Natural England Joint Publication JP044

# Introduction to Freshwater Wetlands for Improving Water Quality

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WWT

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*Bassenthwaite Lake (Cumbria),*
*a mesotrophic lake*
*© Natural England/Peter Wakely*

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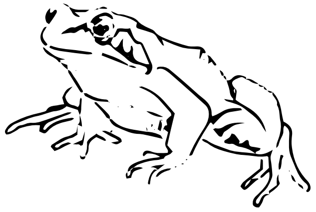
# Contents





# Summary

Poor water quality - particularly nutrient enrichment- is a major problem for many of our lakes, rivers, estuaries and other aquatic habitats. Both phosphorus and nitrogen are responsible for eutrophication impacts, to varying degrees in different situations. This pollution is leading to widespread failures of objectives associated with the Water Environment Regulations, protected wildlife sites and priority habitats and species. The aim of this report is to provide an overview and summarise the science, experience and case studies relating to the use of freshwater wetlands for improving water quality. It is aimed at those new to using wetlands for tackling water quality wanting to understand the potential wetlands have and those that are looking to identify potential wetland opportunities or are at the feasibility or planning stages of implementing wetland interventions.

One of the benefits of wetlands is their ability to remove pollutants through a range of physical, chemical, and biological processes. These naturally occurring processes adsorb, sequester, transform, and remove the nutrients and other pollutants as the water flows slowly through the wetland. There is a large body of evidence from across the globe that demonstrates the effectiveness of wetlands in removing a range of different pollutants.

As well as achieving significant reductions to pollution within a catchment, the other potential benefits of wetlands should not be ignored. They can contribute to the creation and restoration of habitats across the landscape, a more resilient water supply, flood regulation, opportunities for recreation and education, as well as carbon sequestration.

There are a range of wetlands that can contribute to improving water quality, from constructed wetlands with the very specific aim of removing pollutants, to integrated constructed wetlands (ICWs) which look to optimise water quality enhancements whilst also providing other benefits, to the restoration of fully naturally functioning wetlands for biodiversity.

Natural wetlands are immensely important for biodiversity and have been subject to widespread elimination and degradation over many centuries. It is estimated that around 90% of wetlands in England had been lost by the 20th Century. The demise of natural wetlands has led to their restoration being a major priority in biodiversity conservation. Restoring naturally functioning freshwater wetlands in catchments as part of the strategy for nature recovery in England provides major opportunities for improving water quality, for downstream ecosystems and human uses.

There are a number of key principles which can be applied to guide decision making around the use of wetlands for improving water quality. These are:

1) The restoration or creation of wetlands can make an important contribution to improving water quality by 1) restoring fully naturally functioning wetlands in pollution source areas and 2) restoring or constructing wetlands for pollutant removal in places where the source of the pollution can not be removed.

2) Developing a full understanding of hydrological processes and water quality issues within a catchment helps decision making on the best locations and opportunities for creation of ICWs or restoration of naturally functioning wetlands and can help ensure join up on delivery of multiple ecosystem services.

3) Cherish the remaining examples of naturally functioning wetlands and take opportunities to restore them elsewhere for biodiversity objectives, reinstating natural function wherever feasible.

4) Where the full restoration of natural function is not feasible, develop ICWs that provide the most resilient and sustainable solutions, maximising multiple benefits.

5) The use of ICWs can help improve water quality and hydrology thereby facilitating the restoration of more naturally functioning wetlands downstream.

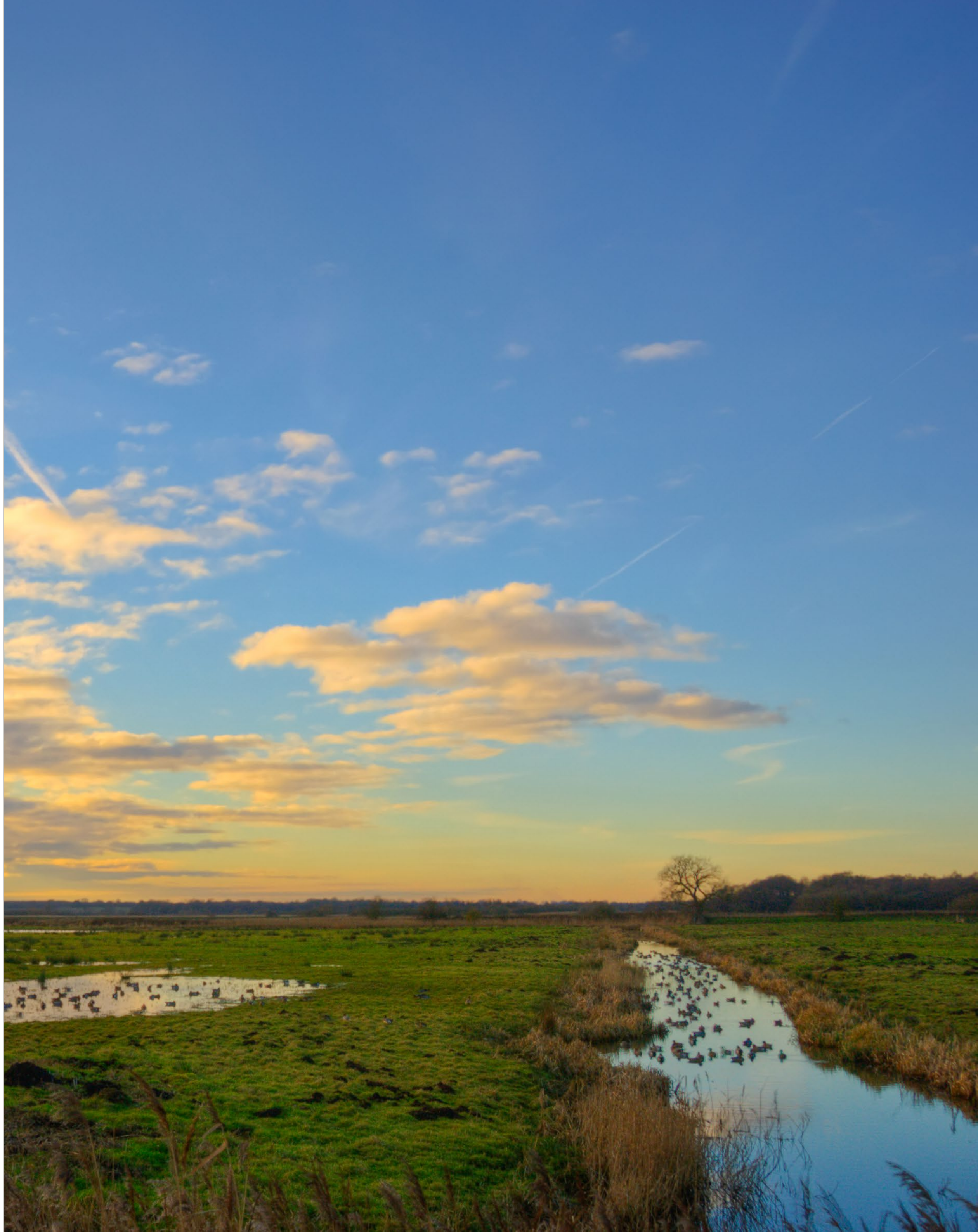
6) The creation or restoration of wetlands will only be part of the solution for improving water quality. Other interventions to reduce sources, break pathways and improve the resilience of ecosystems are needed to address the scale of the water quality problems in many catchments. This involves targeted land use change to natural vegetation in

critical parts of the catchment and effective soil and nutrient conservation elsewhere.

Understanding the sources, pathways and receptors provides a useful basis for identifying the best locations within a catchment for potential wetland intervention opportunities. Planning projects at the catchment scale - even retrospectively if a site has been offered - creates a useful understanding of the catchment's relationship with pollution, potential constraints and the range of outcomes that are looking to be achieved across the catchment. Through this it is then possible to understand to what degree, any specific wetland scheme may contribute to reducing pollution as well as wider catchment objectives. Through considerations such as these, a clear set of aims can be set which can inform the specific design of the wetland intervention.

There are multiple situations, and locations, where wetlands can be used within a catchment to help reduce pollution. This includes downstream of sewage treatment works, urban areas, roads, agricultural areas, storm overflows. In situations where watercourses are heavily modified and of poor water quality it may be desirable to divert part of their flows through wetlands, reinstating natural structure and function as far as possible. Different sources have different characteristics in terms of the likely concentrations of different pollutants as well as the temporal variability of the flow and water quality. Understanding this is important as it will influence the design and type of wetland and in turn the treatment efficiency that may be possible.

The final section of the report specifically focuses on ICWs and the site specific considerations that effect there design and implementation. There are a range of factors which will influence the treatment efficacy, such as the hydraulic loading rate, hydraulic retention time, which will influence the size of the wetland, the wetland vegetation type, and the underlying soil condition. There are also a number of constraints and potential trade-offs that need to be factored in such as specific treatment aims, costs, permit or consent requirements, and the multiple benefits looking to be achieved. There are also a number of important hazards that need to be considered carefully before implementation of any interventions. Therefore the development of wetlands requires significant technical knowledge of these factors and the complexities that could arise, alongside a clear understanding of the objectives. In most cases it will therefore be important to get specialist advice to ensure that all of these factors are thoroughly considered, and that the specific project, and its design, is fit for purpose.



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# Aim and Scope

The aim of this report is to provide an overview and summarise the science, experience, and case studies relating to the use of freshwater wetlands for improving water quality. It looks to point to a range of other available resources and tools including those that can help support the practical application of freshwater wetlands for this purpose.

The primary intended audience for this report is Natural England and Environment Agency staff. However it may also be useful for others interested in an introduction to using wetlands to improve water quality.

It is aimed at those new to using wetlands for tackling water quality wanting to understand the potential wetlands have. It may also be of use for those that are looking to identify potential wetland opportunities or are at the feasibility or planning stages of implementing wetland interventions.

This report focuses on freshwater wetlands and the water quality benefits they can provide. It explores a wide range of wetlands from constructed to naturally functioning wetlands and their potential roles in helping to improve water quality and examines the principles around their use for improving water quality, the trade offs and the wide range of potential multiple benefits they can provide. It also looks at the potential drivers and funding opportunities available for delivery.

The experiences and learning for a number of these different wetland opportunities are explored further in the case studies at the end of the report.

The site scale section of this report focuses on Integrated Constructed Wetlands (ICWs), including the practical and management issues and constraints that have been experienced in their implementation and how this influences design their potential design. It also considers the efficiency of pollutant removal of ICWs in different situations.

# How to Use This Report

Much has been written on how treatment wetlands can be used and designed to mitigate against the damaging effects of poor water quality. It is not the ambition of this guide to repeat such information. This report is intended as a concise summary, providing signposts to more detailed evidence, information and tools which may be of use.

The introduction section provides some basics on wetlands and their use for tackling water quality, aimed at those new to this area. It also sets out some important principles around the use of wetlands and the potential trade off with restoring naturally functioning wetlands for nature conservation.

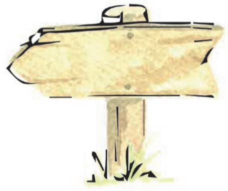
Throughout the report hyper links or references are provided to other useful evidence sources or tools. Key resources are highlighted by the use of the signpost icon.

Selected case studies are included at the back of the report, demonstrating the range of opportunities that exist.

The Appendix contains actively linked online tools, further information and references.

Whilst this report aims to provide an overview of the opportunities for wetland restoration, modification and creation, and the kinds of water quality improvements that might be achieved, in most situations additional specialist advice will be required before interventions are enacted. This is particularly the case for all aspects of constructed wetlands.

These pink boxes represent key information



*Useful resources are 'Signposted'.*

# An Introduction to Wetlands for Water Quality

*Ditch And Reeds on Pevensey Levels © Natural England/Peter Wakely.*

# Wetland Facts

## Biodiversity

- Globally, 40% of the world's biodiversity relies on freshwater wetlands. Yet they only cover around 1% of the planet.[1]
- 84% of Mires and Bogs and 46% of freshwater habitats in Europe are considered to be critically endangered, endangered or vulnerable.[2] This makes mires and bogs the most threatened terrestrial or freshwater habitat in Europe.
- Wetlands make up only 3% of the UK but are home to around 10% of all our species.[1]
- 13% of freshwater species are threatened with extinction in Great Britain,[3] a symptom of the decline in water quality and loss of habitat across the nations.
- 63% of water dependent European sites in England are impacted or at risk from water quality.[4]

## Water Quality Benefits

- Natural wetlands have developed according to natural hydrological pathways. They play a key role in regulating flows[5] and in processing nutrients and fine sediment.[6, 7, 8]
- Treatment wetlands, constructed in order to clean up contaminated hydrological pathways, can trap and retain up to 60% of metals and 90% sediment,[9] and remove significant levels of nitrogen and phosphorus from the water column. More detail on removal rates for N and P can be found on page 70.
- Wetlands can play a role in cleaning our drinking water and reducing the need for and cost of treatment.[9]

## Other Ecosystem Services

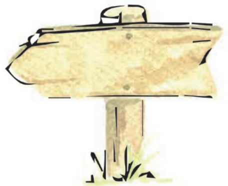
- Wetlands provide a natural protection against floods and storm surges by slowing and storing water and buffering us from the sea.[7, 9]
- When wetlands are in good health, they can provide excellent protection against climate change through sequestering carbon.[7, 10, 11] When wetlands are destroyed or damaged, they can release carbon and other greenhouse gases into the atmosphere.[12, 13]
- Wetlands can play a role in maintaining local climate and reducing temperatures.[12, 13]
- Engagement with wetland environments is good for our health and wellbeing.[14] Our connection with nature is essential for maintaining our wellbeing.[15]
- They can provide a source food (e.g....... fishing and aquaculture).[7, 16]
- Wetlands can provide recreational opportunities e.g. fishing, swimming, sailing, birdwatching etc.[17]
- Wetlands can provide educational opportunities for learning about hydrological processes and biodiversity.[18, 19]

*Steart Marshes*
*© WWT*

# Water Quality Impacts

Water quality impacts - particularly eutrophication from nitrogen and phosphorus - are a major contributing factor for failure to meet Water Framework Directive targets[20, 21] and for the unfavourable condition of water dependent European Sites[4] and Sites of Special Scientific Interest (SSSIs).

This report focuses on the use of wetlands to address nitrogen and phosphorus issues as well as siltation. However there are a wide range of other pollutants that are having environmental impacts, which wetlands can also help address, for example persistent organic pollutants, BOD, bacteria, pathogens and metals, as well as a range of newly emerging chemicals. Additional information on pollutants is provided in the appendix.



Appendix

Additional pollutant information is provided within the Appendix pp.116-119

There are various forms of phosphorus e.g. soluble reactive phosphorus, total phosphorus, particulate phosphorus and also nitrogen e.g. nitrate, nitrite, ammonia.

The chemical form in which these nutrients exist affects bioavailability, transport pathways and the extent of removal within a wetland. It also needs to be recognised that through different processes one form can be converted to another form. It is therefore important to understand the nutrient(s) and the form(s) that are of interest, to ensure that when looking at undertaking monitoring, determining efficiency or designing a wetland to remove nutrients, the relevant form is considered.

The presence of treatment wetlands within a catchment can support the ability to restore fully naturally functioning wetlands.

There are also various potential sources of phosphorus, nitrogen and sediment. Typical sources of phosphorus and nitrogen include:

- Livestock manure and slurry
- Inorganic fertilisers
- Sewage discharges
- Sewer leakage and sewer overflows
- Sewage sludge application to land
- Industrial discharges
- Urban/road run off
- Atmospheric deposition

Natural export

The relative contribution and importance of these different sources varies for nitrogen and phosphorus and will vary for different catchments. For example for nitrogen agricultural run off via surface or groundwater is often the most significant source. Atmospheric deposition and sewage discharges are also often important sources. Whereas phosphorus readily binds to sediment and therefore the most significant sources are usually surface run off from agricultural land and sewage discharges.

Typical sources of sediment include runoff from exposed or disturbed land, bank erosion, roads and construction activities.

It is important to understand the potential sources to be able to identify potential opportunities for wetland interventions and understand the nature of the source, as this can have implications for the design of wetland interventions.

*Nutrient enrichment in Somerset Levels ©Mark R Taylor*

# Why Wetlands?

This report focuses on the potential role of a range of freshwater wetlands, restored and created, to address water quality problems - especially those linked to eutrophication. It also considers the multifunctional benefits that using wetlands can provide.

## What are Wetlands?

The Ramsar Convention on wetlands is an inter government treaty that provides the framework for national action and international cooperation for the conservation and wise used of wetlands and their resources. It defines wetlands as '.... areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters'.[22]

## Current Wetland Status and Future Potential

It is estimated that by the end of the 20th Century, we had lost as much as 90% of all wetlands in England.[23]

Many of the pressures affecting the distribution and quality of freshwater habitat in the UK relate to historical land drainage. In addition, poor water management across many sectors has resulted in widespread damage and the further restriction of wetland habitats.

Freshwater wetlands can protect downstream habitats from pollution. Their loss in the catchment potentially increases the connectivity between pollution pathways and sensitive aquatic receptors.

In addition to this historic destruction, modern threats persist. These include agricultural intensification, climate change, urbanisation, pollution, invasive species and changes to water and woodland management. The loss of wetland habitat across the world continues at a rate three times faster than forests.[24]

However, good water management is progressing, across the country. And simultaneously, the balance of wetland loss can be reversed.

These freshwater wetlands, if present in the landscape, can help mitigate the pollution problem, and bring tremendous biodiversity benefits, not only to their immediate surrounds, but also within the wider catchment.

The creation and restoration of wetlands across catchments is a vital opportunity to restore biodiversity, build resilience in the face of climate change, and deliver multiple benefits that we need.

