al*., (2007) conclude that insufficient external loading reduction, internal phosphorus loading and absence of stable submerged macrophyte communities to stabilize the clear-water state are the most probable causes for this relapse to earlier conditions.

3.3.7.10 Deliverability and certainty

Both sediment removal and biomanipulation are well established and proven methods of lake restoration, with a high degree of certainty in the medium-term, but would very likely require repeating, in conjunction with catchment wide interventions to avoid a return to the original turbid state. Deliverability is likely to be dependent on funding and the ease of upscaling measures to all broadland lakes. Insufficient funding may limit the applicability of these measures to deliver nutrient neutrality.

3.3.7.11 Cost estimate

Based on previous broad restoration projects cost estimates are:

- Sediment removal: £60,000/ha (best estimate) to £50,000/ha to £100,000/ ha (lower/ upper estimates); and
- Biomanipulation: £6,500/ha (best estimate) to £3,00/ha £15,000/ha (lower/ upper estimates).

However, these figures date from 2008. The Bank of England inflation calculator (2023) suggests costs today would be approximately £90,000/ha (best estimate for) sediment removal, and approximately £10,000 for biomanipulation.

3.3.7.12 Summary

Key considerations for Broadland restoration are summarised in **Table 3-22**.

Table 3-22 Broadland restoration key considerations

Key considerations	
Description of solution	Broadland restoration aims to recreate clear water with healthy aquatic plant growth, which provides a habitat for wildlife. Key areas for intervention in terms of environmental restoration include: ■ Suction dredging – removing nutrient-rich mud from the bottom of rivers and lakes; ■ Biomanipulation – removing the fish which eat water fleas, giving the water fleas a chance to graze algae and clear the water; and ■ Educating boat users about environmentally friendly boating
Delivery timescale	Minimum is likely to be one to two years/ lake
Duration of operation	Up to several decades, depending on funding
Nutrient removal	TP removal potential: Experiments showed 50% decrease in phosphorus release from sediment after dredging TN removal potential: Work at Barton Broad did not measure N removal, but it is likely that the direct removal of sediment would contribute significantly to reduced N levels.
Applicability	Shallow freshwater lakes. Further research is required to establish a framework for scaling up across all Broadland lakes
Management and maintenance	Management required to repeat dredging and biomanipulation to achieve success beyond 10 years, with further repetition over decadal timescales
Additional benefits	Water quality improvements will contribute to achieving WFD targets; water quality increased water depth for navigation
Best available evidence	Yes
Wider environmental considerations	Dredging and greater ease of navigation could impact suspended sediment levels in the water column. Wave energy from boating also contributes to bank erosion, loss of reed swamps and increased sediment yield to lakes. Reducing scrub encroachment and shading effect at lake margins, where reed swamps grow is important for dragonfly larvae, snails, *daphnia*, and fish, as well as helping to resist erosion.

Key considerations	
Evidence of effectiveness	Yes – beyond reasonable scientific doubt
Precautionary	Yes
Securable in perpetuity	Yes – assuming appropriate funding
Cost estimation	Best estimates are £6,500/ha and £60,000/ha for biomanipulation and sediment removal, respectively.

3.3.8 Beaver reintroduction

3.3.8.1 Description of solution

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 3.8**) (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.

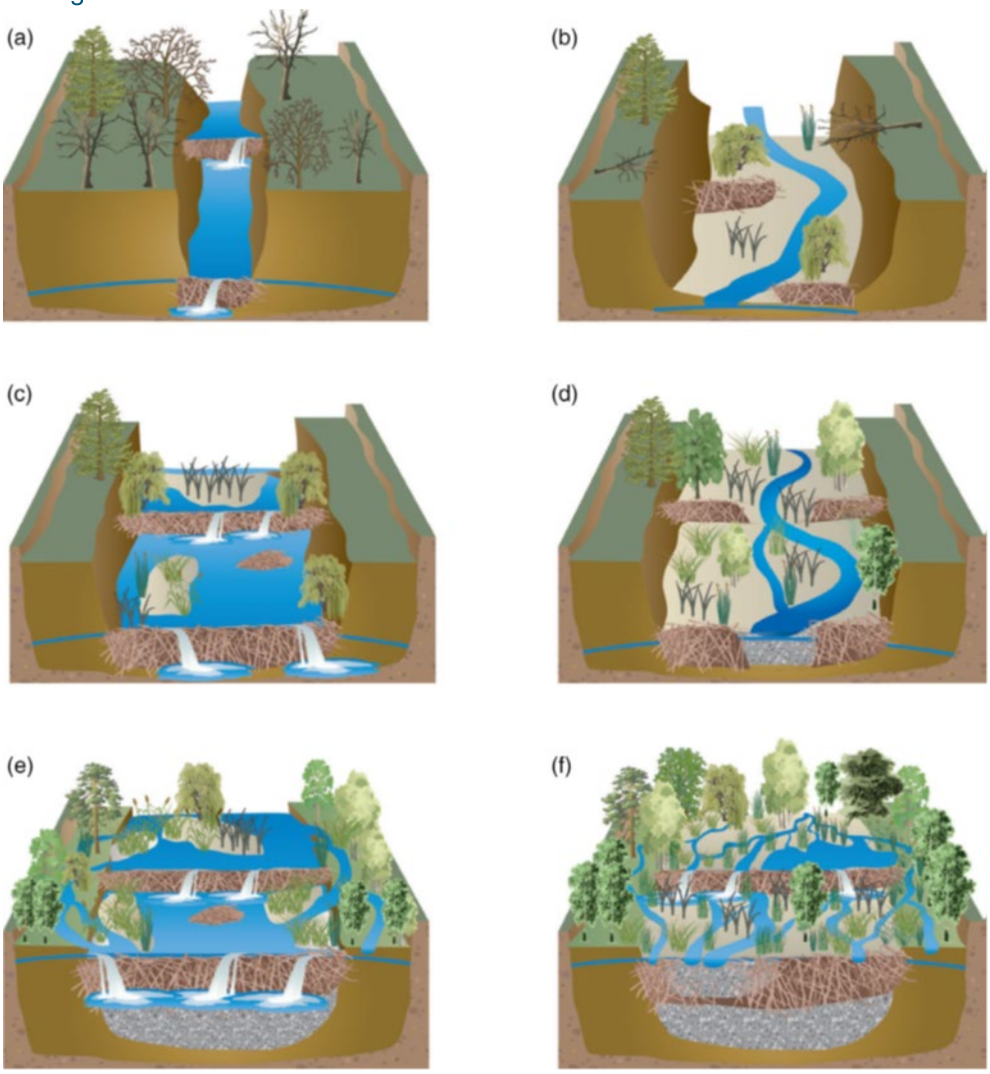

Figure 3.8 Conceptualisation of the geomorphic changes beaver damming can have on incised streams:

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. These ponds are locations of increased sediment deposition, which can in turn result in a set of linked processes that together can remove or retain N and P 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 that remove nutrients as are seen in beaver dam and pond complexes but unlike beaver impacts, they are not supported by a large body of academic research into their water quality impacts (most research focusses on logjams for 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, using the literature on the impacts of beaver damming on nutrient removal as the evidence-base for beaver reintroduction/ logjams as a nutrient mitigation option.

3.3.8.2 Nutrient removal

Recent reviews of the impact of beavers on river systems presents contrasting evidence on the impact of beaver impacts on N and P 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 N and P removal in streams, with more consistent reductions seen for N. 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 N and P removal in rivers as a result 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 3.8d**. Progression to beaver meadows is likely to result in more sustained N and P removal.

Reviews by Geris *et al.*, (2020) and Larsen *et al.*, (2021) also support the potential for beaver impacts to result in N removal but corroborate the findings of Ecke *et al.*, (2017) that suggest P removal is less consistent[9] (**Figure 3.9**). Geris *et al.*, (2020) found more consistency in studies that showed that particulate forms of P were deposited and retained, at least temporarily, in ponds behind beaver dams, but that subsequent release of SRP from sediments results in inconsistent results for reductions in dissolved P concentrations downstream of beaver dams.

[9] Note that most studies focus on the impacts of beaver on SRP removal and there are few studies that assess the impact on total phosphorus removal.

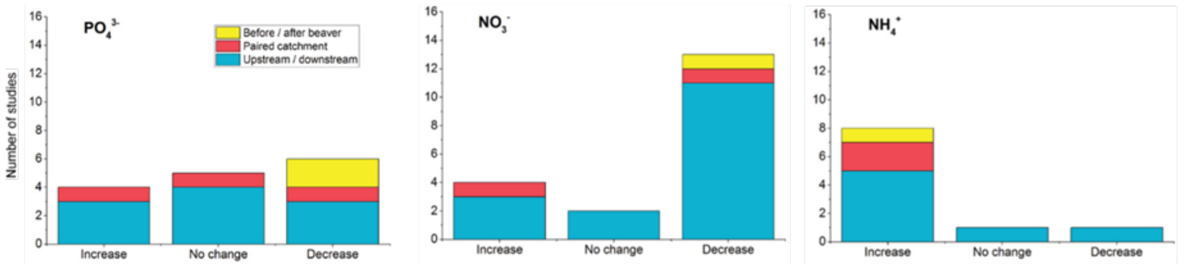

Figure 3.9: Number of studies reporting increases, decreases or no change in SRP (PO_4^{3-}), nitrate (NO_3^-) and ammonia (NH_4^+) concentration as a result of beaver activity.
Each bar shows the number of studies for different study designs that sampled either before/ after beaver introduction, sampled a paired reference catchment or sampled upstream/ downstream of beaver impacts.

The processes that retain P within beaver dam and pond complexes are predominantly related to P deposition of the P fraction 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 (**Figure 3.9**), it is thought that the denitrification rates seen in beaver ponds are sufficient for them to mainly be N sinks.

Most studies of the impacts of beavers on nutrient removal focus on studies from North America. It has been noted that differences in population density and the intensity of agricultural land use in the UK and some European countries means that there are differences between the impacts of beavers in North America and Europe that may limit the relevance of American studies in a European context (Brazier *et al*., 2021). Studies of the impact of beaver on nutrient dynamics in UK rivers have been conducted by Puttock *et al*., (2017, 2018) and Law *et al*., (2016), both of whom reported reductions in N and P concentrations and/ or loads in rivers where beavers have created dam and pond complexes.

Similarly, Čiuldiene *et al*., (2020) and Smith *et al*., (2020) present results from studies in Europe that also show beavers have the potential to cause reductions in N and P downstream of damming activity. **Table 3-23** collates key information from these studies and highlights that each study recorded N and P reductions resulting from beaver activities, with a wide range of reductions recorded across the different study sites. Puttock *et al*., (2018) studied the accumulation of sediments and N in a complex of beaver dams and ponds in Devon and reported that a total of 910 kg TN accumulated in 13 ponds that were built over period of five years.

Table 3-23 Results from studies of beaver impacts on nitrogen and 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% PO_4 reduction	Yes

Study	Location	Study length	Upstream to downstream Nutrient concentration reductions		Accounted for seasonality?
			N	P	
Law *et al*., (2016)	Blairgowrie, Scotland	1 year	32% NO_3 reduction	25% PO_4 reduction	Yes
Smith *et al*., (2020)	Brandenburg, Germany	1 year	3.8% NO_3 reduction	46% PO_4 reduction and 13% TP reduction	Yes
Čiuldiene *et al*., (2020)	Northwest Lithuania	< 1 year	60% TN reduction	20% TP reduction	No

Previous research has shown that beaver impacts on streams can result in the removal of N and P, including in a UK context, but that for P, and to a lesser extent N, 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.

3.3.8.3 Delivery timescale

Puttock *et al*., (2017) reported that following the introduction of a breeding pair of beavers to a stream in Devon (2010), there was a four-year period of construction during which 13 dams were built. Once constructed, the beavers maintained the dams, i.e., there was no new dam construction, just repair activities. Furthermore, the flooded area behind the dams reached its maximum extent within five years of the beaver's release.

As N and P removal has been suggested to increase with pond area (Puttock *et al*., 2017), the timescales reported for the beaver reintroduction programme in Devon suggests that it may take four to five years for a beaver reintroduction scheme to reach peak nutrient removal efficiency. It should also be noted that a beaver scheme for nutrient mitigation will also need to allow time for finding a suitable release site, which is likely to take at least six-months and potentially longer.

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.

3.3.8.4 Duration of operation

It is difficult to estimate the period over which beavers may remain in situ and therefore how long a beaver reintroduction scheme may continue to provide nutrient mitigation for, assuming it is effective for N and P removal to begin with (noting issues detailed above with some studies showing beaver activities can be sources for N and P). However, if beavers change a river environment sufficiently to result in the establishment of a beaver meadow, the impact may be self-sustaining. There is a lot of uncertainty over how long a beaver reintroduction scheme may continue to provide nutrient mitigation for.

Engineered logjams can be designed to increase the probability that they will remain in place in the long-term, assuming the location and design of a logjam accounts for energy of stream and its capacity to wash the dam away. Being able to maintain logjams also increases the chance of long-term operation and nutrient removal. The potential for dam blowout and large-scale sediment release and/ or the change from a sink to a source of nutrient are the key issues that may impact the long-term operation of a logjam scheme.

3.3.8.5 Applicability

Beavers previously had a range that spanned much of Europe and would be suitable to release in Norfolk. Indeed, the Norfolk Rivers Trust have a beaver reintroduction scheme in North Norfolk[10]. It is important to recognise that beavers will not dam rivers where they have deep enough water to remain safe. In larger, deeper rivers beaver will burrow into banks and not build dams, removing the key activity that increases nutrient removal processes.

As such, beaver reintroduction schemes for N and P removal are best suited to small, low order streams which they are more likely to dam. Beaver reintroduction and logjam schemes are best applied to low gradient streams as these will help to minimise flow energy during high flow events, and therefore reduce the risk of dam blowouts and associated sediment and nutrient releases.

3.3.8.6 Management and maintenance requirements

For beaver reintroduction schemes, the scheme should require little maintenance of management and there are limited possible interventions if beavers migrate around a catchment or die and are not replaced by offspring. Beavers are often released to enclosures initially, to facilitate their establishment in a new environment, but for conservation purposes beaver should be able to expand their range and are unlikely to be kept in enclosures for the long-term.

Logjams provide a better ability for management and maintenance. Most management and maintenance will be adaptive and in response to dam failures. Management plans for logjams should include a monitoring programme using visual inspections to check the integrity of dams and trigger remedial work to fix dams and maintain ponding if dams start to fail. Inspections following periods of medium and/ or high flow events will be most effective to target maintenance efforts.

Water quality monitoring could also be used as part of an adaptive management regime that could trigger remedial work such as sediment removal should nutrient removal efficiencies be seen to reduce. Monitoring of water quality and flow may also be able to show if a scheme is performing better than expected, thus releasing additional mitigation.

3.3.8.7 Additional benefits

Beaver reintroduction schemes may have a variety of additional benefits (Brazier *et al*., 2021), including:

- NFM – dams increase in-channel water storage, hydraulic roughness and lateral connectivity with floodplains resulting in the attenuation of flood peaks;
- Biodiversity improvements – beaver dam and pond complexes increase habitat diversity, which has in turn been linked to increased plant and invertebrate biodiversity, and better habitats for fish; and
- Amenity value – beaver reintroduction can result in an increase in wildlife tourism.

Similar NFM and biodiversity benefits are likely to be delivered by a well-designed logjam scheme, however these schemes are less likely to have the same level of amenity benefit as people tend to be attracted to macro-fauna such as beavers compared with increases in plant, invertebrate and fish abundance.

[10] *https://norfolkriverstrust.org/beavers/, accessed on 23/01/2023.*

3.3.8.8 Wider environmental considerations

Beaver reintroduction and engineered logjam schemes will result in localised increases in flood risk due to increased floodplain connectivity in the area of beaver dams/ logjams. Increased water table height may also have an impact on the ability to cultivate riparian areas that are not inundated with water. There will be a need for a FRA to support a beaver reintroduction/ logjam scheme.

Engagement with landowners and land managers regarding the change to local hydrology will also be required. Owing to the issues that can be caused by loss of riparian land and from beavers eating crops and forestry trees, there can be issues with the perception of beavers in rural environments (Brazier *et al*., 2021). Logjams scheme do not have the same issue with risks of crop and tree loss but would have similar impacts on the loss of riparian land due to more permanent rewetting.

Both beaver and logjam schemes will impact the hydrology, geomorphology, water quality and ecology of a stream. Although these impacts are likely to be positive, if the scheme is planned for deployment on WFD waterbody, a WFD Assessment will be required. Depending on the proximity to designated Habitats Sites, a HRA may also be needed.

Installation of logjams may need construction work and the use of machinery within the boundary of a river channel. If a logjam scheme is planned for a main river, permission may be required from the Environment Agency to complete the works. In summary, 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.

3.3.8.9 Evidence of effectiveness

The evidence for demonstrating the effectiveness of beaver reintroduction/ logjam schemes is based on a literature review of research that has assessed the impacts of beavers on water quality in rivers. The evidence is mixed and more consistent for removal of N by beaver activity when compared to the evidence of P removal. However, studies in the UK support the potential for beaver activities to reduce both N and P concentrations and loads in rivers (summarised in **Figure 3.9**).

Based on the range of N and P removal efficiencies reported in the literature, estimates of the efficacy of beaver reintroduction/ logjam schemes will need to be suitably precautionary if a percentage efficiency is set prior to the delivery of a scheme.

3.3.8.10 Deliverability and certainty

There are likely to be barriers to the deliverability of beaver reintroduction schemes. Finding suitable sites and managing the process of reintroduction is likely to be quite resource intensive, requiring highly specialised ecology services. It is noted, however, that the Norfolk Rivers Trust have already done a beaver reintroduction scheme in the county and may be able to support other schemes.

Logjam schemes are likely to be more deliverable, as once suitable sites are found the design process for a scheme is simpler, without the added complexity of releasing animals into the wild. Certainty of nutrient removal is hard to secure with a beaver reintroduction scheme. Releasing the beavers into enclosures will help to reduce the risk they move to other areas of catchment, but there is always a risk that the beavers do

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not survive the reintroduction process and how effective they will be at damming a river cannot be predicted in advance.

Certainty of nutrient removal is easier to achieve with logjam schemes. A correctly designed logjam scheme that promotes ponding behind logjams should promote the processes that remove nutrients in beaver dam and pond complexes. For both beaver and logjam schemes, certainty needs to be considered within the bounds of the evidence-base for the impact of beavers on nutrient removal, especially noting the issues with P removal detailed above.

3.3.8.11 Cost estimate

Information on the cost for beaver reintroduction schemes is not that readily available, likely in large part due to a relatively small number of these projects in the UK. One of the flagship beaver reintroduction schemes in England, the Devon Beaver Project, has estimated cost of reintroduction as up to £700,000[11]. It is noted that the Devon Beaver Project is a large research project and costs for a nutrient mitigation scheme involving beaver release are likely to be lower.

More information is available for costs associated with the deployment of engineered logjams. **Table 3-24** shows that these schemes have relatively low deployment costs, however they do not account for the potential land costs associated with buying land that may be inundated by a scheme, so are likely to be underestimates. Owing to the uncertainties associated with the amount of N and P mitigation a logjam scheme would deliver, it is not possible to estimate cost mitigation for 1kg of N or P.

Table 3-24 Example costs for the deployment of engineered logjam schemes

Reference	Project	Costs
Mott (2006)	Tittesworth, Peak District National Park – installation of logjams along 700m length of small tributary	Approx. £25,000
Mott (2006)	River Trent at Wolseley Bridge, Staffordshire – input of mature beech tree to river as part of bank reprofiling	Small part of wider £21,000 scheme
Keating *et al*., (2015)	Not project specific – Environment Agency cost estimates for installation of logjams	£821 per 100m for four logjam deflectors per 100m reach. Costs do not include site surveys and assessments

3.3.8.12 Summary

Key considerations for beaver reintroduction are summarised in **Table 3-25.**

Table 3-25 Summary beaver reintroduction key considerations

Key considerations	
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

[11] https://www.rewildingbritain.org.uk/blog/englands-only-wild-beavers-need-our-help, *accessed on 23/01/2023.*

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Key considerations	
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 TN removal potential: Variable, with UK and European studies reporting P removal efficiencies between 4%-60%. Studies report a mix of N fractions, not always providing data on TN
Applicability	NA
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

3.4 Runoff management solutions

3.4.1 Taking land out of agricultural use

3.4.1.1 Description of solution

Taking land out of agricultural use involves replacing high nutrient exporting agricultural land with low exporting land such as semi-natural grassland, woodland, or energy crops, e.g., willow or *Miscanthus*. Soil erosion which can lead to nutrient mobilisation is also likely to decrease with time as soil is stabilised by more continuous vegetation cover. Reversion of previously agricultural land to a more natural state will eventually reduce P and N leaching to natural background rates.

In addition, measures can be imposed which actively uptake nutrients and limit the impact of legacy phosphates. One method is to propose uptake by vegetation, which will also reduce the risk of soil erosion. Vegetation may include using the site for woodland, energy crops or cover crops.

Other methods include blocking drains on drained land (or alternatively installing a field-wetland). Sharpley (2003) and Dodd *et al*., (2014) suggested that ploughing to reduce nutrient stratification and redistribute and dilute enriched topsoil can decrease concentrations by half leading to reduced surface runoff losses. Monitoring may also be able to demonstrate that nutrient loading is returning to background levels.

Woodland planting is one mechanism of accelerating the transition to background nutrient concentrations. Natural England advice suggests 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 per hectare.

Maintenance of woodland is easy to verify and well established. Woodland planting may be secured without land purchase. Native tree species would also be the preferred choice, although it may be necessary to consider climate resilience and the use of non-native species to account for long-term climate change effects. Nutrient reductions would be calculated using the Norfolk Nutrient Budget Calculator (Royal HaskoningDHV, 2022) and assuming a runoff coefficient of 0.02kg TP/ha/yr and 3kg TN/ha/yr.

Energy crops such as *Miscanthus* (silvergrass/ elephant grass) are generally considered to have a higher soluble nutrient uptake than woodland and should be considered. *Miscanthus* is also ideally suited to marginal land that provide little value for generating income, e.g., it can be grown for biofuel. There is also the possibility to harvest the *Miscanthus* after five to 10 years.

However, this would have a lower biodiversity benefit and would be unable to retrieve as much income through potential monetised biodiversity schemes as more natural planting would.

3.4.1.2 Nutrient removal

The nutrient reduction calculations assume that farms will be operating according to best practice and not polluting. This is to ensure that potential pollution from agriculture is not traded to another sector, which would then discharge this load back in the catchment in the form of new housing. This will also ensure that mitigation schemes do not compromise the ability to deliver long term WFD targets.

The Norfolk Nutrient Budget Calculator (Royal HaskoningDHV, 2022) can be used to determine the nutrient mitigation achieved. Alternatively, Defra's Farmscoper Tool can be used to calculate nutrient reductions and the associated cost. The Tool was developed by ADAS (Agricultural Development and Advisory Service) for Department for Environment Food and Rural Affairs (DEFRA) to enable the assessment of the cost and effectiveness of one or more diffuse pollution mitigation methods at the farm scale.

The tool estimates baseline emissions of a suite of different pollutants and predicts the mitigation potential against these pollutants and quantifies potential benefits for biodiversity. The tool can be set up to model most basic farm types by changing livestock numbers, crop areas, fertiliser rates, soil type and climate. In this way the effects of taking land out of production or changing land use can be assessed. The typical catchment characteristics for the River Wensum, Yare and Bure sub-catchments are presented in **Table 3-26.**

Table 3-26 Typical rainfall and drainage characteristics of the Wensum, Yare and Bure catchments derived from the Norfolk Nutrient Budget Calculator (Royal HaskoningDHV, 2022)

Sub-catchment	Rainfall (mm/yr)	Drainage type	Nitrate Vulnerable Zone (NVZ)?
Wensum	700-750	Slightly Impeded	Yes
Yare	650-675	Slightly Impeded	Yes
Bure	675-700	Freely draining	Yes

Assuming the catchment characteristics outlined in **Table 3-26**, the typical agricultural nutrient runoff rates for each catchment are presented in **Table 3-27**.

Table 3-27 Typical agricultural nutrient runoff rates in the Wensum, Yare and Bure sub-catchments

Land Use	Phosphorus runoff coefficient (Kg TP/ha/yr)			Nitrogen runoff coefficient (Kg TN/ha/yr)		
	Wensum	Yare	Bure	Wensum	Yare	Bure
Dairy	0.41	0.27	0.14	17	23	36
Lowland grazing	0.22	0.15	0.10	14	11	18
Mixed livestock	0.60	0.29	0.09	24	21	35
Poultry	0.70	0.39	0.16	178	159	229
Pig	0.72	0.35	0.08	73	65	90
Horticulture	0.66	0.31	0.05	19	1	23
Cereals	0.73	0.34	0.06	24	19	26
General arable	0.64	0.29	0.05	22	17	28

The east of England is dominated by cereal farms, which account for 51% of the total farmed area and general cropping farms which account for 33% of the farmed area (DEFRA, 2021). The River Wensum sub-catchment results have the greatest phosphorus runoff coefficients within the Norfolk nutrient neutrality catchment as a result of the higher annual rainfall. A cereal farm within the Wensum catchment has a runoff coefficient of 0.73 kg TP/ha/yr compared to a comparable farm in the Bure catchment with a runoff coefficient of 0.05 kg TP/ha/yr.

