# Framework Approach for Responding to Wetland Mitigation Proposals

Prepared for:

**Natural England**

Prepared by:

# Document Purpose & Details

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This document has been prepared for Natural England by a partnership of wetland designers from the CWA and The Rivers Trust. The document describes a framework for the evaluation of constructed wetland applications by Natural England officers. It will be used to structure detailed design guidance which will be released later this year.

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# PART A Introduction

## A.1 Objective of the Framework

The objective of the Framework is to enable Natural England (NE) staff to adequately and appropriately comment on wetland proposals and designs which are focused on Nutrient Neutrality mitigation.

The Framework is a high-level decision-support system to assist NE staff in the evaluation of wetland mitigation proposals which have been designed primarily to achieve sustainable improvements in water quality through nutrient reductions (with an emphasis on nitrogen (N) and phosphorus (P)) in order to offset proposed nutrient impacts (e.g. from development proposals). The Framework is designed to aid NE staff to identify wetland proposals which are unreliable, unlikely to meet their objectives, are not sufficiently precautionary and unlikely to satisfy the requirements of the Conservation of Habitats and Species Regulations 2017 (herein the Habitat Regulations) or are inappropriate in the proposed location due to a range of factors.

Many wetlands are of course constructed in response to objectives that do not relate to nutrient reduction or the Habitat Regulations. Such wetlands may be expected to provide many benefits to society without being relied upon as an offset to any environmentally damaging activity, therefore there is no need to quantify such benefits. The rigorous assessment approach described by this Framework should not apply in those cases.

## A.2 What is (and isn't) a Treatment Wetland?

**Treatment Wetlands** (see Box 1A for definition) A key element for all Treatment Wetlands is that they receive well defined source of water and are managed to improve the quality of that water through creating and maintaining the appropriate water depths and flows. The ability to control the hydrology of Treatment Wetlands is critical to their successful operation (Kadlec and Wallace, 2009). Consequently, Treatment Wetlands differ from a variety of more informal wetland types because, even though they are natural systems or mimic the functioning of natural wetlands, the characteristics and quantity of the water entering them (the influent) are well understood and have been clearly defined, see Stage 3 pp 25. For instance, effluent leaving a wastewater treatment works that is subject to a permitted and consented discharge (in terms of the concentration of certain parameters and the rate of flows) would be readily defined and would lend itself to improvement in a treatment wetland, whereas a riparian wetland in a river backwater would not typically lend its-self to a clear understanding of the nature and quantity of the water entering the system. Consequently, the ability to characterise the influent hydrology (and its

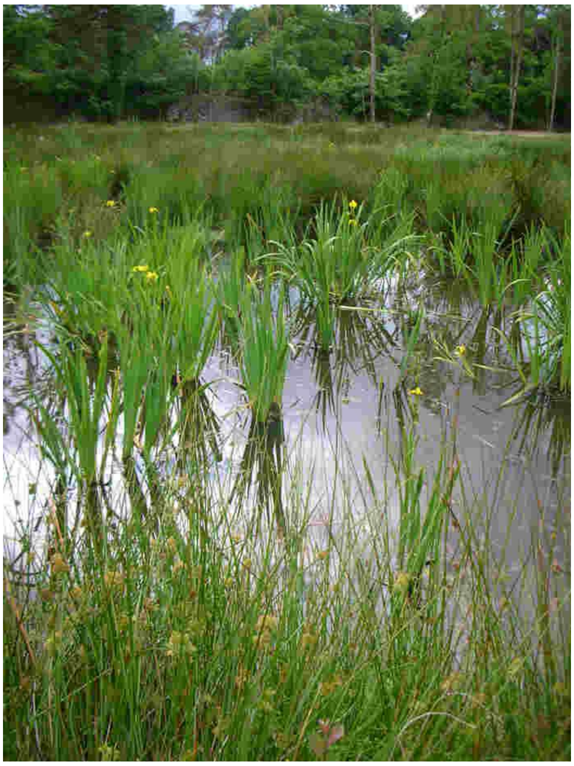


*Figure 1.1 Integrated constructed wetland at Glaslough, County Monaghan, Ireland ©R. J. McInnes*

associated water quality), combined with a robust design process, increases the level of certainty that nutrient reductions will be achieved for Treatment Wetlands.