As a result, this area of work is increasingly recognised as having all-round benefits by policymakers, and progress is being made in those sectors most responsible for pollution.

*White Faced Darter © Helen Wake*

# Wetland Hydrology and Water Quality

Wetland habitats are shaped by many natural factors, and over the centuries by the influence of human modifications in the landscape. Hydrology is of primary importance - especially when considering the pathways for pollutants to enter or leave wetlands - and the principal dynamics of this are shown below. It is important to understand that the balance of hydrological influences will vary, and that not all of the following water transport mechanisms will necessarily be present in each type of wetland.

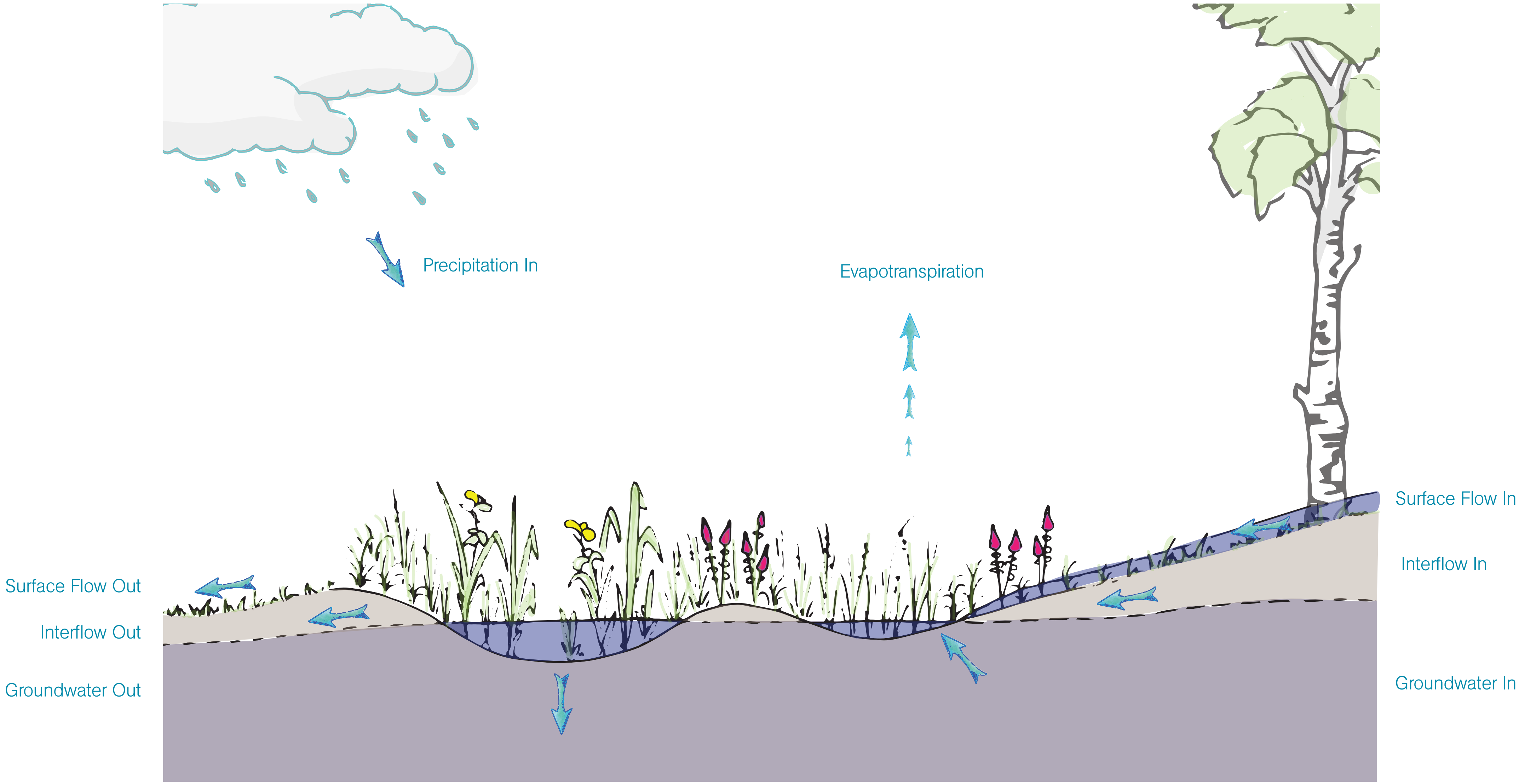



Figure 1 - Wetland Hydrology

## Precipitation

Water can enter a wetland in the most immediate fashion through precipitation. Some seasonal and ephemeral wetlands rely only on precipitation for their water supply.

## Evaporation and Evapotranspiration

Water has a gaseous phase and this describes evaporation. As plants transpire water is also lost as evapotranspiration. The relative level and structure of vegetation, as well as the amount of open water and climatic conditions, will influence evaporation and evapotranspiration.

## Surface Flow

Water can enter or leave a wetland at the surface via diffuse flows, or through specific surface channels. Channel flow includes rivers, streams and human-made channels such as ditches. Diffuse flows in and out of wetlands can include overland (sheet) flow, as well as flood water.

The type, and quality of surface flow is heavily influenced by precipitation and by position in the landscape (notably topography, land-use and soil type).

## Interflow

Water that infiltrates the ground can move laterally through the unsaturated zone and this is known as interflow. Interflow may 'exfiltrate' - that is, water returns to the surface where it can become overland flow, or feeds directly into a surface water body such as a river, stream or lake.

## Groundwater

Groundwater is water that has infiltrated into the ground. It is considered to be all water below the surface of the ground that is within the saturation zone.

Groundwater discharge can provide water directly to surface waters and wetlands - including through springs and seepages.

Wetlands also discharge via infiltration, to groundwater. Groundwater provides about one-third of public water supplies in England and Wales. Refer to Table 2 for detail of Source Protection Zones (SPZs).

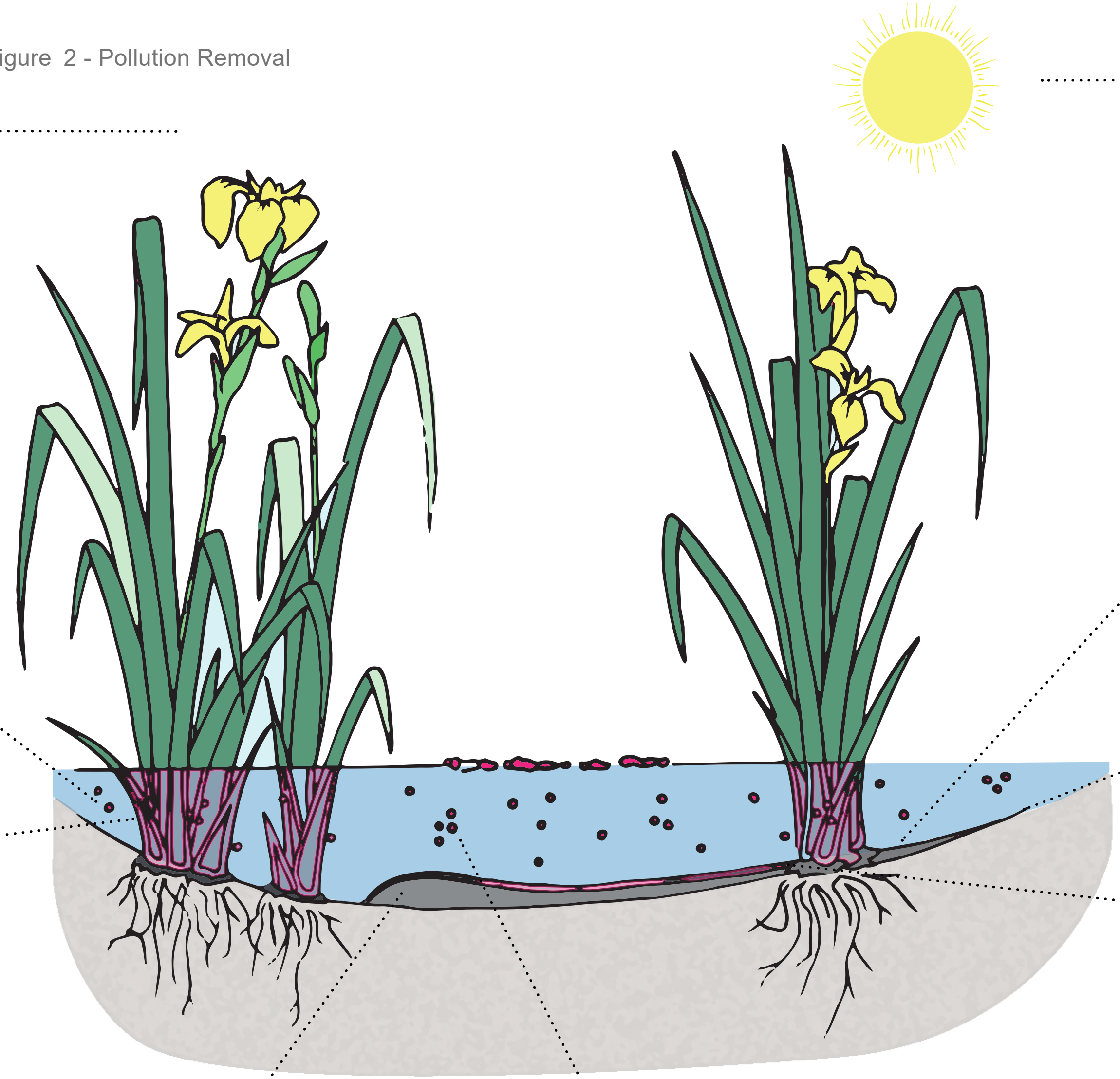
**The quantity, quality, and longevity of the wetland habitat created will depend heavily on the suitability of the flow regime.**

*River Bain headwaters, Lincolnshire Wolds*
*Credit © Natural England/Neil Pike*

# Pollutant Removal in Wetlands

There are a range of physical, chemical, and biological processes which act in combination to remove pollutants. Some of the key processes are presented below. Not all are present within different wetland types, and not all wetland types have permanent standing water.

Figure 2 - Pollution Removal



Volatalisation - this is the transfer of a compound from a solid or solution, into the atmosphere. It is an effective process for the removal of ammonia from the water column, volatile hydrocarbons, and synthetic organics.

Biofiltration - pollutants that are conveyed with sediment may be filtered. Effective for BOD/COD, P, hydrocarbons, and synthetic organics

Uptake by plants - especially via biofilm on plant structure and nutrients in the soil. It is important to note that die-back of vegetation can release nutrients.

Photolysis - from UV exposure - commonly associated with the degradation of pathogens.

Biodegradation is a microbial process occurring in the biofilm on the plant structure and in the soil and water. An example is the oxidation of ammonia into nitrates and nitrites. Nitrate for example, can then be easily taken up by plants but can also be lost as water pollution.

Denitrification is the microbial process of reducing nitrate and nitrite to gaseous forms of nitrogen, principally nitrous oxide (N2O) and di-nitrogen (N2). A large range of microorganisms can denitrify.

Adsorption is when pollutants such as phosphorus attach or bind to the surface of growing media - such as soil or sediment. pH and differences in soil type can have significant impact on adsorption of pollutants, and owing to saturation of the media, the process becomes less effective, unless replaced.

Sedimentation - many pollutants will bind to sediment. The trapping of sediment in wetland features is achieved principally by controlling flow velocity, and through barriers that encourage sedimentation. Requires periodic removal, and design to compensate. Effective for removing heavy metals and dissolved nutrients through precipitation.

Precipitation - this is the most common mechanism for removing soluble metals. It is a binding of compounds and elements by chemical reaction. Precipitation can bind most heavy metals and dissolved nutrients. This process is also responsive to changes in pH.

# Types of Wetlands

**There are a range of wetlands that can contribute to improving water quality, from constructed wetlands with the very specific aim of removing pollutants, to ICWs which look to optimise water quality enhancements whilst also providing other benefits, to restoration of fully naturally functioning wetlands for biodiversity.**

## Constructed Wetlands

Constructed wetlands are specifically designed and created to optimise pollutant removal efficiencies. Three common types of constructed wetlands have evolved in Europe since the 1950s for managing pollution: Vertical Flow Wetlands (VF), Horizontal Subsurface Flow Wetlands (HSSF) and Free Water Surface Wetlands (FWS). Constructed wetlands offer measurable water quality benefits as they exist as a response to polluted waters, but tend to provide lesser multiple benefits.

### Vertical Flow Wetlands

In vertical flow wetlands the water flows vertically down through the filter matrix to the bottom where it is collected. Käthe Seidel, a German botanist, developed a series of Vertical Flow, and HSSF filter beds in the 1950s and 60s. Vertical Flow wetlands were developed to provide higher levels of oxygen transfer. They have, as a result, the ability to oxidise ammonia. Very concentrated wastewaters can be treated in vertical flow wetlands.

### Horizontal Subsurface Flow Wetlands

In 1985 the first two HSSF constructed wetlands were built in the United Kingdom (where they are commonly called reed bed treatment systems). HSSF wetlands consist of gravel or soil beds, planted with emergent wetland vegetation. They are typically designed to treat primary effluent, following screening. Flow passes beneath the surface of the media and flows in and around the roots and rhizomes of the plants.

### Free Water Surface (FWS) Wetlands

The IJsselmeerpolders Development Authority in Flevoland, The Netherlands, constructed the first European FWS wetland in 1967.



FWS wetlands contain areas of open water, floating vegetation, and emergent vegetation. Of all the treatment wetland types, they can offer habitat benefits most similar to natural wetlands, and attract a variety of wildlife.

FWS wetlands are used in many different situations, for example to polish effluent from secondary treatment processes, as well as for surface water treatment, and for animal wastewater treatment.

## Integrated Constructed Wetlands (ICWs)

Integrated Constructed Wetlands are FWS Wetlands but they also include elements of good landscape fit, biodiversity and habitat enhancement into their design, therefore offering a range of multifunctional benefits.

The ICW concept has been developed from work that started in 1990 to improve the water quality and associated natural resources in the catchment of the Dunhill-Annestown stream in south County Waterford, Ireland. The ICW initiative focused on an entire catchment, taking some inspiration from the 'small watershed technique' that was developed at Hubbard Brook, New Hampshire USA.

The Integrated Constructed Wetland concept arises from the limitations associated with addressing just the need of water treatment itself. Focus on this single driver was thought to ignore many of the links that wetland have with the natural and human environments.

As such, a series of fundamental principals have evolved, that define the ICW concept:

- The containment and treatment of influents within emergent vegetation
- Landscape 'Fit' - aesthetic placement of the wetland features into the local landscape and enhancement of the site's ancillary values
- Enhanced biodiversity
- Largely self-managing
- The use of local soil material (wherever possible)

**ICWs can offer significant biodiversity gains, both locally and downstream. Biodiversity within such a wetland maybe necessarily restricted however, by its working functions.**

## Naturally Functioning Freshwater Wetlands

Fully naturally functioning wetlands are rare, as wetlands have been subject to widespread elimination and degradation over many centuries. The aspiration for the conservation of freshwater and wetland habitats is to restore natural processes, free from anthropogenic impacts, with a characteristic mosaic of species.

This leads to naturally functioning wetlands being located in the landscape according to natural hydrological pathways, water supply and retention, nutrient and sediment regimes and natural hydrological and biological connectivity. It is these natural environmental processes that determine the characteristic biological communities present.

Table 1 sets out indicators (hydrological, geomorphological, chemical, biological) for a naturally functioning wetland. These conditions provide the best defence against climate change, through maximising the ability for these ecosystems to adapt to changing conditions, as well as enhancing natural capital, for instance through restoring the ability of landscapes to moderate flooding and store water and carbon.

In practical terms there are major socio-economic constraints on the extent to which natural function can be achieved in England. This varies however depending on human population density and the spatial distribution of anthropogenic activities such as agriculture. It is important to recognise there are immovable constraints and the extent to which any wetland can operate to natural processes will be dependent on the site specific circumstances.

Fully naturally functioning wetlands should have high water quality. Restoration of natural wetlands is best targeted in pollution source areas where the source of pollution can be removed and the wetland can be fed by high quality water.

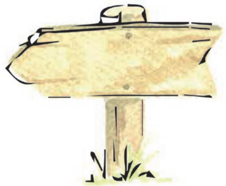
Wetland pollutant removal processes (see pg 24/25) will still occur in a fully naturally functioning wetland, however the amount of pollutant removed will be less due to the lower levels present and because they are not specifically designed and optimised for pollutant removal.



Table 1 - Indicators of Natural Function, excerpt from A Narrative for Conserving Freshwater and Wetland Habitats in England

| Indicator (Natural Processes) | Context |
| --- | --- |
| Lateral connectivity with surrounding semi-natural habitats and open waters | This allows the development of natural transitions and the restoration of hydrological integrity across the core wetland system. Not only does this confer greater resilience to wetlands and associated ecosystems, it should provide conditions for the full range of dependent species. |
| Connectivity - frequency of habitat occurrence | Wetlands need to provide a network of characteristic habitats in their own right but need also to provide landscape scale refugia and stepping stones for a range of aquatic and terrestrial biota that are associated with wetlands and other habitats. |
| Natural hydrological regime | Natural hydrological regimes are fundamental to healthy wetland ecosystems. Extreme fluctuations and loss of fluctuations both potentially cause the loss of species. |
| Naturalness of water quality regime | High water quality is a critical requirement for protecting and restoring characteristic biological communities. Nutrient status is a key factor, and nutrient enrichment is implicated in a range of ecosystem effects. Others include acidification, organic pollution, and toxic pollution. |
| Absence of non-native species | Non-native species can modify wetland habitats and directly alter characteristic assemblages to a considerable degree. |
| Naturalness of biological community | The extent to which the biological community is characteristic of the wetland in its unimpacted state is a fundamental biodiversity consideration. However, the practicalities of assessment and its linkage to natural habitat function are problematic. |

We must aim to restore natural function within wetland habitats - and the environmental conditions that support them - if we are to achieve international and national biodiversity targets.