N runoff rates are greatest in the Bure sub-catchment due to the freely draining nature of the soil. Cereal farms within this sub-catchment have a runoff rate of 26 kg TN/ha/yr. The difference between the agricultural land runoff rate (typically 0.06 – 0.73 kg TP/ha/yr and 19 – 26 kg TN/ha/yr) and the future runoff rate (which would be 0.02kg TP/ha/yr and 3kg TN/ha/yr) is generally small which results in a large amount of land required to offset developments. However, cereal farms and general arable farms typically have some of the highest nutrient runoff rates for both phosphorus and N.

There are some conditions where nutrient loading rates from agricultural land are higher, and the land take is not as significant, e.g., pig and poultry farming. However, there is likely to be limited availability of taking these lands out of use within the catchment due to a relative lack of abundance within the areas impacted by nutrient neutrality.

Due to the significant land take that would be required to deliver this solution as a long-term measure, it is unlikely that at a strategic scale this would provide anything more than a short-term solution to bridge the gap until more efficient and effective longer-term solutions can be developed. There is the potential for land to be leased on short term solutions without the need for purchase. Management agreements are likely to be needed to ensure the land remains out of agricultural use.

3.4.1.3 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.

3.4.1.4 Duration of operation

This solution could potentially be implemented over a variety of timescales. It could be used as a temporary measure, with land taken out of production but otherwise unchanged. Alternatively, it could also be used as a longer-term (impermanent) reversion from agriculture, or as a permanent solution that could be maintained in perpetuity if the land is used for non-agricultural purposes.

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3.4.1.5 Applicability

Unlikely to be applicable to indoor pig or poultry farms, but applicable to most other farm types.

3.4.1.6 Management and maintenance requirements

Miscanthus takes one to two years to establish, during which time no additional fertiliser is required. Once established, *Miscanthus* needs less fertiliser than most other farming practices. Harvesting needs to be completed every two to four years. Energy Crop Schemes are available.

3.4.1.7 Additional benefits

Energy crops can be used for coppice and provide fuel for renewable energy and therefore carbon offsetting. Schemes will provide carbon sequestration and will qualify for biodiversity net gain as well as nutrient neutrality credits.

3.4.1.8 Wider environmental considerations

Implementation of this option is unlikely to be significantly constrained by wider environmental factors. Should the solution be used to provide a significant amount of long-term mitigation or used to provide a substantial amount of short-term mitigation then this could impact on regional food production in Norfolk. Removing agricultural land which will achieve minimal nutrient reductions, e.g., some agricultural land in the Bure catchment, should be considered against the impact of food supply and maintaining the agricultural characteristic of the County.

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, i.e., it is used as a long-term solution. This could be further exacerbated when coupled with the impact of mandatory biodiversity net gain which is expected to be adopted in November 2023 through the Environment Bill 2020. Biodiversity net gain credits will be available in a similar way to nutrient credits. As such, land with high biodiversity credit potential will become sought after by developers to provide offsite BNG, increasing its market value.

3.4.1.9 Evidence of effectiveness

Repeated applications of fertilizers and animal waste results in the build-up of P in soil (commonly known as ‘legacy P’). N build up in soil can still occur, but N is typically more mobile and does not present such a long-term problem. Long-term field experiments have shown that a large proportion (> 70%) of the surplus P added via fertilisers remains in the soil, some in forms not readily available to crops (Pavinto *et al*., 2020).

Taking land out of agricultural use has an immediate impact on its nutrient output, i.e., a reduction in fertiliser application will lead to reduced concentrations of both P and N in the surface water runoff following rainfall events. However, some legacy nutrients will be retained in the soil and will be transported to watercourses via runoff at a later date. Legacy nutrients can increase the assumed future runoff coefficient, and therefore the desired nutrient removal may not be achieved.

The time taken for soils to reduce to agronomic targets and background concentrations varies depending on soil types and nutrient concentrations (Dodd *et al*., 2012). A study by McCollum (1991) indicated that soil concentration 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. Loamy soils in arable production are typical of the characteristics seen in large parts of the Bure catchment.

Gatiboni *et al.,* (2021) found that the median time to reach agronomic targets was <1 year but as high as 11 years. However, the time taken to reach environmental targets purely by cessation of phosphorus fertiliser would be 26 – 55 years. This is consistent with Dodd *et al.,* (2012) which estimated that following cessation of P application to grassland, the time taken for surface runoff to reduce to acceptable levels is 23 – 44

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years. However, legacy nutrients can be mitigated by allowing some biomass to continue to grow on the land (refer to **Section 3.4.3**)

3.4.1.10 Deliverability and 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 with regards to their effectiveness.

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. Norfolk, as an area, is a major food producer for the UK and this may impact the actual uptake of this solution by landowners. As a result, financial incentives will need to be attractive and agreements likely to be temporary or impermanent.

3.4.1.11 Cost estimate

There are two main types of agricultural tenancies:

- Full agricultural tenancies, which are subject to the Agricultural Holdings Act 1986.
- Farm business tenancies, which are subject to the Agricultural Tenancies Act 1995.

Most tenancy agreements made after 1 September 1995 are subject to the Agricultural Tenancies Act 1995 and are commonly known as Farm Business Tenancies.

Table 3-28 presents the rental rates for farming types across England for 2019 and 2020 (the latest data available at the time of writing). Note that there is a degree of fluctuation in prices between the different years.

Table 3-28 FBT rental rates (£/ ha) for farming types in England (Source: Defra, 2022)

Farm Type	Rental price (£/ ha)	
	2019	2020
Cereal	263	261
General cropping	298	367
Dairy	271	283
Grazing livestock	79	81
Lowland grazing	128	166
All Farms	222	239

The average rental price in the East of England during 2019 is £231/ha. The average removal potential is approximately 0.5kg/ha/yr. It is expected that a short-term price inflation of agricultural land will increase the rental price above the baseline figures presented in **Table 3-29.**

Table 3-29 FBT rental rates (£/ha) for FBT farms in the East of England (Source: Defra, 2021)

Farm Type	Rental price (£/ ha)	
	2019	2020
East of England FBT	281	314
England	222	239

The East of England average value of all arable land types is estimated to be £24,500/ha in 2022 (Savills, 2022). Farmscoper Tool was used to identify the likely cost from loss of production. A cost of £506/ha is assumed which is derived from a loss of production (£889) offset against the saving from no crop/ field management (£383).

Agricultural land may qualify for agricultural tax relief, and it is likely that taking land out of agricultural production long term could have a tax implication which may cause this to be economically unviable and a barrier to delivery. Some solutions may cease to be eligible for agricultural relief and may qualify for financial benefits via the CSS. Other capital costs associated with woodland planting, grass conversion and planting cover crops may result in a short-term negative cash flow. Maintenance costs, e.g., harvesting, cutting, are expected to be minimal and offset by sales of products.

3.4.1.12 Mitigation potential

Table 3-30 and **Table 3-31** present an example of the mitigation achieved and equivalent housing for taking land out of agricultural use. This assuming that land is taken out of a cereal use and put into woodland/ semi-natural grassland use. The housing equivalent assumes a phosphorus permit limit of 1 mg/l and a N limit of 25 mg/l. The cost estimate assumes that land is purchased and also accounts for loss of production. No monitoring costs are assumed as this may only be necessary for some applications.

The number of houses mitigated/ cost of mitigation is provided for both P and N. The cost estimate indicates that a solution provides more N than P. As such, the more expensive P cost estimate is the most relevant costs estimation to review regarding this solution because a development has to mitigate both P and N. A solution that achieves P mitigation will likely deliver an excess of N mitigation and therefore not be considered to achieve nutrient neutrality balance.

Table 3-30 Phosphorus mitigation and cost estimation for taking various agricultural land out of use

Sub-catchment	Area (ha)	Mitigation (kg TP/yr)	Dwelling equivalent	Cost estimation (£)	£/kg TP/yr over 80 years	£/dwelling over 80 years
Wensum	1	0.71	10	25,006	35,220	2,389
	5	3.6	52	125,030		
	10	7.1	105	250,060		
	25	17.8	262	625,150		
Yare	1	0.3	5	25,006	78,144	5,301
	5	1.6	24	125,030		
	10	3.2	47	250,060		
	25	8	118	625,150		
Bure	1	0.04	1	25,006	625,150	42,407
	5	0.2	3	125,030		
	10	0.4	6	250,060		
	25	1	15	625,150		

Table 3-31 Nitrogen mitigation and cost estimation for taking various agricultural land out of use

Sub-catchment	Area (ha)	Mitigation (kg TN/yr)	Dwelling equivalent	Cost estimation (£)	£/kg TN/yr over 80 years	£/dwelling over 80 years
Wensum	1	20.8	11	25,006	1,205	2,272
	5	103.8	55	125,030		
	10	207.5	110	250,060		
	25	518.8	275	625,150		
Yare	1	16.2	9	25,006	1,541	2,903
	5	81.2	43	125,030		
	10	162.3	86	250,060		
	25	405.8	215	625,150		
Bure	1	22.8	12	25,006	1,099	2,071
	5	113.8	60	125,030		
	10	227.5	121	250,060		
	25	568.8	302	625,150		

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Table 3-30 highlights the difference the location can have on the amount of P mitigation that can be achieved by taking agricultural land out of use. Approximately 17 times more mitigation can be achieved in the Wensum sub-catchment compared to the Bure sub-catchment, which leads to a marked difference in the cost.

Table 3-31 indicates that N removal rates are consistent across the sub-catchments and typically have a lower £/dwelling cost compared to P mitigation. In order to be 'nutrient neutral,' a development must satisfy both the excess P and N. Therefore, the costs to achieve P neutrality is more representative of the likely costs incurred from a development to achieve nutrient neutrality.

3.4.1.13 Summary

Table 3-32 presents a range of considerations when taking land out of agricultural use for nutrient offsetting.

Table 3-32 Taking land out of agricultural use key considerations

Key considerations	
Description of solution	Taking land out of agricultural use involves replacing high nutrient exporting agricultural land with low exporting land such as semi-natural grassland, woodland, or energy crops, e.g., willow or *Miscanthus*. Reversion of previously agricultural land to a more natural state will eventually reduce P and N leaching to natural background rates. In addition, measures, such as uptake by vegetation, can be imposed which actively uptake nutrients and limit the impact of legacy phosphates.
Delivery timescale	Short-term
Duration of operation	Temporary, impermanent, permanent
Nutrient removal	TP removal potential: Average mitigation removal rate of 0.04 – 0.71 kg TP/ha/yr TN removal potential: Average mitigation removal rate of 16 – 23 kg TN/ha/yr
Applicability	Unlikely to be applicable to indoor pig or poultry farms, but applicable to other farm types
Management and maintenance	For *Miscanthus* growing – no fertiliser needs to be added until it is established and less needs to be applied than most farming practices Harvesting needs to be completed every two to four years Energy Crop Schemes are available
Additional benefits	■ Energy crops can be used for coppice ■ Biodiversity net gain potential
Best available evidence	Yes – Although some doubt may remain over legacy phosphates and may require further research or monitoring to gain a better understanding
Wider environmental considerations	Significant long-term or substantial short-term use of this solution could impact regional food production in Norfolk. 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.
Evidence of effectiveness	Yes – beyond reasonable scientific doubt
Precautionary	Yes
Securable in perpetuity	Yes – However, it is unlikely this solution would be used for long term solutions Plantations may need to prove they can be in place for the lifetime of the development or offer a fallback option with an equivalent nutrient removal
Cost estimation	The average rental price in the East of England for farms is £314/ha The average purchase price in the East of England for farms is £24,500/ha The cost from the loss of production is estimated to be £506/ha The cost estimate per dwelling is approximately £2,389, £5,301 and £42,407 for the Wensum, Yare ad Bure catchments, respectively

3.4.2 Conversion of agricultural land to solar farms

3.4.2.1 Description of solution

A solar farm is a renewable energy installation with a large number of solar panels which are set up in order to generate electricity. Solar farm installation can reduce P input by:

- a reduction in number of grazing livestock and therefore P manure in livestock output by either reducing the density of grazing animal or removal of livestock from agricultural land; and
- removal of agricultural land usage and therefore removal of nutrient inputs from fertiliser or waste applied to land from agricultural benefit to enhance crop growth.

A solar farm installation can also be used for provision of nutrient credits. The lifetime of such a scheme can be estimated as approximately 40 years.

Planning developments ‘autonomous measure’ position

Nutrient neutrality principles may be met with schemes such as conversion of agricultural land to solar farms. However, to achieve compliance with the Habitats Regulations 2017, any proposed development identified at the planning stage that may have an adverse effect on the integrity of a site’s habitat, e.g., the proposed mitigation is not specifically for the purpose of nutrient mitigation, may not be agreed that ‘in principle’ as a mitigation measure complaint with the Habitats Regulations 2017.

The ’Dutch N’ case made the following distinctions:

- an ‘autonomous measure’ is such that unless solar farms are installed for the singular reason of nutrient mitigation, i.e., those which are likely to come forward regardless of any proposed development which might have adverse effects on the integrity of a site’s habitats.
- ‘bespoke’ mitigation measures, developed specifically to mitigate impacts of a proposed development, i.e., a scheme which are being delivered in combination and through a related proposed development, e.g., a residential development, to mitigate the nutrients from the primary proposed development.

Natural England may be able to comment upon a scheme and the supporting justification and/ or evidence. However, the position is that if the primary purpose of scheme is for power generation for example, with the unintended consequence of providing mitigation, and the primary intent is not to provide nutrient mitigation, the scheme may not be considered as acceptable nutrient mitigation.

3.4.2.2 Nutrient removal

P is removed or reduced according to the cessation of usage of land as agricultural land or reduction correlated with reduction of grazing animal density. The Norfolk Nutrient Budget Calculator (Royal HaskoningDHV, 2022) has been used to estimate the effectiveness of this solution.

These calculations would need to be refined using Farmscoper Tool and site-specific information input related to fertiliser type and/ or manure application. The initial calculations undertaken provide the following ranges:

- Total P Average mitigation removal rate of 0.04 – 0.71 kg TP/ha/yr; and
- Total N removal potential Average mitigation removal rate of 16.23 – 22.75 kg TN/ha/yr.

3.4.2.3 Delivery timescale

An estimated timeframe of less than five years is required to gain approval and install a solar farm. Solar farms are a less intensive land use than typical agricultural operations and produce significantly fewer nutrients. Therefore, solar farms have a lower environmental and nutrient impact, meaning existing or imminent solar farms could be used for nutrient mitigation in the short-term.

3.4.2.4 Duration of operation

A solar farm is estimated to operate for approximately 40 years, and the change of land use is therefore considered to be permanent following the definitions set out in **Table 3-2**. However, it is important to note that operation and maintenance costs could potentially exceed the cost for renewal of the solar farm after 40 years. As such, the solution may not reach the threshold to be classified as 'securable in perpetuity' (80-125 years) unless a longer-term agreement between the operator and landowner is in place, e.g., to replace photovoltaic cells with new infrastructure at the end of their economic lifespan.

3.4.2.5 Applicability

Solar farm installation is applicable to areas of Norfolk where there is available agricultural land which can be used, available connections to the National Grid and planning applications have been received for such schemes within Norfolk.

Some key considerations when proposing a solar farm installation in Norfolk, some areas of which are heavily designated or protected, primarily include visual impacts on the landscape and/ or character of the area, and heritage assets. A farm would need to be located and designed so it does not have an unacceptable impact on these receptors.

3.4.2.6 Management and maintenance requirements

Once land is no longer in agricultural use, further land management and maintenance is not anticipated. Should land be retained as both agricultural land and solar farm usage with reduced livestock density, it will be necessary to monitor livestock numbers. It may be necessary to determine a threshold number for specific grazing animal species and monitor in order to keep the number below the threshold.

If the land is not kept in agricultural use, the occasional cutting of vegetation will be necessary to avoid shading of the solar panels. The solar arrays will also require maintenance to ensure that they remain operational and are working efficiency.

3.4.2.7 Additional benefits

Renewable energy, e.g., solar panels, can be provided in addition to nutrient mitigation, which has a small carbon footprint than energy generated by such as fossil fuels. Therefore, solar farms provide an affordable and feasible nutrient mitigation option as they are simple to install.

Solar farms may also offer opportunities for biodiversity net gain by changing land use, e.g., from a grass monocrop, and presenting an opportunity to create diverse plant assemblages that would not ordinarily be present or survive in an open field.

3.4.2.8 Wider environmental considerations

Available sunlight in the United Kingdom is a limiting factor on investment in solar farms which outweigh the returns on the purpose for energy production. The construction of the solar farm infrastructure can have a negative impact on the environment, e.g., natural resource depletion and use of fossil fuels, in other countries, to manufacture the solar panels, and localised pollution through poor environmental management practices during the construction phase use.

Priority sites for installation of solar farms should ideally be brownfield land, which can be challenging to repurpose. Providing incentive to develop solar farm on agricultural land could disincentivise installation and therefore usage of brownfield land.

3.4.2.9 Evidence of effectiveness

Indicative calculations which have not been subject to review have been undertaken using the nutrient calculator using available data and the evidence indicates this can be an effective solution. Further information on the effectiveness or removing land from agricultural production is provided in **Section 3.4.1**.

3.4.2.10 Deliverability and certainty

Reducing the stocking density of livestock on agricultural land reduces P and N output over time. However, reducing stocking density provides less certainty than complete conversion from agricultural land. Therefore, complete conversion from agricultural land to solar farm is a more viable and certain solution. There is potential for the lease and planning permission as a mechanism to secure a legally enforceable scheme.

3.4.2.11 Cost estimate

Land rental or lease costs and construction costs can be offset against energy sale price per watt. Reference should be made to the cost estimate in **Section 3.6.1.11**.

3.4.2.12 Summary

Table 3-33 presents the key considerations for the option to convert agricultural land to solar farms.

Table 3-33 Conversion of agricultural land to solar farm key considerations

Key considerations	
Description of solution	A solar farm is a renewable energy installation with many solar panels which generate electricity. Solar farm installation can reduce P input by: ■ a reduction in number of grazing livestock and therefore P manure in livestock output by either reducing the density of grazing animal or removal of livestock from agricultural land; and ■ removal of agricultural land usage and therefore removal of nutrient inputs from fertiliser or waste applied to land from agricultural benefit to enhance crop growth. A solar farm installation can also be used for provision of nutrient credits
Delivery timescale	Short-term
Duration of operation	Permanent
Nutrient removal	TP between 0.04 – 0.71kg TP/ha/yr TN between 16.3 – 22.8kg TN/ha/yr
Applicability	All available agricultural land
Management and maintenance	Livestock number monitoring
Additional benefits	■ Renewable energy ■ BNG potential ■ Water quality
Best available evidence	No
Wider environmental considerations	The construction cost of the solar farm infrastructure can cause pollution, environmental degradation, and pressure on natural resources in other areas or countries. Solar farms should ideally be installed on brownfield land, which can be difficult to repurpose.
Evidence of effectivity	Yes, when using the evidence presented in **Section 3.4.1** Taking land out of agricultural use as a proxy
Precautionary	Yes - Precautionary principles can be adopted
Securable in perpetuity	Yes
Cost estimation	Costs are variable between landowners

3.4.3 Cessation of fertiliser and manure application

3.4.3.1 Description of solution

Where full land abandonment is not available, a change of farming practices or cessation of fertiliser application may be applicable. Stopping fertiliser or manure application will have an immediate short-term impact by reducing the amount of soluble nutrient runoff that is usually 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.

In a study of long-term, i.e., 45 years, land use, cropping without fertilisation reduced legacy phosphorus significantly (Zhang *et al*., 2020). This was also confirmed in Zhang *et al.,* (2020) where after 11 years of cultivation, in which the yield and phosphorus uptake by maize-soybean crops was not affected by withdrawal of phosphate fertilizer down to the critical level, legacy phosphorus was significantly reduced. The study also found that reliance on legacy phosphorus improved farmers' economic margins and reduced the soil test phosphorus levels to safe levels for surrounding catchments.

Legacy phosphorus does serve as a potential source for crop use and could potentially decrease the dependence on external fertilisers. An alternative option to ceasing fertiliser application would be to apply the correct amount of fertiliser that is required rather than applying a constant amount. However, the nutrient removal is more variable, and the release of credits would only be available following soil sampling.

Nutrient mitigation achieved is also likely to be less than ceasing fertiliser application all together. This solution would only be applicable to farmers who currently apply at constant rates. This solution could be employed as a temporary solution and validated through monitoring of soils.

3.4.3.2 Nutrient removal

Cessation of fertiliser allows land to still be farmed whilst also providing nutrient 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.

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 three to four visits per year, including an initial round of sampling to establish the baseline conditions. This solution would be best implemented on farms in arable use as removing a biomass will reduce legacy P values.

However, it could also be extended to farms with grazing and mixed livestock. This method would have a significant impact on crop yields, with the greatest impact on responsive crops such as potatoes and some vegetables, which may increase the cost of this solution for these farming types. Where implemented on livestock farms, the soils should have P indices of two.

P levels can be farmed down through cutting for silage without fertiliser application which will quickly reduce excess P. This would prevent approximately 30kg/ha of P application that would normally be added after each cut (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)

studied the relationship between soluble and particulate phosphorus in nine major UK Rivers and found that particulate P in agricultural and rural setting made up 50% of the TP.

As such, it was assumed that particulate P makes up 50% of TP. Therefore, the TP removal values for cessation of fertiliser and manure application is assumed to be 25%. Newell Price *et al*., (2011) estimates that nitrate losses would be approximately 90% from the cessation of fertiliser. The P and N removal that can be achieved for each farming typology is presented in **Table 3-34** and **Table 3-35.**

Table 3-34 Phosphorus removal from the temporary cessation of fertiliser and manure application

Farm type	Phosphorus removal from cessation of fertiliser / manure application (kg TP/ha/yr)		
	Wensum	Yare	Bure
Dairy	0.10	0.07	0.04
Lowland grazing	0.06	0.04	0.03
Mixed livestock	0.15	0.07	0.02
Poultry	0.18	0.10	0.04
Pig	0.18	0.09	0.02
Horticulture	0.17	0.08	0.01
Cereals	0.18	0.09	0.02
General arable	0.16	0.07	0.01

Table 3-35 Nitrogen removal from the temporary cessation of fertiliser and manure application

Farm type	Nitrogen removal from cessation of fertiliser / manure application (kg TN/ha/yr)		
	Wensum	Yare	Bure
Dairy	15.5	20.5	32.3
Lowland grazing	12.3	10.1	16.3
Mixed livestock	21.7	18.9	31.1
Poultry	160.1	142.9	205.8
Pig	65.9	58.1	80.8
Horticulture	17.2	13.95	20.4
Cereals	21.38	17.31	23.18
General arable	19.6	15.7	25

The impact of legacy P limits the reduction potential that can be achieved through ceasing fertiliser application, i.e., because P is more readily retained in the soil it will be regularly captured by and encountered in surface water runoff. P concentrations are also more difficult to remove and mitigate in comparison to increased quantities of N that can be easily removed and provide a more viable solution.

Table 3-36 and **Table 3-37** provide an indication of the likely mitigation that could be delivered and associated costs in each sub-catchment. This assumes a 10ha cereal farm would cease fertiliser application and the costs outlined in **Table 3-38**.

Table 3-36 Potential phosphorus mitigation and associated costs

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Sub-catchment	Mitigation	Dwelling equivalent	Cost estimation (£)	£/kg TP/yr for each year	£/dwelling for each year	£/kg TP/yr over 80 years	£/dwelling over 80 years
Wensum	1.8	27	12,744	6,983	474	558,637	37,896
Yare	0.85	13	12,744	14,993	1,017	1,199,426	81,364
Bure	0.2	2	12,744	84,959	5,763	6,796,747	461,062

Table 3-37 Potential nitrogen mitigation and associated costs

Sub-catchment	Mitigation	Dwelling equivalent	Cost estimation (£)	£/kg TN/yr for each year	£/dwelling for each year	£/kg TN/yr over 80 years	£/dwelling over 80 years
Wensum	213.8	113	12,744	60	112	4,770	8,988
Yare	173.1	92	12,744	74	139	5,891	11,100
Bure	231.8	123	12,744	55	104	4,399	8,290

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. However, allowing crop production to continue could be more appealing to farmers and will not have as detrimental of an impact on food supplies. The phosphorus mitigation is limited and leads to significant costs for mitigation.

3.4.3.3 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.

3.4.3.4 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 be similar to taking land out of agricultural use (**Section 3.4.1**).

3.4.3.5 Applicability

This solution is applicable to all types of arable agriculture where natural or synthetic fertilisers are applied.

3.4.3.6 Management and maintenance requirements

No maintenance required.

3.4.3.7 Additional benefits

Land could be selected strategically to help buffer from other pollution sources, e.g., suspended sediment.

3.4.3.8 Wider environmental considerations

Implementation of this option is unlikely to be significantly constrained by wider environmental factors. If the solution is over-used, then the reduced yield could result in localised food supply issues. However, this would not have the same impact as taking land out of agricultural use as crops are still being produced.

3.4.3.9 Evidence of effectiveness

Information on the effectiveness or removing land from agricultural production is provided in **Section 3.4.1**.

3.4.3.10 Deliverability and certainty

Certainty that fertiliser application has ceased can be provided through soil sampling which could be conducted in Spring (following typical spring application) for each year the solution is in place.

3.4.3.11 Cost estimate

Table 3-38 outlines the likely costs associated with this solution, both for arable and grassland farming. 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 8t/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.

Table 3-38 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**

3.4.3.12 Summary

Table 3-39 presents a range of considerations for cessation of fertiliser/ manure application for phosphate offsetting.