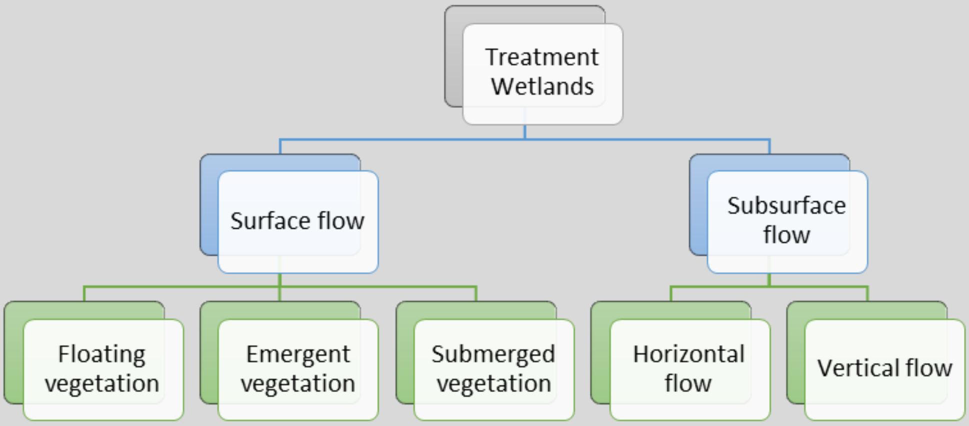
*Figure 1.2 Surface flow **Treatment Wetland**, Czech Republic. ©R. J. McInnes*

There are many different types of Treatment Wetlands. Common types include systems which have water flowing horizontally above the ground surface (often termed free water surface wetlands or sometimes integrated constructed wetlands); systems where the water passes almost horizontally through a medium (such as sand or gravel) below the ground surface (often termed subsurface flow wetlands); wetlands which are characterised by water flowing vertically through the wetland and its substrate (vertical flow wetlands); wetlands which are dominated by floating vegetation over a depth of water; and hybrid systems which might contain elements of all or some of these types of Treatment Wetlands. Some Treatment Wetlands have many of the characteristics of natural wetland ecosystems and fit seamlessly into the landscape (Figure 1.1) whilst other Treatment Wetlands are designed to be discrete areas of water management infrastructure which appear isolated in their wider environment (Figure 1.2). Treatment Wetlands can also form a component within sustainable drainage systems (SuDS) where they are designed and managed to treat a known influent rate and quality.  In practice, most wetlands that have been well designed to effectively remove nutrient from water tend to be “free water surface” wetlands which are rather large compared with the quantity of water fed to them (a low Hydraulic Loading Rate (HLR)) and this framework concentrates on this type of wetland.  Other approaches may also be successful, such as enhancing the performance of wetlands with chemically reactive planting media, however the approaches are too varied to be covered effectively within this guidance.

**BOX 1A: TREATMENT WETLANDS (higher confidence)**

**Treatment Wetlands are either natural or constructed systems managed in a specific manner to treat a source of water which contains undesirable, harmful or potentially poisonous substances. Such wetlands treat the incoming water through a variety of physical, chemical and biological processes including sedimentation, plant uptake, adsorption, precipitation, filtration and transformations.**

**There are many types of Treatment Wetlands. The typical, basic types are shown in the graphic below:**




***"Not"* Treatment Wetlands** (BOX 1B) Whilst the success or failure of a Treatment Wetland is contingent upon creating and maintaining the correct water depths and flows, many other wetlands can be used to improve water quality including using existing natural wetlands or creating new wetland features (Box 1B). For instance, surface water-fed wetlands have been used in agricultural landscapes to treat diffuse overland flows from arable land. A variety of wetland features can be utilised in these farmed environments to address water quality concerns including swales, in-ditch wetlands, sediment traps and ponds (Mackenzie and McIlwraith, 2015) without any particular need to quantify the flows and loads entering the system. Similarly, in the urban environment, a range of wetland features, such as swales, filter strips, detention basins and ponds, have been widely used as elements of sustainable drainage systems (SuDS) which not only manage rainfall and run off in developments but also control pollution, recharge groundwater, control flooding, and often provide landscape and environmental enhancement (Woods Ballard et al., 2015). Additionally, there can be opportunities to combine water quality improvements and ambitions to reduce nutrient levels within wider habitat enhancement schemes. For instance, enhancing or reinstating the connection between a river and its floodplain may provide an opportunity to consider water quality management objectives. Similarly, in-channel or riverbank enhancement schemes can be effective in accumulating

*Figure 1. 3 Created in-channel berm, River Cray, Orpington. ©R.J.McInnes*

sediments, for instance through the creation of low-level berms (Plate 1.3) or two stage channels. Often the restoration of rivers and floodplains can involve diverting water flows from the main the channel and hence the opportunity arises to manage water quality. All these wetlands are likely to contribute towards the goal of water quality improvement, however, unless the inlet water is somehow controlled and quantified, the amount of nutrient removal cannot be predicted with sufficient certainty to allow nutrient credits to be released. Furthermore, within dynamic environments, such as floodplains, most nutrient storage processes do not result in a permanent removal of nutrients and those that do are difficult to quantify (Gordon et al., 2020).