[Natural England Research Report NERR064](Natural England Research Report NERR064)

*A Narrative for Conserving Freshwater and Wetland Habitats in England*

# Using Wetlands to Reduce Pollution

Trade offs and constraints will often be encountered when creating or restoring wetlands. This will influence decision making on which wetland type is most appropriate in any location and this will be dependent on the objectives and outcomes that are looking to be achieved.

## Trade Offs

There is a clear trade off between the scale of the water quality improvement and the biodiversity gain or level of naturalness achieved. The greater the pollutant load into the wetland the greater the potential is for pollutant removal. Whilst on the other hand the greater pollutant load that is above the natural regime, the greater the impact on biodiversity and the deviation from the characteristic species mosaic.

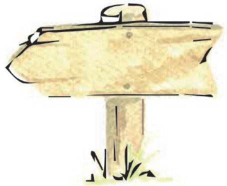
That is not to say though that wetlands with high pollutant loads, do not provide biodiversity benefits. Rather that they will provide a different biodiversity to that which might be considered 'natural', but can still be very beneficial in increasing certain biodiversity interests. For example they can be great habitats for aquatic invertebrates and amphibians and in turn they can become feeding places for birds, bats, reptiles etc. Whilst these may not be rare species they can be widespread species that are no longer as common because of habitat loss.

In reality there is a spectrum of wetlands with the primary aim to improve water quality moving from highly engineered wetlands that are less naturally functioning and deliver fewer multiple benefits through to those that are highly naturally functioning except for the water quality regime. This is where lines blur with the restoration of fully naturally functioning wetlands primarily for biodiversity where the aim would be to restore natural function including the natural water quality regime. Even where looking to restore fully naturally functioning wetlands there will be a spectrum depending on how far it is possible to restore all aspects of natural function.

There will also be similar trade offs with the type and scale of multiple benefits that can be achieved depending on the desired outcomes.

Therefore the type of wetland which might be appropriate and the multiple benefits that can be achieved in any location in a catchment will vary depending on the local circumstances and what is possible and desirable.

The potential multiple benefits that can be achieved through the restoration or creation of ICWs or restoration of fully naturally functioning wetlands are explored further in the following section.



Natural England Research Report NERR071

Generating more Integrated Biodiversity Objectives Rationale, Principles and Practice.

*Water rail - elusive dwellers of freshwater wetlands - are thinly distributed as breeding birds across the UK @ Mark R Taylor*

# Multiple Benefits of Wetlands

A great number of multiple benefits accrue from restoring naturally functioning habitats. Similarly, the enhancement of water quality through Integrated Constructed Wetlands (ICW)s should also seek to consider, as part of a feasibility assessment, those multiple benefits that can be derived.

Wetlands can provide a range of ecosystem services and therefore there is the potential to accrue a range of multiple benefits alongside improving water quality through the creation or restoration of wetlands.

Naturally functioning habitats, for example, can offer the best expression of biodiversity, whilst delivering other essential ecosystem services such as water supply, flood regulation, and resilience to climate change and some albeit limited water quality improvement.

Similarly, an ICW can offer excellent water quality gains, while also supporting services such as flood regulation, biodiversity improvements, recreation and education, well-being and resilience to climate change.

Although wetlands can provide a wide range of benefits, there are trade off's and therefore not all will be able to be maximised in any one wetland.

## Biodiversity

Wetlands make up only 3% of the UK but are home to around 10% of all our species.[25] As this figure demonstrates, wetlands can support tremendous biodiversity.

Naturally functioning wetlands have the best potential to offer the greatest diversity, however ICWs have been shown to increase in-situ biodiversity. For example monitoring of the Frogshall ICW showed an increase in the mean number of bird species at that location.[26] An increase in in-situ biodiversity is often due to the presence of a new habitat providing greater habitat variability for a wider range of species.

There will always be a trade off between the focus and purpose of an ICW being nutrient removal and therefore being targeted where there are higher nutrients and the fact that higher nutrient levels will restrict species to those more tolerant of those higher nutrient levels. However even where nutrient levels are higher they can be great habitats for the more nutrient tolerant aquatic invertebrates and amphibians and in turn they can become feeding places for birds, bats, reptiles etc. The presence of multiple pools or cells within an ICW can help provide a range of nutrient levels throughout the wetland therefore increasing the biodiversity potential of the overall wetland.

The creation or restoration of wetlands not only increases the biodiversity at the wetland itself but can also protect and enhance biodiversity of the aquatic habitats further downstream by regulating flow and improving water quality regimes.

## Flood Regulation

The creation and restoration of wetlands including restoration of floodplain wetlands alongside other nature based solutions are a more sustainable solution to reducing flood risk and mitigating for the impacts of climate change such as changing weather patterns.

Wetlands can soak up and retain rainfall, or flood waters encouraging natural losses through evapotranspiration, and interception. Thereby potentially releasing less water and more slowly, thereby reducing the risk of flooding downstream.

Achieving additional flood storage at the same time as water quality improvement is a delicate balance that requires careful technical design, but it is possible.

The level of natural function to be achieved, and the associated biological communities will determine the appropriateness of seeking flood mitigation. In more engineered scenarios, such as certain ICWs where treatment aims are high, landscape fit should remain a key consideration. Additional flood capacity above normal water levels (this additional capacity is often referred to as 'Freeboard') must be balanced with a potential impact on ecology, water quality and aesthetics.

In addition multifunctional benefits can be achieved if adjacent land is suitable for runoff attenuation. For example, designing a controlled overflow to adjoining shallow features can maximise losses (such as evapotranspiration and infiltration, where viable), keep regular water depths to safe levels, and offer multifunctional greenspace that is dry the great majority of the time.

## Water Resources

Water resources refers to the supply of water for human or biodiversity use. In relation to human use this can include the abstraction of water for drinking water, but also includes the supply of water for agriculture and industry, as well as bathing waters.

Water quality improvements through wetlands can improve drinking water quality. They can also help to regulate and maintain the supply of water through enabling infiltration to groundwater where suitable, or releasing slowly to surface waters.

They can also provide some degree of buffering against drought through the fact that they store and release water more slowly.

## Climate Change

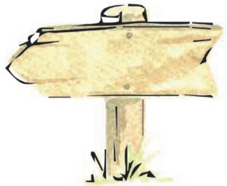
Climate Change is recognised as an important policy area in both the Agriculture Bill and the 25YEP.

Healthy wetlands can be a vital tool in mitigating against climate change. Wetlands can capture and store carbon. The wetland plants take up carbon via photosynthesis and build plant biomass, which accumulates in the soil as organic matter storing the carbon. Wetlands can be very effective sinks for carbon. Wetlands also release carbon to the atmosphere in the form of the greenhouse gases CO2 and CH4 (methane). The balance between carbon uptake and release varies due to numerous factors including wetland type and condition and determines their ability to act as a carbon sink.

They can also help us adapt and increase resilience to the effects of climate change such as the increased frequency of flooding, drought and heat waves, through reducing or buffering the impacts from these events. They can also play a role in maintaining local climate and reducing temperatures. For example, the evaporation and transpiration of water from vegetation has a local cooling effect.

The presence of wetland networks and corridors also allow wetland-dependent plants and animals to adapt in response to changing climatic conditions by moving to new areas.

But wetlands will also need to adapt to the changes, and measures that build such resilience. Wetlands that are highly modified or degraded may be more sensitive and less resilient to climate change. Therefore the more naturally functioning a wetland is, the greater its resilience will be to climate change.



Ramsar briefing Note 10

Wetland restoration for climate change resilience

## Health and Wellbeing

The wellbeing derived from proximity to nature is an understanding derived from the early works of environmental psychologists such as Kaplan, and Ulrich.

There is a move to looking at nature-based health interventions for improving health and wellbeing. Blue spaces, defined as environments that predominately consist of water, thereby including wetlands, have been shown to be better at promoting wellbeing than green space.

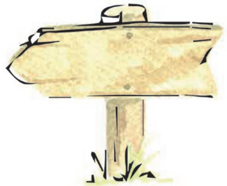
The engagement with blue spaces has been shown to provide a range of mental and general health benefits including reducing anxiety and stress and improving metal and emotional wellbeing.

## Education and Recreation

Wetlands can provide a range of recreational opportunities, such as bird watching, walking and kayaking, Conservation and treatment aims will dictate the suitability of public access, but where possible, these are excellent benefits to achieve.

Wetlands can represent an excellent educational resource, demonstrating hydrological processes, as well as extensive plant and animal communities.

Community groups are an excellent means of developing support and long-lasting enthusiasm for a project, from the early stages. Such groups can help with the creation, monitoring and protection of features.



Firs Farm Urban Wetlands Case Study

An urban wetland with significant benefits for water quality and community.

# Principles of Using Wetlands for Water Quality Improvements

Before embarking on a project involving wetland restoration or creation to improve water quality it is worth considering some key principles. These can provide a key reference point for decision making around the use of wetlands for improving water quality.

The following principles can help understand how wetlands can be part of a wider catchment pollution reduction intervention strategy and how they can be best used to provide benefits across a range of objectives. They also help to avoid conflict between the restoration of naturally functioning wetlands primarily for biodiversity and the creation of wetlands specifically for targeted water quality improvements.

The principles are:

1) The restoration or creation of wetlands can make an important contribution to improving water quality by 1) restoring fully naturally functioning wetlands in pollution source areas and 2) restoring or constructing wetlands for pollutant removal in places where the source of the pollution can not be removed.

2) Developing a full understanding of hydrological processes and water quality issues within a catchment helps decision making on the best locations and opportunities for creation of ICWs or restoration of naturally functioning wetlands and can help ensure join up on delivery of multiple ecosystem services.

3) Cherish the remaining examples of naturally functioning wetlands and take opportunities to restore them elsewhere for biodiversity objectives, reinstating natural function wherever feasible.

4) Where the full restoration of natural function is not feasible, develop ICWs that provide the most resilient and sustainable solutions, maximising multiple benefits.

5) The use of ICWs can help improve water quality and hydrology thereby facilitating the restoration of more naturally functioning wetlands downstream.

6) The creation or restoration of wetlands will only be part of the solution for improving water quality. Other interventions to reduce sources, break pathways and improve the resilience of ecosystems are needed to address the scale of the water quality problems in many catchments. This involves targeted land use change to natural vegetation in critical parts of the catchment and effective soil and nutrient conservation elsewhere.

To know what action might be appropriate it is essential to seek to understand the system as it would operate under natural processes, understand present and historical modifications and their impacts, and plan from that foundation.

*Minsmere Heaths and Marshes*
*©NE/Peter Wakely*

# Drivers for the Delivery of Wetlands

**Various drivers and mechanisms exist for the creation or restoration of wetlands. Some drivers have water quality improvements as their primary aim; such as the Water Framework Directive. In other cases, water quality improvement will be a secondary benefit. Some of the principal drivers are discussed below.**

A summary of the current key drivers for water quality improvements through wetlands can be seen in table 3. This table is not exhaustive.

The 25 Year Environment Plan (25YEP), of January 2018, includes the development of a Nature Recovery Network, that aims to provide:

'500,000 hectares of additional wildlife habitat, more effectively linking existing protected sites and landscapes, as well as urban green and blue infrastructure'.

As one of the key vehicles for delivering the 25 Year Environment Plan (25YEP), the Environment Act will be one of the principal drivers for improving biodiversity and water quality, therefore potentailly driving wetland creation, restoration and the use of intergrated constructed wetlands.

The Water Environment (Water Framework Directive (WFD)) Regulations (hereby refered to as WFD) and the Habitat Regulations are also key drivers as the restoration and creation of wetlands can play a role in achieving the objectives for both of these

The new ELM scheme will become the cornerstone of UK agricultural policy, aimed at achieving the goals of the 25 Year Environment Plan and will be looking to pay for multiple benefits including clean and plentiful water, mitigation of and adaptation to climate change, and thriving plants and wildlife.




Table 2 - Summary of Key Current Drivers for Water Quality Improvements through Wetlands

| Driver | Description | Water Quality Benefits |
|---|---|---|
| Water Environment (WFD) Regulations | Requirement to achieve Good Ecological Status (GES) for water bodies and achieve Protected Area objectives (e.g. drinking water, Habitat Sites). Includes development of 9 River Basin Management Plans which include a programme of measures which are revised every 6 years. | Monitoring, identification of measures needed to meet water quality objectives |
| Source Protection Zones | Safeguards drinking water quality. Prevents pollution entering groundwater or rivers. | Treatment wetlands can be used - often at the end of a cascade of SuDS devices - to polish water prior to infiltration. |
| Habitat Regulations | The Habitat Regulations provide protection to habitats and species of European importance,(through the designation of SAC and SPAs) which include freshwater and wetland habitats and species. Management plans to conserve or restore sties are developed and there is a requirement to ensure no deterioration. In addition the Habitat Regulations Assessment process ensures that there will be no adverse effect on site integrity from new planning or development. | Diffuse water pollution or nutrient management plans are developed to restore water quality to achieve favourable consideration status of European sites. These identify measures needed to restore the site which can include wetland creation or restoration. HRAs can lead to a requirement for Nutrient Neutrality from development; of which wetlands can be one means of achieving this. |
| Wildlife and Countryside Act | Gives protection to nationally important species (especially those at threat), controls the release of non-native species, and enhances the protection of Sites of Special Scientific Interest (SSSI) | Wetlands themselves are SSSI features which may need restoration. SSSIs unfavourable for water quality require whole catchment approaches to protection of water quality through Diffuse water pollution plans. |
| Ramsar | International treaty for conservation of wetlands. | Designated wetlands, Requirements to improve including water quality. |
| Surface Water Management Plans | These are used to assess the risk of surface water flooding, and plan investment and action to manage this flood risk. | Wetlands can offer flood regulation services. |

# Funding for the Delivery of Wetlands

**The funding mechanisms for improvements can be direct, or it can be derived from other funding objectives, as described in the previous section. As the UK leaves the EU and develops independent legislation, a growing trend is the funding of Ecosystem Services.**

The key funding opportunities for water quality improvements through wetlands can be seen in table 5. This list is not exhaustive.

Central funding for environmental protections is undergoing change. The Agriculture Bill delivers the powers for Government to fund farmers for the provision of 'public goods – such as better air and water quality, improved access to the countryside and measures to reduce flooding'. The environmental land management scheme will be the mechanism through which these measures are funded and delivered, which could include the creation of ICW or restoration of naturally functioning wetlands.

The requirement for Nutrient Neutrality in relation to Habitats sites that are unfavourable for water quality (N and/or P) to ensure that new development does not add to the existing problem, provides a mechanism for funding and delivering wetlands. Wetlands are one measure that can be implemented to provide a reduction in nutrients to offset any increase from the development.

Catchment Nutrient Balancing (CNB) and flexible permitting also provides opportunities for water companies to be more innovative in their solutions to reduce their impact on water quality. For example, through CNB Water companies are able to pay for action on other sources e.g. agriculture or miss-connections, which could include the installation of wetlands, in order to reduce the cost or provide additional benefits over and above traditional end of pipe treatment upgrades.

Case studies within this document are also a guide to sources of possible funding, whilst giving an idea of relative construction cost.



Table 3 - Key Funding for Water Quality Improvements through Wetlands

| Body | Mechanism | Notes |
|---|---|---|
| Central Government | Agri-Environment Schemes | Delivery of the 3 new Environmental Land Management schemes, will be phased in over the coming 7 years. |
| Water Companies | Periodic Review of Business Plans including the WINEP e.g. through catchment nutrient balancing and flexible permitting | The process of producing water company business plans is regulated by OFWAT and EA, with specialist advice from NE as the government's statutory advisors on nature conservation. |
| Highways Authority | Designated Funds | Delivery of environmental improvement schemes |
| Local Government/ Developers | Nutrient Neutrality - Developer funding/Developer Contribution Scheme/Section 106 | Nutrient neutrality measures which can include creation or restoration of wetlands can be funded directly by developers or via the local authority through the use of section 106/developer contribution types approaches. |
| Central Government | Flood and Coastal Erosion Risk Management (FCERM) | Funding for FCERM is administered through DEFRA, the EA and the Department for Levelling up, Housing and Communities |
| ENTRUST | Landfill Communities Fund | Funding stipulations can vary, but a defined area of work within the ENTRUST regulation is the conservation or promotion of biodiversity |
| Local Authority | Community Infrastructure Levy | Local infrastructure funding in line with Development Plans |
| National Lottery | Community Fund | Includes the Climate Action Fund |
| Local/Small Charity Funds | Various | Local funds can facilitate projects and lead to excellent buy-in |

# Identifying Wetland Opportunities Within a Catchment

© Andy Harmer

# Catchment Overview

**Planning projects at the catchment scale - even retrospectively if a site has been offered - creates a useful understanding of the catchment's relationship with pollution, and the multiple physical and socio-economic layers that can inform a suitable response. In this section we explore some of wetland opportunities that are available within a catchment to improve water quality and some of the key tools and approaches available to help identification of those opportunities.**

Catchment planning can be broadly separated into two useful steps:
1) Understanding risk
2) Identifying opportunities through a closer look at certain key physical and socio-economic characteristics of the catchment.