Table 3-39 Cessation of fertiliser and manure application key considerations

Key considerations	
Description of solution	Where full land abandonment is not available, a change of farming practices or cessation of fertiliser application may be applicable. Stopping fertiliser or manure application will have an immediate short-term impact by reducing the amount of soluble nutrient runoff that is usually 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.
Delivery timescale	Short-term
Duration of operation	Temporary
Nutrient removal	TP removal potential: 0.02 – 0.2 kg/ha/yr TN removal potential: 17.3 – 21.4 kg/ha/yr
Applicability	Arable and Grassland
Management and maintenance	None
Additional benefits	Positioning of farms could be strategic 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	Implementation of this option is unlikely to be significantly constrained by wider environmental factors. If the solution is over-used, then the reduced yield could result in localised food supply issues, but to a lesser degree than taking land out of agricultural use.

Key considerations	
Evidence of effectiveness	Yes
Precautionary	Yes
Securable in perpetuity	No – likely to be utilised as a bridging solution
Cost estimation	Arable: £1,274 ha/yr

3.4.4 Farm management measures

3.4.4.1 Description of solution

Farm management measures which are specific to individual farms could be relevant in reducing P and N being released into watercourses. The focus of farm management techniques is generally related to sediments, rather than nutrients, however, the nutrients are associated with suspended solids runoff so therefore the two are inter-related.

Fertiliser management using Defra Fertiliser Recommendations in the Nutrient Management Guide RB209 (updated 2022), are calculated according to season and agronomic calculations for planned crop production sowing and crop uptake, baseline P in soil, field slope, fertiliser application timing etc. Detailed information with respect to taking land out of agricultural use and cessation of fertiliser or manure application is detailed in **Sections 3.4.1** and **3.4.3** respectively.

To manage the supply of surface water runoff, sediment, and nutrients from agricultural fields into the drainage network, the following measures laid out in **Table 3-40** can be considered.

Table 3-40 Surface water runoff, sediment, and nutrient farm management measures

Nutrient Method	Description
Controlled grazing	Controlled grazing and pasture management reduces the concentration of nutrients found in manure in a single area which reduces nutrient overloading, reduces sediment runoff through minimising soil compaction, and allows the regrowth of covering vegetation. Grazing management plans are specific to each farm and may help to achieve more days grazing per year using grazing rotations, therefore reducing hay supplementation. Plans are likely to include the use of fencing to distribute grazing pressure and promote plant regrowth.
Bank stabilisation	Trees and shrubs along watercourses help stabilise banks as well as offer habitat for fish, insects, bird, and mammals. Techniques can include vegetative revetment to slow erosion rates.
Field drainage and ditch management	Nutrient reduction to watercourses can be achieved via the design of field drains. For example, where the outfall pipe of a field drain is left short of the watercourse, so that percolation through a natural floodplain allows nutrient capture and uptake into vegetation. Buffer zones such as this also have additional benefits such as filtering soil, silt, and other material.
Farm traffic management	Farm traffic management can reduce soil compaction and issues associated with this and reducing use of heavy machinery close to watercourses which can damage banksides, bankside vegetation and destabilise banks. Management may include rotating the use of farm tracks throughout the year, reducing overuse of certain tracks.
Detention ponds	Detention ponds are basins/depressions which are usually dry and are designed to temporally store and slowly release runoff water to meet flow and water quality criteria. Water leaves the basin via a restricted outflow control leading to a longer detention time and improved particulate pollution sedimentation. Pollution removal improved by including features such as pre-treatment sediment traps, deeper areas

Nutrient Method	Description
	at or near inlets and low flow channels. These can also provide flood control by providing additional flood detention storage.

3.4.4.2 Nutrient removal

There is a large degree of uncertainty in relation to nutrient removal rate, as it is dependent on multiple variables such as location, soil type, rainfall, frequency of de-silting and is likely to differ between locations. Quantitative nutrient data is required according to site-specific variables to seek optimal locations. Pilot trials should be undertaken to determine the best management measures to optimise their usage.

3.4.4.3 Delivery timescale

Short to medium term to establish farm management measures. A survey from a qualified and experienced ecologist would be required to the relevant river stretch ahead of commencement of construction works which establish management measures. Works may need to be limited outside of breeding seasons, for example, to avoid vulnerable times such as spring/ summer for some birds and mammal fish spawning.

3.4.4.4 Duration of operation

Once the farm management measures have been established it is assumed that they will be long term solutions.

3.4.4.5 Applicability

This nature-based solution is applicable for all farm typologies.

3.4.4.6 Management and maintenance requirements

Management and maintenance requirements are likely to include periodic cutting vegetation, clearing and dredging of artificial ditches. Ditch maintenance may need to be on a rotational basis to minimise damage to ditch banks. This would be done by the farm operator.

3.4.4.7 Additional benefits

Dependent on the measures selected by the farm operator, the solution can reduce the sediment supply to downstream watercourses, this can result in the following additional benefits:

- The amount of land being lost to erosion can be reduced;
- Improvement of soils and therefore crop yields, animal health and production;
- BNG; and,
- The reduction in pollution and therefore better compliance with legislation.

3.4.4.8 Wider environmental considerations

Periodic removal of the sediment containing nutrients and any other chemicals which have collected requires consideration, with respect to re-use or waste disposal in addition to any environmental considerations related to removal and transport.

3.4.4.9 Evidence of effectiveness

There is limited evidence of the effectiveness of farm management measures in the removal of nutrients. The solution is likely to have some effectiveness in the removal of sediment-associated nutrients, it is less likely to be effective at removing nutrients transported in dissolved phase. The solution is therefore likely to be more effective in removing P than N, although there is a large uncertainty regarding its effectiveness. As such, monitoring and potentially pilot trials would be required to provide representative data which measures nutrient removal rate potential.

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3.4.4.10 Deliverability and certainty

There is a large amount of uncertainty regarding the removal rate. This is dependent upon several parameters which determine variable success. Furthermore, many of the options, e.g., farm traffic movements, do not have the required certainty to provide nutrient neutrality mitigation.

3.4.4.11 Cost estimate

The cost of farm management measurements can vary dependent on the contractor undertaking the works and what measures are being implemented.

3.4.4.12 Summary

Key considerations for farm management measures are summarised in **Table 3-41**.

Table 3-41 Farm management measures key considerations

Key considerations	
Description of solution	Farm management measures which are specific to individual farms could be relevant in reducing P and N being released into watercourses. The focus of farm management techniques is generally related to sediments, rather than nutrients. To manage the supply of surface water runoff, sediment, and nutrients from agricultural fields into the drainage network, the following measures can be considered: ■ Controlled grazing; ■ Bank stabilisation; ■ Field drainage and ditch management;' and ■ Farm traffic management
Delivery timescale	Short/medium term
Duration of operation	Permanent
Nutrient removal	Large uncertainty
Applicability	All applicable
Management and maintenance	Periodic cutting vegetation Clearing and dredging of artificial ditches Ditch maintenance
Additional benefits	The amount of land being lost to erosion; Improvement of soil quality BNG; and, Reduction in pollution
Best available evidence	No
Wider environmental considerations	Periodic removal of the sediment containing nutrients and any other chemicals which have collected requires consideration, with respect to re-use or waste disposal in addition to any environmental considerations related to removal and transport.
Evidence of effectiveness	Yes – the effectiveness can vary considerable under different conditions, poor design, and poor management.
Precautionary	Yes
Securable in perpetuity	No – the solutions do not have the required certainty to meet the requirements of the Habitat Regulations.
Cost estimation	Can vary depending on the management measure selected.

3.4.5 Cover crops

3.4.5.1 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 the uncertainty in removal values, soil sampling and monitoring may be required to establish the baseline and phosphate reduction.

3.4.5.2 Nutrient removal

Published P reduction rates are variable within the literature. Some studies suggest significant phosphorus removal can be achieved, such a study by Novotny and Olem (1994) which suggested phosphorus removal of 30-50% and Sharpley and Smith (1991) which found an average reduction of 77% from four different studies. However, other investigation concluded that changes to phosphorus losses were not significant, e.g., Kleinman *et al.*, 2005.

Published N reductions values are also variable within the literature. Kaspar and Singer (2011) studied nitrate reductions from cover crops for 16 studies and found that the reduction in leaching losses ranged from 6 to 94%. Spier *et al.*, 2022 found that cover crops consistently reduced tile drain nitrate loss by 27-72%. Similarly, Hanrahn *et al.*, (2018) measured median nitrate savings of 69-90% compared to fields without cover crops during winter/ spring. Kaspar *et al.*, (2012) observed nitrate reductions of 48% over five years using rye winter crop.

Numerous studies have demonstrated that cover crops' uptake of N lowers the possibility of nitrate losses due to leaching over the winter. Having less soil runoff also means having less phosphate linked to soil particles to lose. Examples of these studies include:

- A study conducted by The New Farming Systems (NFS) Project with a view to explore ways of improving the sustainability, stability and output of conventional arable farming systems started in 2007 with additional study in 2011 on a sandy loan soil at Morley in Norfolk.

  Research has shown advantages in terms of improved soil properties, favourable yield responses, and increases in financial margins over fertiliser input related with the employment of particular cover crop systems.

- A study conducted by NFS over two seasons with farmers from Kellogg's Origins Natural Heritage (Origins^{TM}) in sites in Leicestershire have revealed mean N leaching reductions of approximately 43% (mean values for 2015 and 2016 were approximately 40% and 46%, respectively, or 38kg/ha and 25 kg/ha, respectively, of N).

  The results of other studies in this field are consistent with this. To help crops and the larger soil system, this N will be kept in the soil. For this use, a variety of fast-growing cover crops are appropriate (Stobart, 2016).

- Another study was conducted on a 143ha commercial arable farm in Norfolk, UK, to determine the effectiveness of cover crops in reducing farm-scale nutrient losses with a cover crop of winter oilseed radish (Raphanus sativus).

  Various observations were made from the year 2012 to 2015 and according to the results, oilseed radish had no effect on phosphate (P) losses but reduced nitrate (NO_3-N) leaching losses in soil water by 75-97% in comparison to the fallow land (Cooper *et al*., 2017).

Table 3-42 and **Table 3-43** provide an indication of the likely mitigation that could be delivered and associated costs in each sub-catchment. This assumes 1ha of cover crops on cereal land and that payments are equivalent to £124 per hectare.

Table 3-42 Estimated TP mitigation and associated costs in each sub-catchment

Sub-catchment	Mitigation	Dwelling equivalent	Cost estimation (£)	£/kg TP/yr for each year	£/dwelling for each year	£/kg TP/yr over 80 years	£/dwelling over 80 years
Wensum	0.22	3	124	566	38	45,297	3,073
Yare	0.10	2	124	1,216	82	97,255	6,597
Bure	0.02	0	124	6,889	467	551,111	37,385

Table 3-43 Estimated TN mitigation and associated costs in each sub-catchment

Sub-catchment	Mitigation	Dwelling equivalent	Cost estimation (£)	£/kg TN/yr for each year	£/dwelling for each year	£/kg TN/yr over 80 years	£/dwelling over 80 years
Wensum	7.1	4	124	17	33	1,392	2,624
Yare	5.8	3	124	21	41	1,720	3,240
Bure	7.7	4	124	16	30	1,284	2,420

3.4.5.3 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.

3.4.5.4 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.

3.4.5.5 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.

3.4.5.6 Management and maintenance requirements

There will be annual maintenance requirements associated with preparation, planting, destruction, and cultivation of cover crops.

3.4.5.7 Additional benefits

Reduces soil erosion, improves water quality, and increases biodiversity due to habitat creation. Cover crops also provide winter cover and habitat for birds, mammals, and insects.

3.4.5.8 Wider environmental considerations

Implementation of this option is unlikely to be significantly constrained by wider environmental factors.

3.4.5.9 Evidence of effectiveness

Although there is scientific evidence to suggest that cover crops are effective in reducing the supply of phosphorus and N from agricultural land, estimates show considerable variation (**Section 3.4.5.1**). 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%.

3.4.5.10 Deliverability and certainty

Certainty that the solution has been delivered and will continue to be delivered can be provided through site visits, aerial imagery, and submission of photos from landowners. Monitoring of local watercourses can be conducted to confirm the predicted removal rates are achieved.

3.4.5.11 Cost estimate

Annual maintenance costs estimated to be £150/ha/yr (AHDB, 2020) £124/ha.

3.4.5.12 Summary

Table 3-44 presents a range of considerations for using cover crops for nutrient offsetting.

Table 3-44 Cover crops key considerations

Key considerations	
Description of solution	Surface runoff and erosion represents a principal mechanism for nutrient loss from many agricultural systems. Cover crops help maintain soil cover and are especially useful to mitigate erosion on high-risk sloping land. They are best employed when land would otherwise be left bare during the crop rotation process.
Delivery timescale	Short-term
Duration of operation	Impermanent
Nutrient removal	Large uncertainty - Assumed to be 30% removal
Applicability	Arable farms (particularly cereals)
Management and maintenance	Time and money costs associated with preparation, planting, destruction, and cultivation.
Additional benefits	■ Water quality ■ Habitat creation
Best available evidence	No – phosphate reduction estimates are highly variable
Wider environmental considerations	Implementation of this option is unlikely to be significantly constrained by wider environmental factors
Evidence of effectiveness	Yes
Precautionary	Yes
Securable in perpetuity	Yes – management agreements will likely need to be put in place, especially where land in leased
Cost estimation	Maintenance costs: £150/ha/yr (AHDB, 2020) £124/ha

3.4.6 Installing Sustainable Drainage Systems in new developments

3.4.6.1 Description of solution

SuDS are efficient sediment traps and reduce 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. Examples include basins and ponds, filter strips and swales, constructed wetlands, soakaways, infiltration basins, gravelled areas, and porous paving. SuDS systems require design specific to a development site and the phosphate reduction efficacy can vary between options.

3.4.6.2 SuDS typologies

SuDS systems that promote infiltration of water and settlement of sediment will have the greatest benefit for phosphorus removal. Similarly, SuDS that provide an environment for vegetation to uptake phosphorus will achieve good phosphorus 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.

SuDS wetlands should typically comprise of an initial sediment fallout pond, a variety of deeper zones and shallow macrophyte zones (**Figure 3.10**). The wetlands should also be able to accommodate additional volume for excess rain. Regular wetland maintenance is also essential to ensure that removal rates are maintained and to ensure that an accumulation of phosphorus enriched sediment does not become a source rather than a sink. Indicative cost estimates are presented in **Section 3.4.6.12**.

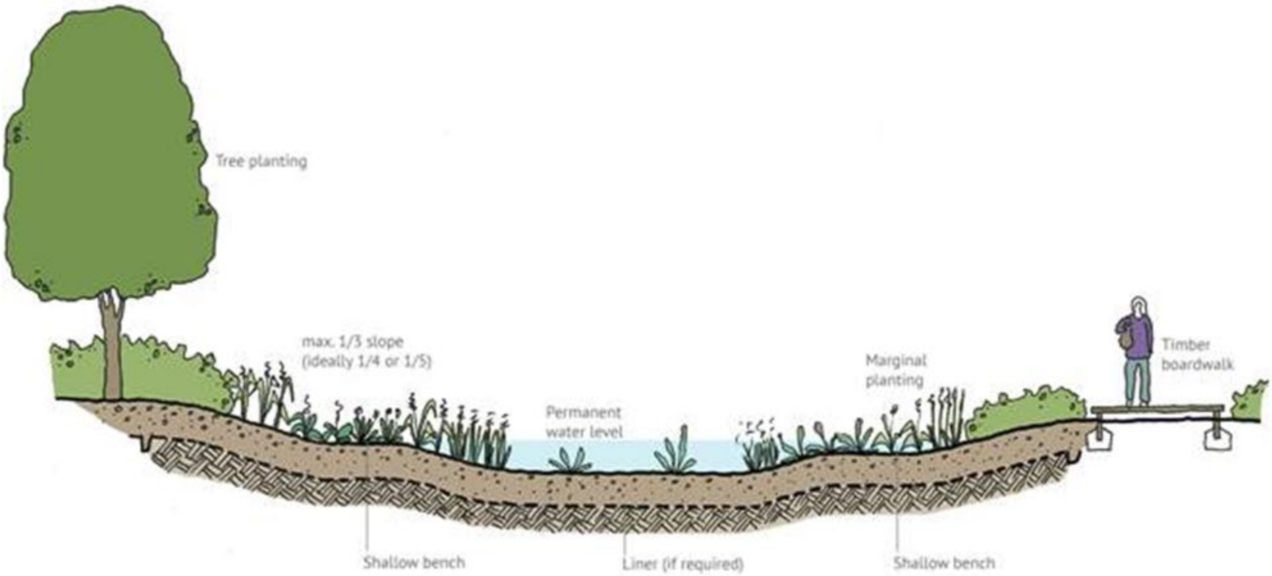

Figure 3.10 Example of SuDS wetland (Source: Susdrain)

Swales are shallow, relatively wide, and vegetated depressions that are designed to store and convey runoff and remove pollutants. They can also be used as conveyance structures to transfer runoff into the next stage of the SuDS treatment process. They are fairly easy to incorporate, with low capital costs and simple maintenance. They are best suited to low gradients on both sides and can be enhanced by placing check dams across the swale to reduce flow rate (**Figure 3.11**).

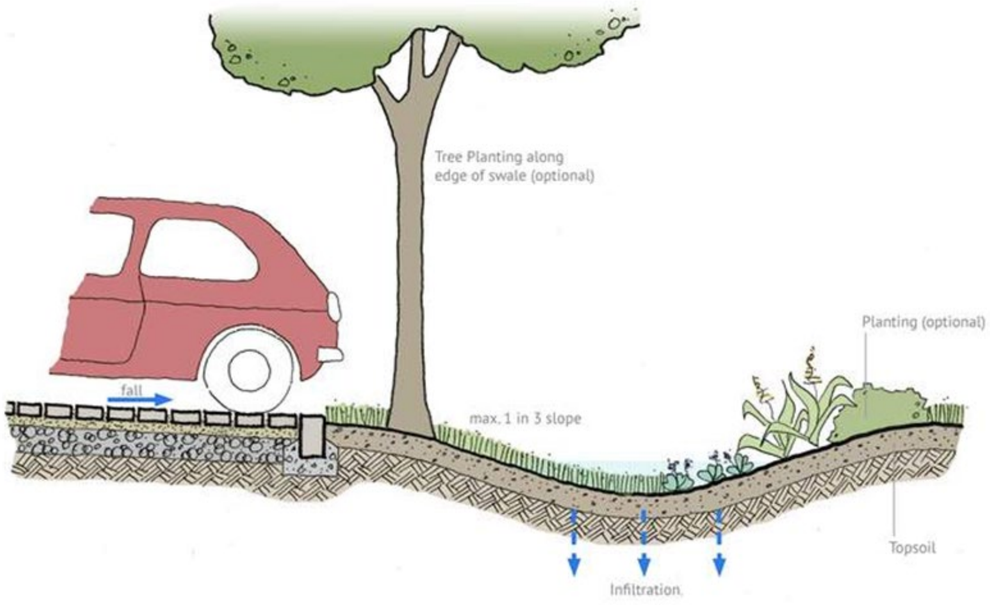

Figure 3.11 Example of swales and conveyance channels (Source: Susdrain)

Filter strips are gently sloping, vegetated strips of land that slow conveyance and promote infiltration. They typically lie between hard-surfaces and a receiving stream/ surface water collection (**Figure 3.12**). Runoff is primarily by overland sheet flow. They are easy to construct and have low capital costs. They are unsuitable where the slope gradients are too steep

Figure 3.12 Example of filter strips (Source: Susdrain)

Bioretention areas are landscaped depressions which use enhanced vegetation and filtration to remove pollution and reduce runoff (**Figure 3.13**). They are aimed at managing and treating runoff from frequent rainfall events. They are very effective at removing pollutants and flexible to install into the landscape.

Figure 3.13 Example of a rain garden (Source: Welshwildlife.org)

Source control is also a key method in reducing runoff. Permeable paving can attenuate flow and increase infiltration. Green roofs also provide interception storage and treat some of the more frequent but smaller, polluting rainfall events. The latest advice provided by Natural England suggests that they may be able to give more details on how SuDS should be incorporated into the calculator and the mitigation potential this may have. Further details to this solution will be given following the guidance from Natural England. SuDS can be best incorporated into new developments where they can be designed from an early stage to achieve the greatest impact.

The use of SuDS should be encouraged as this will treat excess phosphorus on site. Furthermore, the Norfolk County Council (as Lead Local Flood Authority) drainage design standards for highways[12] indicate Norfolk County Council seeks to reduce the rate of surface water run-off through the use of SuDS and the Norfolk Local Flood Risk Management Strategy (2015) encourages SuDS approaches in new developments and considers retrofitting SuDS within existing settlements.

The Strategy takes information from Authorities respective Surface Water Management Plans (SWMP)[13] some of which identify SuDS to be used where appropriate. This is likely to be most applicable larger urban areas such as Dereham, Wymondham, Aylsham, and Norwich where the SuDS manual (CIRIA, 2015) sets out further design approaches. Other areas such as Poringland in South Norfolk may not be appropriate for SuDS as the use of infiltration methods could create new or aggravate existing local groundwater flooding problems by increasing the rate at which rainwater enters the ground.

[12] https://www.norfolk.gov.uk/rubbish-recycling-and-planning/planning-applications/highway-guidance-for-development/drainage
[13] https://www.norfolk.gov.uk/what-we-do-and-how-we-work/policy-performance-and-partnerships/policies-and-strategies/environment-and-planning-policies/flood-and-water-management-policies/surface-water-management-plans

Urban retrofitting can be used to install SuDS. To accommodate surface water run-off from existing developments and built-up areas Strategic driven retrofitting can achieve phosphorus reductions and can be combined with the need for urban regeneration and flood reduction.

3.4.6.3 Nutrient removal

Many of the components of a SuDS design do not have a strong evidence base to determine removal efficiencies. Lucke *et al*., (2014) reported total phosphorus removal of 20 - 23% under runoff simulation. Lucke *et al*., (2014) reviewed a range of other published data and found slightly higher mean TP reduction of 48%. Moderate phosphorus reductions associated with swales suggest they would be best used alongside a suite of other measures to achieve a greater cumulative impact and achieve neutrality, e.g., as a part of SuDS schemes used in new housing developments.

As such, Construction Industry Research, and Information Association (CIRIA) guidance (2022) on SuDS provides more information on the likely TP reduction rates. SuDS are well-established and familiar to many developers and are likely to be an attractive method for achieving on-site mitigation.

3.4.6.4 Delivery timescale

A requirement to implement SuDS as part of all new developments can be established in the short term.

3.4.6.5 Duration of operation

Once installed, SuDS are assumed to be permanent drainage and nutrient management solutions.

3.4.6.6 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. Retrofitting of SuDS is more location specific to ensure the greatest return.

3.4.6.7 Management and maintenance requirements

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. Key maintenance tasks are outlined in **Table 3-45.** Sedimentation will eventually compromise some aspects of the SuDS function and rejuvenation measures will be necessary (Kadlec and Wallace, 2009).

Table 3-45 SuDS maintenance tasks

Activity	Indicative frequency	Typical tasks
Routine/ regular maintenance	Monthly (for normal care of SuDS)	■ litter picking ■ grass cutting ■ inspection of inlets, outlets, and control structures
Occasional maintenance	Annually (dependent on the design)	■ silt control around components ■ vegetation management around components ■ suction sweeping of permeable paving ■ silt removal from catchpits, soakaways, and cellular storage
Remedial maintenance	As required (tasks to repair problems due to damage or vandalism)	■ inlet/ outlet repair ■ erosion repairs ■ reinstatement of edgings ■ reinstatement following pollution ■ removal of silt build up

3.4.6.8 Additional benefits

SuDS can provide multiple benefits other than phosphorus removal. They mimic natural drainage process and reduce the quantity of runoff from developments as well as providing amenity, improved quality of water,

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habitat creation and biodiversity benefits. Where appropriately designed and used, a SuDS treatment train will reduce runoff and storm flow, which can lead to a reduction in combined sewage overflows.

3.4.6.9 Wider environmental considerations

The use of SuDS in new developments is unlikely to be significantly constrained by wider environmental factors.

3.4.6.10 Evidence of effectiveness

As discussed in **Section 3.4.6.3**, 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.

3.4.6.11 Deliverability and certainty

SuDS are often permanent features which are designed for the lifetime of developments. SuDS will typically provide additional benefits other than nutrient removal which are fundamental to the functionality of the development, e.g., surface water attenuation.

3.4.6.12 Summary of Draft CIRIA C808 'Using SuDS to reduce phosphorus in surface water runoff' schedule

The CIRIA C808 (Bradley *et al*., 2022) document; '*Using SuDS to reduce phosphorus in surface water runoff*' has been informally issued and is summarised in this section. The document was prepared following agreement of the schedule with Natural England. It works towards definitive recommendations for the use of SuDS for P removal.

The document sets out SuDS deployment via 'treatment trains' to achieve good practice P removal which are expected to be set out at outline and full planning applications stages. A precautionary reduction in the runoff rate of P from new developments can be achieved for developments that secure the good practice SuDS set out in the document. For the design of an effective SuDS management train, varying site characteristics need to be understood, these include:

- Soil characteristics – soil type, permeability, pre-existing nutrient content and infiltration of surface water capacity;
- Groundwater level and seasonal changes;
- Vulnerability of underlying groundwater; and
- Receiving watercourse characteristics – type, location, flow rate and size of receiving watercourse.