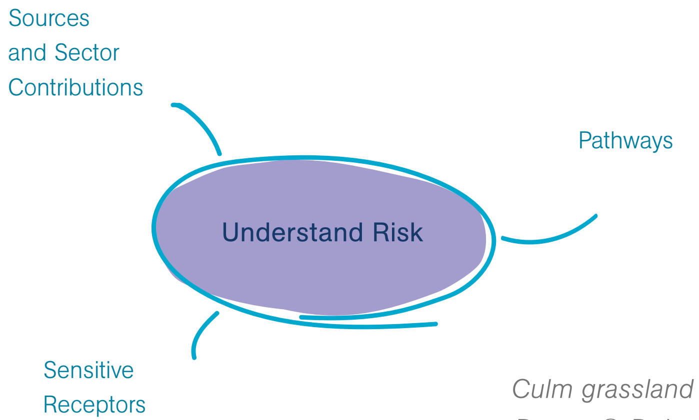
Early engagement with [Catchment Partnerships](#) can help to ensure that all strategic opportunities, planned interventions and local intelligence are fully understood. and taken into account.

There are many online tools to assist this process; these are listed, and linked, in the Appendix.

## Step 1 - Understand Risk

The concept of considering sources, pathways and the sensitive receptors (Figure 3) is helpful for identifying high risk locations within in a catchment where wetland interventions might usefully be deployed.

Figure 3. The Sources of pollution, the Pathways through which it can travel, and the character/sensitivity of Receptors.




### Sources

There are several means to identify those Sectors and Land-uses that contribute to known pollution problems within the Catchment.

Useful tools include the Environment Agency Catchment Explorer, and the Water Quality Archive. The Rivers Trust have a user-friendly rivers map with overall water body status and further links to the detailed assessments of the Catchment Explorer, for each water body, called How Healthy is your River?

Members of CaBA have access to the CaBA data package, which includes a 150 layers related to understanding catchments and risks. Many of the layers are Open Data and can be freely accessed by non-CaBA members through the CaBA Evidence Review Tool.

Condition assessments of designated sites, and reasons for adverse conditions (including water quality) can be found at Natural England's Designated Sites View. Additional tools exist for understanding the contribution of various sectors and activities to pollution. These are referred to as 'Source Apportionment' tools, several of which are linked within the Appendix.

One potentially polluting source - sewage outfalls- can be neatly tracked in a comprehensive interactive map, also by the Rivers Trust, called Is My River Fit To Swim In?

*Culm grassland at West Yeo Farm, Devon © Deborah Deveney RSPB*

## Pathways

Understanding the pathways that exist for pollution transport, will identify the likelihood of pollution reaching freshwater systems and sensitive sites (Receptors).

Pathways for pollution are diverse, and can vary in nature, according to the source of pollution and flow dynamics. Pathways can include channels of many different sorts, surface and sub-surface flows (including groundwater), piped drainage, and roads.

Major pathways - such as streams and rivers - can also be sensitive receptors. These aquatic environments can be impacted at the same time as transporting pollution to other sensitive receptors.

Tools such as SCIMAP identify the surface water hydrological connectivity which provides a guide as to where in the landscape diffuse pollution is likely to originate and the potential pathways. It also specifically looks at erosion risk and identifies the fine sediment risk within an area and the likely high risk sediment source areas.

Other methods exist to understand pollution pathways, such as the mapping of headwater stream quality. The comparison of the observed and expected presence of invertebrate indicator species in headwater streams provide good indicators of water quality and may help as a proxy to identify sources.

Simple surface water flow routes (unrelated to sources of pollution) can be identified using tools such as the Risk of Flooding from Surface Water datasets, as these identify areas of high flow and accumulation.

**The degree of nutrient reduction that wetlands can achieve across a catchment will be directly related to the proportion of pathway flow that can be directed through them.**

*Bearded Tit © Mark R Taylor*

## Receptors

The level of adverse influence that pollution could have is dependent, not only on the likelihood of transport, but also partly on the sensitivity of Receptors.

A pristine biological community for example could be badly damaged by minor disruptions to water quality. Different habitats and species have different sensitivities and tolerances to different pollutants which will determine the biological community changes that any pollutant will have.

For the purpose of this guide, Protected Areas and aquatic environments are considered Sensitive Receptors.

Protected Areas can include sensitive groundwaters, and these can be identified through the Magic Maps portal.

It is also important to recognize that the protection of aquatic environments includes Coastal Areas.

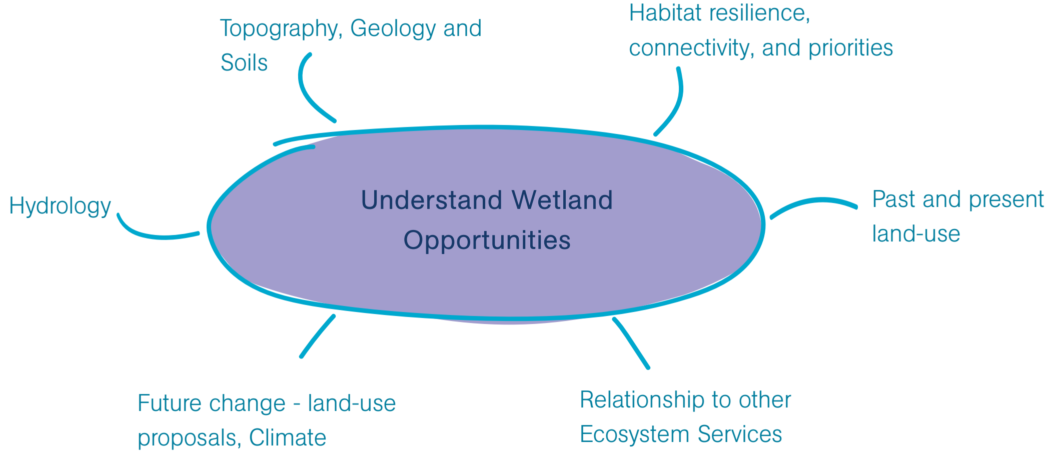
Special Areas of Conservation, Special Protection Areas, Marine Conservation Zones, Sites of Special Scientific Interest and Shellfish Waters Protected Areas are especially vulnerable to freshwater pollution, and the direct connectivity of any pollution to such areas should be considered within this opening analysis.

Figure 3 overleaf shows some of the possible Sources, Pathways and Receptors of Pollution that may be found within a catchment.

## Step 2 - Understand Wetland Opportunities

**Once risk, via sources, pathways and receptors have been identified, the catchment picture becomes a little more clear. There are a range of physical and socio-economic factors (figure 4) as well as the principles outlined in the previous section, which can inform decision making on the location and type of wetland opportunities that would be most appropriate.**

Figure 4. Physical and Socio-economic factors, as well as Ecosystem Services require analysis at this stage.




### Topography, Geology and Soils

In part, this will have been understood during the first step, as pollution pathways, particularly, are influenced by such physical character.

LiDAR data is of an ever increasing fidelity, and through conversion using GIS software, or converted using specialist online mapping companies, this EA dataset can be interpreted as contour maps or colour gradients, to understand topography. It can also be used to map flow accumulation at a range of scales.

Geology and soils maps are available online. These can indicate areas of suitably low soil permeability for example. Soil maps can also show the presence or previous presence of peat. These demonstrate wetland conditions, and therefore indicate potential scope for restoration.

Soilscapes gives a good overview of the key properties of the soils in a catchment, including type, permeability, as well as groundwater vulnerabilities

### Hydrology

Hydrology can be further analysed during this phase. This is important, so any proposed wetland can thrive, offering the greatest possible water quality, and biodiversity benefits for the situation. Where there is relatively unimpacted flow, and high water quality, more naturally functioning wetlands can flourish.

Where water quality is more impacted by human activities and can not feasibly be restored, treatment measures can be considered, to protect downstream aquatic (and related) environments.

Flow types for treatment, can be broadly subdivided into constant (or near), and ephemeral flow. Constant flows can include supply from sewage treatment works, and steady groundwater flows. More continuous flows can result in steady treatment efficiencies.

Ephemeral flows will be largely precipitation-fed. Periodically wet features such as swales and other common SuDS features offer excellent water quality benefits, and can be easily incorporated with multi-functional land-use along all stages of pollution pathways. SuDS treatment efficiencies are considered within this guide, for this reason.

## Future Change

Integrating wetlands with proposals for future development and water quality measures needs consideration.

Local Authorities will have developed Local Plans, highlighting areas that are earmarked for development.

Proposals for measures to improve catchment quality, informed by the River Basin Management Plans, will be underway and reviewed within the RBMP cycle.

Furthering conversation and evidence building with Stakeholders - including Water Companies - is a useful and expedient means of gaining an overview.

## Ecosystem Services

Understanding the potential relationship that a proposed wetland may have with other Ecosystem Services is important.

Climate Change is an important consideration, in terms of the local impact, and what mitigation may be required. Local climate predictions (particularly regarding rainfall) vary significantly, and this should be accounted for. Despite regional variations, there are broad trends that we can expect. The most recent UK Climate Predictions (UKCP18) suggest a move towards warmer, wetter winters and hotter, drier summers.

The CEH Climate Change Tool can be used to assess regional variation in the impacts of climate change on various wetland habitats within the UK.

## Past and Present Hazards

Failure to understand past and present land use - as a means of assessing for hazards - could prevent a nominated project from being successful. Such hazards include historic landfill, mining operations, industrial activity and within urban areas and surroundings, unexploded ordnance (UXOs).

The implication of such findings is not always clear cut, but each can create obstacles to economically viable schemes.

## Habitat Resilience, Connectivity, and Priorities

In order to deliver the most resilience for proposed schemes, habitat connections and linkages can be considered at the earliest planning stages. Creating such resilience will aid in the delivery of multiple ecosystem services, particularly adaptation to Climate Change.

The Government's 25 Year Environment Plan published (January 2018) includes a commitment to "develop a Nature Recovery Network to protect and restore wildlife, and provide opportunities to re-introduce species that we have lost from our countryside."

The Nature Recovery Network is a joined up network of marine and terrestrial habitats where nature and people can thrive. The format - delivered through Local Nature Partnerships - is an active, adaptive spatial plan.
Such maps will show existing nature assets - including protected sites and wildlife-rich habitats - and could help to identify key opportunities.

## What Does This Look Like?

In the subsequent pages, a visual example of what this two step process for a catchment is explored. The potential sources, pathways and receptors, followed by some potential wetland opportunities are identified.

*Woolston Eyes SSSI*
*© Andy Harmer*

# Understanding Risk - Sources, Pathways, and Receptors

Sources, pathways and receptors can be considered in order to understand the risk of pollution. This helps to create an understanding of the contributing sectors, their location and connections to receptors. Examples are shown below.

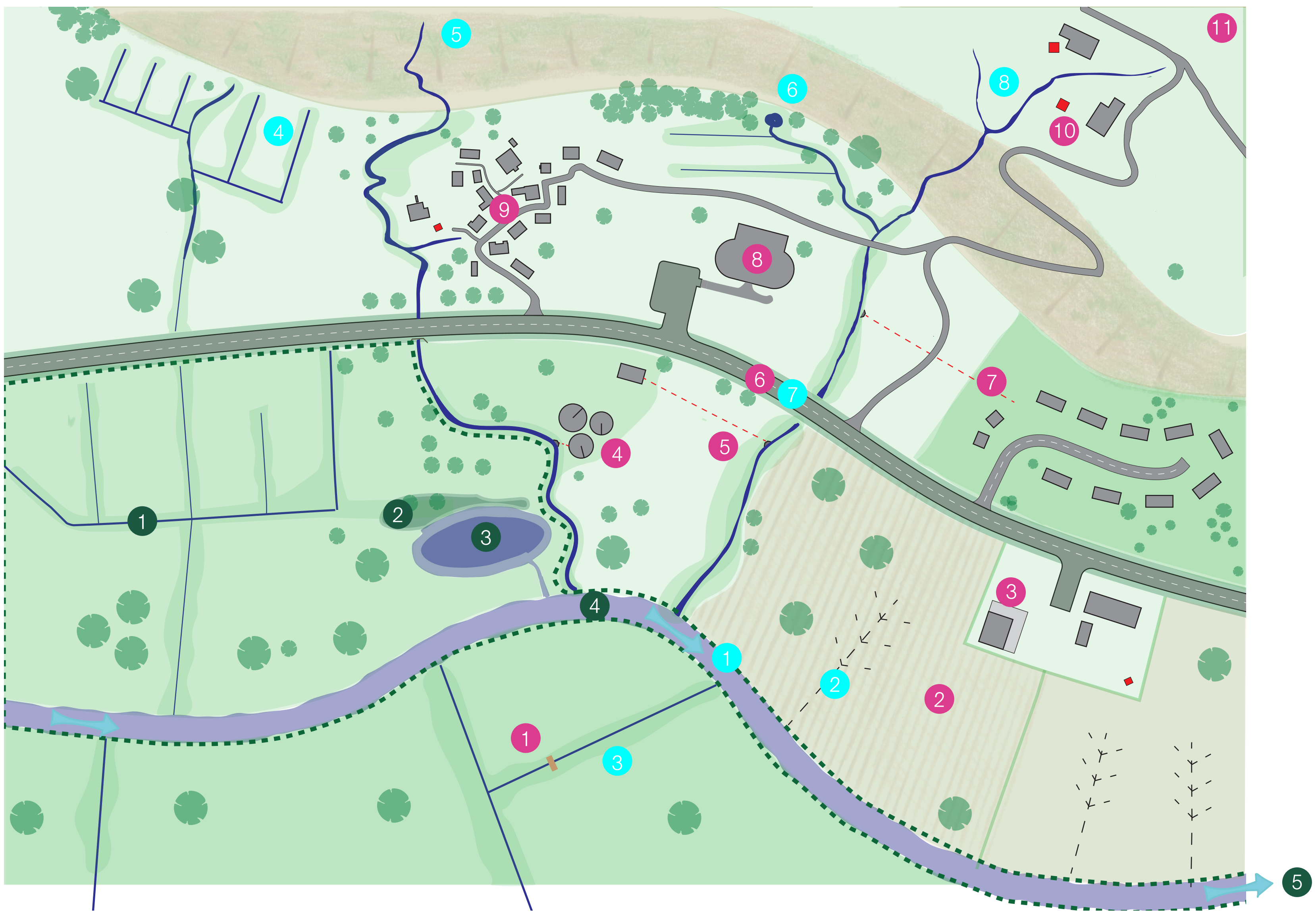


Figure 5 - The S-P-R Model for Risk

**Sources**

1. Agriculture on drained floodplain
2. Arable Land
3. Farmyard
4. Water Company Sewage Treatment Works
5. Combined Sewer Overflow
6. Road
7. Residential development
8. Industrial surface water runoff
9. Semi-urban/Urban Settlement
10. Private Sewage Treatment Works or Septic Tank
11. Agricultural Land

**Pathways**

1. Groundwater feed to River
2. Field drains
3. Ditch
4. Springhead (drained with ditches)
5. Headwater Stream
6. Groundwater-fed spring
7. Road
8. Headwater Streams

**Receptors**

SSSI Boundary

1. Ditches within SSSI
2. Groundwater-fed wetland within SSSI
3. Lake within SSSI
4. River
5. Downstream MCZ/Shellfish/Sensitive Coastal Waters/Estuarine SAC/SPA

# Understanding the Wetland Opportunities

Wetland opportunities can range from land-use change (exchanging previously polluting land in favour of wetland features), restoration of naturally functioning wetlands, to treatment wetlands downstream of a pollution source e.g. Sewage Treatment Works. Below is a snapshot of some possible opportunities.


Figure 6 - Wetland Opportunities

Opportunities

1 Agricultural land restored to wetland, removal of pollution source
2 Restoration of naturally functioning wetland in headwater
3 Private sewage treatment works to ICW
4 Restoration of naturally functioning footslope wetland, includes reduction of groundwater pollution sources.
5 ICW in Industrial Park
6 Wetland feature within SuDS train
7 Combined sewer overflow to Constructed Wetland then to ICW
8 ICW to polish STW effluent with amenity and biodiversity benefits
9 Constructed Farm wetland and swale
10 Field drains blocked
11 Riparian Buffer Zone with interception of sub-surface flow for treatment at rhizosphere
12 Stage zero river restoration, includes wetland restoration and removal of polluting land use.
13 River water pumped/diverted through ICW
14 Restoration of naturally functioning wetland buffer to SSSI lake.
15 Conservation management of ditches and water level within SSSI to maximise resilience to hyper-eutrophication
16 Highways runoff bypassed through ICW
17 Wetland enhancement at wet ground
18 Increased retention time/vegetation/blocking and infilling of ditches outside SSSI boundary.
19 Headwater river restoration with associated wetland habitat mosaics with new public access.

# Further Catchment Considerations

Additional catchment considerations are summarised below. These are some of the important factors to bear in mind when scoping for wetland opportunities, as they can have a bearing on the choices made and success of proposed projects.

## Summarising Existing Land-use

Understanding land-use patterns within the catchment, can lead to a greater understanding of pollution within the catchment. The contributions that each sector makes are often directly related to their extent in the catchment.

The Landscape Classifications tab in MagicMap can give a broad overview of land type. CEHs Land cover map 2015 can also be useful and can be viewed on the CaBA evidence review tool.

Urban areas and their peripheries should not be discounted when analysing potential wetland projects - proximity to populations can be an advantage particularly when scoping for multiple benefits and aiming for water quality treatment at, or near source.

## Historical Changes

The Side-by-side mapping tool allows you to see two maps next to each other and is an excellent resource that can reveal interesting changes to physical geography and land use over time. It is therefore useful to understand potential issues such as where there might be contamination. It includes maps that date back to the 19th century.

## Understand Monitoring

Monitoring is a useful means of gathering evidence for multiple benefits that can be derived from wetlands, particularly of water quality, and biodiversity patterns. Flood regulation is a critical driver in many instances, baseline evidence may be considered important for this parameter too.

To build a picture of where, and how, monitoring is being done, a conversation with the Catchment Partnership and Environment Agency is a good starting point. The Catchment Based Approach has a useful guide on water quality monitoring.

## Understand Flood Risk

Flood Zones are based on the likelihood of an area flooding. Areas in Flood Zone 1 are the least likely to flood, and land in Flood Zone 3 is most likely to flood. As a result, restrictions within Flood Zone 1 are often less than within Flood Zone 3.

Reconnection of the floodplain - and associated wetlands - to the river can dramatically reduce flooding downstream in many cases. However, material change within the flood zone can be problematic, if it reduces flood storage capacity. In many cases work within the flood zone may require an EA environmental permit and/or planning permission.

CaBA Website

Links to local partnerships and an excellent resource library

## Understand Abstraction

The Environment Agency controls how much water is abstracted, by means of a permitting system. A water Abstraction Licence is required, if abstracting more than 20 cubic metres of water a day from a watercourse or underground water reserve in England.

The EA use the Catchment Abstraction Management Strategy process (CAMS), and abstraction licensing strategies to control abstraction. These were introduced primarily to help abstractors know where water is likely to be available in advance of making an application. As a result, they currently focus on how much water is available for new applications in a given catchment or sub-catchment.

In future proposed Water Abstraction Plans, a Catchment Focus will be included, that brings together catchment partners with abstractors. This is intended to cater more fully for the needs of the environment, alongside the need of abstraction for human use.

# ICW Site Considerations



# Understanding Your Site

This chapter focuses on ICWs and explores the influence of physical geography, of water quality and flow dynamics, and the basics of treatment design and maintenance. Practical site constraints are also discussed, as well as some of the key legislative requirements. In this first section the key factors that are important to understand about your site that will effect the design of any ICW are explored.

## Topography and Hydrology

The topography and hydrological pathways will influence the type of ICW that might have the best landscape fit, as well as the design, particularly around how the water will enter the wetland and the nature of the flows within it.

At the surface, topography and natural flow routes, as well as modified flow routes can be mapped, either by hand, through CAD software or using GIS and Lidar or other height data. For surface flows, this can easily done with a contour map to hand. Surface flow will fall perpendicular to contour lines.

Below ground, the interaction of water with varying soils and geology can be more difficult to determine. Landslips and natural depressions, as well as biological indicators such as plant communities can be useful indicators across the seasons.

Mapping such features as these can help to build a clearer idea of the situation.

## Soils

Understanding the type of soil is also important as this will influence the potential connectivity to groundwater.

Soilscapes and British Geological Society Maps are an excellent resource for identifying broad soil types in the area. It is necessary to ground-truth any assumptions.

Local knowledge is an excellent starting point for verification at the feasibility stage. If farmed, the farmer will usually have an intimate understanding of their soil types. Plant indicators are another good means of approximating soil types.

Excavation and soil testing must be carried out by a qualified person, partly owing to the possible presence of services, and contamination. Some services (typically communication cables) can be very shallow, and some contaminants (asbestos) if disturbed can easily become airborne.



If soil is available (without digging) for field identification, then handling soil can be a good test for approximate structure. Soil horizons will vary with depth.

| | |
|---|---|
| Clay soil - | is sticky to handle and can be easily rolled into a ball shape. |
| Silty soil - | has a silky feel, and can be rolled into sausage-like strips. |
| Peaty soil - | almost black to look at, and spongy to the touch. |
| Sandy soil - | gritty when handled and will not form distinct shapes like clay. |

## Protecting Groundwaters

In particular scenarios, such as Source Protection Zones, introducing infiltration of anything but clean water is not allowed.

If sufficient clay is not present within site soils, a liner may be required. A liner may be reworked material in situ, imported clays or man made impermeable materials. The type of lining will be dictated by the environmental conditions taking into account groundwater vulnerability at and around the site. The use of a liner should be assessed in terms of cost, and sustainability at an early stage.

The strength of the polluting influents, the presence of prior treatment stages, as well as the sensitivity of groundwaters are key influences in this equation, and require technical input as well as consultation with statutory bodies. If treatment stages can sufficiently clean the water, infiltration can become feasible in the right context, subject to the right risk assessments. This idea is shown below.

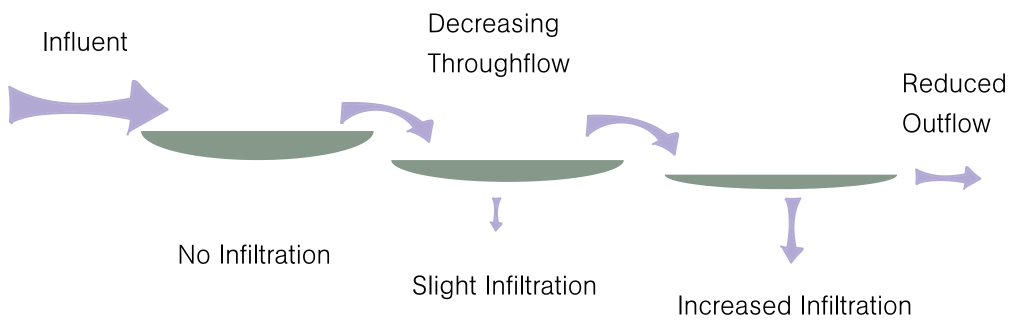



Figure 7 - Infiltration potential increases with ongoing improvements in water quality

## Historical Land Use

The historical use of the site and the potential presence of unexploded ordnance (UXO) have the potential to affect whether the site is an appropriate location for an ICW or the need for additional measures and consideration in the design and implementation.

A preliminary UXO Risk Assessment can provide an initial screening report that includes a 'probability assessment' of UXO risk. Local knowledge and discussions with landowners can also reveal interesting history.

Contamination can commonly be associated with industrial heritage, as well as landfill, mining operations, construction and agricultural activities.

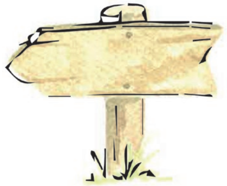
Land is legally defined as 'contaminated land' where substances are causing or could cause:

- Significant harm to people, property or protected species
- Significant pollution of surface waters (for example lakes and rivers) or groundwater
- harm to people as a result of radioactivity

Land can be contaminated by things like:

- heavy metals, such as arsenic, cadmium and lead
- oils and tars
- chemical substances and preparations, like solvents
- gases
- asbestos
- radioactive substances

DEFRA Data Services Platform hosts spatial data on historic landfills and the interactive maps provide a good basis from which to assess for likely contamination through previous landfill activities. Data can also be downloaded from here for desk based GIS mapping or viewed on the CaBA Evidence Review Tool.

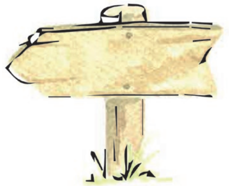


Historic Landfill

A spatial mapping of historic landfill activities

There is no substitute for walking potential sites - this will ground-truth much of the work already done, and it could also create new questions.

A general overview of the site's history is important. An excellent resource for this is side-by-side mapping, where modern satellite imagery is split on screen with historical maps dating back to the 18th century.



Side by Side Maps

National Library of Scotland host this excellent resource

LiDAR (Light Detection and Ranging) measures the height of the ground surface and other features in large areas of landscape with a very high resolution and accuracy. Drones can also capture highly detailed height data using photogrammetry.

Otherwise hard to detect archaeological features can be seen this way. Such surveying can sometimes verify the presence of archaeological sites, if a suspected risk.

*SuD wetland near Martock in Somerset Levels © Mark R Taylor*

# Understanding Sources of Water

A key consideration in scoping measures for water quality treatment, is the concentration of nutrients in water entering an ICW and understanding the flow rates that can influence this. The source of the pollution is critical to this understanding.

The concentration of nutrients in water entering an ICW is a key determinant in deciding where it should be located for best effect. The greater the pollutant load into the wetland the greater the potential is for pollutant removal. Locations where there is often high pollutant concentrations include downstream of agricultural diffuse and point sources, urban areas, roads, industrial sources and waste water treatment works. ICWs can also be effectively used to improve in stream water quality through diverting flows from rivers or streams through a wetland though the flow rate and inflow concentrations will need to be carefully considered.

Different sources have different characteristics in terms of the pollutants present, their concentrations, temporal variability and flow rates. Understanding this is important as it will influence the design of any ICW along with what treatment efficiency may be possible.

## Agriculture

Agriculture is the largest contributor to nitrate pollution[27] and one of the top two contributors for phosphorus alongside sewage works.[20] Sixty nine percent of the English landscape is farmed ,[28] and the impact that this is having on water quality is becoming ever more important as pollution from the water industry is in decline across most catchments.

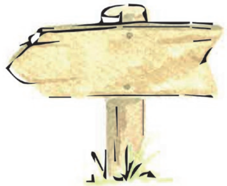
As with urban runoff, the pollutant concentration from agriculture is generally not stable, it is influenced by rainfall patterns, as well as fertilizing regimes. Unlike urban contexts however, the permeability and extent of agricultural soils more easily facilitates infiltration into the ground, where pollution can be transported through interflow, and groundwater.

A review by Newman et al (2015)[29] indicated that the conservation, restoration or construction of on-farm wetlands provides a very effective solution for reducing ammonium and ammonia, total nitrogen, soluble reactive phosphate, total phosphorus, suspended sediments and both chemical oxygen demand and biological oxygen demand.

Small areas with high loadings are not very efficient at removal of suspended solids, and there appears to be a minimum size at which 80% removal rates are always achieved of approximately 2,500 m2.[29] Suspended solids removal is related to removal of total P as most P from agriculture is sediment bound. Therefore targeting areas where there is a high risk of sediment loss is a useful measure that can be informed by easily identified features such as crop layout, slope and intermediate pollutant pathways.

In the design of any ICW, volume and size must be carefully considered to prevent erosive scour and mobilization/ onward travel of the sediment. Provision for sediment removal is also a useful early consideration, if high loads are anticipated.

A useful guide to the options and design considerations for constructed farm wetlands is the WWT Constructed Farm Wetland guide.



Constructed Farm Wetlands

A guide to managing agricultural pollution within farm wetlands

© David Norton WWT

## Urban and Highway Runoff

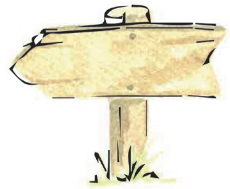
In urban and highway runoff, the pollutant concentration is not stable, but there are general trends. Pre-treatment in robust SuDs features can protect ongoing habitats, such as wetlands, and maximise there biodiversity potential.

The first 10-15mm of rainfall and the road runoff it generates carries much of the pollution (such as sediment, hydrocarbons and heavy metals), and is often known as the 'first flush' volume. Targeting this is useful in terms of water quality. Technical input is required to specify detailed runoff targets as geographical variation, runoff coefficients, interception losses and infiltration rates will vary the amount of actual storage required.

Of course, it is possible to design for greater likely storm events than the 'first flush' event, if space and water depths will allow. This can offer additional flood protection if this is factored into the design.

In retrofit scenarios, any additional rainfall volume beyond the planned amount must be positively managed, bypassed, or returned to its previous point of discharge.

The Environment Agency's constructed wetlands and links with sustainable drainage systems technical report provides further details on the design and use of wetlands for improving water quality in urban environments.

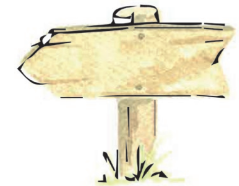


Constructed Wetlands and SUDs

Constructed Wetlands and Link with Sustainable Drainage Systems

Where flows are to be taken to a wetland, pre-treatment in such SuDS features maybe necessary (such as within swales, or bioretention features) to ensure that ongoing water is of sufficient quality for amenity and biodiversity benefits, and so that adaption of management is feasible.

There are many SuDS features that are well-suited to managing water quality in urban and highway environments. SuDS features are often largely dry, or, in the case of ponds, can have additional capacity to take floodwater above the normal water level. SuDS can include the use of wetlands. The principal of reducing pollution through the application of an ongoing treatment train is explained within the SuDS Manual, by way of a pollution index approach.



C753 SuDS Manual 2015

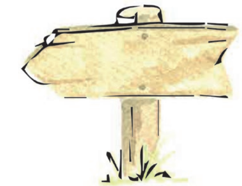
Guidance and technical detail including extensive water quality instruction.

### Road Water Quality Study

Roads (and associated vehicular use) can both generate, and act as pathways for pollution.

A new study has identified and mapped those roads in outer London that have the greatest potential to contribute towards pollution in rivers.

This has been done to help identify the best locations for interventions to address the issue. The modelling equates to nearly 40,000km, 75% of London's major roads.



Road Runoff Water Quality Map

A model to predict the amount of (vehicular) pollution deposited on major roads in outer London.

Firs Farm Constructed Wetland
© Thames21/Enfield Council

## Waste Water

Wetland processes can offer additional cleaning of flows after sewage treatment. This applies to Water Company wastewater treatment works, as well as private domestic systems such as package treatment plants.

A relatively controlled flow rate results from the continuous supply of wastewater. Variations in flow rates do occur sometimes as a result of seasonal input fluctuations (e.g. areas with increased tourist population in summer) or during high rainfall events where there are combined sewer systems which include surface water runoff as well as sewage effluent.

In relation to combined sewers maximum flows to the wastewater treatment works are capped and excess flows during high rainfall events are managed by Combined Sewer Overflows (CSO). CSOs discharge intermittently untreated sewage effluent, albeit during high rainfall events when it will be more diluted and there will be greater dilution potential in the receiving water. However depending on the timing, frequency and location of the CSO they can still have significant effects on water quality. Details on the locations and spill duration of CSOs is held by the Environment Agency and has been used to create an interactive map by the Rivers Trust.

A European example of an ICW that is designed to intercept a CSO (maintaining more regular treatment from a river feed) is linked below.

[Gorla Maggiore, Italy](Gorla Maggiore, Italy)

A European example of an ICW with public amenity as a key driver.

## Diverting Channel Flows

Whilst every effort should be made to control pollution at source to prevent poor quality water reaching sensitive receptors, in many cases the required reductions will not be realised in the foreseeable future. In these situations a parallel approach may be warranted whereby the high-value wetland receptor is 'buffered' by an ICW or in stream waters are diverted through a wetland. This may help to provide increased resilience at the receptor while the longer term need to reduce upstream sources is fully addressed

Passive-functioning diversions require less maintenance, (and if maintenance is required, it is less costly than a technological equivalent). Passive solutions for diverting from incised channels can include take-off structures, overspills and flow diverters that allow continuity in the stream, but may divert high flow.

Continuous in-stream dams and weirs should be avoided due to impacts on fish passage.

It is also appropriate to assess the stretch of river to see if other low-lying areas could be utilized better than the incised section.

If over-spills and high flow diverters are not feasible then pumping is a suitable next option to consider. Solar and wind pumps will deliver some flow in the correct conditions, but perhaps intermittently.

Depending on the water balance, intermittent delivery is not necessarily a problem. Controlled pumping can be of benefit in calculating flows, and treatment levels within a wetland.

When diverting flow from a river or a stream, it is important to bear in mind that even relatively small catchments can deliver powerful flows during intense rain.

Treatment benefits can be lost if floodwaters are allowed to flush pollutants (deposited temporarily within the wetland) into the aquatic environment. The risk of this is increased if the proposed treatment wetland is within an active floodplain.

*Cromhall ICW ©Wessex Water*

# Treatment Efficiency

**The treatment efficiencies of integrated constructed wetlands in relation to phosphorus, nitrogen and sediment are explored in this section. This study of efficiencies is limited to Free Water Surface (FWS) Wetlands only, because there is a significant body of evidence to draw from, as well as their ability to offer many other benefits, such as increases in biodiversity.**

Averaged treatment efficiencies show the typical amount of pollution that a wetland can be expected to remove from the water column. Treatment efficiencies are also sometimes called 'removal rate efficiencies', and are expressed as a percentage rate.

There are two key factors that determine the efficiency of a FWS wetland.

Firstly, the health of the wetland is very important. This is most easily controlled through correct technical design and maintenance, and is discussed in later pages. The efficiency rates given within these pages assume that the wetland is operating efficiently and under normal (designed) conditions.

Secondly, the type and concentration of pollution can vary widely, according to context. For example, some wetlands can be entirely precipitation driven, while others may have a near continuous feed of polluted water to manage. The concentration of incoming pollution plays an important role in determining treatment efficiency, with higher inflow concentrations generally resulting in higher removal efficiency.

Pollution type and concentration can be accurately predicted through modelling, at the technical design stage.

To summarize treatment efficiency within such variability is complex. As a means of offering some typical efficiencies, a large number of trials, categorised according to their pollution context, have been averaged for the purpose of this guide.

The four key sources of trials data used are Ellis *et al.* (2003),[30] Kadlec and Wallace (2009),[31] Land *et al.* (2016),[6] and Dotro *et al* (2021).[32]



## Precipitation-Driven FWS Wetlands

The concentration of incoming pollution plays an important role in determining treatment efficiency, with higher inflow concentrations generally resulting in higher removal efficiency.

This relationship between treatment efficiency and (incoming) pollution concentration explains why FWS wetland efficiencies that manage agricultural run off can demonstrate some of the highest removal rates of Total Nitrogen, and Total Phosphorus: both nutrients can be found in significant concentrations. Typical efficiencies for FWS wetlands managing agricultural runoff are 60% for TN[6], and 52.9% for TP.[31]

Silt pollution is another common feature of agricultural runoff. FWS wetlands that manage high silt loads can demonstrate excellent removal efficiencies, but require a pre-settlement basin in the wetland design, to achieve optimum function. Kadlec and Wallace cite an 87% mean reduction in TSS for FWS wetlands that have such a pre-settlement basin. Within the studied wetlands, the settlement basin area equates to 15-20% of the total wetland area, and between 4-7 days retention time.[31]

Highways produce different pollution, as well as different patterns of runoff. Inevitably, in this context, the treatment of TN and TP are negligible owing to low concentrations at source. But the high presence of silt and metals pollution results in relatively elevated treatment for each. The typical average removal rate of TSS from highways runoff by FWS wetlands is 73%.[30] The range of likely removal rates for metals pollution is between 40-90%.[30]

Urban runoff is a combination of various potential polluting sources. This is because it is a mixed landscape - including domestic, industrial and civic elements.