The principles of P capture and removal with respect to residential developments are set out as:

1. Ground infiltration of water from residential developments where conditions allow without a risk of groundwater pollution should be the first step of P pollution control;
2. Sediment capture via SuDS can remove a proportion of P in runoff for sites where conditions are such that runoff infiltration cannot work. A SuDS can also protect further treatment device from sediment accumulation;
3. Vegetation within a treatment device captures dissolved phase P and supports P associated with particulates to be captured;
4. The treatment train hierarchy starts with infiltration, sedimentation, reduction of suspended solids, and plants to take up dissolved phase P; and
5. Enhancement of such devices can be made with the inclusion of P specific treatment media.

The documents include 16 site-specific factors to be considered with respect to design and monitoring effectiveness of SuDS which ranges from establishing 'legacy' P in respect of previous land use and consideration of sustainability of construction materials. The document also lists an order of SuDS components/ devices:

1. Primary components comprise source control such as permeable paving, spillage control (such as oil/ water interceptors), sedimentation devices, such as vortex grit separators. Rain and stormwater capture and reuse system installation in properties and landscaped areas. Capture and reuse systems reduce flow into SuDS (and form part of other solutions for Norfolk Authorities described in Demand Management Solutions (**Section 3.6**);
2. Secondary components comprise additional removal of suspended solids and dissolved P from ponds, basins, wetlands, floating wetlands, and willow beds;
3. Tertiary components comprise downstream of sedimentation devices, stormwater filters and granular treatment media beds. Treatment is more effective via this component when the runoff water has been subject to some degree of 'cleaning' prior to this point; and
4. All-in-one devices components are described as bio-retention zones (which are typically shallow landscaped in-ground depressions) and tree pits.

The document includes a flow chart with suggested good practice design methodology. The quantity calculation set out in the following steps in key:

- Step 1 – P in the runoff each year.
- Step 2 – runoff that can be infiltrated to ground using SuDS.
- Step 3 – remaining P that can be removed using SuDS.
- Step 4 – P contained in runoff which bypasses the SuDS without treatment in heavy rain events.
- Step 5 - P to be mitigated offsite (that remaining at the end of Steps 3 and 4).

The document provides information for the detailed design of individual components of SuDS, such as wetlands, ponds, bioretention zones/ rain gardens and other examples include:

- Swales which are linear in-ground depressions;
- Detention basins and retention basins which capture runoff during rain events and detain water using a flow control device and release after the rainfall event. Detention basics are generally dry and retention basins have standing water in between rain events;
- Tree pits are constructed depressions similar to bioretention zones;
- Floating wetlands are constructed on permanent water bodies, the roots grow into the water and remove P and ca also offer sediment removal via root growth;
- Filter strips which are formed by a grassy strip with a gentle downward include to allow flow towards another SuDS device; and
- Filter drains, which are granular coarse stone-filled trenches which capture sediment from water runoff in the void spaces.

The document provides a modelling statement which describes the methodology used for modelling pollutant efficiencies of different SuDS management train. It also 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 3-46**.

Table 3-46 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	Filter drain	Willow beds	Permeable pavement	Vortex grit separator	Oil water separator	Stormwater filter	Granular treatment media	Rainwater and stormwater capture
Sediment capture capability	28%	28%	28%	38%	38% settled in pond	44%	44%	22%	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	12%	50%	50%	Test results provided by manufacturer	Nil	Nil	Nil	Nil	100%	Nil	Nil	Nil	Up to 90% if the media selected specifically for P capture		N/A
TP removal	15.4%	20.8%	37.9%	43.4%	20.9%	24.2%	24.2%	12.1%	12.1%	100%	20.9%	15.4%	15.4%	64.7%	64.7%	N/A

3.4.6.13 Cost estimate

Table 3-47 and **Table 3-48** present outline cost estimates for various SuDS types.

Table 3-47 SuDS costs for buffers, bunds and wetlands (edited from Vinten et al., (2017))

Measure	Recurrent costs	Capital costs
8m buffer	£495 ha/yr for 6m buffer	Nil
20m buffer	£495 ha/yr for 18m buffer	Nil
Retention bund	Nil	£7 million bund £10.5/m^2 excavation £5.5/m^2 perimeter fence

Table 3-48 Indicative capital costs for SuDS options (edited from Environment Agency (2015)) and relative performance edited from C808 CIRIA, (2022)

SuDS Option	Cost estimation	Source
Green roofs	£80/m^2 - £90/m^2	Bamfield, 2005
Rainwater harvesting (water butts)	£100 - £243 per property	Stovin & Swan, 2007
Advanced rainwater harvesting	£2,100 - £3,700 per residential property £45/m^2 for residential properties	Environment Agency, 2007 RainCycle, 2005
Greywater re-use	£3,000 per residential property	Environment Agency, 2007
Permeable paving	£30/m^2 - £54/m^2	CIRIA, 2007 Environment Agency, 2007
Filter drains/ perforated pipes	£120/m^2 £100/m^3 - £140/m^3	Environment Agency, 2007 CIRIA, 2007
Swales	£10/m^2 – £15/m^2	Environment Agency, 2007 CIRIA, 2007
Infiltration basin	£10/m^3 – £15/m^3 stored volume	CIRIA, 2007
Soakaways	£450 - £550 per soakaway	Stovin & Swan, 2007
Infiltration trench	£60/m^2 £55/m^3 - £65/m^3 stored volume	Environment Agency, 2007 CIRIA, 2007
Filter strip	£2/m^2 - £4/m^2	CIRIA, 2007
Constructed wetland	£25/m^3 - £30/m^3 stored volume	CIRIA, 2007
Retention pond	£16/m^3 pond £25/m^3 - £30/m^3 stored volume	Sniffer, 2006 CIRIA,2007
Detention basin	£15/m^3 - £55/m^3 stored volume	CIRIA, 2007 Stovin & Swan, 2007

SuDS Option	Cost estimation	Source
Onsite attenuation and storage	£449/m^3 - £518/m^3 for reinforced concrete storage tank	Stovin & Swan, 2007

3.4.6.14 Summary

Table 3-49 presents the key considerations for the use of SuDS for nutrient offsetting or reduction.

Table 3-49 SuDS key considerations

Key considerations	
Description of solution	SuDS are efficient sediment traps and reduce the amount of runoff entering watercourses. SuDS slow flow and promote infiltration, allowing rainfall to enter the groundwater where it falls. Examples include basins and ponds, filter strips and swales, constructed wetlands, soakaways, infiltration basins, gravelled areas, and porous paving
Delivery timescale	Short-term
Duration of operation	Permanent
Nutrient removal	TP removal potential: Highly variable and will likely need site specific calculations. The CIRIA C808 (2022) 'Using SuDS to reduce phosphorus in surface water runoff' document summarises the varying sediment capture capability (which ranges from 22 to 44%) and dissolved P capture/ removal (which ranges from nil to 100%). TN removal potential: Highly variable and will likely need site specific calculations
Applicability	All new dwellings
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
Additional benefits	■ Water quality ■ Reduced erosion ■ Habitat creation ■ 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	No
Precautionary	Yes
Securable in perpetuity	Yes – maintenance agreements may be required
Cost estimation	See **Table 3-73** and **Table 3-74.**

3.4.7 Retrofitting Sustainable Drainage Systems in existing developments

3.4.7.1 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. Examples include basins and ponds, filter strips and swales, constructed wetlands, soakaways, infiltration basins, gravelled areas, and porous paving. SuDS systems require design specific to a development site and the P reduction efficacy can vary.

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3.4.7.2 SuDS typologies

SuDS systems that promote infiltration of water and settlement of sediment will have the greatest benefit for P removal. Similarly, SuDS that provide an environment for vegetation to uptake P will achieve good P 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.

However, urban retrofitting can be used to install SuDS. This will accommodate surface run-off from existing developments and built-up areas. Strategic driven retrofitting can achieve P reductions and can be combined with the need for urban regeneration and flood reduction. The following SuDS typologies would be suitable for urban retrofitting.

3.4.7.3 Swale

Swales are shallow, relatively wide, and vegetated depressions that are designed to store and convey runoff and remove pollutants. They can also be used as conveyance structures to transfer runoff into a drainage system. They are fairly easy to incorporate, with low capital costs and simple maintenance. They are best suited to low gradients on both sides and can be enhanced by placing check dams across the swale to reduce flow rate (**Figure 3.11**).

3.4.7.4 Filter Strip

Filter strips are gently, sloping, vegetated strips of land that slow conveyance and promote infiltration. They typically lie between hard-surfaces and a receiving stream/ surface water collection (**Figure 3.12**). Runoff is primarily by overland sheet flow. They are easy to construct and have low capital costs and are unsuitable where the slow gradients are too steep.

3.4.7.5 Bioretention

Bioretention areas are landscaped depressions which can use enhanced vegetation and filtration to remove pollution and reduce runoff (**Figure 3.13**). They are aimed at managing and treating runoff from frequent rainfall events. They are very effective at removing pollutants and flexible to install into the landscape.

3.4.7.6 Filter Drains

Filter drains are stone-filled trenches that run alongside a road, path, or rail/ tram line. The sediment captured in the void spaces between the stones, and often they have an underdrain beneath them. They can include a layer of treatment media to capture specific pollutants. They are easy to construct and have low capital costs. Filter drains can be lined or unlined, depending on pollutant loads and soil conditions so there is a risk of them allowing P pollution to migrate down into the underlying groundwater.

3.4.7.7 Tree Pits

Tree pits are designed so that the tree thrives in a constructed area which prevents compaction around the tree roots. The area around the tree trunk at surface may be covered with porous resin or similar, or it may be left as open soil surface and planted with small plants. They are easy to construct and have low capital costs.

Tree pits do not need much maintenance, for the reduction of P pollution from the surrounding urban surfaces, it is important to clean up fallen leaves from the tree before they degrade and release soluble P into the storm water. The nature of the media put into the pit will be very important, if the imported soil is high in P it may cause an increase in P in runoff. In addition, tree pits have a huge capacity to attenuate water and much of the water is taken up by the tree.

Discharges from the tree pits only occur when there is a lot of sustained rainfall, and that infiltration and attenuation capacity removes most of the TP from the downstream environment.

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3.4.7.8 Porous Paving

Porous paving consists of a surface that allows surface water to run through. There are layers of sand/ aggregate below the porous surface to allow infiltration. There is no vegetation and often not much soil beneath the paving, so the P capture capability is limited. They are easy to construct and have low capital costs.

3.4.7.9 Nutrient removal

CIRIA guidance (2022) on SuDS will provide more information on the likely TP reduction rates. There is no evidence base for the reduction of TN from SuDS. The TN reductions rates would be highly variable and will need specific calculations.

3.4.7.10 Delivery timescale

A requirement to retrofit SuDS into a new development can be established in the short term.

3.4.7.11 Duration of operation

Once installed, SuDS are assumed to be permanent drainage and nutrient management solutions.

3.4.7.12 Applicability

Retrofitting of SuDS is more location specific to ensure the greatest return. This solution should be designed from the earliest possible stage. The size of the site will control the design and nutrient removal potential. SuDS are proven to work more effectively in a treatment train, as such it may not be possible to achieve this with retrofitting SuDS. Some SuDS are more effective at treating sediment or dissolved P and this could be impacted by the current drainage systems.

3.4.7.13 Management and maintenance requirements

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. Key maintenance tasks are outlined below in **Table 3-50**. Sedimentation will eventually comprise some aspects of the SuDS function and rejuvenation measures will be necessary (Kadlec and Wallace, 2009).

Table 3-50 SuDS maintenance tasks.

Activity	Indicative frequency	Typical tasks
Routine/ regular maintenance	Monthly (for normal care of SuDS)	■ Litter picking ■ Grass cutting ■ Inspection of inlets, outlets, and control structures
Occasional maintenance	Annually (dependant on the design)	■ Silt control around components ■ Vegetation management around components ■ Suction sweeping of permeable paving ■ Silt removal from catchpits, soakaways, and cellular storage
Remedial maintenance	As required (tasks to repair problems due to damage or vandalism)	■ Inlet/ outlet repair ■ Erosion repairs ■ Reinstatement of edgings ■ Reinstatement following pollution ■ Removal of silt build up

3.4.7.14 Additional benefits

SuDS mimic natural drainage process and reduce the quantity of runoff from developments as well as providing amenity and biodiversity benefits. Where appropriately designed and used, a SuDS treatment train will reduce runoff and storm flow, which can lead to a reduction in combined sewage overflows.

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3.4.7.15 Wider environmental considerations

The use of SuDS in new developments is unlikely to be significantly constrained by wider environmental factors.

3.4.7.16 Evidence of effectiveness

There is currently limited evidence to demonstrate the efficiency of SuDS measures in the removal of nutrients from run off. However, parallels could potentially be drawn with the evidence base for their effectiveness in attenuating flows and reducing sediment supply.

3.4.7.17 Deliverability and certainty

SuDS are often permanent features which are designed for the lifetime of developments. SuDS will typically provide additional benefits other than nutrient removal which are fundamental to the functionality of the development, e.g., surface water attenuation.

3.4.7.18 Cost estimate

Table 3-51 present outline cost estimates for various SuDS types.

Table 3-51 Indicative capital costs for SuDS options (edited from Environment Agency (2015)) and relative performance (CIRIA, 2022)

SuDS Option	Cost estimation	Source	Dissolved P capture/ removal rate (sediment capture capability) from C808 CIRIA 2022
Swale	£10/m^2 – £15/m^2	CIRIA, 2007 Environment Agency, 2007	See **Table 3-46**
Filter Strip	£2/m^2 - £4/m^2	CIRIA, 2007	
Bioretention	£55/m^3 – £65/m^3 stored volume £75/m – £99/m length £60/m^2	CIRIA, 2007	
Filter Drains	£120/m^2	Environment Agency, 2007 CIRIA, 2007	
Tree Pits	40/m^2	SuSDrain.org, 2016	
Porous Paving	£30/m^2 – £54/m^2	CIRIA, 2007 Environment Agency, 2007	

The costs may differ due to the secondary costs arising from disconnection and transfer of storm water from the existing systems. Comparisons between the variation in costs for new developments and those associated with retrofitting are limited.

3.4.7.19 Summary

Table 3-52 presents the key considerations for the use of retrofitting SuDS for nutrient offsetting or reduction.

Table 3-52 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
Delivery Timescale	Short-term
Duration of operation	Permanent

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Key considerations	
Nutrient removal	Highly variable and will likely need specific calculations
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 ■ 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	No
Precautionary	Yes
Securable in perpetuity	Yes – maintenance agreements may be required
Cost estimation	Varies, see **section 3.4.7.12** above

3.5 Wastewater management solutions

3.5.1 Expedite planned improvements to treatment works

3.5.1.1 Description of solution

Bringing forward scheduled improvements to treatment works which are planned to be online by 2025 or 2030, will lead to increased nutrient reductions above and beyond what was originally planned. 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 deadline provides temporary mitigation which is above and beyond what was originally planned.

The operational costs could be paid for through contributions to the water company, for which there is an existing mechanism to accept and spend this money, or through the Environment Agency insisting that schemes should be completed and operational at the start of AMP cycles. Upgrades are planned to the WRCs at Aylsham, Southrepps and Swardeston at the end of the current AMP cycle, i.e., by 2025.

Upgrades are planned to WRCs at Belaugh, Briston, Bylaugh-Near Church, Whitlingham, Dereham-Rushmeadow, Forncett, Hempnall-Fritton, Long Stratton, Mattishall, Reepham, Stalham, Swardeston, Saxlingham, Fakenham, Wymondham, and Aylsham by the end of the next AMP cycle, i.e., by 2030.

3.5.1.2 Nutrient removal

The potential savings that could be achieved by bringing forward upgrades planned to be in place by 2025 are presented in **Table 3-53**. Contributions to cover the operational costs could achieve 1,407.94 kg/ yr of short-term mitigation that could be utilised until December 2024. The largest reductions can be achieved at Swardeston WRCs which is unpermitted and therefore assumed to have an effluent concentration of 6mg/l.

The large population served by Aylsham also results in significant TP mitigation opportunities. Swardeston would provide mitigation in the Yare catchment, which has the largest mitigation burden, whereas Alysham and Southrepps would provide mitigation in the Bure catchment. TN reductions are uncertain and may vary between wastewater treatment works.

Table 3-53 Potential phosphorus reductions associated with upgrades to WRCs planned by 2025

WRC	TP loading under current permit limits (kg/yr)	TP loading under future permit limits (kg/yr)	TP Mitigation from bringing forward improvements (kg/yr)
Aylsham	359.5	215.7	143.8
Southrepps	115.4	22.8	92.6
Swardeston	1,246.3	74.8	1,171.5
Total	**1,721.2**	**313.3**	**1,407.9**

Contributions to cover the operational costs could achieve 1,407.9 kg/yr of short-term mitigation that could be utilised until December 2024. The largest reductions can be achieved at Swardeston WRC which is currently unpermitted and therefore assumed to have an effluent concentration of 6mg/l. The large population served by Aylsham also results in significant TP mitigation opportunities.

Swardeston would provide mitigation in the Yare catchment (which has the largest mitigation burden) whereas Alysham and Southrepps would provide mitigation in the Bure and Ant catchments, respectively. The upgrades scheduled to be in place by 2025 do not include any reductions to the TN permit limit. Therefore, it was assumed that expediting these schemes would not provide any TN mitigation.

The potential savings that could be achieved by bringing forward upgrades planned to be in place by 2030 are presented in **Table 3-54**. This demonstrates that considerable reductions in nutrient loading could be achieved (14,244 kg/yr P and 289,139 kg/yr N). The greatest benefit in reductions of both P and N would be achieved by bringing forward proposed upgrades to Whitlingham WRC, reflecting the large population served by this asset.

Improvements at Dereham-Rushmeadow, Forncett, Hempnall-Fritton, Mattishall and Saxlingham could also deliver significant benefits for P concentrations, while the greatest reductions in N concentrations could be realised through the improvement of the WRCs at Dereham-Rushmeadow, Fakenham, Wymondham, and Aylsham.

Table 3-54 Potential nutrient reductions associated with upgrades to WRCs planned by 2030

WRC	Phosphorus			Nitrogen			Catchment
	TP loading under current or 2025 permit limits (kg/yr)	TP loading under proposed 2030 permit limits (kg/yr)	TP Mitigation from bringing forward improvements (kg/yr)	TN loading under current or 2025 permit limits (kg/yr)	TN loading under proposed 2030 permit limits (kg/yr)	TN Mitigation from bringing forward improvements (kg/yr)	
Aylsham	221	92	129	10,231	3,683	6,548	Bure
Belaugh	388	83	305	9,234	3,328	5,916	Bure
Briston	78	26	52	2,818	1,015	1,804	Bure
Bylaugh-Near Church	255	30	225	3,378	1,216	2,162	Wensum
Dereham-Rushmeadow	773	229	544	25,413	9,149	16,264	Wensum

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WRC	Phosphorus			Nitrogen			Catchment
	TP loading under current or 2025 permit limits (kg/yr)	TP loading under proposed 2030 permit limits (kg/yr)	TP Mitigation from bringing forward improvements (kg/yr)	TN loading under current or 2025 permit limits (kg/yr)	TN loading under proposed 2030 permit limits (kg/yr)	TN Mitigation from bringing forward improvements (kg/yr)	
Fakenham	604	151	453	16,791	6,045	10,746	Wensum
Forncett	744	28	716	3,102	1,117	1,985	Yare
Hempnall-Fritton	663	25	638	2,762	994	1,768	Yare
Long Stratton	193	59	134	6,505	2,342	4,163	Yare
Mattishall	897	34	864	3,740	1,346	2,393	Wensum
Reepham	157	43	115	4,740	1,706	3,034	Wensum
Saxlingham	610	23	587	2,541	15	1,626	Yare
Stalham	295	77	218	5,876	3,087	2,789	Ant
Swardeston	76	47	28	5,256	1,892	3,364	Yare
Whitlingham	11,893	2,973	8,920	330,364	118,910	211,454	Yare
Wymondham	500	185	216	20,505	7,382	13,123	Yare
Total	**18,346**	**4,104**	**14,244**	**453,265**	**164,127**	**289,139**	**-**

3.5.1.3 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.

3.5.1.4 Duration of operation

This solution is a temporary solution that would provide mitigation up to the end of the AMP cycle, assumed to be online by 2025 or 2030, as planned upgrades cannot be used as mitigation. .

3.5.1.5 Applicability

This solution is only applicable to WRCs where upgrades are planned between 2025 and 2030, as highlighted in **Table 3-54**, which identifies the catchments where improvements could deliver mitigation.

3.5.1.6 Management and maintenance requirements

Normal maintenance and monitoring requirements would be fulfilled by the water company.

3.5.1.7 Additional benefits

This solution is unlikely to deliver any wider environmental benefits.

3.5.1.8 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.

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3.5.1.9 Evidence of effectiveness

The WRC upgrades will employ industry best practise in order to achieve the desired TP and TN effluent concentrations. Mandatory monitoring of effluent quality can be used to verify the intended reductions have been achieved.

3.5.1.10 Deliverability and certainty

Agreements with water companies will be required to implement this solution. These agreements will provide the certainty that the solution will be implemented and the intended timescales.

Although the improvements at individual WRCs may themselves be permanent, the solution only provides temporary mitigation up until the point the upgrades were originally scheduled to come online.

3.5.1.11 Cost estimate

Costs are uncertain and would need to be provided by AWS. It is anticipated that nutrient credits would be used to pay for, or contribute partly towards, upgrades of some of the WRCs. The likely costs associated with expediting improvements will be the operational and management costs, e.g., phosphorus dosing & energy costs, to operate to a lower permit limit.

3.5.1.12 Summary

Table 3-55 presents the key considerations for the expedition of planned improvements to WRCs in the catchment prior to 2025.

Table 3-55 Expedite planned improvements to WRCs prior to 2025 key considerations

Key considerations	
Description of solution	Bringing forward scheduled improvements to treatment works which are planned to be online by 2025 or 2030, will lead to increased nutrient reductions above and beyond what was originally planned. Upgrades to WRCs in advance of AMP deadlines and operating WRCs at the permit limit in advance of deadline provides temporary mitigation which is above and beyond what was originally planned.
Delivery timescale	Short-term
Duration of operation	Temporary – up to 2025
Nutrient removal	TP removal potential: 1,407.9 kg/yr of mitigation could be delivered assuming all three schemes come forward in 2025 14,244 kg TP/yr of mitigation could be delivered if all schemes are expedited prior to 2030 TN removal potential: 289,139 kg TN/yr of mitigation could be delivered if all schemes are expedited prior to 2030
Applicability	WRCs planned for upgrades in 2025 and 2030
Management and maintenance	Normal maintenance carried out by water company
Additional benefits	No
Best available evidence	Yes
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	Yes
Precautionary	Yes
Securable in perpetuity	Yes - the schemes would go beyond what was originally planned
Cost estimation	The costs for improving water treatment works or WRCs are uncertain as they are bespoke to facility scheme and would need to be provided by AWS on a case-by-case basis.

3.5.2 Improve existing wastewater treatment infrastructure

3.5.2.1 Description of solution

Much of the additional nutrient load from new residential and commercial development comes from the increase in wastewater production that results from the additional population occupying new developments. Raw sewage entering a municipal WRC is highly enriched in N and P. Most WRCs 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 N and P concentration and load in the final treated effluent discharged by a WRC (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 AWS and as such, a relatively small number of WRCs have tertiary treatment to remove nutrients (**Table 3-56**).

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 for N and/ or P removal by 2030. TAL concentrations for N and P in treated wastewater are 10 mg TN/L and 0.25 mg TP/L, respectively. **Table 3-56** provides an estimate of the number of WRCs that may be getting TAL upgrades by 2030. It should be noted that various of these WRCs already have nutrient stripping for P.

WRCs that are getting nutrient stripping installed either during AMP7 (to 2025) of AMP8 (to 2030), will result in a notable reduction in the amount of mitigation needed for developments that connect to these WRCs. However, these upgrades do not provide nutrient mitigation in of themselves. Improvements of existing WRCs for the purposes of nutrient mitigation would require installation of nutrient.

Table 3-56 Nutrient stripping at WRCs in the Broads and Wensum catchments currently with nutrient stripping and getting upgraded to have nutrient stripping by 2025, and the number of WRCs that may get nutrient stripping to Technically Achievable Limits

No. of WRCs	No. of WRCs with nutrient stripping currently		No. of WRCs getting nutrient stripping installed by 2025		No. WRCs that may get TAL upgrades in 2030	
80	N	P	N	P	N	P
	0	21	0	1	14	13

3.5.2.2 Nutrient removal

Tertiary treatment to remove nutrients through wastewater treatment may utilise different processes, depending on the removal technology used at a given WRC. These technologies can be grouped into biological and chemical removal. For N, nutrient stripping at WRCs predominantly relies on biological treatment technologies (Kang *et al*., 2008; Rahimi *et al*., 2020).

These biological processes may be augmented by bioelectrical stimulation of nutrient removal mechanisms (Rahimi *et al*., 2020). In general, removal mechanisms for N in wastewater treatment rely on the biochemical cycling of N that converts N from organic and ammoniacal forms through a series of chemical transformations that end with denitrification, which converts nitrate to di-nitrogen gas that is released, harmlessly, to the atmosphere. This process removes dissolved N from wastewater, reducing risks associated with N pollution in waters receiving treated wastewater discharges.

For P, both biological and physico-chemical processes can be used to strip P from wastewater (Bunce *et al*., 2018; Rout *et al*., 2021). Physico-chemical removal of P from wastewater can be achieved through three mechanisms: adsorption of dissolved P to an adsorptive media; chemical precipitation of dissolved P using

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metal salts to bond dissolved P into precipitates that settle out of treated wastewater prior discharge; and ion exchange, which takes advantage of certain chemical characteristics of dissolved P related to its predominantly negatively charged molecules, meaning dissolved P will bind with a positively charged media.

Biological P removal relies on either P uptake by phosphorus accumulating organisms in an activated sludge system, or by algae-based treatment systems. Algae-based systems have been reported to have lower treatment efficiencies and are less widely used (Bunce *et al*., 2018). The various nutrient removal technologies used in wastewater treatment have been established through extensive process engineering research and can deliver nutrient removal with high certainty.

Because nutrient stripping at WRCs is an engineered process, it is possible to place limits on nutrient concentrations in effluent discharges from a WRC. The Environment Agency are thus able to place numeric limits on the concentrations of N and P that can be discharged from a WRC where nutrient stripping technology has been installed. **Table 3-57** shows the range of P concentrations that will be enforced by the Environment Agency post-2025 and the number of WRCs at each permit level.

AWS must comply with these permit concentrations and the Environment Agency monitor the effluent discharges from each permit limited WRC to check compliance. As shown above (**Table 3-56**), there are no WRCs with N stripping in the Broads catchment. In areas of England affected by Nutrient Neutrality, the majority of WRCs with N permits are found in the Solent region, with permits in the range of 10-15 mg TN/l that need to be achieved in final effluent discharges.

Table 3-57 Permits that will be active at WRCs in the Broads and Wensum catchments post-2025

P permits post-2025 (mg/L)	Number of WRCs
0.4	1
0.6	1
0.8	2
1	13
2	4
2.5	1

The upgrade of a WRC to include nutrient stripping technology combined with a permit limited concentration of N and P in the discharge from a WRC post-upgrade provides an easy means to calculate nutrient load reductions. As a hypothetical example of the nutrient removal potential of upgrading a WRC, a worked example using the permitted dry weather flow (DWF)[14] at Weasenham St. Peter WRC in Breckland is shown below:

- DWF at Weasenham St. Peter WRC: 32m^3/day
- Assumed N and P concentrations for non-permit limited WRCs: 25mg TN/L and 6mg TP/L, respectively
- Calculate daily load from Weasenham St. Peter WRC in kg/yr:
  - For N: (25mg TN/L x 32m^3/day x 1,000)/ 106 x 365.3 = 292.2kg TN/yr
  - For P: (6mg TN/L x 32m^3/day x 1,000)/ 106 x 365.25 = 70.1kg TP/yr
- N and P concentrations if WRC is upgraded to TAL and secured with a permit: 10mg TN/L and 0.25mg TP L, respectively

[14] *The Environment Agency set DWF permits at some WRCs. This places an upper limit on the wastewater flow rate through a WRC at times when it has not been raining, hence 'dry weather flow'.*

- Calculate daily load from Weasenham St. Peter WRC in kg/yr:
  - For N: (10mg TN/L x 32m^3/day x 1,000)/ 106 x 365.25 = 116.9kg TN/yr
  - For P: (0.2 mg TN/L x 32m^3/day x 1,000)/ 106 x 365.25 = 2.9kg TP yr
- Reduction in nutrient loading due to the upgrade:
  - For N: 292.2kg TN/yr - 116.9kg TN/yr = 175.3kg TN/yr
  - For P: 70.1kg TP/yr - 2.9kg TP/yr = 67.2kg TP/yr

It should be noted that a WRC may not discharge at its DWF constantly, so the above calculations may not represent the actual nutrient reductions that would be achieved by an upgrade of Weasenham St. Peter WRC. However, this worked example illustrates how an upgrade would result in nutrient load reductions to the Wensum and Broads SACs, with these load reductions usable as mitigation for new development.

3.5.2.3 Delivery timescale

Nutrient stripping upgrades at WRCs are normally delivered as part of AMP cycles. These cycles last five years, however the allocation of funding for WRC upgrades is done through the Ofwat Price Review (PR) process which starts around two years into an AMP cycle allocate funding for the following AMP. Water companies started work on PR24 in 2022, with PR24 completing in 2024 when water companies will finalise spending commitments on WRC upgrades and other work programmes for the period 2025-2030.

This means WRC upgrades funded as part of AMP cycle investments take between seven to eight years to be delivered. If nutrient stripping upgrades could be funded outside of the AMP cycle, then they may be able to be delivered faster. However, the significant requirements for design, environmental assessments and planning permission will mean that an upgrade scheme would still be likely to take three to four years at least.

3.5.2.4 Duration of operation

WRC upgrades are an engineered solution that should be able to deliver mitigation in perpetuity, assuming that wastewater treatment infrastructure is properly operated and maintained. Operation of WRCs by a water company, i.e., AWS, should provide confidence that nutrient stripping infrastructure at a WRC will be properly managed and maintained in the long-term.

3.5.2.5 Applicability

As can be seen in **Table 3-56**, there are around 69 WRCs in the Broads and Wensum catchments that do not have nutrient permits. This means there are a lot of potential opportunities for WRC upgrades to deliver nutrient mitigation. However, nutrient stripping upgrades require significant capital and operational expenditure.

There is a need to work closely with AWS to determine which of the numerous WRCs that could be upgraded would pass a cost-benefit analysis as many of them are very small and would not generate much mitigation given the costs associated with the scheme. The high costs associated with upgrades to WRCs also mean there is a need to ensure that an upgraded WRC would provide mitigation to a large area of the affected catchments.

Installation of a WRC upgrade requires land for new infrastructure. Lots of small WRCs have limited to no additional land within the curtilage of an existing site, which would make a site unfeasible if land around the existing WRC infrastructure cannot be acquired. Limitations around cost, locations to serve a large catchment area and land availability means that although there are a lot of potential sites for WRC upgrades in the affected catchment areas, the actual number of viable sites might be a lot smaller.

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3.5.2.6 Management and maintenance requirements

Nutrient stripping technologies and WRCs more generally require management and maintenance by skilled operators. As such, there is a need for nutrient stripping upgrades to be owned by a water company, i.e., AWS, as these companies have skilled resources with the capability to manage and maintain nutrient stripping infrastructure at a WRC.

For P removal using chemical dosing, there is a need for considerable input from WRC operators to use the correct chemical dosage to maintain P removal processes at the required level. The significant long-term management and maintenance requirements for WRCs and nutrient stripping infrastructure result in a considerable operational expenditure that would need to be factored into the costs of this mitigation solution.

3.5.2.7 Additional benefits

Nutrient stripping upgrades at WRCs are 'grey' infrastructure and have no additional benefits besides nutrient removal. Indeed, nutrient stripping upgrades tend to have associated negative impacts on the environment. Increased wastewater treatment has previously been estimated to result in over 110,000 tonnes per year of additional CO_2 emissions (Georges *et al*., 2009). Increased carbon emission result from both the construction and operational phases of a WRC upgrade.

There are also additional water quality issues that result from chemical dosing for P removal, especially where aluminium-based metal salts are used to remove P by precipitation, as increased aluminium concentrations in discharges from WRCs can cause ecotoxicity risks, particularly for fish. Where wetlands/ reed beds are proposed as a form of tertiary treatment, the additional benefits are expected to be limited.

3.5.2.8 Wider environmental considerations

Installation of nutrient stripping technology at a WRC requires engineering works that will in turn require planning permission. Planning applications need to be supported by a range of environmental assessments, including:

- FRA – assessing risks of flooding during both construction and operational phases of a WRC upgrade;
- Hydrogeological impact assessment – assessing the groundwater impacts of any excavation works and subsurface infrastructure;
- HRA – assessing potential impacts of the proposed works on designated sites, both from construction and operation;
- WFD assessment – assessing potential impacts on WFD waterbodies that may result from a change in water quality in a WRC discharge; and
- Construction works will require a Construction and Environmental Management Plan (CEMP) to reduce risks on the environment associated with the construction phase of a WRC upgrade project.

3.5.2.9 Evidence of effectiveness

Nutrient stripping upgrades to WRCs utilise process engineering approaches that are supported by a significant evidence-base that shows their effectiveness. The evidence-base for the effectiveness of nutrient stripping is sufficient for the Environment Agency to proscribe numerical permits to control nutrient concentrations in the discharges from WRCs.

3.5.2.10 Deliverability and certainty

Assuming that nutrient stripping upgrades can be delivered as nutrient mitigation solution for Nutrient Neutrality, they have high certainty due to the engineered nature of the solution. Deliverability is likely to hinge on how to route funding to AWS to pay for upgrades. AWS will have the expertise to deliver nutrient stripping upgrade schemes, but the Water Sector's highly regulated funding mechanisms may make it problematic to get money from developers to AWS.

There may also be short-term resource issues within AWS, as they would need to find staff to support nutrient stripping upgrade projects which are not part of the existing programme of work they are currently planning. Lack of resource may delay the delivery nutrient stripping upgrade projects for the purpose of Nutrient Neutrality.

3.5.2.11 Cost estimate

Costs for nutrient stripping upgrades at WRCs vary, however most projects are likely to cost in excess of £1 million and costs for upgrades will increase with the size of the required upgrade scheme. During the current AMP cycle (AMP7), £2.2 billion has been earmarked to deliver around 1,000 P removal schemes[15], resulting in an approximate average cost of £2.2 million per WRC upgrade scheme.

This cost aligns closely to values reported by AWS for PR19 spending on P removal schemes, which is estimated at an average of £2.8 million per scheme[16]. United Utilities have reported higher costs for P removal schemes at their WRCs, which are estimated to average £5.1 million per P upgrade scheme over AMP7[17]. These values highlight the significant costs associated with WRC nutrient stripping upgrade schemes.

3.5.2.12 Summary

Key considerations for improving existing wastewater treatment infrastructure are summarised in **Table 3-58.**

Table 3-58 Improving existing wastewater treatment infrastructure key considerations

Key considerations	
Description of solution	Much of the additional nutrient load from new residential and commercial development comes from the increase in wastewater production that results from the additional population occupying new developments. Raw sewage entering a municipal WRC is highly enriched in N and P The LURB is proposing a mandate for all WRCs that serve more than 2000 people to be upgraded for N and/ or P removal by 2030. However, these upgrades do not provide nutrient mitigation in of themselves. Improvements of existing WRCs for the purposes of nutrient mitigation would require installation of nutrient stripping at WRCs that are not scheduled for an upgrade as part of current programmes of work
Delivery timescale	Minimum is likely to be three to four years, with delivery through AMP cycles likely to take seven to eight years
Duration of operation	80+ years, assuming the system managed and maintained
Nutrient removal	TP removal potential: Technically achievable limit of 0.25 mg TP/ L in treated effluent, equivalent to > 90% removal efficiency TN removal potential: Technically achievable limit of 10 mg TN/ L in treated effluent, with removal efficiencies generally > 70%
Applicability	Around 69 WRCs in the Broads and Wensum catchments
Management and maintenance	Management and maintenance required by skilled professionals working for a water and sewerage company.

[15] https://www.processindustryinformer.com/managing-the-cost-of-phosphorous-removal-in-amp7/, *accessed on: 17/01/2023*
[16] https://www.anglianwater.co.uk/siteassets/household/about-us/05-pr19-wastewater-data-tables-commentary.pdf, *accessed on 17/01/2023*
[17] https://www.unitedutilities.com/globalassets/z_corporate-site/pr19/supplementary/s6027_enhancement_wastewater_1.pdf, *accessed on 17/01/2013.*

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Key considerations	
Additional benefits	None
Wider environmental considerations	Installation of nutrient stripping technology at a WRC requires engineering works that will in turn require planning permission. Planning applications need to be supported by a range of environmental assessments, including: ■ FRA ■ Hydrogeological impact assessment ■ HRA ■ WFD assessment ■ CEMP
Best available evidence	Yes
Evidence of effectiveness	Yes
Precautionary	Yes
Securable in perpetuity	Yes – assuming appropriate management and maintenance
Cost estimation[18]	Variable depending on the size of a scheme, with an estimated average of £2.8 million per scheme

3.5.3 Improve existing wastewater distribution infrastructure (reduce leakage from foul sewer network)

3.5.3.1 Description of solution

Due to the age of water distribution networks in the UK, leakage from sewer and (drinking) water mains are a potential source of groundwater nutrient pollution (Reynolds & Barrett, 2003). 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 and drinking water in water distribution networks means leaks can create sources of N and P to the River Wensum and the Norfolk Broads designated sites.

Studies of nutrient pollution in groundwater often cite sewer and mains water networks as sources of N and P, 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.

3.5.3.2 Nutrient removal

The mechanism for nutrient removal by reducing leakage from sewer and water mains is simple, leakage is a source of nutrients and reducing leakage reduces an anthropogenic source of nutrients to the environment. 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 (Goody

[18] *Environment Agency. 2015. Cost estimation for land use and run-off – summary of evidence (Report –SC080039/R12). (https://assets.publishing.service.gov.uk/media/6034eefdd3bf7f264e517436/Cost_estimation_for_land_use_and_run-off.pdf)*

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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, with results for the Anglian River Basin District (RBD) suggesting leakage could account for as much as 100.3t P/yr (Ascott *et al*., 2016).

This study also estimated the amount of P from leaking water mains that may follow faster flow pathways to reach surface water more quickly vs the amount that may enter groundwater. They suggested that in the Anglian RBD, 84.2t P/yr may flow to surface water, with 16.1t P/yr reaching groundwater and thus taking longer to reach surface water bodies. 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.

3.5.3.3 Delivery timescale

There are two components to the delivery timescale for leakage reduction schemes. Firstly, there is the time taken to complete the actual infrastructure works. When AWS respond to emergency leaks, they will often fix the leak within 24 hours[19]. This shows that the process of repairing leaking sewer and water mains is not a barrier to fast deployment. The larger time requirement is likely to come from finding leaking sewers and water mains. AWS have invested in technological advances to help detect leaks[20], but it is not clear how long leak identification and location processes take.

There is also a potential need to factor in additional time to schedule leak reduction work for nutrient mitigation if it is being delivered by AWS on top of existing leak reduction programmes being delivered through the AMP cycle. Using contractors external to AWS to find and fix leaks may reduce any delays related to scheduling leakage reduction works but would require engagement with AWS to get access to their assets. 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.

The second consideration related to delivery timescales is how lag times may affect how long it takes for nutrient removal by leakage reduction to have an impact on the Wensum or Broads designated sites. Water leaking from sewer and water mains enters subsurface flow pathways. The time taken for water to traverse these pathways before discharge to surface water is highly variable and depends on local geological conditions and the distance from the site of the leak to the nearest surface water body.

It is noted that Ascott *et al*., (2016) suggest P loads from leaking water mains may largely reach surface waters quickly in the Anglian RBD, but it is also noted that much of the western half of the affected catchment area is underlain by chalk geology which supports higher rates of water transfer to deeper groundwater with associated increases in lag times.

Where leaks do enter deeper groundwater, there may be a lag of years to decades before an impact on N and P loading to receiving surface waters in the Wensum and Broads designated sites may be seen, which in turn means there may be a lag time before the nutrient removal from fixing leaks starts to yield a benefit to receiving waters. This lag time issue should be considered in proposals for leakage reduction as a means of providing nutrient mitigation.

[19] *https://www.anglianwater.co.uk/services/water-supply/leakage/, accessed on 27/01/2023.*
[20] *https://www.anglianwater.co.uk/environment/investing-in-the-future-of-water/finding-and-fixing-leaks/*

3.5.3.4 Duration of operation

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[21]. New sewer pipes have been suggested to have a lifespan of over 100 years[22].

This indicates that based on pipe materials, fixing sewer leaks may provide nutrient mitigation in perpetuity (> 80 years) but fixing water mains may not. Furthermore, failure of pipe materials is not the only reason for leaking sewers and water mains. Improper installation and ground movements can also contribute to pipe failures and leakage (Wakida & Lerner, 2005), both of which are hard to predict and thus add uncertainty to the duration of a fixed leak.

Owing to the unpredictable nature of pipe failures and associated leakage, it is hard to say with confidence that reducing leakage from sewers and water mains will provide an in perpetuity nutrient mitigation measure.

3.5.3.5 Applicability

AWS maintains a network of 76,000 km of sewers and 38,185 km of water mains[23], meaning there will be plenty of opportunities within the Broads and Wensum catchments to fix leaking sewer and water mains to provide nutrient mitigation. Because of the density of water distribution networks in urban areas, the nutrient pollution associated with leakage is generally concentrated in these areas (Ascott *et al*., 2016). As such, reducing leakage from sewers and water mains will be best targeted in towns and cities within the affected catchment areas.

The issue of lag times related to local geological conditions should also be considered. If local geology means nutrient mitigation from reducing leakage will not impact the Wensum or Broads designated sites for years or even decades, it is less applicable as a nutrient mitigation measure in these areas, at least to target the immediate problem caused by the requirement for Nutrient Neutral development.

Using leakage reduction as part of a wider set of measures for long-term strategic solutions to the underlying diffuse pollution issues that are causing failure of nutrient targets in the Broads and Wensum designated sites will be less sensitive to the issues that may be posed by lag times.

3.5.3.6 Management and maintenance requirements

Prevention is better than the cure and as such, AWS are putting considerable effort into preventing leaks in the first place rather than having to fix them when they occur[24]. A leakage reduction scheme for the purposes of nutrient mitigation should include management and maintenance plans that help to prolong the life of the repaired pipe, such as using pressure management in water mains, and using technology20 to detect pipe defects before they result in leaks.

This will help to increase the duration of operation for a leakage reduction nutrient mitigation scheme and could help the scheme to achieve mitigation in perpetuity. Given the specialist requirements for fixing leaks from sewer and water mains, and the ownership of these assets by AWS, management and maintenance will need to be conducted by AWS and their contractors, with an allowance for this work in the costs for leakage reduction scheme for nutrient mitigation.

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[21] *https://ukwir.org/long-term-aging-of-polyethylene-*
[22] *https://piperehabspecialists.com/how-long-do-sewer-pipes-last/ and https://www.drainmasterohio.com/how-long-do-sewer-lines-last/, accessed on 27/01/2023*
[23] *https://www.anglianwater.co.uk/about-us/media/fast-facts/, accessed on 27/01/2023*
[24] *https://www.anglianwater.co.uk/services/water-supply/leakage/pressure-management/ and https://www.anglianwater.co.uk/news/anglian-water-first-water-company-in-uk-to-trial-new-leakage-tech-in-live-water-mains/, accessed on 27/01/2023*

3.5.3.7 Additional benefits

There are limited additional benefits from leakage reduction schemes. The key additional benefit is a reduced need for abstraction for water supply from reducing leakage from water mains. As the Anglian RBD is a water scarce area of England, reducing abstraction from surface water and groundwater is a particular priority that can have a variety of associated benefits for the health of aquatic ecosystems. Reduction in leakage, particularly from sewers, will also result in a reduction in other forms of water pollution such as microbiological contamination of groundwater and surface water.

3.5.3.8 Wider environmental considerations

Leakage reduction requires engineering works that, due to most sewer and water mains being laid under roads, are likely to require street works. This may require a street works permit; however, utility companies are often exempt from needing to apply for street works permit. Consideration should be given to minimising traffic disruption due to street works required for fixing leaking pipes.

Construction work should also consider wider environmental impacts that could result from excavation work and the use of plant machinery that may mobilise fine sediment and/ or result in hydrocarbon or other chemical pollution. A CEMP may be needed to support leakage reduction works and reduce these risks.

3.5.3.9 Evidence of effectiveness

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. Most of these studies provide details on the potential N or P load that results from sewer and water main leakage, which is evidence of the potential effectiveness of leakage reduction as a nutrient mitigation measure. However, reducing leakage does not translate to a direct reduction of N and P inputs to receiving groundwater or surface waterbodies.

Nutrient pollution from leaking sewer and water pipes will travel through soil and rock layers, which will cause some attenuation of the nutrient load due to P sorption to soils and sediment and loss of N through denitrification. There is a significant range in the potential reductions in nutrient load that will occur along subsurface flow pathways, with studies citing P removal efficiencies from 0.4% to 99% for different types of soil and sediment (Penn *et al*., 2017), while denitrification rates will vary markedly depending on whether leakage from sewers and water mains encounters a mix of oxic and anoxic subsurface conditions.

Proposals for nutrient mitigation schemes using leakage reductions should provide a consideration of the reduction in the nutrient 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.

3.5.3.10 Deliverability and certainty

Fixing leaking sewers and water mains is standard construction and engineering process that is frequently delivered by AWS and other skilled contractors. Assuming AWS and/ or skilled contractors can provide resource to complete leakage reduction works, these schemes are highly deliverable from a practical perspective. Barriers to deliverability may be encountered in any schemes that involve routing funding from developers to AWS to finance leakage reduction works.

Leakage reduction is targeted by Ofwat, with performance commitments, programmes of work and associated budgeting from water companies that may make it hard to finance leakage reduction nutrient mitigation schemes with developer contributions. As detailed above, reduction in N and P associated with nutrient removal processes in soils means that leakage reduction schemes will need to have consideration of the actual nutrient reduction benefit for receiving waterbodies.

Owing to the complexity of the nutrient reduction processes that can occur along subsurface flow pathways, this will add some uncertainty to estimates of nutrient reductions that can be achieved by a leakage reduction scheme. Suitably precautionary estimates of the reduction in N and P from leakage reduction, accounting for hydrogeological factors, will be needed as part of proposals for a nutrient mitigation using leakage reduction.

3.5.3.11 Cost estimate

In the current AMP cycle (AMP7), AWS proposed £136.9 million in costs to maintain their current leakage performance, based on data from 2017 that showed leakage of 5m^3/km/day from water mains[25]. Further analysis suggests that to reduce leakage by 27 Ml/d would cost £27.4 million per year, or around £1 million per 1 Ml/d. Based on an average P concentration in drinking water of 1mg P/l (Gooddy *et al*., 2015) and N concentrations of 5.2 mg N/l (Wakida & Lerner, 2005), this suggests:

- 1 Ml/d leaked drinking water = 1kg P/d and 5.2 kg N/d = 365 kg P/yr and 1,898 kg N/yr.
- Cost of reducing 1Ml/d leakage is ~ £1 million, therefore it would cost ~£1 million to reduce 365 kg P/yr and 1,898 kg N/yr, assuming no attenuation of N and P on subsurface flow pathways (see above).

These costs are indicative and will vary depending on project-specific costs, the actual concentration of N and P in leaked water and the degree of potential attenuation. For example:

- Assume leakage follows subsurface pathways that result in a 60% reduction P load and 35% reduction in N load before leaked water reaches the Wensum or Broads designated sites.
- 1 Ml/d leaked drinking water = 365 kg TP/ yr * 0.4 and 1,898 kg TN/yr *0.65 = 146 kg TP/yr and 1,234 kg TN/yr reduction in nutrient loading to a designated site.
- Costs may be closer to ~£1m for mitigating 146 kg TP/yr and 1,234 kg TN/yr.

Again, these costs are indicative and intended to highlight the potential variation in costs for leakage reduction mitigation schemes. It is also noted that data on costs for fixing sewer leaks have not been found but that due to the higher concentrations of N and P in raw sewage relative to drinking water, targeting leakage reductions on mains sewers may be more a cost-effective approach to nutrient mitigation.

3.5.3.12 Summary

Key considerations for the improvement to the existing water distribution infrastructure (reduce leakage from foul sewer and main water network) is summarised in **Table 3-59**.

Table 3-59 Improvement to the existing water distribution infrastructure (reduce leakage from foul sewer and main water network) key considerations

Key considerations	
Description of development	Water mains are a potential source of groundwater nutrient pollution due to water. Nutrient enrichment of wastewater and drinking water in water distribution networks means leaks can create sources of N and P to the River Wensum and the Norfolk Broads designated sites. Fixing leaks from water distribution networks can reduce nutrient inputs to the environment and provide mitigation.
Delivery timescale	Completion of infrastructure works < 1 year. Lag times due to hydrogeology may mean impact from mitigation scheme is not seen for years to decades
Duration of operation	Pipe materials may last > 80 years but pipe failures due to ground movements and other factors mean duration may be < 80 years

[25] https://www.anglianwater.co.uk/siteassets/household/about-us/leakage-cost-adjustment-claim.pdf, *accessed on 27/01/2023.*

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Key considerations	
Nutrient removal	TP removal potential: 365kg P/yr and 4,380kg P/yr from reducing 1 Ml/d of leakage from drinking water and sewer mains, respectively. This is based on published concentrations of P in drinking water and raw sewage and does not account for attenuation TN removal potential: Leaking water mains could cause loading of 7.7kg N/ha/yr, leaking sewers may cause loading of 2.7kg N/ha/yr, based on data from Nottingham. These estimates do not account for attenuation.
Applicability	Water mains
Management and maintenance	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
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
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
Precautionary	Yes, assuming allowance for attenuation of N and P on subsurface flow pathways
Securable in perpetuity	Yes, assuming robust maintenance and management plans
Cost estimation	~£1 million to reduce 365 kg P/yr and 1,898 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

3.5.4 Install portable treatment works

3.5.4.1 Description of solution

Portable treatment works can be used as a secondary treatment system designed specifically for nutrient removal (**Table 3-60**). They are typically used by water companies during upgrades. One container can typically serve up to 20,000 PE. The containers are modular so can be used in parallel to handle variable flows.

They are typically built inside standard 20ft shipping containers making them easy to install and move to another site (**Figure 3.14**). They could 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.

Figure 3.14 Example of a portable containerised wastewater treatment works (Source: Vikaspumps.com)

Technically, the portable treatment works can be used for treating river water. However, there may be some difficulties in preventing plants, fish, and invasive species from entering the system and pre-treatment would be needed. In this case, the systems could be used on proposed wetland creation sites during the design and construction phase to deliver short-term nutrient mitigation. Agreement with AWSis likely to be required to link the current WRC effluent to the portable treatment works. Adjacent land rental may also be required.