Typical average removal rate efficiencies for FWS wetlands within an urban context are TN 33% and TP 52%[6], and TSS 76%.[30]

## Managing Wastewater

Freewater surface wetlands can also be used for secondary or tertiary treatment or polishing of effluent from wastewater treatment plants. The nature of water supply to the wetland in this context although influenced by precipitation at times, is a more continuous supply of water with a relatively stable pollution content.

The typical average removal efficiency of TN is 49% and TSS is 68% for FWS wetlands in tertiary domestic treatment.[6]

A review by Cranfield[32] of phosphorus removal performance found that:

- About 80% of the 44 tertiary wetlands without upstream P removal produced annual average outlet TP ≤ 3 mg/L and systems receiving inlet TP concentration less than 3.2 mg/L and a TP load lower than 28.5 mg/m2/yr, outlet annual average TP concentrations were consistently below 1 mg/L.
- Systems with upstream P removal technologies showed annual average effluent TP concentrations were consistently below 0.35 mg/L when fed with TP of 0.09-0.75 mg/L.
- 96% or tertiary systems had no start up period.
- 85% of systems showed no seasonality in effluent TP concentrations.
- Secondary SFW can capture TP, but the extent of removal could not be reliably quantified.
- There was no significant difference observed for year-on-year changes in annual average outlet TP concentrations for secondary treatment or tertiary SFWs with upstream P removal.

## SuDS Treatment Efficiencies

It is also important to remember that a variety of other treatment opportunities exist in addition to FWS wetlands that can be incorporated into ICW designs, for managing precipitation driven pollution.

Periodically wet SuDS features have excellent treatment potential. In many cases, these can be used in conjunction with wetlands.

Median pollutant mass removal rates of swales, for example, have been reported as 76% for TSS, 55% for TP and 50% for TN. Significant reductions in total zinc and copper event mean concentrations have been observed in performance studies with a median value of 60%, but results have varied widely.[33]

In addition to vegetated features, various hard landscape solutions to pollution also exist within the SuDS tool kit. Few are more effective than correctly designed permeable paving above aggregate drainage layers, which should always be considered for source control where the opportunity affords.

## Efficiency and Wetland Health

As mentioned at the outset of this section, the health of a wetland is a vital determinant of treatment efficiency. Technical design considers many different parameters in order to achieve this state of optimum health and function.

The specification of an appropriate maintenance regime is one requirement of this final design stage, that is tailored in order to deliver the long term water quality benefits required.

Well-designed wetlands can handle even extreme pollution events, although the efficiency of a system can be impacted by a 'shock' load. In such a scenario, it is accepted that the efficiency of the system may be lowered for a period of time afterwards, as the natural system recovers.

## Maintenance

Typical maintenance tasks to maintain optimal efficiency include:

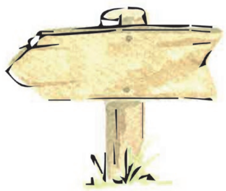
- Rotational cutting of vegetation
- De-silting operations to maintain efficient hydraulics
- Maintenance of biodiversity and prevention of scrub encroachment
- Sampling and monitoring against target standards
- Inspection and maintenance of material elements such as pipes

*Wetland Treatment Swale*
*© WWT Consulting*

# Key Factors Affecting ICW Design

**The ability of wetlands to treat pollution is affected by a variety of factors which influence the design of an ICW. Some of the key factors influencing the design of ICWs are explored.**

There are various factors and considerations which affect the design of an ICW, many of which are linked or interact. A basic overview of the key factors are considered here. Designing a wetland however requires significant technical knowledge of the factors, how they interact and the complexities arising and therefore it will be important to get specialist advice on the design of any ICWs. The Constructed Wetlands Association provides details on approved designers and constructors.



Constructed Wetland Association

Information on constructed wetlands, and links to approved specialists.

## Hydraulic Retention Time and Loading

Perhaps the most important factors influencing treatment design, are hydraulic retention time (HRT) and hydraulic loading rate (HLR).

HRT is the average time that water remains in the wetland. HLR is the rate at which the water enters the wetland expressed in volume per unit area per unit time or depth of water per unit area per unit time.

HRT and HLR influence the performance of the chemical and biological removal processes and therefore the treatment efficiency of the wetland. Typically a high effluent loading rate coupled with a short residence time will overload an ICW, in that it will not provide sufficient contact time for physical, chemical and biological removal of pollutants.

To ensure the desired or optimised treatment efficiency is achieved it is important a wetland is designed with an appropriate HRT and HLR for the pollutant removal processes controlling the pollutants(s) the wetland is being designed for.

Factors which can affect the retention time include the aspect ratio of the wetland (i.e. width : length), the vegetation, substrate porosity, depth of water, and bed slope.

Over time, preferential flow, where the water finds a preferential, easier route thought a wetland can occur, which would compromise the actual HRT and therefore treatment efficiency. Prevention of this 'channelling' effect through good design and maintenance is vital. This can be addressed by using cross ditches that run perpendicular to the flow; these allow the mixing of water in the wetland and they prevent preferential (channel) flow.

## Hydrological Effectiveness

Hydrological effectiveness describes the interaction between the competing (and sometimes conflicting) factors of retention time, inflow characteristics and storage volume.

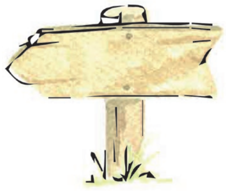
The treatment performance of a constructed wetland results from the combined effect of the hydrological effectiveness and the treatment efficiency.

## Plug Flow

Hydraulic efficiency describes the extent to which plug flow conditions are achieved within a wetland.

In general, free water surface wetlands function best when surface waters that enter can move through as a single wave or unit, fully displacing the wet pond volume – a phenomena known as plug flow.

By preventing 'short-circuiting', this flow pattern maximises the hydraulic retention time, which enhances settlement of sediment – a key process in wetland treatment.



Treatment Wetlands

Kadlec and Wallace (2009) - Treatment Wetlands

## Sizing, Treatment Aims and Cost

The size and volume of the wetland is crucial in controlling both the hydraulic loading and retention time and therefore treatment efficiency and performance.

Specific treatment aims can be targeted through an ICW. For example, a specific treatment performance may be required where there is an environmental permit limit that needs to be met.

Surface area is an important factor in achieving high levels of treatment and therefore where high treatment performance is required a large wetland area may be a requirement. This can substantially increase the cost. Therefore in these circumstances alternatives could be considered, (including comparing any additional benefits), such as using smaller, catchment-wide wetland measures for improving water quality or other treatment technologies.

Optimum sizing of the wetland is more difficult where the water source is intermittent and it is difficult to predict the scale, timing and frequency.

## Sediment

Managing sediment can be a serious design consideration - many pollutants will bind to sediment.

Often, sediment loads can be controlled by well-designed inlets, and effective pre-treatment in transitional areas, prior to the wetland.

These areas are designed for such sediment loads, need to be resilient, and should be easily maintained. An example of light sediment control is the grassed filter strip (encouraging wide, lateral flows of water across a shallow gradient).

Heavier sedimentation would quickly build on such a feature, and so may require deeper controls. Such features could be open water, and of a depth to allow a controlled accumulation of sediment. It is likely that an adjacent nominated area needs to be identified for deposition of any dredged sediment within such a proposal.

This depth will be defined principally by the incoming sediment loads, but should be considered in relation to multifunctional benefits, including public access and safety.

## Soil Nutrient Levels

Creating wetlands on soils that have a high phosphorus index can mean that the phosphorus is mobilised by the wetland. Therefore the wetland may have higher than expected phosphorus in its outflow for a period of time and could take longer to achieve the desired output levels.

## Risk of Failure

If a proposal is intended to admit additional surface water flows, then planning for exceedance (through failure or unforeseen volumes) is very important in order to protect downstream areas. Guidance on planning for exceedance can be found in the SuDS Manual II.

## Treatment Cells

Multiple treatment cells are important as they can help to reduce preferential flow. They also assist any required maintenance, as they are often separated by a series of access routes. In addition, it is possible to take individual cells off-line for maintenance (see Figure 5), while maintaining a level of treatment.

This approach also enables the combination of different treatment processes such as ponds, floating wetlands, marsh and wet grassland, and brings with it diverse habitat potential.

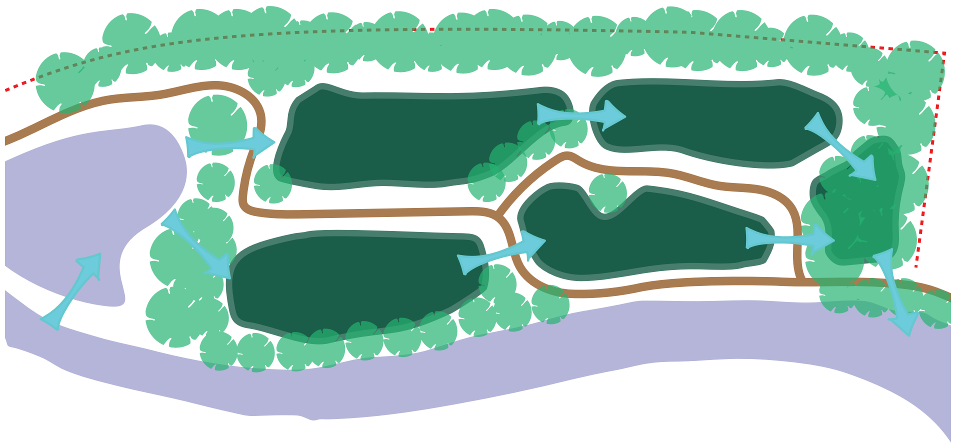


Figure 8 - Certain cells can be deliberately shut for maintenance, while offering some level of treatment in others.

## Vegetation Type

Different types of vegetation effect the removal of pollutants through different processes and this can vary for different pollutants. Therefore the choice of vegetation for a specific design and desired outcome needs to be carefully considered..

Macrophytes predominantly remove phosphorus through their physical presence of stabilising and encouraging settlement deposition and increasing the microbial surface area. They can also assimilate phosphorous but this is thought to make a relatively small contribution.

Submerged macrophytes have additional P removal mechanisms which are less active in emergent macrophytes such as direct P uptake from the water column and pH mediated co-precipitation of P with calcium carbonate.

Wetlands with low influent phosphorus concentrations and submerged aquatic communities have been shown to remove phosphorus down to very low concentrations, this is particularly the case in systems with high calcium carbonate. However it is suggested that they are less effective than emergent plants in higher phosphorus concentrations above 1mg/l.

Therefore the types of vegetation that will maximise treatment efficiency may vary depending on the phosphorus concentration of the influent and may vary for different cells of an ICW.

## Multiple Benefits

ICWs can provide a range of ecosystem services alongside delivering improvements in water quality as set out in the introduction of this report.

Although ICWs can provide a wide range of benefits, there are trade offs and therefore not all will be able to be maximised in any one wetland.

The outcome that is being looked for, along with the nature and source of the input, as well as any constraints (e.g. land availability or location) will determine the multiple benefits that it may be possible to achieve.

Consideration of the delivery of multiple benefits at the design stage will be important in order to design a wetland that will maximise what is achievable.

*Ingoldisthorpe ICW © Norfolk Rivers Trust*

# Further Considerations

## Consents, Licences, Permits and Permissions

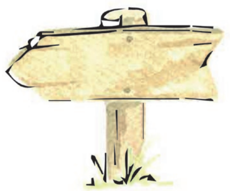
There are a number of potential consents, licences, permissions or permits that may need to be obtained when undertaking any wetland interventions. Which may be required will depend on the specifics of the location and the work proposed. Table 5 below outlines the common ones for wetland interventions.

Early engagement with the relevant authorities will help understand what is required and any constraints.

Table 5 - Common consents, permits, permissions or licences for wetland interventions

| Permit/Licence/ Consent | What for? | Who from? |
|---|---|---|
| Environmental permit | Flood risk activities on main rivers OR Discharge of contaminated water to surface or ground waters OR Waste permits. | Environment Agency |
| Land drainage consent | Flood risk activities on non main rivers | Internal drainage board (IDB) if in IDB area or local flood authority (i.e. local authority) |
| Water abstraction or impoundments licence | Abstraction of water OR Creation of an impoundments such as a weir, dam or sluice. [34] | Environment Agency |
| Wildlife licence | Work which may disturb, remove protected species or their habitats, includes species such as great crested newts, badgers, otters etc | Natural England |
| SSSI consent or assent | SSSI landowners require consent and public bodies require assent where they are undertaking works on land within an SSSI or for assent also off-site, which could damage the SSSI features. | Natural England |
| Planning permission | Building, engineering or other works, in, on, over or under land, or the making of any material change in the use of any buildings or other land. | Local Planning Authority |



Internal Drainage Boards Map

Interactive map of IDBs

## Monitoring

Monitoring of projects is important, in building an evidence base for the water quality, biodiversity and multiple other benefits that can be achieved.

A record of baseline conditions is necessary in order to measure future changes.

The technology for water quality monitoring is becoming more easily accessible, and it is possible that other catchment stakeholders will have access to equipment.

Including biological indicators in monitoring and assessment programmes can demonstrate the biodiversity benefits, and ensure any biodiversity objectives are achieved.

Determining and monitoring the actual treatment efficiencies of the wetland will be important to ensure that it is working as required. This is be particularly important if there is an environmental discharge permit for the wetland outflow which need to be complied with. Where this is not the case, it is still useful to understand what the wetland is achieving and if there is any deterioration and therefore when maintenance interventions might be required.

The most common way to evaluate the pollution retention rate or treatment efficiency in a wetland is to monitor and compare the pollutant loads of the inlet and outlet waters, respectively. Which pollutants are monitored will be dependent on which are of interest.

Knowing treatment efficiency is not enough though to understand the load removed or the load discharged by the wetland. Flow data (together with efficiency rates) is essential for working out the mass removal rates. Concurrent water quality and flow data is required, in order that this analysis be accurate.

Community groups can help with the creation, monitoring and protection of features.

## Managing Hazards

### Health and Safety

The Construction (Design and Management) 2015 Regulations are intended to ensure that health and safety issues are properly considered during a project's development. Such safety needs to be planned for, both during construction and the lifespan of the project.

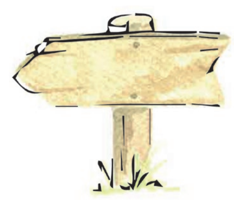
It is important that there is a thorough understanding of CDM. The regulations are legally binding and place responsibility on Designers for Safety, Health and Environment (SHE) risk assessment and mitigation. There are courses available such as CDM for Principal Designers which are provided by the Construction Industry Training Board (CITB).

[CDM(2015)]

Essential Health and Safety processes

### Presence of Services

Infrastructure needs maintenance, and those responsible for such equipment require access to them. To ensure this, access is protected by ordering 'easements' or rights of way for the maintaining body, on immediately surrounding land. Services - both above and below ground - such as water, electricity, gas and fibre optics require such easements. Service providers will provide maps upon request, and there are also online tools available (see signpost below), although these are not complete inventories of all services. Identifying services locations and easements early on can save considerable time and cost later on. It will inform site choice, location of features and design.



[Linesearch beforeUdig]

Check proposed works against over 75 asset owners' utility asset records.





### Use of Machinery

The need for heavy machinery is dependent on the scale of engineering, which is determined in part by the water treatment requirements.

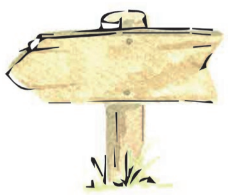
Wetland projects that require excavation, and soil movement must consider access and programming for such movement. Difficult access can elevate cost.

Gradient is also a consideration here - cut and fill levels can be increased with site slopes, and sites that have steep sections must be considered in terms of safe access.

In addition, good soil management is essential in order to reap biodiversity benefits (such as healthy lateral connections), and this requires careful planning.

### Invasive Non Native Species

Measures to control Invasive species should be regarded as general site care, and not specific to wetlands. The PlantTracker project is a collaboration between the Environmental regulators of the UK. The aim is to locate incidences of a number of high priority invasive plant species. It is a useful mapping resource.



[PlantTracker]

Crowd-sourcing data on Invasive species

**The quality of influent will be one of the greatest determinants of maintenance needs. In the case of poor incoming water quality, it is essential to consider maintenance early. Where water quality is higher, and facilitates greater levels of natural function, wetlands should be largely self-maintaining.**

# Case Studies

# Restoration of Quoisley Meres, Cheshire.

Natural England Research Report 071 Generating more integrated biodiversity objectives – rationale, principles and practice

## Formation

Quoisley Meres in south Cheshire are part of the wetland complex known as the Meres and Mosses of the West Midlands. This wetland area developed following the retreat of the glaciers from the last Ice Age. The glaciers left a very hummocky landscape in which ridges of sand, gravel and till created basins in which lakes subsequently developed. Some of these lakes became peatlands as the lakes were infilled with organic matter from fens and swamp woodlands. Quoisley Meres sit within one of these basins, which drains to the west and at one time formed the head of a peat-filled valley.

*Authors: Mainstone, Chris & Jefferson, R. & Diack, Iain & Alonso, Isabel & Crowle, Alistair & Rees, Sue & Goldberg, Emma & Webb, Jon & Drewitt, Allan & Taylor, Ian & Cox, Jonathan & Edgar, Paul & Walsh, Kat. (2018).*

## Hydrology

The site is fed by a mixture of surface run-off and groundwater derived both from the shallow sand and gravel aquifer, which outflows in numerous springs and seepages on surrounding slopes, particularly to the south and east and possibly directly from below.