3.5.4.2 Nutrient removal

Using portable treatment works whilst WRCs are undergoing infrastructure upgrades could reduce phosphorus effluent to 0.5mg/l. This would represent a large decrease from unpermitted sites which are assumed to operate at 6mg/l. For example, using portable treatment works at Swardeston could achieve a short-term phosphorus reduction of 1,156 kg/yr TP, equivalent to 17,046 new dwellings draining to a WRC with a permit limit of 1mg/l, e.g., Whitlingham.

The purchase cost of the portable treatment works is £50,000, and the plants have an assumed lifetime of 40 years. Therefore, two portable treatment works would need to be purchased, bringing the total cost to £100,000. Maintenance would be £2,000 p/a over the lifespan of 80 years, bringing the total to £160,000 for the lifetime of the treatment works.

The average value of arable land in Norfolk is approximately £23,500 per hectare (Strutt & Parker, 2022), and so constitutes the approximate assumed cost of purchasing a 1ha site for the treatment works. Therefore, the total cost of the portable treatment works over a 1ha area would equal approximately £283,500. The greatest phosphorus reductions will be achieved through installing portable treatment works to existing WRC which do not have phosphorus stripping technologies coupled with those serving a large population. Examples are included in **Table 3-60.**

Table 3-60 Potential phosphorus reductions associated with portable treatment works

Wastewater Treatment works	TP loading under current permit limits (kg/yr)	TP loading portable treatment works (kg/yr)	TP Mitigation (kg/yr)	Dwelling equivalent
Swardeston	1,261.5	105.1	1,156.4	17,047
Shipdham	469.1	39.1	430	6,339
Stoke Holy cross	382.1	31.8	350.3	5,163

Wastewater Treatment works	TP loading under current permit limits (kg/yr)	TP loading portable treatment works (kg/yr)	TP Mitigation (kg/yr)	Dwelling equivalent
Saxlingham	609.9	50.8	559.1	8,242
Total	**2,722.6**	**226.9**	**2,495.7**	**36,791**

The upgrades are likely to have some impact on N effluent concentrations. However, there is greater uncertainty of the final effluent concentrations.

3.5.4.3 Delivery timescale

Portable treatment works 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 direct discharges from the portable treatment works.

3.5.4.4 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 portable treatment works to be used over longer timescales as an impermanent solution, although costs may be proportionately high.

3.5.4.5 Applicability

This solution is most likely to be applicable for use in a WRC alongside existing treatment equipment.

3.5.4.6 Management and maintenance requirements

Some maintenance of the system required to an equivalent of a few hours a week.

3.5.4.7 Additional benefits

This solution is unlikely to deliver any wider environmental benefits.

3.5.4.8 Wider environmental considerations

The use of portable treatment works could potentially have implications for the local population depending on its placement within and the size of the WRC, including visual impact, noise, and odour. Energy use may also be an important consideration. Disposal of waste produced by the portable works may need to be removed and handled appropriately. There is the potential for the waste to be applied as a replacement to imported fertiliser.

3.5.4.9 Evidence of effectiveness

The manufacturers of portable treatment plants have undertaken detailed testing of their performance and are able to provide certainty regarding the level of nutrient removal that can be achieved.

3.5.4.10 Deliverability and certainty

Agreements with water companies will be required to implement this solution. These agreements will provide the certainty that the solution will be implemented and the intended timescales. Consultation would also be required with the Environment Agency who are the regulatory body overseeing the permit limits of WRC. Permitting timetables are expected to be three to six months.

3.5.4.11 Cost estimate

Given the bespoke nature of the systems for nutrient removal, it is likely that the systems would need to be purchased. Rental is available for standard portable treatment works systems, but it is unlikely to be available for bespoke systems which are likely to be required in this case to achieve the nutrient effluent concentrations.

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Capital costs vary depending on the size of the potable treatment plant. Costs are expected to range from between £10,000 for treatment at small WRCs and £100,000 for treatment at the larger WRCs. Maintenance costs of £1,000 - £5,000 per year are expected but vary depending on the size/ number of potable treatment plants.

3.5.4.12 Summary

Table 3-61 presents the key considerations for the installation of portable treatment works for nutrient reduction.

Table 3-61 Portable treatment plant key considerations

Key considerations	
Description of solution	Portable treatment works can be used as a secondary treatment system designed specifically for nutrient removal. They could 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	Short-term
Duration of operation	Temporary
Nutrient removal	TP removal potential: Effluent to 0.5mg/l can be achieved. This can apply to all existing houses served by the WRC TN removal potential: TN effluent concentrations are uncertain
Applicability	This solution is most likely to be applicable for use in a WRC alongside existing treatment equipment
Management and maintenance	Some maintenance on the system is required, equivalent to a few hours a week
Additional benefits	Water quality improvements
Best available evidence	Yes
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 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	Yes
Precautionary	Yes
Securable in perpetuity	Yes
Cost estimation	Capital costs £10,000 - £100,000 depending on size. Maintenance costs £1,000 - £5,000 a year

3.5.5 Rectifying misconnections to combined systems

3.5.5.1 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.

3.5.5.2 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[26]. It is unlikely that there will be many opportunities for monitoring misconnections to retrieve meaningful data on the nutrient reductions.

3.5.5.3 Delivery timescale

Rectifying a misconnection to a surface water drain can be established in the short term.

3.5.5.4 Duration of operation

Once the misconnection has been remediated, it is assumed to be a permanent drainage and nutrient management solution.

3.5.5.5 Applicability

This solution could be applied to existing properties in order to provide mitigation for new dwellings.

3.5.5.6 Management and maintenance requirements

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.

3.5.5.7 Additional benefits

The rectifying of misconnected surface water drainage networks will reduce the volume of pollutants entering the clean water system of the catchment.

3.5.5.8 Wider environmental considerations

The rectifying of misconnections is unlikely to be significantly constrained by wider environmental factors.

3.5.5.9 Evidence of effectiveness

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.

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

3.5.5.10 Deliverability and certainty

The rectifying of misconnections to surface water drainage networks are permanent features which will typically provide benefits for the lifetime of the development. 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.

3.5.5.11 Cost estimate

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.

3.5.5.12 Summary

Table 3-62 presents the key considerations for rectifying misconnection to the surface water drainage network for nutrient offsetting or reduction.

Table 3-62 Rectifying misconnections to the sewers key considerations

Key considerations	
Description of development	Misconnections occur 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
Delivery Timescale	Short-term
Duration of operation	Permanent
Nutrient removal	Highly variable and will likely need specific calculations
Management and maintenance requirements	Correction of the misconnection is the duty of the property owner. The local water company will ensure the correction is performed satisfactorily
Applicability	Existing properties
Additional benefits	None
Best available evidence	No – Generic assumptions are likely to be required. Monitoring, where possible, can be used to determine the actual efficacy of specific schemes
Wider environmental considerations	The rectifying of misconnections is unlikely to be significantly constrained by wider environmental factors
Evidence of effectiveness	Yes
Precautionary	Yes
Securable in perpetuity	Yes
Cost estimation	Varies

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3.5.6 Promote connection to PTPs

3.5.6.1 Description of solution

Foul drainage should be connected to a public foul sewer wherever this is reasonably practicable. Small developments connection should be made to a public sewer where the main network is within 30m. This is on the provision that the developer has the right to construct the foul drainage over any intervening private land. For larger developments it may be economic to connect to a public sewer even where the sewer is some distance away. Some developments are connected to combined systems which increases the loading of phosphates and nutrients on the current system.

The Environment Agency will decide what's reasonable based on:

- How close the site is to an existing public foul sewer
- The cost of connecting to a public foul sewer compared with the cost of installing a sewage treatment system
- Whether there's anything in the landscape that would stop a connection to the public sewer - for example a large road
- Whether sewage treatment system would have any environmental benefits - for example if it reuses treated effluent

Under present guidance, the Environment Agency will not provide a permit for a sewage treatment system if it's reasonable to connect to the public foul sewer. However, many rural WRCs do not have any nutrient stripping currently or planned for the future. As a result, the nutrient loads from these WRCs can be significantly higher than those from a PTP (particularly with additional P stripping).

Therefore, overriding the current regulations would reduce nutrient loads from wastewater in these cases. This solution only applies to new dwellings and does not propose to disconnect existing properties from the mains.

3.5.6.2 Nutrient removal

The River Wensum SAC & Broads SAC Nutrient Budget Calculator has been utilised to calculate the potential savings of disconnecting from a sewer system that does not connect to a treatment works that has P stripping technology. The treatment works that are listed do not have nutrient stripping technology currently and it is not planned to be installed by 2030. To calculate the PTP loading, 0.50 mg/l for the P discharge level has been selected as this is the average value for PTP with P stripping technology.

Table 3-63 2030 loadings vs PTP loadings for phosphorous

Treatment works	Dwellings expected (2023-2038)	Current Discharge (mg/l)	Current loading (kg/yr)	2030 Discharge concentration (mg/l)	2030 loading (kg/yr)	PTP loading (kg/yr)	Saving (kg/yr)
Ashwellthorpe	12	6	5.4	6	5.4	0.5	5
Barnham Broom	45	6	20.4	6	204	1.7	18.7
Corpustry	19	6	8.6	6	8.6	0.7	7.9
Hockering	85	6	38.4	6	38.4	3.2	35.2
Roughton	24	1.3	2.4	1.3	2.4	0.9	1.5
Rackheath	265	1.8	36	1.8	36	10	26

Treatment works	Dwellings expected (2023-2038)	Current Discharge (mg/l)	Current loading (kg/yr)	2030 Discharge concentration (mg/l)	2030 loading (kg/yr)	PTP loading (kg/yr)	Saving (kg/yr)
Shipdham	381	6	172.5	6	172.5	14.5	158.2
Total	**831**	**-**	**283.7**		**283.7**	**31.3**	**252.4**

Table 3-63 shows that installing PTP with P stripping technology allows for a saving of 252.37 kg/yr of P. It is assumed that PTPs would have a similar TN effluent concentration to WRCs. Therefore, no mitigation would be achievable.

3.5.6.3 Delivery timescale

The installation time of a new PTP can vary but can be established within the short term.

3.5.6.4 Duration of operation

Once the PTP has been installed, it is assumed to be a long-term drainage and nutrient management solution.

3.5.6.5 Applicability

This solution could significantly reduce the mitigation required to reduce excess nutrient loading from developments.

3.5.6.6 Management and maintenance requirements

Management of the PTP will be undertaken by the homeowner. Where additional P stripping is used, this should be carried out in accordance with instructions.

3.5.6.7 Additional benefits

The disconnection from main sewers will reduce the number of pollutants entering the catchment.

3.5.6.8 Wider environmental considerations

The disconnection from main sewers is unlikely to be significantly constrained by the wider environmental factors.

3.5.6.9 Evidence of effectiveness

Accredited and tested PTPs provide sufficient certainty of the achievable effluent concentrations in order to calculate the nutrient mitigation achieved.

3.5.6.10 Deliverability and certainty

The disconnection from the main sewer is often a permanent feature which typically provide benefits for the lifetime of the development. Consultation with Natural England and the Environment Agency would be needed to agree locations where there is a clear benefit from connecting to PTPs rather than the mains, in order to overcome the existing guidance.

3.5.6.11 Cost estimate

The cost of a new package treatment plan with phosphate stripping tech can vary around £10,000. Costs may differ due to secondary costs arising from the installation and running costs.

3.5.6.12 Summary

Table 3-64 presents the key considerations for disconnection from main sewers for nutrient offsetting or reduction.

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Table 3-64 Disconnection from main sewers key considerations

Key considerations	
Description of solution	Foul drainage should be connected to a public foul sewer wherever this is reasonably practicable. Small developments connection should be made to a public sewer where the main network is within 30m. Some developments are connected to combined systems which increases the loading of phosphates and nutrients on the current system. The Environment Agency will decide what's reasonable based on: ■ How close the site is to an existing public foul sewer ■ The cost of connecting to a public foul sewer compared with the cost of installing a sewage treatment system ■ Whether there's anything in the landscape that would stop a connection to the public sewer - for example a large road ■ Whether sewage treatment system would have any environmental benefits - for example if it reuses treated effluent
Delivery timescale	Short term
Duration of operation	Long term
Nutrient removal	TP removal potential: 252.4 kg/yr
Applicability	Dwellings
Management and maintenance	Homeowner
Additional benefits	None
Best available evidence	Yes
Wider environmental considerations	The disconnection from main sewers is unlikely to be significantly constrained by the wider environmental factors
Evidence of effectiveness	Yes
Precautionary	Yes
Securable in perpetuity	Yes
Cost estimation	£10,000 for the installation of the package treatment plant. Maintenance and running costs can vary

3.5.7 Use alternative wastewater treatment providers

3.5.7.1 Description of solution

New Appointments and Variations (NAV) are companies that provide sewerage services to customers in an area which is currently or previously provided by the incumbent monopoly provider. These companies are Ofwat regulated. Companies that are not defined by region and that can operate anywhere in England and Wales could potentially provide alternative wastewater solutions.

Alternative WRCs providers will treat foul drainage from new developments by designing, consenting, and building an alternative treatment works. They are typically reserved for large developments (minimum 500 dwellings). It is possible for multiple customers to make up the numbers to the minimum number of dwellings, however, due to the significant cost of laying pipework (£1 million per km), the sites need to be adjoining.

The sewage effluent would not outfall would need to be in close proximity to a watercourse and would not rely on any existing AWS infrastructure. The maintenance of the treatment works would be paid for via normal foul drainage bills. However, the WRC would need to be located within the boundary of the development it is serving or on adjacent land under the same ownership.

Using alternative wastewater providers would be most applicable where a development is currently proposed to connect to a WRC with no or limited nutrient stripping currently or in the future. Alternative providers would be able to build bespoke treatment works which can achieve the desired effluent concentrations and outperform the proposed WRC.

3.5.7.2 Nutrient removal

The alternative WRC providers build bespoke plant for developments which includes nutrient stripping. Assuming this solution is used on a housing development of approximately 500 dwellings, draining to a WRC of 1mg/l, this could deliver a phosphate reduction of 10.8kg/yr.

With an expected cost of £1,950,000 this solution could be delivered at a cost of £180,000 per kg/yr. N has not been considered in this solution as the alternative wastewater providers did not provide a TN concentration.

3.5.7.3 Delivery timescale

Setting up an alternative wastewater provider typically takes up to three years to deliver and set up; they can be implemented over a long timescale. The WRC would need to comply with permits and ensure that visual and odour impacts are limited.

3.5.7.4 Duration of operation

This solution is a permanent solution.

3.5.7.5 Applicability

This solution would not completely mitigate excess nutrient loading from developments and mitigation would still be required through other solutions. However, it could significantly reduce the mitigation required which could potentially be addressed through on-site measures such as SuDS.

3.5.7.6 Management and maintenance requirements

The management and maintenance will be provided by the local operator. The maintenance of this system is paid through foul drainage bills.

3.5.7.7 Additional benefits

Can be integrated with SuDS to deliver flood risk benefits and amenity space.

3.5.7.8 Wider environmental considerations

Implementing this scheme is unlikely be significantly constrained by the wider environment.

3.5.7.9 Evidence of effectiveness

Phosphorus effluent concentrations of 0.5mg/l are achievable, which is very close to industry best removal rates. The evidence of effectiveness for the removal of TN cannot be calculated as the wastewater providers did not provide the TN effluent concentrations.

3.5.7.10 Deliverability and certainty

Confirmation on the TN effluent concentrations will need to be obtained from the alternative wastewater treatment provider. It can be assumed that once an alternative wastewater provider has been commissioned, they would be in operation for the lifetime of the development. If the wastewater provider was to be replaced, a similar provider will be selected which has at least the same effluent quality.

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3.5.7.11 Cost estimate

Alternative wastewater providers costs can vary depending on the size of the development they are serving. **Table 3-65** below outlines the costs estimates for various sizes of WRC.

Table 3-65 Typical costs and removal rates achievable through alternative WRC providers

Plant size (PE)	Capex (£ million)	Land uptake (m^2)	Number of dwellings	£/ dwelling
1,200	1.9	600	500	3,900
2,700	2.4	1,000	1,125	2,178
5,600	3.3	1,750	2,333	1,414
7,000	3.8	2,100	2,917	1,303

3.5.7.12 Summary

Table 3 66 presents the key considerations for the use of alternative wastewater providers for nutrient offsetting or reduction.

Table 3-66 Alternative wastewater providers key considerations

Key considerations	
Description of solution	NAV provide sewerage services in an area which is currently or previously provided by the incumbent monopoly provider. Companies that are not defined by region and that can operate anywhere in England and Wales could potentially provide alternative wastewater solutions. Alternative WRCs providers will treat foul drainage from new developments by designing, consenting, and building an alternative treatment works. Using alternative wastewater providers would be most applicable where a development is currently proposed to connect to a WRC with no or limited nutrient stripping currently or in the future. Alternative providers would be able to build bespoke treatment works which can achieve the desired effluent concentrations and outperform the proposed WRC.
Delivery timescale	Long-term – typically 2.5 – three years
Duration of operation	Long-term
Nutrient removal	TP removal potential: Effluent to 0.5mg/l can be achieved TN removal potential: Unknown at this stage
Applicability	Maintenance paid through foul drainage bill
Management and maintenance	Can be integrated with SuDS to deliver flood risk benefits and amenity space
Additional benefits	Yes
Best available evidence	Yes
Wider environmental considerations	Implementing this scheme is unlikely be significantly constrained by the wider environment
Evidence of effectiveness	Yes
Precautionary	Yes
Securable in perpetuity	Yes
Cost estimation	Capital costs: £1,950,000+

3.5.8 Installation of Package Treatment Plants

3.5.8.1 Description of solution

PTPs can be used to treat wastewater onsite and are normally used where the connection to the main sewer network is not possible. Septic Tanks (ST) are an alternative type of basic onsite wastewater treatment along with PTPs. However, phosphate reductions are typically low with ST (O'Keeffe *et al*., 2015) and effluent may require further treatment, e.g., by a soakaway.

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 (May & Woods, 2015). 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. **Table 3-67** outlines the default values that PTPs and STs are assumed to operate at.

The Natural England significance of ST around freshwater SSSIs (May *et al*., 2016) report indicates that small sewage discharges, mainly septic tank systems but also PTPs, potentially pose a significant environmental risk to freshwater habitats. An assumption is made that a default ST will have an effluent concentration of 11.6 mg/l TP and 96.3mg/l TN. A default PTP will have an effluent concentration of 9.7mg/l TP and 72.9mg/l TN.

The effluent quality of a new PTP is variable, but typically around 2 - 3mg/l TP and 25-50mg/l TN for PTP without P stripping and as low as 0.4 - 0.5 mg/l TP for a PTP with additional P stripping. Therefore, replacing one default septic tank serving one property with a PTP with P stripping will deliver 0.9kg/yr TP and 4.8kg/yr TN. This is a best-case scenario calculation to provide an indication.

Information indicates there are over 1,500 PTPs or ST at high risk of causing pollution in the combined Yare and Wensum catchments (out of an expected 9,250 unsewered properties) (May *et al*., 2016). The mitigation that can be achieved is very good and the costs are relatively low (up to £10,000 to replace with the addition of management and maintenance costs). The management and maintenance of these new PTPs would need to be guaranteed to achieve credits.

It may be possible to identify unsewered properties via a request for information to the water company. Alternatively, a private company may be able to provide this data for a fee. A challenge may be encountered with engagement of the public and incentivising people to proceed with such a scheme. Construction costs would be paid to the homeowner, as well as an additional incentive to cover disturbance.

Table 3-67 Default performance values for PTPs and septic tanks (Natural England, 2022)

Treatment plant	Default TP effluent concentration (mg/l)	Default TN effluent concentration (mg/l)
Package treatment plant	9.7	72.9
Septic tank	11.6	96.3

PTPs with additional phosphate stripping can achieve effluent concentrations as low as 0.4mg/l. **Table 3-68** outlines some of the reductions available through leading manufacturers. N effluent concentrations are assumed to be 55mg/l for PTPs.

Table 3-68 Main PTP manufacturers phosphate removal rates

System	Removal rate / concentration	Source
Graf One2clean plus	95.1% / 1.6mg/l	https://www.graf.info/fileadmin/media/Catalogue_Wastewater_Treatment_Solutions.pdf

System	Removal rate / concentration	Source
Graf Klaro E Professional KL24plus	94.5% / 0.4mg/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)

Reed beds or wetland treatment systems can be used to provide secondary or tertiary treatment of effluent from PTPs. The systems purify the effluent as it moves through the gravel bed and is taken up by the roots. Both HF and vertical flow systems are suitable. To achieve the highest rates of phosphorus removal, a PTP that has additional phosphate stripping could be used.

However, this required additional maintenance that would need to be secured via maintenance agreements. The PTP or ST must comply with the general binding rules (Environment Agency, 2021) or a permit will be required. It may be possible for PTPs to be discharged to surface water, whereas STs must not discharge effluent to surface water.

PTPs or ST that drain to a field must be compliant with the Building Regulations to be used as mitigation. Part H2 of the Building Regulations 2010 requires that they are located:

- A minimum of 10m from watercourses;
- 50m from a point of abstraction of any groundwater supply;
- Not in any groundwater Source Protection Zone 1;
- At least 15m from any building; and
- Sufficiently far from any other drainage fields.

For the solutions to be achievable in perpetuity, maintenance would need to be in places for the lifetime of the development. Maintenance and regular emptying of PTPs and ST is required under rules 11 and 12 of the General Binding Rules (Environment Agency, 2021). The waste biproducts of PTPs are likely to be classified as sewage sludge and would need to be disposed according to requirements of the Environment Agency.

3.5.8.2 Nutrient removal

Assuming a default PTP is replaced with a new PTP with a TP effluent concentration of 0.5mg/l, approximately 0.9kg/yr could be saved. The replacement would have an estimated additional cost of approximately £42,000. This is equivalent to £46,153 kg TP/yr reduction. This would also deliver a TN saving of 4.86kg TN/yr, equivalent to £8,824 kg TN/yr.

3.5.8.3 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.

3.5.8.4 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 nutrient removal in the future.

3.5.8.5 Applicability

PTP and ST replacements could potentially be applicable to all residential developments that are not currently be connected to the existing foul sewer network.

3.5.8.6 Management and maintenance requirements

Some maintenance of the PTP would be required. Where additional P stripping is used, this should be applied in accordance with the design instructions.

3.5.8.7 Additional benefits

This solution is unlikely to deliver any wider environmental benefits.

3.5.8.8 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.

3.5.8.9 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. 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 meet British Standards (BS EN 12566) with certification setting out the mean concentration of the effluent from that system.

Testing for TN and TP is not a mandatory requirement of the British Standard for PTPs therefore not all PTPs will have undergone these tests. However, where a certificate (or test results from a separate independent test, if one was conducted but not included on the certificate) can be provided, this serves as sufficient proof of the concentrations the effluent will reach. There is no need to obtain any additional monitoring evidence in these cases. Recommended PTPs have accredited certification and bear CE/ UKCA marking.

In July 2022, the Herefordshire district council granted planning permission to a private development (Canon Frome Court) to install PTP (Otto Graf KLARO E - sequencing batch reactor with P precipitant). This development involves the conversion of two outbuildings into three new residential dwellings with approval for all existing and future foul drainage to discharge through a connection to a new shared PTP. The outfall from the PTP is into the River Frome and compliant with the Habitats Regulations 2017 and the Herefordshire Local Plan core strategies.

3.5.8.10 Deliverability and certainty

Confirmation on the number of PTP installations that can be provided would be obtained via reports from contractors carrying out the works. It can be assumed that once installed, the PTP would be in operation for its lifetime, and would be replaced by a similar system which has at least the same effluent quality.

3.5.8.11 Cost estimate

PTP cost varies according to the size required and PTPs with additional P stripping typically cost more than standard models. Upfront costs are typically £2,000 to £2,500 for plants serving four to five persons and up to £5,000 for plants serving 15/ 20 persons.

Installation costs may vary but are likely to be within the thousands of £. Average annual costs for PTPs with additional phosphate stripping for operating and maintenance (including emptying) are typically £400 - £600. Assuming a PTP cost of £5,000, installation cost of £5,000 and operational costs of £32,000 over 80 years, the total cost of this solution per PTP is expected to be £42,000.

3.5.8.12 Summary

Table 3-69 presents the key considerations for the use of PTPs for nutrient offsetting.

Table 3-69 Package Treatment Plants key considerations

Key considerations	
Description of solution	PTPs can be used to treat wastewater onsite and are normally used where the connection to the main sewer network is not possible. ST are an alternative type of basic onsite wastewater treatment along with PTPs. 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.
Delivery timescale	Short-term
Duration of operation	Permanent
Nutrient removal	TP removal potential: Variable, e.g., 0.4 – 2 mg/l TN removal potential: Variable, e.g., 25-50 mg/l
Applicability	All residential developments that cannot currently be connected to the existing foul sewer network
Management and maintenance	Annual cleaning required in most cases. Phosphate stripping may be required to achieve highest P removal rates
Additional benefits	Additional water quality benefits Flood risk Habitat creation Amenity space when combined with SuDS/ Wetlands
Best available evidence	Yes
Wider environmental considerations	Potential implications for the local population, including visual impact, noise, and odour. Energy use may also be an important consideration
Evidence of effectiveness	Yes
Precautionary	Yes
Securable in perpetuity	Yes
Cost estimation per PTP	Capital costs: approx. £10,000 Operational costs: £400 - £600 per annum

3.5.9 Upgrade existing private sewage systems

3.5.9.1 Description of solution

Upgrading private sewage systems to connect to the main sewers can be beneficial in the removal of nutrients due to the technology within water treatment plants compared to old private sewage systems. This solution is applicable to villages/ clusters of dwellings which are currently served by private sewer systems which could be connected to the mains sewer. This will require the construction of a new sewer and lateral drains, as well as decommissioning of any private systems.