## Modified Drainage

Progressive drainage of the basin and its surrounds had by the 1960s left the site as two distinct meres. The groundwater outflows on surrounding slopes were drained by pipes and ditches. In common with nearly all of the other meres in the area, drainage of the basin bottom was affected by deepening the outflow, drainage of the area immediately around the meres and digging of radial ditches through the peat body. The impacts of this included loss of area of open water, wet fen and swamp and shrinkage of peat and a concomitant increase in the area of drier ground that was more suitable for agricultural exploitation.

*Quoisely Meres June 1999*

## SSSI Designation

It was in this modified state that the site was designated as a site of special scientific interest in the 1960s, with features of interest identified as open water and rushy grassland.
Over time, however, and in the absence of regular ditch maintenance, the artificially deepened outflow began to re-vegetate and slow the flow of water from the basin. This resulted in gradual re-wetting of the basin floor, with the two meres increasing in size and lesser pond-sedge and bottle sedge swamp spreading into areas regarded as 'grassland'.
This in effect was destroying one of the 'interest' features of the site, namely the wet grassland.

## Restoration of a Natural Hydrological Regime

Initial thoughts were to re-instate regular ditch clearance to restore grassland. However, following survey of the developing wetland habitats and identifying the desirability of restoring a more natural hydrological regime it was decided that the outflow should be 'formally' and permanently restored to something more like its original state. Following a feasibility study, which considered options for blocking, and potential impacts on the site and neighbouring ground, around 20m of the outflow downstream of the mere mouth was infilled with material gathered from surrounding land.

The area of swamp has continued to increase, with anticipated benefits for the already very large population of Desmoulin's Whorl Snail.

# Frogshall Integrated Constructed Wetland 2014



The Frogshall wetland was constructed in 2014 by Norfolk Rivers Trust (NRT). It receives the treated effluent from Northrepps Water Recycling Centre and cleanses it before it is discharged to the River Mun, a Norfolk chalk stream. It was in response to algal blooms on a downstream lake and is designed to reduce the amount of phosphate entering the river.

River Management Catchment - Anglian (North Norfolk)
Project Coordinators - Norfolk Rivers Trust and Rob McInnes (RM Wetlands and Environment)
Site area - 0.8 ha
Wetland area - 0.4 ha

## Prior Water Quality Status

Although the river was rated good for phosphate at the WFD sampling point some way downstream, an on-line lake 2km from the water recycling centre was suffering from regular and lethal algal blooms. Water sampling showed phosphate levels to be high, and traceable back to the water recycling centre.

## Other Drivers

Norfolk has lost a high proportion of its wetlands and one of the key objectives was to re-construct wetland habitat within the catchment.





## Regulation and Legislation

There were no regulatory phosphate limits at the recycling centre, and none placed on the wetland. However, the Environment Agency were concerned that by diverting the effluent from the river, the project would be denuding a short stretch of its flow. A water transfer licence was eventually granted.

## Landscape Fit

No material was taken onto or away from site during construction. There was sufficient clay present on site to line the individual cells and construct the bunds, and the soil removed to excavate the cells was sculpted around the remainder of the site to make the wetland appear as natural as possible.

## Water Quality Benefits of the Scheme

Water sampling by Norfolk Rivers Trust and UEA has shown that the wetland reduces concentrations of phosphate by 75 to 90 %. The wetland also reduces ammonia and nitrate concentrations, although the input is not particularly high.

## Wider Benefits

The ecology of the River Mun changed rapidly after the wetland was constructed. The plant community became less dominated by fool's watercress Apium nodiflorum, allowing other species to thrive. The invertebrate community also changed, showing a rapid increase in general abundance and also in diversity. Visually, the algal blooms have appeared less severe year on year, and the plant community in the lake is beginning to return.

Ecological monitoring within the wetland has shown it is well used by dragonflies and birds, particularly those species that feed on seeds and aquatic invertebrates. The wetland has had significant community benefits, receiving several school visits and enticing local ecologists and archaeologists to help during planning and construction.

## Management Proposals

The site management will be dictated by on-going performance of the wetland as the advice and science are conflicting. We envisage clearing vegetation in one cell every few years should performance start to drop. During the initial five years we have occasionally thinned dominant species and removed sapling growth from the borders. We have also occasionally adjusted water levels.

## Funding / Assistance

Norfolk Rivers Trust fully funded the project.

## Cost

Total construction cost was in the region of £24,000 with an additional £10,000 spent on accredited monitoring in the following five years.

## Learning

The Frogshall wetland has demonstrated to a water company that wetlands are effective and consistent water cleansers which can be delivered at very little cost and with very low maintenance and operational costs. Frogshall also demonstrated the potential to involve the community in planning and delivery of wetland projects.

*A Common Whitethroat at Frogshall ICW*
*©Norfolk Rivers Trust*

# Ingoldisthorpe Integrated Constructed Wetland 2018



The Ingoldisthorpe wetland was constructed in 2018 by Norfolk Rivers Trust (NRT) and was funded by Anglian Water. It receives the treated effluent from Ingoldisthorpe Water Recycling Centre and cleanses it before it is discharged to the River Ingol, a spring-fed chalk stream. It was commissioned to reduce the amount of ammonia discharged to the river but is also an effective phosphate and carbon sink.

River Management Catchment - Anglian (North West Norfolk)
Project Coordinators - Norfolk Rivers Trust and Rob McInnes (RM Wetlands and Environment)
Anglian Water, Environment Agency
Site area - 3 ha
Wetland area - 1 ha

## Prior Water Quality Status

WFD Moderate overall (2016), poor for phosphate, high for other water quality elements

## Other Drivers

The single sewage works in the catchment had an ammonia failure, resulting in a new tighter consent

## Regulation And Legislation

Changing phosphate and ammonia discharge consents at the works provided the initial driver to deliver the wetland, but also prolonged negotiations as Anglian Water and the Environment Agency had to be certain the effluent would meet the set standards.






## Landscape Fit

No material was taken onto or away from site during construction. There was sufficient clay present on site to line the individual cells and construct the bunds, and the soil removed to excavate the cells was sculpted around the remainder of the site to make the wetland appear as natural as possible.

## Water Quality Benefits

Monitoring by Anglian Water and University of East Anglia has shown that the wetland significantly reduces the amount of phosphate and nitrate going into the river.
The wetland has also been put through the national CIPs (Chemicals Investigation Program) scheme to examine how it may treat a wide suite of potential pollutants.

## Wider Benefits

The Environment Agency are committed to carrying out on-going plant and invertebrate monitoring in the River Ingol to assess the ecological impact on the river. Norfolk Rivers Trust has carried out a wide range of ecological surveys on the wetland itself, and has observed increasing numbers and diversity of bats, breeding birds and dragonflies. Water voles have already colonised all four cells of the wetland.
The wetland has become an asset to the community who enjoy regular guided walks there, and to the primary school who have helped with planting and do an annual bio-blitz.

## Management Proposals

Anglian Water provided Norfolk Rivers Trust with an annual maintenance budget. The actual site management will be dictated by on-going performance of the wetland as the advice and science are conflicting.  It is envisaged that should performance drop, vegetation clearance would be undertaken in one cell every few years. During the initial two years NRT have planted bare areas and removed willow and alder saplings from the banks to prevent over-shading.

## Funding / Assistance

Anglian Water fully funded the project, from feasibility to construction and 20 year site lease and maintenance.

## Total Project Cost

Total construction cost was in the region of £180,000 with an additional £10,000 spent on further planting and monitoring in the first two years.

## Learning

The most challenging parts of the project were the permitting and financing negotiations with Anglian Water and the Environment Agency and the contracts between Norfolk Rivers Trust and the land-owner and Norfolk Rivers Trust and Anglian Water.  These negotiations added significantly to the project delivery time and are also a major risk that should be factored into future projects.

©Norfolk Rivers Trust

# Culm Grassland Natural Flood Management

*Culm grassland © Deborah Deveney RSPB*

*©Devon Wildlife Trust*

This project sets out to demonstrate that rivers draining natural wetland habitats were much cleaner that those emanating from more intensively farmed landscapes. The project also sought to demonstrate the important role that Culm grasslands play in storing and regulating water flows, reducing flooding, as well as the role that Culm soils play in trapping carbon.

Team - Dr Richard Brazier, Dr Alan Puttock, Exeter University, Mark Elliott from the Devon Wildlife Trust.
Funding: Environment Agency, The Higher Education Innovation Fund, Devon Wildlife Trust and the Northern Devon Nature Improvement Area.

The lowlands of the UK's western regions were once characterised by florally-rich, unimproved grasslands known in Devon and Cornwall as Culm grasslands, and more widely as Rhôs pasture. As recently as the 1950s they covered 40,000 ha of the South West. Due to the intensification of agriculture only 10 per cent of these grasslands survive. They are the definition of a fragmented ecosystem.

The Culm Grassland Natural Flood Management project - led by the University of Exeter and Devon Wildlife Trust - is a detailed comparison of the variable ecosystem services that culm grasslands can provide, in comparison to Intensively Managed Grassland (IMG).

Stowford Moor SSSI is a designated site, with the overlapping designation of Culm Grasslands SAC. Between July 2010 and January 2013, high temporal monitoring of water quality after rainfall events was collected from the Stowford Moor SSSI.

To allow comparison, nearby agriculturally improved catchments - the Den Brook and Aller catchments - were similarly monitored during rainfall events.

Median phosphorous levels recorded below Stowford between July 2010 and January 2013 were 30μg /l (ranged between 0 and 398μg/l). These were lower than both the Aller, where median levels were 45μg/l, and the Den Brook catchment where they ranged from 90 to 5870μg/l.

Sediment losses showed a similar pattern of worsening water quality within agriculturally improved catchments. In the SSSI, the median levels for sediment within the water column (TSS) were 24mg/l compared with higher 78mg/l in the Aller agricultural catchment.

Monitoring and comparison of culm grassland and agricultural catchments, indicated that culm grassland soils hold more water, store more carbon, and that water leaving a culm dominated catchment was of a consistently higher quality than intensively managed, agriculturally dominated catchments.

Please refer to: Puttock A., & Brazier R., **Culm Grasslands Proof of Concept Phase 1** for methodology and full results.

# Firs Farm Urban Wetland

© Enfield Council

Firs Farm wetlands is a combined wetlands and flood storage area, within a public park, that mitigates the impact of diffuse urban pollution, reduces flood risk and enhances community green space.

River Catchment - River Lee
Project Coordinators - Enfield Council Thames21
PM, Delivery and Design - Enfield Council
Site Area (ha) - 2.4
Wetland Area(s) (ha) - 3,300m²
1,000m² pond;
500m de-culverted watercourse;
30,000m³ overall flood storage provided on site for extreme events (up to the 1 in 100 AEP)

## Prior Water Quality Status

- Ammonia WFD classification "moderate"
- Phosphate WFD classification "poor"
- BOD WFD classification "poor"

## Other Drivers

- Deculverting of a historic watercourse
- Reduction in flood risk
- Community cohesion
- Biodiversity

## Regulation And Legislation

The new flood storage area is below the threshold of a statutory reservoir (25,000m$^3$). Nevertheless, earthworks were designed to this standard by a Qualified Reservoir Engineer.



© Enfield Council

## Landscape Fit and SuDS Features

- 2.4ha habitat enhancements
- Outdoor classroom, a bird-hide and a dipping platform
- Viewing and seating areas with associated planting
- Deculverting
- Bioretention channel
- Wetlands and pond
- Cycleway, footbridges and decking
- Permeable surfaces

Site-won spoil was used to create the flood bund. To enhance access and safety, gradients to the wetland cells are designed to have a maximum fall of 1 in 3. An analysis of sight-lines, in and out of site - particularly concerning adjacent houses - was an important element of landscape design.

## Water Quality Benefits

Testing for parameters of phosphate, nitrogen, $BOD_5$, total coliforms and heavy metals have shown a significant drop in mean concentrations of all, showing an improvement in the WFD status in three of the parameters

- Mean decrease of 91.85% in ammonia, improving the WFD classification from "moderate" to "very good".
- Decrease of 77.86% in phosphate, improving the WFD classification from "poor" to "moderate".
- Mean decrease of 29.99% in BOD (Biological Oxygen Demand), improving WFD classification from "poor" to "moderate"

## Wider Benefits

There have been noticeable increases in wildlife and particularly bird-life. The project has dramatically altered the landscape and environment of the area.

Previously there were very few features of note, entrances to the park were undefined and there were limited reasons to visit the site. The transformation of the site has given members of the public a reason to use the site, and enjoy the biodiversity benefits. Contribution to a common project has brought the community together.asset management programme.

## Management Proposals

The scheme sits within a public park which itself requires routine maintenance.

A management plan for the site was developed which includes cutting of wetland vegetation, inspection of inlets and outlets to check for blockages caused by silt, vegetation, litter and other debris.

Thames21 and the Friends of Firs Farm Community Group organise supplementary activities such as litter picking and vegetation management.

Parts of the scheme which are considered flood defence assets are to be inspected as part of a formal flood

## Funding / Assistance

Funding from a range of project partners and sources, highlighting the importance and opportunities that can be realised through securing a range of funding streams. Funding Partners:

Enfield Council: Funding, delivery and project management
EA: Funding (Flood Risk Management)
Thames Water: Funding (Community Investment Fund)
TFL: Funding (cycleway)
GLA: Funding (Big Green Fund)

## Total Project Cost

The overall cost of the delivered scheme was £1m. Construction costs approximately £950,000



© Enfield Council

## Learning

- Establishing initial drainage conditions in the site and veracity of existing plans
- A part of the open watercourse required routing through a line of woodland, a suitable point was chosen due to a natural gap, however excavating around tree roots still presented a problem
- A part of the design for the watercourse required very close interaction with football pitches, which needed moving part way through the playing seasons
- Incorporating several sewers and various inlets and outlets can require design and subsequent adjustments of levels
- The challenge of misconnections from the foul sewer system upstream can become evident in the wetlands. Therefore it is crucial to work in partnership with water companies on schemes such as this to advance a programme of identifying and tackling misconnections upstream of the outfall.

# North Devon Estuary Project Cheglinch Farm Wetland

*Aerial photography of the Wetland tiers*

Cheglinch Farm Wetlands treat two sources of surface water. The first system manages runoff from the yard; waters are collected and transferred via pipework to the first sediment pond, and then through a series of treatment cells. An outlet swale from here leads to the watercourse. A second system manages runoff from Cheglinch's cow track. Baffle ditches run alongside the cow track and transfer these waters from the trackway into a leaky pond system where waters are allowed to infiltrate. It is important to note that all systems within the Estuary Project only manage surface water, no point source pollution (such as slurry or liquor) is taken to the systems.

River Catchment - River Caen – Upper
Project Coordinators - The North Devon Biosphere Foundation
Partner - Environment Agency
Site Area (ha)- 0.74
Wetland Area(s) (ha)- 0.13

## Prior Water Quality Status

Upper Caen
2016 – Overall Water Body – good
2016 – Ammonia – high
2016 – Phosphate – good

## Other Drivers

Flood Regulation and Biodiversity

*First small swale leaving wetland © Sophia Craddock NDBS*

## Opportunities and Barriers

Treatment in this way, by separating clean from dirty waters in the yard, reduced the volume of dirty waters entering the dairy farms slurry storage facilities, in turn reducing the landowner's costs associated with storage and spreading. Barriers included the cost associated with the works.

## Integration

By working closely with the landowners to produce a wetland design that would work for them, including a cross drain, swale with baffles, leaky pond, two clay lined settling ponds, vegetated filtration weir, flow control bunds and small ponds.

This design also needed to work with the farm system, and so access and circulation were carefully considered - a piped flow was taken from the yard as such.

## Water Quality Benefits

Combined with other catchment measures and efforts and infrastructure works, where incentives worked with regulation to support the step change in water quality from 2014 – 2015, taking the River Caen catchment from 'poor' to 'moderate' overall water body WFD status.

## Wider Benefits

Observed – on farm habitat creation, ecological diversity, runoff attenuation, amenity value for Cheglinch's on farm camp site.

## Management Proposals

Low management – to encourage habitats to develop, neighbouring soils to recover and carbon to be sequestered.

## Funding/Assistance

North Devon Biosphere Estuary Project Grant of £7,500

## Total Project Cost

£10,000

## Learning

The previously existing problem of farm runoff that had adverse impact on the receiving watercourse could be mitigated against by maximising infiltration.

The farming calendar needs to be taken in to account when planning works. For example at lambing, calving or ploughing season, landowners will be very busy and potentially too busy to take part in the project.

### North Devon Estuary Project

Funding by the Environment Agency (EA) enabled the North Devon Biosphere to provide funds and support to farmers in Taw Torridge Estuary through the Estuary Project. This work is helping to reduce diffuse pollution from agriculture, create new wildlife habitats (notably for native white-clawed crayfish), and reduce flood risk.

*A different farm wetland managing SW runoff as part of the Estuary Project - Boode Farm © Sophia Craddock NDBS*

# North Devon Estuary Project
# Fullabrook Farm Wetland

*Fullabrook Pond*
*© Sophia Craddock NDBS*

The system was designed principally to manage sediment. Rainwater from roofs and yard runoff enter directly into a 220m sinuous swale. The swale feeds two wetland ponds, designed to settle out any remaining sediment. The wetland ponds allow controlled infiltration as a principal means of discharge.

Catchment - Lower Caen
Project Coordinators - The North Devon Biosphere Foundation
Site Area - 0.17ha
Wetland Area - 0.04ha

## Prior Water Quality Status

2016 – Overall Water Body – moderate
Ammonia – high
Phosphate – moderate

## Other Drivers

Flood Regulation and Biodiversity

## Opportunities and Barriers

Small forebay areas within the extensive swale allow retention of flows, and encourage infiltration and remediation of any minimal pollution or pathogen. Barriers include constraints owing to the sometimes steep gradients, that restricted the local of features and their size.

## Regulation and Legislation

EA as partners were regularly consulted on all project work.



*Fullabrook System North*
*© Sophia Craddock NDBS*

## Integration

The use of local soils allowed infiltration (following extensive pre-treatment within the swale) within wetland features. Features were designed along the contour, to maximise their efficiency and integrate within the landscape. Shallow side slopes to basins were used where possible.

## Water Quality Benefits

Combined with other catchment measures and infrastructure works, where incentives were used alongside regulation to support the step change in water quality from 2014 – 2015, the river Caen catchment went from ‘poor’ to ‘moderate’ overall water body WFD status.

## Wider Benefits

Observed – habitat creation and ecological diversity.

## Management Proposals

Low management – to encourage habitats to develop, soils to recover and carbon to be sequestered.

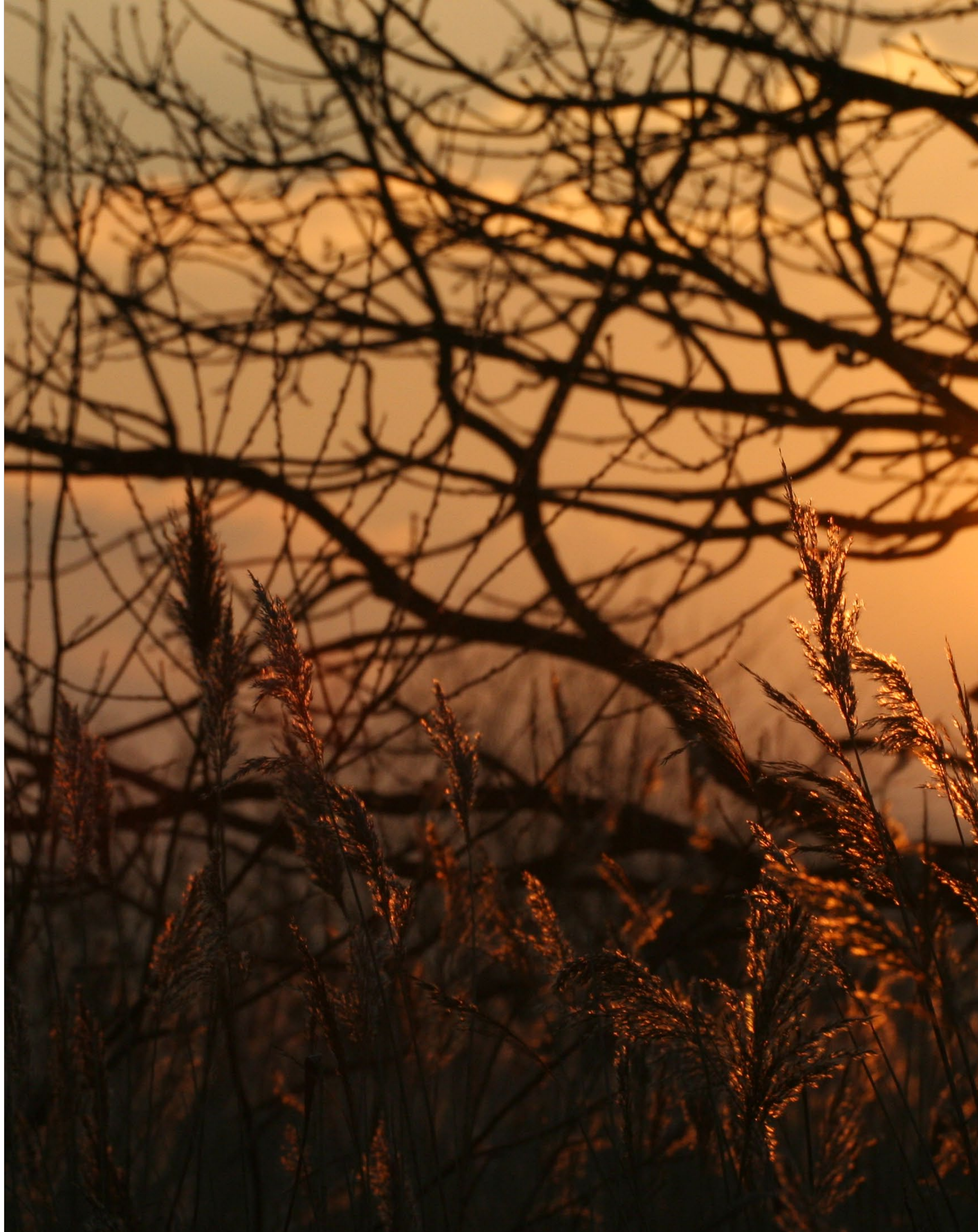
## Funding/Assistance

North Devon Biosphere Estuary Project Grant of £14,743.76

## Total Project Cost

£29,487.52

# Appendix



# Pollutant - Notes

| Pollutant | Abbreviation | Key Facts | Environmental Impact | Likely Sources |
|---|---|---|---|---|
| Biological Oxygen Demand | BOD | This is the measure of the oxygen consumption of micro-organisms in the degradation of organic matter. It is often reported as BOD5 which is the 5 day biochemical oxygen demand and measures the quantity of biodegradable organic matter contained in a water sample. | Through the high demand for oxygen, the dissolved oxygen levels in the receiving waters can drop considerably. The resident ecology suffers from an oxygen deficient environment. In some cases, this can result in a water body becoming anaerobic with serious ecological consequences. | Prevalent from agricultural and industrial sources as well as sewage outfalls from septic tanks and combined sewer overflows. Leachate from silage clamps can have BOD concentrations of 12,000-90,000mg/l, dairy slurry 5,000-10,000mg/l and milk up to 140,000mg/l. |
| Chemical Oxygen Demand | COD | This is the measure of the amount of oxygen consumed by reactions (oxidation of compounds) in a water sample. Both BOD and COD are commonly expressed in mg/l (milligrams of oxygen consumed per litre of sample water). | | |
| Ammoniacal-nitrogen | NH3-N/NH4-N | This is the measure of ammonia nitrogen, NH3-N and NH4-N are different physico-chemical forms. It is one of the principal forms of nitrogen in wastewaters (more than half of TN) and, due to its role in environmental degradation, it often forms one of the main drivers for design. | NH3-N is also known as free ammonia. It is toxic to micro-organisms, fish and other aquatic life as it can permeate the cell membrane. It is also a contributor to eutrophication. Ammonia from fertilizers spread on agricultural fields will oxidise in soils. | Domestic sewage consists of c. 60% ammonia and 40% organic nitrogen. The majority of organic nitrogen in most wetland systems comes from urea. |
| Nitrite | NO2- | Oxidised nitrogen is an intermediate product of the nitrification process. It is unstable in wetland systems and readily converts to nitrate. | Nitrite and nitrate are toxic to fish, mammals and other aquatic life. They cause eutrophication and high algal and plant growth. Nitrite is not chemically stable in wetlands and readily converts to Nitrate, which is stable and would persist if it were not for energy consuming, biological nitrogen transforming processes. | Sources include chlorinated effluents, cleaning products, potato and vegetable processing wastewaters, certain herbicides and pesticides and fertilizers. Oxidised nitrogen is also present in agricultural runoff due to oxidation of ammonia fertilizers. |
| Nitrate | NO3- | Oxidised nitrogen, the final form in the nitrification process. It is the most common form in water. | | |
| Total Nitrogen | TN | This is the measure of the sum of organic and inorganic nitrogen species including ammonia-nitrogen, nitrite-nitrogen and nitrate-nitrogen. | TN is used as a water quality parameter in most wastewater treatment and permits, see above for environmental impacts of nitrogen species. | |

| Pollutant | Abbreviation | Key Facts | Environmental Impact | Likely Sources |
|---|---|---|---|---|
| Orthophosphate | OP; PO4-P | This is also known as Soluble Reactive Phosphorus (SRP), it is the form of Phosphorus that is most readily utilized and taken up by biota in the water environment. | Phosphorus is usually considered as a limiting nutrient in aquatic ecosystems. The available quantity controls (limits) the rate at which aquatic plants and algae are produced. Depending on the sensitivity of the water course, even low concentrations can lead to eutrophication. | Phosphorus is found in sewage, agricultural runoff |
| Total Phosphorus | TP | This is the sum of reactive, condensed and organic Phosphorus. It is the typical parameter used for water quality analysis and for permitting discharges of effluent. | | |
| Total Suspended Solids | TSS | The measure of particles larger than 2 microns (1 micron =1/100th mm), which are not dissolved, in a water sample. It is recorded as the dry weight of the particles and includes anything from silt and sand to algae. | Particulates provide surface areas for pollutants to bind to, such as phosphorus, heavy metals and pesticides. Suspended solids also absorb heat energy and can increase water temperature, which in turn can decrease dissolved oxygen levels. As suspended solids are deposited, they can smother vegetation, invertebrates, fish eggs and fish gills. | Surface runoff from agricultural land (soil erosion), highways, roofs (atmospheric deposition being washed off during rainfall). |
| Fuels and General Hydrocarbons | Diesel, petrol, oil, hydraulic fluid | Fuel and oil spills on farms, forecourts and driveways can be washed into surface water drains and end up in water courses. | They are toxic to wildlife, inhibit plant growth and can be persistent in the environment. | Surface runoff from roads, driveways, yards, forecourts and re-fuelling areas. |
| Polycyclic Aromatic Hydrocarbons | PAHs | Most PAHs do not readily dissolve in water, however, lower molecular weight PAHs tend to be more water soluble. They are slow to degrade in the environment and accumulate in sediments. Sources include fuels, oils and tyre wear/debris on roads. | They are toxic and have been found to be one of the main toxicants in sediments contaminated with road runoff. They are slow to degrade and can accumulate in sediments. | Surface runoff from roads and driveways |
| Fats, Oils and Grease | FOG | These are typically associated with municipal and domestic wastewaters. | Depletion of oxygen in polluted waters, potential toxicity and smothering of aquatic organisms and plants. | Septic tanks, combined sewer over-flows (CSOs), sewer miss-connections. |
| Acidity | PH | The standard measure in pH units from 0 to 14 for how acidic or basic a water sample is. pH 7 is neutral, less than 7 is acidic and greater than 7 is basic. | The pH of water is critical to the stability, behaviour and form of different pollutants. It can increase the toxicity of metals and chemicals, increase metal leaching, impact the sorption capacity of substrates to bind compounds and pollutants such as phosphorus and can impact and stress animal systems. | Industrial wastewaters, chemical pollution, changes in water body chemistry (anaerobic/aerobic). |
| Metals – of which key ones are: | Arsenic (As), Cadmium (Cd), Cobalt (Co), Copper (Cu), Iron (Fe), Lead (Pb), Manganese (Mn), Nickel (Ni), Selenium (Se), Zinc (Zn). | Heavy metals broadly includes those with an atomic number greater than 20, but excludes alkali metals, alkaline earths, lanthanides and actinides. When the pH of a water body falls, metals become more soluble and therefore more mobile. | Bioaccumulation leading to toxic effects and concentration up the food chain. Electron transfer reactions connected with oxygen can produce toxic oxyradicals. Benthic organisms are typically the most directly affected as the benthos is the final repository of particulates washed into the aquatic ecosystem. | Mine wastewaters, drainage of old mine workings, highway runoff, industrial effluents, leachate from landfill sites. |

# Tools for Development

## Water Quality, Resources and Pollution Sources

| Tool (Linked) | Indicates | Comments |
|---|---|---|
| Catchment Data Explorer | A useful tool for identifying broad water quality patterns across a catchment, and identifying issues at a water body level. | Apportionment tables are available at the Operational Catchment level for some Operational Catchments (Bristol Avon is an example) as a very useful summary of Sources of DWP |
| CaBA Data Package and Evidence Review Tool | A useful  tool that provide access to a number GIS layers suitable for supporting catchment management in one place. | The datasets are displayed, interpreted and grouped to help identify catchment characteristics, issues, causes opportunities, existing action and monitoring. |
| EA Water Quality Archive | Provides data on water quality measurements | Samples are taken at sampling points around England and can be from coastal or estuarine waters, rivers, lakes, ponds, canals or groundwaters. They are taken for a number of purposes including compliance assessment against discharge permits, investigation of pollution incidents or environmental monitoring. |
| SAGIS | Apportionment tool to identify polluting sources and their relative contribution of N or P to an individual water body | Identifies the relative contribution of different sources within a catchment for P and N including, agriculture, STWs, urban, highways, small sewage discharges, industrial sources, CSOs. |
| SCIMAP Diffuse Pollution Risk | Erosion/Sediment Loss. Indicates where hydrologically connected and risky land uses can be best targeted to prevent erosion, which in turn will help reduce the release of adsorbed nutrients such as P. | SCIMAP does not account for soil variability within a catchment, under the assumption that erosion risk is related mainly to land cover and that soil types within a catchment do not vary substantially. connectivity model used by SCIMAP assumes that sediment transport is completely driven by overland flow |
| SEPARATE | For each WFD water body in England a spreadsheet contains the apportionment of phosphate, sediment and nitrogen from different sources such as agriculture, STWs, bank erosion. | DEFRA-funded project (Water Quality0223) to develop a field tool kit for ecological targeting of agricultural diffuse pollution mitigation measures. |
| FARMSCOPER | Can be used to calculate pollutant losses from agriculture at a variety of scales from  the whole of England, a range of catchments and individual farms. | FARM Scale Optimisation of Pollutant Emission Reductions is a DEFRA-funded tool developed to help understand nutrient losses from different farm types and to identify the farm scale measures that are most likely to help reduce these losses. |
| Headwater Stream Quality | Biological monitoring working party based on the principle that macro-invertebrates differ in their perceived sensitivity or tolerance to organic pollution | Freshwater invertebrates are good indicators of water quality - This map is based on invertebrates in the smallest headwater streams. |
| Sewerage Information | Sewer system mapping | Request from Water Company |
| Is My River Fit to Swim In? | The locations of sewage outfalls | Hosted by the Rivers Trust on ESRI, as a map to help swimmers assess likely presence of sewage outfalls to rivers. |
| DG5 Flooding | Priority sewers for catchment management | Water Companies hold information on sewers vulnerable to flooding. This can be referred to as DG5 Flooding and is sensitive. |
| Magic Map Various | CS scoring/designations for water quality | Water Quality Priority Areas (Generally),as well as Groundwater Water Quality Priorities, P, N, Pesticide, Sediment Priorities, WFD Catchments, Flood Risk Management Priorities |
| 1in30 WWNP AEP, 1in100 AEP | Possible runoff attenuation features for 1 in 30 AEP and 1 in 100 AEP | Locations of high flow accumulation which provide opportunity to temporarily store water and attenuate during a 1 in 30 Annual Exceedance Probability event. Note - targeting smaller rainfall events than the 1 in 30 likely event, with appropriate flow diversions in place, can be highly effective in managing pollution. |

## Identifying Biodiversity Links

| Identification Tool | Indicates | Comments |
|---|---|---|
| Wetland Habitat | Wetland habitat distribution and extents on magicmap | Uncertain of completeness |
| Biodiversity Opportunity Mapping | Biodiversity | These are available in some Local Authorities and represent an excellent resource for targeting habitat creation work and maximising the benefit of the work to the local system. |
| NE Designated Sites View | Site condition, features, and objectives | If present, reasons for adverse condition status are given. |
| Priority River Habitat - National | Consists of rivers and streams that exhibit a high degree of naturalness | Evaluates four main components of habitat integrity: hydrological, physical, physico-chemical (water quality) and biological. |
| Priority River Habitat - Headwater Areas | Classification of the naturalness of headwaters (defined as streams with a catchment area of <10km2 to coincide with WFD typology boundaries) | Uses land cover data as a surrogate for direct information on river habitat condition (information which is generally lacking on headwaters) |

## Identifying Physical Character and Land Use

| Identification Tool | Indicates | Comments |
|---|---|---|
| LiDAR Mapping | Topography | Terrain/surface heights at different resolutions. Requires conversion tools to read. |
| Flood Maps for Planning | Flood risk zones 1-3,  defence and flood storage areas | Note - omission of barriers and defences in calculation |
| Surface Water Flood Maps | Flood extents from surface water | Based on LiDAR information requires careful interpretation |
| Soilscapes | Soil type and distribution | Gives a good overview of the key properties of the soils in a catchment, including type, permeability, as well as groundwater vulnerabilities |
| Geology and Soils - BGA | British geological survey mapping | Bedrock and superficial deposits |
| Future Flows | Climate projections for river levels and groundwater levels | Four types of p datasets showing projections for hydrological aspects (precipitation and evaporation) groundwater modelling and projected river flow. |
| Environment Data | Historic landfill | Interactive mapping of historic landfill sites |
| Designations Maps | Location and condition of SSSI, NNR, LNR, Ramsar Sites | Sites in unfavourable condition are seen in red |
| Planning and Development | Future development proposals | Site allocations can show where ‘green/blue’ opportunity areas have been targeted. |
| WWNP | Working with Natural Processes (WWNP) | EA Maps to indicate opportunities for NFM within a catchment - and include identification of slowly permeable soils, floodplain areas where water storage can be enhanced, as well as locations for potential storage during various predicted rainfall events. |
| Land Cover Map 2015 | Land Cover Information | Derived from satellite images and digital cartography and provides land cover information for the entire UK. Land cover is based on UK Biodiversity Action Plan Broad Habitats classes. |

# Additional Reading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