3.5.9.2 Nutrient removal

The River Wensum SAC & Broads SAC Nutrient Budget Calculator has been utilised to calculate the loading of P caused by one dwelling in the catchment of the treatment works listed below. **Table 3-70** shows the difference in treatments works operating at TAL that have nutrient stripping technology against the default package treatment plant for one dwelling.

Table 3-70 PTP loadings vs WRC TAL Loadings

	TP loading	TN loading
Default PTP discharge concentration (mg/l)	9.7	72.9
Default PTP loading (kg/yr)	0.96	7.2
WRC discharge concentration (mg/l)	0.225	9
WRC loading (kg/yr)	0.02	0.89
Difference (kg/yr)	-0.94	-6.4

Table 3-70 shows that a difference of 0.94 kg TP/yr and 6.4kg TN/yr can be saved from an existing dwelling when moving from a traditional PTP to directly connecting to a sewer that is operating at the TAL.

Table 3-71 below shows the difference in treatments works operating at TAL that have nutrient stripping technology against the default septic tank for one dwelling.

Table 3-71 PTP loadings vs WRC TAL Loadings

	TP loading	TN loading
Default PTP discharge concentration (mg/l)	11.6	96.3
Default PTP loading (kg/yr)	1.2	9.6
WRC discharge concentration (mg/l)	0.225	9
WRC loading (kg/yr)	0.02	0.89
Difference (kg/yr)	-1.1	-8.7

Table 3-71 shows that a difference of 1.1kg TP/yr and 8.7kg TN/yr can be saved from an existing dwelling when moving from a traditional ST to directly connecting to a sewer that is operating at the TAL.

3.5.9.3 Delivery timescale

The solution is considered to have a medium-term timescale. Obtaining permits to establish a new connection to an existing sewer can be achieved within the short term. However, the installation of new connections will be completed within the medium term. Before a pipe can be laid, the route needs to be planned. This will consider many aspects, including:

- Assessing the directness of possible routes;
- The construction and maintenance costs;
- the disruptive effect of the works (to traffic, businesses, and individuals);
- engineering considerations including access for construction works;
- the desirability of achieving gravity flow;
- the avoidance of sites of environmental and archaeological importance; and
- existing buried and overhead services and infrastructure.

3.5.9.4 Duration of operation

Once the existing sewage system has been upgraded, it is assumed to be a permanent nutrient management solution that will provide mitigation in perpetuity.

3.5.9.5 Applicability

This solution is applicable to villages which are currently not connected to mains sewers, but where it would be practical and costs-effective to do so. The greatest nutrient savings would be achieved by connecting to WRCs which are schedules to be achieving TAL by 2030.

3.5.9.6 Management and maintenance requirements

Typically, the homeowner is responsible for the drains inside their property boundary and the sewerage company is responsible for the lateral drains and sewers. Where a pumping station is required, occasional maintenance will be necessary to ensure correct function.

Costs for maintenance of the sewer and drains under the responsibility of the sewerage company is expected to be covered through wastewater bills. The Local Authority would be liable for any repair costs inside of the homeowner’s property boundary where the Local Authority has insisted on a connection.

3.5.9.7 Additional benefits

Upgrading the sewage system may have additional benefits such as improving the local sewer network and water quality in the area.

3.5.9.8 Wider environmental considerations

The upgrading of existing private sewage systems is unlikely to be significantly constrained by the wider environmental factors.

3.5.9.9 Evidence of effectiveness

Natural England guidance (2022) has been used to calculate the expected nutrient mitigation from this solution. The default effluent concentrations for package treatment plants and ST are derived from available literature and represent the average reported TP and TN values stated.

3.5.9.10 Deliverability and certainty

Upgrading the existing sewage system is often a permanent feature and provides benefits for the lifetime of the development. If the nearest public sewer is more than a hundred feet from a property and the existing drain runs into an adequate cesspool or septic tank, the local authority can’t insist that a property connects to the public sewer. However, the local authority can insist if they agree to pay for the additional costs of connection, including construction, maintenance, and repairs.

3.5.9.11 Cost estimate

The cost of the installing a new connection is estimated to be around £1,146,500 per 1km of pipeline. This was derived from the Anglian Water Developer charging arrangement 2022-2023 (AWS, 2022). Charges vary according to the diameter of the sewer, the surface in which it is laid, the material of which the sewer will be comprised and the depth of the pipe. **Table 3-72** outlines the typical costs expected per km of pipeline and make worst-case assumptions, e.g., pumping station required.

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Table 3-72 Cost estimate for upgrading existing private sewage systems

Parameter	£/km
Sewer	£800,000
Manhole	£15,000
Project management and design	£80,000
Traffic management	£1,500
Pumping station	£250,000
Total	**£1,146,500**

Additional costs may be included where:

- Contaminated land is involved;
- Sewer may cross or impinge upon a dual carriageway, motorway, or river (bank to bank width <5m);
- Where the sewer construction cannot be satisfied without involving complex engineering;
- Where the construction is so unusual in nature that it cannot be satisfied through the costs set out in the fixed charge calculations; and
- Third party costs are payable, e.g., Street closure fees, third-party ownership compensation.

3.5.9.12 Mitigation potential

An assessment of suitable villages was undertaken to identify the most applicable areas for this solution. General assumptions were made on the number of dwellings that would be connected to the mains, the length of pipeline required, and the nutrient mitigation assumptions outlined in **Table 3-73.** A conservative approach was adopted which assumed that all private sewage systems are PTPs.

The assessment included the consideration of sites of environmental and archaeological importance, whether rivers would need to be crossed, if flows could be gravity driven and a cost-benefit analysis. Villages which were considered impractical or not cost-effective were excluded.

Table 3-73 and **Table 3-74** present the findings and the likely mitigation potential for each village connection scheme. Should all the identified villages be connected to the relevant mains sewer, a total of 23.1km of pipeline would be required with an estimated cost of £26,484,150.

The solution offers the potential to mitigate a total of 388 kg TP/yr, which is a significant amount of the total mitigation required. This is equivalent to 5,720 new dwellings draining to a WRC operating at a permit limit of 1mg/l. The cost per kg/yr of mitigation is £68,811.

A total of 2,582 kg TN/yr could be mitigated, which is equivalent to 1,370 new dwellings. This is considerably fewer dwellings mitigated compared to the TP mitigation and is primarily due to the significant difference in TP effluent concentration between existing PTPs and WRCs operating to the TAL.

Whilst the solution is not as effective for TN removal, many land-based schemes provide significantly more TN mitigation than TP mitigation and could be used to meet some of the shortfall. Further assessment is required to confirm the feasibility and identify the favoured schemes.

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Table 3-73 TP mitigation potential and likely costs per village connection scheme

Location	Catchment	Treatment works	No. of properties connected	TP mitigation (kg/yr)	Dwellings mitigated	Pipeline length (km)	Cost	£ / kg/yr	£ / dwelling	Gravity driven?	Comments
Horningtoft	Wensum	Fakenham	30	28.2	416	2.2	£2,522,300	£89,311	£6,058	Yes	
Wood Norton	Wensum	Foulsham	50	43.8	645	4.5	£5,159,250	£117,883	£7,997	Yes	
Marlingford	Yare	Whitlingham	40	37.7	555	2	£2,293,000	£60,894	£4,131	No	WRC within 95% of DWF permit
East Carleton	Yare	Swardeston	40	37.7	555	1.8	£2,063,700	£54,805	£3,718	Yes	
Spooner row	Yare	Forncett End	80	75.3	1,110	5	£5,732,500	£76,117	£5,163	No	
Tharston	Yare	Long Stratton	30	28.2	416	1.2	£1,375,800	£48,715	£3,305	Yes	
Dereham Road	Yare	Mattishall	25	23.5	347	1.6	£1,834,400	£77,944	£5,287	No	
Edgefield	Bure	Edgefield	30	28.9	426	0.5	£573,250	£19,827	£1,345	No	
Tuttington	Bure	Aylsham	50	47.1	694	1.8	£2,063,700	£43,844	£2,974	Yes	WRC within 95% of DWF permit
Worstead	Ant	Belaugh	40	37.7	555	2.5	£2,866,250	£76,117	£5,163	No	
Total	-	**-**	**415**	**388**	**5,720**	**23.1**	**£26,484,150**	**£68,250**	**£4,630**	-	

Table 3-74 TN mitigation potential and likely costs per village connection scheme

Location	Catchment	Treatment works	No. of properties connected	TN mitigation (kg/yr)	Dwellings mitigated	Pipeline length (km)	Cost	£ / kg/yr	£ / dwelling	Gravity driven?	Comments
Horningtoft	Wensum	Fakenham	30	190.46	101	2.2	£2,522,300	£13,243	£24,954	Yes	
Wood Norton	Wensum	Foulsham	50	237.96	126	4.5	£5,159,250	£21,682	£40,855	Yes	
Marlingford	Yare	Whitlingham	40	253.95	135	2	£2,293,000	£9,029	£17,014	No	WRC within 95% of DWF permit
East Carleton	Yare	Swardeston	40	253.95	135	1.8	£2,063,700	£8,126	£15,313	Yes	
Spooner row	Yare	Forncett End	80	507.90	270	5	£5,732,500	£11,287	£21,268	No	
Tharston	Yare	Long Stratton	30	190.46	101	1.2	£1,375,800	£7,223	£13,611	Yes	
Dereham Road	Yare	Mattishall	25	158.72	84	1.6	£1,834,400	£11,557	£21,778	No	
Edgefield	Bure	Edgefield	30	217.29	115	0.5	£573,250	£2,638	£4,971	No	
Tuttington	Bure	Aylsham	50	317.44	168	1.8	£2,063,700	£6,501	£12,250	Yes	WRC within 95% of DWF permit
Worstead	Ant	Belaugh	40	253.95	135	2.5	£2,866,250	£11,287	£21,268	No	
Total	-	-	**415**	**2582.1**	**1,370**	**23.1**	**£26,484,150.00**	**£10,257**	**£19,327**	-	

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3.5.9.13 Summary

Table 3-75 presents the key considerations for upgrading existing private sewage systems for nutrient offsetting.

Table 3-75 Upgrade existing private sewage systems key considerations

Key considerations	
Description of solution	Upgrading private sewage systems to connect to the main sewers can be beneficial in the removal of nutrients due to the technology within water treatment plants compared to old private sewage systems.
Delivery timescale	Medium term
Duration of operation	Permanent
Nutrient removal	TP removal potential: 0.94 kg - 1.1 kg TP/yr per conversion. TN removal potential: 6.4kg - 8.7kg TN/yr per conversion.
Applicability	Villages / clusters of dwellings which are currently served by private sewer systems which could be connected to the mains sewerage
Management and maintenance	Some maintenance of the sewers and drains will be required.
Additional benefits	Additional water quality benefits.
Best available evidence	Yes
Wider environmental considerations	The upgrading of existing private sewage systems is unlikely to be significantly constrained by the wider environmental factors.
Evidence of effectiveness	Yes
Precautionary	Yes
Securable in perpetuity	No
Cost estimation	£1,146,500 /km of new pipeline

3.5.10 Install cesspools and capture outputs from private sewage systems

3.5.10.1 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 Wensum SAC or The Broads SAC from developments that use this approach. Cesspools are an unsustainable solution that could have a significant increase in carbon production particularly for dwellings in the centre of the catchment where the distance from registered waste facilities will be the greatest.

However, 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.

Furthermore, if water company infrastructure allows for mains connection in the future, the water companies would be obliged to connect and wastewater would then be contributing to loads into the catchment, requiring further mitigation. Maintenance of the cesspools would need to be written as a planning condition as well as into the deeds of the dwelling.

3.5.10.2 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 phosphorus contributions from surface water runoff and therefore achieve phosphorus neutrality. N neutrality could be achieved through land use change either on-site or off-site.

3.5.10.3 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.

3.5.10.4 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.

3.5.10.5 Applicability

This option could potentially be applicable to new or existing developments that cannot currently be connected to the foul drainage network.

3.5.10.6 Management and maintenance requirements

Multiple criteria would need to be met for cesspools to be viable:

- Waste would need to be transferred by a registered waste carrier;
- Waste would need to be transferred to a registered facility outside of the catchment;
- It would require a minimum capacity of 18,000 litres per two users, plus 6,800 litres per each extra user; and
- Planning permission would be required.

The cesspool would need building regulations approval, which includes the following:

- Cesspools should only be considered where mains foul drainage is not practicable;
- Sited at least 7m from any habitable parts of buildings;
- Sited within 30m of vehicle access;
- No opening except for the inlet; and
- Cesspools should be inspected fortnightly for overflow and emptied as required.

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 council can enforce repairs or replacements of cesspools in poor condition.

3.5.10.7 Additional benefits

There are no additional benefits associated with cesspools.

3.5.10.8 Wider environmental considerations

Cesspools are an unsustainable solution that could have a significant increase in carbon production particularly for dwellings in the centre of the catchment where the distance from registered waste facilities will be the greatest. Furthermore, there is also the potential for nutrient loading to the environment from overflows and leakage. However, cesspools could be a viable solution in some locations towards the edge of the catchment where the distance waste would be carried is minimal. Furthermore, if water company infrastructure allows for mains connection in the future, the water companies would be obliged to connect and wastewater would then be contributing to loads into the catchment, requiring further mitigation.

Maintenance of the cesspools would need to be written as a planning condition as well as into the deeds of the dwelling. Where cesspools are used as a short-term bridging solution until longer-term, more sustainable, solutions are in place, then details of these longer-term solution would be required at the time of granting permission. The removal of the cesspool would also need to be included in any planning conditions/ obligations.

This solution also involves moving the nutrient loads from one catchment to another, which could lead to increased nutrient concentrations in these river catchments. However, the receiving catchments are not as heavily designated as the River Wensum SAC and The Broads SAC, which are particularly vulnerable to nutrient loading.

3.5.10.9 Evidence of effectiveness

This solution is reliant on treatment of wastewater at a dedicated WRC therefore it is assumed to be highly effective.

3.5.10.10 Deliverability and certainty

Confirmation on the installation of cesspools can be provided via contractors. Confirmation of waste removal and treatment location can be provided via sludge handling company.

3.5.10.11 Cost estimate

Cesspool costs and installation vary depending on size but are likely to be between £3,000 - £6,000. Emptying requirements are dependent on the capacity of the pit and the average waste volume of the household. On average, emptying would be required every one to two months with a cost of £400 - £700 which will depend on location. This is likely to result in annual costs of £3,200 - £5,600, which over 80 years equates to £256,000 - £448,000 per property.

3.5.10.12 Summary

Table 3-76 presents the key considerations for the use of cesspools for nutrient reduction and/ or offsetting.

Table 3-76 Cesspools key considerations

Key considerations	
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 Wensum SAC or The Broads SAC from developments that use this approach
Delivery timescale	Short-term
Duration of operation	Impermanent
Nutrient removal	100% of wastewater
Applicability	New or existing developments that cannot currently be connected to the foul drainage network
Management and maintenance	Emptying every one to two months Regular inspection
Additional benefits	None

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Key considerations	
Best available evidence	Yes
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	Yes
Precautionary	Yes
Securable in perpetuity	Yes
Cost estimation	Capital costs: approx. £3,000 - £6,000 Operational costs: £3,200 - £5,600 per year

3.6 Demand management solutions

3.6.1 Retrofit water saving measures in existing properties (local authority, registered providers, public buildings)

3.6.1.1 Description of solution

When retrofitting water saving appliances, the water usage saved from the retrofitted properties will be replaced by the additional water demand from new dwellings. As a result, 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. This solution is not applicable to WRCs without a permit limit.

Similarly, WRCs should be operating at close to capacity with little headroom, which is not the case in all the treatment works located within catchment. The Whitlingham treatment works typically operates close to its permit limit and therefore would be suitable. Older dwellings are more likely to include older, less efficient fittings that newer dwellings and therefore generally have higher water usages per person.

There is a greater potential for reducing nutrient loading associated with older rather than more recently constructed dwellings. Certainty over the efficacy of this method is difficult to achieve due to the limited ability to measure reductions. This solution is unlikely to pass the in-perpetuity test for private properties where there are no controls over homeowners changing fittings in the future.

Therefore, this solution is only applicable to existing dwellings where an organisation has control over fittings and any upgrade works. This is likely to include housing owned by Local Authorities, Registered Providers, and public buildings. It is likely that wastewater reductions from new water efficient appliances could be achieved during planned refurbishment of such properties.

The greater water saving is typically achieved through upgrades to bathrooms as opposed to kitchens, with improvements to toilets and showers providing the greatest reductions. An average volume of water usage of around 150 litre/ person/ day can be assumed for existing dwellings in the catchment. The WRC water efficiency calculator (WRC, 2021) has been used to approximate the water usage per appliance/ fitting for usage of 150 litre/ person/ day. The findings are presented in **Table 3-77**.

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Table 3-77: Baseline (150 litre / person/ day) maximum water consumption values for appliances/ fittings

Fitting/ Appliance	Maximum Consumption
Toilet	8 litres
Shower	12 l/ min
Bath	200 litres maximum capacity
Basin taps	9 l/min
Sink taps	10.5 l/min
Dishwasher	1.3 l/place setting
Washing machine	8.2 l/kilogram

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 litre/ person/ day. The Government also introduced an optional requirement of 110 litre/ 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, and some local plans have already incorporated. As a result, these two figures were used as targets when retrofitting water efficient appliances and fittings.

Retrofitting water saving measures is applicable to treatment works served by the following WRCs:

- Aldborough;
- Aylsham;
- Belaugh;
- Bylaugh;
- Coltishall;
- Dereham;
- Foulsham;
- Long Stratton;
- Rackheath;
- Reepham;
- Stalham; and
- Wymondham.

3.6.1.2 Nutrient removal

Actual nutrient reductions will be dependent on the population served and the permit limit of the WRCs. However, a water saving of 40 litre/ person/ day can be achieved from retrofitting a single house with an existing water efficiency of 150 litre/ person/ day to an upgraded efficiency of 110 litre/ person/ day. This would require 2.75 retrofitted dwellings for every new dwelling draining to Whitlingham.

This is equivalent to 0.09 kg/yr TP and 2.5kg/yr TN. The expected cost is £3,988 per new dwelling, a figure derived from a study by Norwich City Council, considered the most up to date and best value to estimate cost. Implementing further water saving measures beyond 110 litre/ person/ day for new dwellings in the catchment would reduce the increased load from wastewater for that new dwelling.

Efficiencies could be drawn from greywater harvesting, which involves the use of recycling systems to collect used water from sinks, dishwashers, showers, and baths, clean it up and plumb it straight back into your toilet, washing machine and outside tap. Greywater typically makes up between 50% - 80% of a household's wastewater – recycled greywater can save approximately 70 litre/ person/ day, equivalent to 0.055kg/yr, in domestic households.

Alongside retrofitting water efficient appliances, greywater harvesting could significantly reduce household consumption and loadings transferred for treatment. A new greywater system may cost £2,000 - £3,000 per dwelling, although it is hard to calculate the payback because it is dependent on current water usage (including whether a meter has been installed), and what kind of system is installed.

3.6.1.3 Delivery timescale

It is anticipated that this solution could be implemented in the short term in housing stock that is under the control of the Local Authority, for example as part of ongoing programmes to upgrade residential properties.

3.6.1.4 Duration of operation

This solution is considered an impermanent solution, given that householders or contractors could potentially change water-efficient fittings with less efficient alternatives in case of failure or if they undertake their own refurbishment.

3.6.1.5 Applicability

This solution is only applicable to housing owned by Local Authorities or Registered Providers.

3.6.1.6 Management and maintenance requirements

For this option to be effective over longer timescales, it will be necessary to ensure that any future refurbishment works, or emergency works are undertaken using fittings that meet the appropriate water efficiency standards.

3.6.1.7 Additional benefits

This option will provide the added benefit of reducing the required water consumption from new developments mitigated through this scheme, i.e., the water consumption will not increase because of new developments. This is an important benefit in an area of water stress. Secondly, water bills will also be reduced for existing dwellings if they are on a meter.

3.6.1.8 Wider environmental considerations

This option is unlikely to be subject to any significant environmental constraints.

3.6.1.9 Evidence of effectiveness

A reduction in water usage in a residential property will lead to a corresponding reduction in wastewater loading. This in turn will mean that there is a reduction in nutrient loading in the discharge from the WRC to which the property is connected. Registered Providers in a different Local Authority undertook a review of and provided historical water bills to demonstrate past consumption and future consumption. In addition, an audit of all properties within their jurisdiction was undertaken which could be a significant expense.

3.6.1.10 Deliverability and certainty

The retrofitting of water efficient fittings to dwellings that control the volume of water consumed can help control water consumption. Should fittings need replacing in the future they will need to be to the same required water consumption or better. AWS are also supportive of proposed upgrades and their advice has given further confidence on the long-term water usage of appliances.

It is considered unlikely that people will make significant changes to fittings that reduce water usage and subsequently reduce water bills. Details on the exact number of retrofits and details of fittings can be provided from contractors. A comparison of water bills pre and post retrofit could also be used to verify water reductions.

3.6.1.11 Cost estimate

A study by Norwich City Council provides an approximate cost estimate per dwelling for installing new appliances/ fittings that are likely to meet the 110 litres/ person/ day limit. The cost estimate is £3,988 per new dwelling, a figure derived from a study by Norwich City Council, considered the most up to date and best value to estimate cost. Implementing further water saving measures beyond 110 litre/ person/ day for new dwellings in the catchment would reduce the increased load from wastewater for that new dwelling.

3.6.1.12 Summary

Table 3-78 shows key considerations associated with retrofitting water saving measures in existing properties (Local Authority, registered providers, public buildings).

Table 3-78 Retrofitting water efficient fittings (Local Authority, registered providers, public buildings) key considerations

Key considerations	
Description of solution	When retrofitting water saving appliances, the water usage saved from the retrofitted properties will be replaced by the additional water demand from new dwellings. As a result, 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
Delivery timescale	Short-term
Duration of operation	Impermanent
Nutrient removal	Wastewater reductions of 40 litre/ person/ day achievable
Applicability	Housing 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
Best available evidence	Yes – The government published calculator would be used for calculating water usage for appliances
Wider environmental considerations	This option is unlikely to be subject to any significant environmental constraints
Evidence of effectiveness	Yes
Precautionary	Yes
Securable in perpetuity	Yes – It is unlikely this solution could be achieved in perpetuity unless the Local Authority or Registered Provider have ownership and control of dwellings that are due to be retrofitted with more water efficient fittings
Cost estimate	£3,988 per new dwelling

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3.6.2 Retrofit water saving measures in existing properties (private housing, commercial and industrial premises)

3.6.2.1 Description of solution

In addition to retrofitting water efficient appliances to housing stock under the control of a Local Authority or Registered Providers (**Section 3.6.1**), it may also be possible to encourage a similar programme for private housing, commercial and industrial premises. This is likely to require an incentive scheme, e.g., operated by the water undertaker and/ or local authorities, to encourage uptake.

3.6.2.2 Nutrient removal

The nutrient reductions can could potentially be achieved are dependent on factors including population size and the permit limit, of the discharge, of the WRCs. It is anticipated that approximately three existing dwellings will need to be retrofitted to mitigate one new dwelling.

3.6.2.3 Delivery timescale

It is likely that wastewater reductions from new water efficient appliances could be achieved during planned refurbishment of such properties. The greater water saving is typically achieved through upgrades to bathrooms as opposed to kitchens, with improvements to toilets and showers providing the greatest reductions. There is no known project or scheme where this has been undertaken on private properties to obtain a timescale delivery estimate.

3.6.2.4 Duration of operation

The driver for duration is dependent upon property owners or tenants adhering to the retrofitted installation. If there is no interference it could offer a permanent duration timescale. However, in the absence of a robust mechanism to ensure that water-efficient fittings remain in place, this is a temporary measure.

3.6.2.5 Applicability

This option is applicable to discharges into the catchment via intercept of input ahead of input into WRCs. It could potentially be applicable to all properties in the catchment.

3.6.2.6 Management and maintenance requirements

Compliance is likely to be difficult to monitor, and although planning conditions on developers could provide some security, further actions to prevent future owners changing fittings are unlikely to be practicable.

3.6.2.7 Additional benefits

This option is unlikely to deliver any additional environmental benefits.

3.6.2.8 Wider environmental considerations

This option may reduce water use in the east of England, an area of the UK, which is under water stress, saving water as a valuable resource. It may also mean lower water bills for residents.

3.6.2.9 Evidence of effectiveness

Certainty over the effectiveness of this method is difficult to achieve due to the limited ability to measure reductions. This solution is unlikely to pass the in-perpetuity test for private properties where there is no control over homeowners changing fittings in the future.

3.6.2.10 Deliverability and certainty

Certainty over the efficacy of this method is difficult to achieve due to the limited ability to measure reductions. Smart meters could be used for tracking loading but is unlikely that existing dwellings will have these fitted in high enough numbers to obtain sufficient data. This solution is also unlikely to pass the in-perpetuity test for private properties where there is no control over homeowners changing fittings in the future.

3.6.2.11 Cost estimate

Cost estimates for this solution are presented in **Section 3.6.1.11.**

3.6.2.12 Summary

Table 3-79 shows key considerations associated with retrofitting water saving measures in existing properties (private housing, commercial and industrial premises).

Table 3-79 Retrofit water saving measures in existing properties (private housing, commercial and industrial premises) key considerations

Key considerations	
Description of solution	In addition to retrofitting water efficient appliances to housing stock under the control of a Local Authority or Registered Providers, it may also be possible to encourage a similar programme for private housing, commercial and industrial premises. This is likely to require an incentive scheme, e.g., operated by the water undertaker and/ or local authorities, to encourage uptake
Delivery timescale	Short-term
Duration of operation	Permanent
Nutrient removal	2.75 – three existing dwellings to every one new dwelling. Nutrient reductions dependant on population served and permit limit of WRCs
Applicability	Discharges into the catchment via intercept of input ahead of input into WRCs. Potential application to all properties in the catchment
Management and maintenance	Replacement parts of the same or better efficiency must be used Monitoring compliance checks required
Additional benefits	Sustainability Water resources
Best available evidence	Yes
Wider environmental considerations	This option may reduce water use in the east of England, an area of the UK, which is under water stress, saving water as a valuable resource. It may also mean lower water bills for residents
Evidence of effectiveness	Yes – The government published calculator would be used for calculating water usage for appliances
Precautionary	Yes
Securable in perpetuity	No - It is unlikely this solution could be achieved in perpetuity unless the Local Authority or Registered Provider have ownership and control of dwellings that are due to be retrofitted with more water efficient fittings
Cost estimation	Capital costs: Approximately £1,450 per property

3.6.3 Incentivise commercial water efficiency and treatment installation

3.6.3.1 Description of solution

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). 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.

3.6.3.2 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).

3.6.3.3 Delivery timescale

Delivery timescale is subject to a change in consent regulation and the requisite consultation process ahead of such change in addition to change enforcement. Operators are also required to install on-site treatment facilities, which may be subject to planning permission. Ahead of this, a feasibility study and possible monitoring programme would be required to prioritise operations which would have an effective result in nutrient removal.

In addition, the current AMP period (AMP7, 2020-2025) during which water companies operate capital investment via does not include additional measures to address phosphate supply from WRCs and they are likely to be considered in the next PR in 2024. On this basis the delivery time is likely to be medium term.

3.6.3.4 Duration of operation

Durability is permanent as it would require the installation of a permanent treatment facility on site.

3.6.3.5 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.

3.6.3.6 Management and maintenance requirements

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.

3.6.3.7 Additional benefits

Other potentially harmful substances within the discharge could also be captured via on site treatment facilities.

3.6.3.8 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.

3.6.3.9 Evidence of effectiveness

Available scientific evidence in relation to the effectiveness is not available at this stage and is required to be catchment and discharge point specific. It is also not possible to apply a precautionary efficacy value in the absence of evidence.

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3.6.3.10 Deliverability and certainty

A discharge consent is a legal agreement and can be enforced and provides a control mechanism, improvement notices and/ or enforcement action can be served which in turn provides certainty and is securable in perpetuity (between 80 - 125 years). Temporary trade effluent discharges which include heating system flushing and groundwater remediation practices also offer less certainty due to the unpredictable and temporary nature.

3.6.3.11 Cost estimate

It is not possible to estimate the cost at this stage of options appraisal. A feasibility study is likely to be required to determine and estimate.

3.6.3.12 Summary

Table 3-80 presents the key considerations for the option to incentivise commercial water efficiency.

Table 3-80 Incentivise commercial water efficiency and treatment installation key considerations

Key considerations	
Description of solution	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
Delivery timescale	Short-term
Duration of operation	Permanent
Nutrient removal	Unknown
Applicability	Applicable to discharges into the catchment via interception of wastewater ahead of input into WRCs and direct to surface water or groundwater
Management and maintenance requirements	Operation of the treatment facility and associated waste disposal works
Additional benefits	Water quality
Best available evidence	No
Evidence of effectiveness	Not possible to determine at this stage
Precautionary	Not possible to determine at this stage
Securable in perpetuity	Yes
Cost estimation	Capital costs: £unknown per ha, operational costs £unknown/ ha/ year

4 Summary

4.1 Summary of potential solutions

The following tables (**Table 4-1** to **Table 4-4**) provides a summary of short-listed solutions that could be used mitigate and offset additional nutrients arising from new developments that could adversely affect the River Wensum and Norfolk Broads SACs. It is likely that a combination of measures will be most effective in nutrient offsetting. For example, incorporating SuDS into new developments, whilst constructing riparian buffer strips to lower the nutrient burden.

A range of techniques can be used in the river catchments, 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 restively short timescales. These solutions typically have greater certainty than runoff and nature-based solutions and if most cases can avoid issues with land purchase/ rental.

Table 4-1 Summary of nature-based solutions

Solution	Delivery timescale	Duration timescale	Nutrient removal potential	Farm type	Management /Maintenance requirements	Additional benefits	Best available evidence?	Effective beyond reasonable scientific doubt?	Precautionary?	Securable in perpetuity?	Cost estimation
Silt traps	Short-term	Impermanent	25% - 75% TP <25% TN	All	Regular de-silting will be required	Water quality	No	Yes	Yes	Yes	Capital costs: £1,000 - £4,000 Maintenance costs: £500/yr
Riparian buffer strips	Short-term	Impermanent	67% TP 65% TN	All	Cutting/Vegetation management	Stabilised riverbanks Water quality Reduced erosion Habitat creation Improved amenity value BNG Carbon offsetting	Yes	Yes	Yes	Yes	Typical costs of £786/ha Wensum: £128 /kg/yr Yare: £275 /kg/yr Bure: £1,503 /kg/yr
Constructed Wetlands	Medium-term	Permanent	Median removal rate of 46% (Land et al., 2016), however rates of > 90% often reported Median removal rate of 37% (Land et al., 2016), however rates of > 90% often reported	All	Silt removal, vegetation removal, maintenance of hydraulic structures, and bed and bank maintenance.	Biodiversity improvements, water quantity and quality (additional to nutrients) management, flood hazard management, carbon offsetting, and amenity and landscape aesthetic benefits	Yes	Yes	Yes	Yes	Varies £250,000 to £750,000
Wet woodlands	Short-term	Permanent	Uncertain - Similar to riparian buffer strips	Riparian land holdings (within FZ3)	Minimal	Recreation carbon sequestration Biodiversity conservation Air pollution reduction Flood risk reduction Biofuel	No	Yes	Yes	Yes	Up to £10,000 per hectare
Willow buffers	Short-term	Impermanent	70% long-term	All	Harvesting every 2-3 years.	Water quality Biodiversity	No	Yes	Yes	Yes	Capital costs: £2,500 per hectare, operational costs £200 - £300 per ha per year
Beetle banks	Short-term	Permanent	Unknown	All	Annual grass cutting	BNG Soil erosion	No	Not possible to determine at this stage	Not possible to determine at this stage	No	Assumed to be similar to riparian buffer strips Wensum: £128 /kg/yr Yare: £275 /kg/yr Bure: £1,503 /kg/yr
Broadland Restoration	Medium-term	Permanent	TP up to 50% TN – unknown	n/a	Management required to repeat dredging and biomanipulation to achieve success beyond 10 years, with further repetition over decadal timescales	Water quality improvements will contribute to achieving WFD targets; water quality increased water depth for navigation	Yes	Yes	Yes	Yes	£60,000 £6,500/ha for sediment removal and biomanipulation
Beaver Reintroduction	Long-term	Permanent, impermanent	Variable P – 20 to 80% removal	n/a	Beaver reintroduction requires little management and maintenance. Logjams require maintenance to repair dams should they	NFM, biodiversity and amenity benefits	Yes	Yes	Yes	Beaver reintroductions – no engineered logjams – yes	No reliable estimate for beaver reintroduction. Engineered logjams in the range of £5,000-25,000, not including

Solution	Delivery timescale	Duration timescale	Nutrient removal potential	Farm type	Management /Maintenance requirements	Additional benefits	Best available evidence?	Effective beyond reasonable scientific doubt?	Precautionary?	Securable in perpetuity?	Cost estimation
			Variable N – 4 to 60% removal		become damaged by high flows						land purchase if required

Table 4-2 Summary of run-off management solutions

Solution	Delivery timescale	Duration timescale	Nutrient removal potential	Farm type	Management /Maintenance requirements	Additional benefits	Best available evidence?	Effective beyond reasonable scientific doubt?	Precautionary?	Securable in perpetuity?	Cost estimation
Taking land out of agricultural use	Short-term	Temporary, impermanent, permanent	0.04 – 0.71 kg TP/ha/yr 16.23 – 22.75 kg TN/ha/yr	Not indoor pig or poultry	For *Miscanthus* growing – no fertiliser needs to be added until it is established and less needs to be applied than most farming practices. Harvesting every 2-4 years Energy Crop Schemes are available	Energy crops Biodiversity net gain potential	Yes	Yes	Yes	Yes	The average rental price in the East of England for farms is £314/ha The average purchase price in the East of England for farms is £24,500/ha £506/ha from loss of production Wensum: £35,220 /kg/yr Yare: £78,144 /kg/yr Bure: £625,150/kg/yr
Conversion of agricultural land to solar farms	Short-term	Permanent	Total P between 15 and 24 kg/yr: and Total N between 783 and 1,279 kg/yr	Arable and pastoral	Livestock number monitoring	Renewable energy Biodiversity net gain potential Water quality	No	Yes	Yes	Yes	unknown
Cessation of fertiliser / manure application	Short-term	Temporary	0.02 – 0.18 TP kg/ha/yr 17.31 – 21.38 TN kg/ha/yr	Arable and Grassland	None	Suspended solids buffer	Yes	Yes	Yes	No	Arable: £1,274.39 ha/yr
Farm Management Measures	Short/medium-term	Impermanent	Large uncertainty for P and N	All	Periodic cutting vegetation Clearing and dredging of artificial ditches Ditch maintenance	The amount of land being lost to erosion. Improvement of soil quality BNG; and, Reduction in pollution	No	Yes	Yes	Yes	Varies
Cover crops	Short-term	Impermanent	Large uncertainty – Assumed to be 30% removal.	Arable farms	Preparation, planting, destruction, cultivation	Water quality Habitat creation	No	Yes	Yes	Yes	Maintenance costs: £150/ha/yr (AHDB, 2020) £124 per hectare
Installing SuDS in new developments	Short-term	Permanent	Highly variable and will likely need site specific calculations.	n/a	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	Water quality Reduced erosion Habitats Improved amenity value	No	No	Yes	Yes	Costs are variable and bespoke to each site. The scale of the SuDS will have a large control on costs

Solution	Delivery timescale	Duration timescale	Nutrient removal potential	Farm type	Management /Maintenance requirements	Additional benefits	Best available evidence?	Effective beyond reasonable scientific doubt?	Precautionary?	Securable in perpetuity?	Cost estimation
Retrofitting SuDS in existing developments	Short term	Permanent	Highly variable and will likely need specific calculations	n/a	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	Water quality Reduced erosion Habitats Improved amenity value	No	No	Yes	Yes	Costs are variable and bespoke to each site. The scale of the SuDS will have a large control on costs

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Table 4-3 Summary of wastewater management solutions

Solution	Delivery timescale	Duration timescale	Nutrient removal potential	Farm type	Management /Maintenance requirements	Additional benefits	Best available evidence?	Effective beyond reasonable scientific doubt?	Precautionary?	Securable in perpetuity?	Cost estimation
Expedite planned improvements to treatment works	Short- term	Temporary	1,407.94 kg/yr of mitigation could be delivered assuming all three schemes come forward.	n/a	Normal maintenance carried out by water company	Potential N reductions	Yes	Yes	Yes	No – because although brought forward, it would not go beyond what was originally planned	Costs are bespoke to each scheme and would need to be provided by Anglian Water
Improve existing wastewater treatment infrastructure	Long-term	Permanent	Technically achievable limit of 0.25 mg TP/L in treated effluent, equivalent to > 90% removal efficiency. Technically achievable limit of 10 mg TN/L in treated effluent, with removal efficiencies generally > 70%.	n/a	Management and maintenance required by skilled professionals working for a water and sewerage company.	None	Yes	Yes	Yes	Yes	Variable depending on the size of a scheme, with an estimated average of £2,800,000 per scheme
Improve existing wastewater distribution infrastructure	Short term	Permanent	365 kg P/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,	n/a	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.
Portable treatment works	Short- term	Temporary	Up to 0.5 mg/l	n/a	Review of limited monitoring data may be required Some maintenance on the system is required, equivalent to a few hours a week	Water quality	Yes	Yes	Yes	Yes	Capital costs £10,000 - £100,000 depending on size. Maintenance costs £1,000 - £5,000 a year
Rectifying misconnections to combined systems	Short term	Permanent	Highly variable and will likely need specific calculations for TP and TN	n/a	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
Incentivise disconnection from combined systems	Short-term	Permanent	TP 252.37 kg/yr	n/a	Homeowner	None	Yes	No	Yes	Yes	£10,000 for the installation of the package treatment

Solution	Delivery timescale	Duration timescale	Nutrient removal potential	Farm type	Management /Maintenance requirements	Additional benefits	Best available evidence?	Effective beyond reasonable scientific doubt?	Precautionary?	Securable in perpetuity?	Cost estimation
											plant. Maintenance and running costs can vary.
Use alternative wastewater treatment providers	Short-term	Permanent	TP - Variable (e.g., 0.4 – 2 mg/l) TN - Variable (e.g., 55 mg/l)	n/a	Annual cleaning required in most cases. Phosphate dosing may be required	Additional water quality benefits Flood risk Habitat creation Amenity space when combined with SuDS / Wetlands	Yes	Yes	Yes	Yes	Capital costs: approx. £5,000 Operational costs: £100 - £200 per annum Per PTP
Install PTPs	Short-term	Permanent	TP removal is variable (e.g., 0.4 – 2 mg/l) TN removal is variable (e.g., 55 mg/l)	n/a	Annual cleaning Phosphate dosing may be required	Additional water quality benefits Flood risk Habitat creation Amenity space when combined with SuDS / Wetlands	Yes	Yes	Yes	Yes	Capital costs: approx. £5,000 Operational costs: £100 - £200 per annum
Upgrade existing private sewage systems	Short/Medium term	Long term	TP -0.71 kg//yr TN – n/a	n/a	None	None	Yes	Yes	Yes	No	£1 million/km of new pipeline
Cesspools and capture private sewage system outputs	Short-term	Impermanent	100% of wastewater	n/a	Emptying every 1 – 2 months Regular inspection	None	Yes	Yes	Yes	Yes	Capital costs: approx. £3,000 - £6,000 Operational costs: £3,200 - £5,600 per year

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Table 4-4 Summary of demand management solutions

Solution	Delivery timescale	Duration timescale	Nutrient removal potential	Farm type	Management /Maintenance requirements	Additional benefits	Best available evidence?	Effective beyond reasonable scientific doubt?	Precautionary?	Securable in perpetuity?	Cost estimation
Retrofit water efficient fittings (Local Authority, registered providers, public buildings)	Short-term	Impermanent	Wastewater reductions of 40 l/person/day achievable	n/a	Replacement parts of the same or better efficiency must be used Monitoring compliance checks required	Sustainability Water resources	Yes	Yes	Yes	Yes	Capital costs: Approximately £1,450 per property
Retrofit water efficient fittings (private housing, commercial and industrial premises)	Short-term	Permanent	2.75 – 3 existing dwellings to every 1 new dwelling. Nutrient reductions dependant on population served and permit limit of WRCs.	n/a	Replacement parts of the same or better efficiency must be used Monitoring compliance checks required	Sustainability Water resources	Yes	Yes	Yes	No	Capital costs: Approximately £1,450 per property
Incentivise commercial water efficiency and treatment installation	Short-term	Permanent	Unknown	n/a	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

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4.2 Suitability of solutions

Table 4-5 outlines the solutions available to each LPA on the basis that it is the LPA delivering the mitigation. The cost effectiveness of each solution is discussed further in **Section 4.3**.

Table 4-5 Suitability of solutions

Solution	Broadland and South Norfolk	Norwich City	Breckland	North Norfolk	Broads Authority	Kings Lynn and West Norfolk
Silt traps	✓	-	✓	✓	✓	✓
Riparian buffer strips	✓	-	✓	✓	✓	✓
Constructed wetlands	✓	-	✓	✓	✓	✓
Wet woodlands	✓	-	✓	✓	✓	✓
Willow buffers	✓	-	✓	✓	✓	✓
Beetle banks	✓	-	✓	✓	✓	✓
Broadland restoration	✓	-	-	✓	✓	-
Beaver reintroduction	✓	-	✓	✓	✓	✓
Taking land out of agricultural use	✓	-	✓	✓	✓	✓
Conversion of agricultural land to solar farms	✓	-	✓	✓	✓	✓
Cessation of fertilizer and manure application	✓	-	✓	✓	✓	✓
Farm management measures	-	-	-	-	-	-
Cover crops	✓	-	✓	✓	✓	✓
Installing SuDS	✓	✓	✓	✓	✓	✓
Retrofitting SuDS	✓	✓	✓	✓	✓	✓
Expedite planned improvements to treatment works	✓	✓	✓	✓	✓	✓
Improve existing wastewater treatment works	✓	✓	✓	✓	✓	✓
Improve existing wastewater distribution	✓	✓	✓	✓	✓	✓
Portable treatment works	✓	✓	✓	✓	✓	✓
Rectify misconnection to surface water	✓	✓	✓	✓	✓	✓
Promote connection to PTPs	✓	-	✓	✓	✓	✓
Use alternative wastewater treatment providers	✓	✓	✓	✓	✓	✓
Upgrade existing private sewer systems	✓	✓	✓	✓	✓	✓
Connecting private sewer systems to the mains	✓	✓	✓	✓	✓	✓

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Solution	Broadland and South Norfolk	Norwich City	Breckland	North Norfolk	Broads Authority	Kings Lynn and West Norfolk
Cesspools	✓	-	✓	✓	✓	✓
Retrofit water saving measures (public)	✓	✓	✓	✓	✓	✓
Retrofit water saving measures (private)	-	-	-	-	-	-
Incentivise commercial water efficiency	✓	✓	✓	✓	✓	✓

4.3 Mitigation requirements

Table 4-6 and **Table 4-7** outline the area (ha) that is required to achieve nutrient neutrality, assuming that only one solution is used to provide the entire mitigation required for each catchment. The wastewater management solutions show the number of PTPs that would need to be replaced or connected to the mains. The calculations set out below apply the nutrient removal rates and costs outlined in **Section 3**.

Table 4-6 shows the lowest £/kg/yr of TP mitigation is achieved through wetland creation and riparian buffer strips. Wastewater management solutions also have good phosphorus removal for the cost involved to set up the solutions. Comparing the £/dwelling for phosphorus mitigation against nitrogen mitigation highlights the inequality from delivering nature-based solutions – with significantly less land required for NN.

Table 4-7 shows that constructed wetlands and riparian buffer strips are also the most cost-effective solutions. Wastewater management solutions are much less effective a delivering nitrogen mitigation than phosphorus mitigation.

Table 4-6 Area/ units required per solution to achieve phosphorus neutrality in each catchment

Solution	Catchment	Area required per year (2023-2025) (ha)	Area required per year (2026-2029) (ha)	Area required per year (2030-2038) (ha)	Total area required (ha)
Silt traps	Wensum	363	115	61	2201
	Yare	8,377	1,694	1,137	42,075
	Bure	3,350	1,462	1,236	26,341
	Ant	212	199	66	2,419
	Thurne	28	0	0	83
	Total	**12,510**	**3,470**	**2,499**	**73,120**
Riparian buffer strips	Wensum	15	5	3	91
	Yare	371	75	50	1,865
	Bure	196	81	69	1,463
	Ant	12	11	4	134
	Thurne	2	0	0	5
	Total	**595**	**172**	**125**	**3,559**
Constructed wetlands	Wensum	5	2	1	31
	Yare	61	12	8	307
	Bure	6	2	2	44
	Ant	0	0	0	4
	Thurne	0	0	0	0
	Total	**72**	**17**	**11**	**386**
Taking agricultural land out of use	Wensum	92	29	15	558
	Yare	2,356	476	320	11,834
	Bure	1,765	731	618	13,171

Solution	Catchment	Area required per year (2023-2025) (ha)	Area required per year (2026-2029) (ha)	Area required per year (2030-2038) (ha)	Total area required (ha)
	Ant	106	99	33	1,210
	Thurne	14	0	0	42
	Total	**4,333**	**1,336**	**986**	**26,814**
Cessation of fertiliser	Wensum	363	115	61	2,201
	Yare	8,337	1,694	1,137	42,075
	Bure	3,530	1,462	1,236	26,341
	Ant	212	199	66	2,419
	Thurne	28	0	0	83
	Total	**12,510**	**3,470**	**2,499**	**73,120**
Cover crops	Wensum	297	94	50	1,801
	Yare	7,540	1,524	1,023	37,867
	Bure	3,530	1,462	1,236	26,341
	Ant	212	199	66	2,419
	Thurne	28	0	0	83
	Total	**11,606**	**3,279**	**2,375**	**68,512**
Upgrade existing private sewer systems	Wensum	72	23	12	435
	Yare	829	168	112	4,161
	Bure	78	32	27	579
	Ant	5	4	1	53
	Thurne	1	0	0	2
	Total	**983**	**227**	**153**	**5,231**
	Wensum	70	22	12	421

Solution	Catchment	Area required per year (2023-2025) (ha)	Area required per year (2026-2029) (ha)	Area required per year (2030-2038) (ha)	Total area required (ha)
Connecting private sewer systems to mains	Yare	802	162	109	4,028
	Bure	75	31	26	560
	Ant	5	4	1	51
	Thurne	1	0	0	2
	Total	**952**	**220**	**148**	**5,064**

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Table 4-7 Area/ units required per solution to achieve nitrogen neutrality in each catchment

Solution	Catchment	Area required per year (2023-2025) (ha)	Area required per year (2026-2029) (ha)	Area required per year (2030-2038) (ha)	Total area required (ha)
Silt traps	Wensum	183	46	8	822
	Yare	1,946	379	143	8,643
	Bure	124	54	33	884
	Ant	11	11	2	112
	Thurne	1	0	0	2
	Total	**2,264**	**490**	**186**	**10,464**
Riparian buffer strips	Wensum	6	2	0	29
	Yare	69	13	5	307
	Bure	5	2	1	37
	Ant	0	0	0	5
	Thurne	0	0	0	0
	Total	**81**	**18**	**7**	**378**
Constructed wetlands	Wensum	1	0	0	5
	Yare	10	2	1	44
	Bure	1	0	0	6
	Ant	0	0	0	1
	Thurne	0	0	0	0
	Total	**12**	**3**	**1**	**56**
Taking agricultural land out of use	Wensum	52	13	2	235
	Yare	577	112	42	2,562
	Bure	35	15	9	250

Solution	Catchment	Area required per year (2023-2025) (ha)	Area required per year (2026-2029) (ha)	Area required per year (2030-2038) (ha)	Total area required (ha)
	Ant	3	3	1	32
	Thurne	0	0	0	1
	Total	**667**	**144**	**54**	**3,079**
Cessation of fertiliser	Wensum	51	13	2	228
	Yare	541	105	40	2,402
	Bure	35	15	9	246
	Ant	3	3	1	31
	Thurne	0	0	0	1
	Total	**629**	**136**	**52**	**2,907**
Cover crops	Wensum	152	38	7	685
	Yare	1,622	316	119	7,205
	Bure	104	45	27	737
	Ant	9	9	2	93
	Thurne	1	0	0	2
	Total	**1,888**	**408**	**155**	**8,722**
Upgrade existing private sewer systems	Wensum	228	57	10	1,026
	Yare	1,967	383	145	8,734
	Bure	168	73	44	1,196
	Ant	14	15	3	151
	Thurne	1	0	0	3
	Total	**2,378**	**528**	**201**	**11,111**
	Wensum	171	43	7	769

Solution	Catchment	Area required per year (2023-2025) (ha)	Area required per year (2026-2029) (ha)	Area required per year (2030-2038) (ha)	Total area required (ha)
Connecting private sewer systems to mains	Yare	1,474	287	108	6,547
	Bure	126	55	33	897
	Ant	11	11	2	113
	Thurne	1	0	0	2
	Total	**1,783**	**396**	**151**	**8,329**

4.4 Next steps

The following sets out the next steps of what is required to develop the solutions into functioning nutrient mitigation solutions:

- Assessment of long-term nutrient mitigation solutions;
- Identification of the preferred solutions to be delivered, the likely costs, timescales, and delivery mechanisms. A mitigation plan should be produced to formulate developer contributions;
- Further engagement with AWS about the preferred schemes and what/ how much of the wastewater and demand management solutions can be implemented;
- A mapping exercise of land in the ownership of the Local Planning Authorities to test the suitability for short-term solutions;
- A database or spreadsheet-based tracking tool to register and record the nutrient loading for each development and through what schemes the loading will be mitigated. This should include details of any legally binding agreements.

  The tool should be able to assign credits from various mitigation schemes at various stages of the development lifetime. The Local Authorities are proactively seeking a solution by working with developers and solution providers to bring forward nutrient neutral development.
- A tracking tool could also be expanded to track 'credits' achieved through mitigation schemes that can be used for biodiversity net gain, carbon offsetting and N mitigation. There are currently no published tools designed for this.
- 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. Conservation covenants can be applied to ecoservices which involve a legal obligation to be attached to land.
- A Mitigation Plan should be established which would set out the key solutions and timescales for expected delivery. This will allow for quantification of when and how many credits will be available.

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