For these type of wetlands nutrient credits can only be claimed based on monitored performance or for the area of landuse change. The basic differences between the wetlands that are Nutrient Treatment Wetlands (and considered in this framework) and those that are not (so are excluded from this framework) is summarised in Table 1.1.

**Table 1.1 Summary of differences between "Treatment Wetlands" and "Not treatment Wetlands".**

| Factor | Treatment Wetlands | Not Treatment Wetlands |
|---|---|---|
| Water source | A fixed or closed water source | An uncontrolled water source |
| Water inflow rates | The likely range of inflow rates is well understood and designed for | Inflow varies in an unpredictable way or is not calculated. |
| Water quality | Variability of water quality is well understood and designed for | Water quality may vary in a way that has not been accounted for in performance calculations. |
| Water level control | Low risk of uncontrolled water levels | Water levels are not controlled |
| Hydraulic retention time | Nominal Hydraulic retention time can be defined and likely variability understood. | Difficult to define hydraulic retention time as inlets and outlets and flow rates are not well defined. |
| Exposure to stochastic events (eg drought and severe storms) | Wetland is designed to deal with drought and flood. | Robustness to storms and droughts will be incidental. |

Examples of two types of Nutrient Treatment Wetland are presented in Figure 1.2 to illustrate some of the variety of situations that may be encountered.

- The wetland on the left is considered to be receiving a consistent inflow from a wastewater treatment system receiving foul water. If the wastewater treatment plant does not receive rainwater, flows and loads may be relatively steady on a day-to-day basis, and easy to define, and if the applicant has done this, the wetland is a Nutrient Treatment Wetland and can be considered in the framework.

- The wetland on the right is treating water from an agricultural catchment that will be driven by rainfall and influenced by the prevailing land use. The flows and loads are more difficult to define. If the applicant has applied best practice to calculate the flows and loads into the wetland (by considering catchment size and weather and climate data), and has designed the wetland to receive water in a controlled way, this too may be considered a treatment wetland. If the inlet flows and loads entering the wetland are not well understood, this wetland will probably still contribute to improvement of water quality, however this improvement cannot be predicted, so nutrient credits cannot be claimed without monitoring.

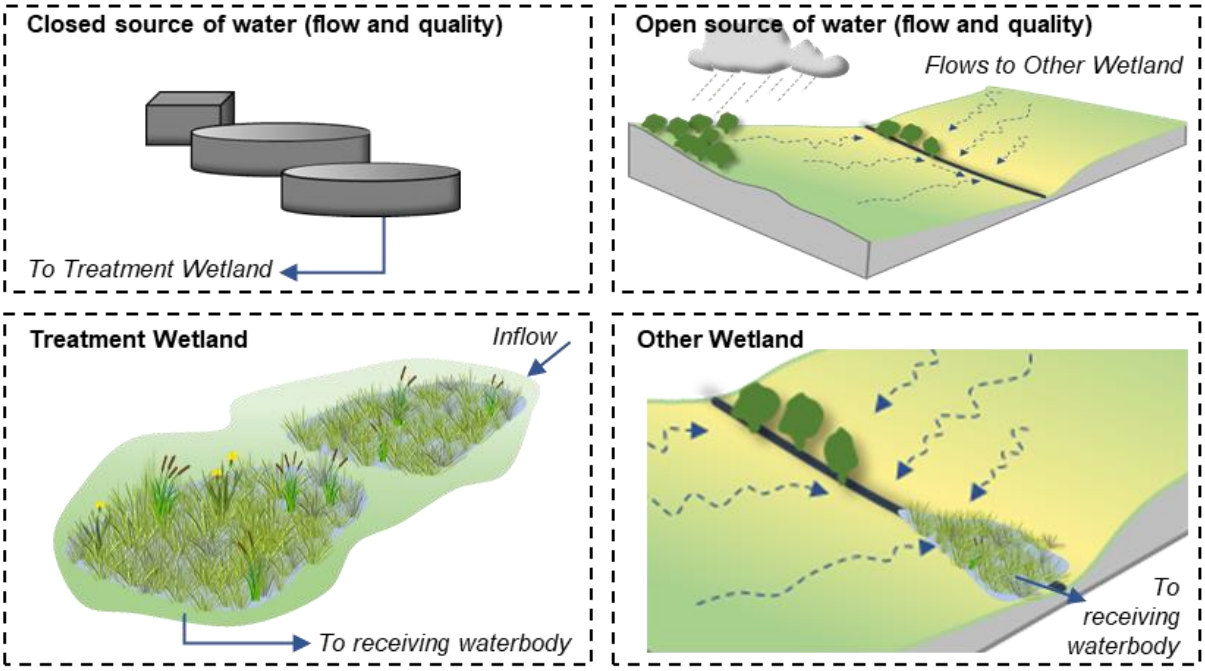


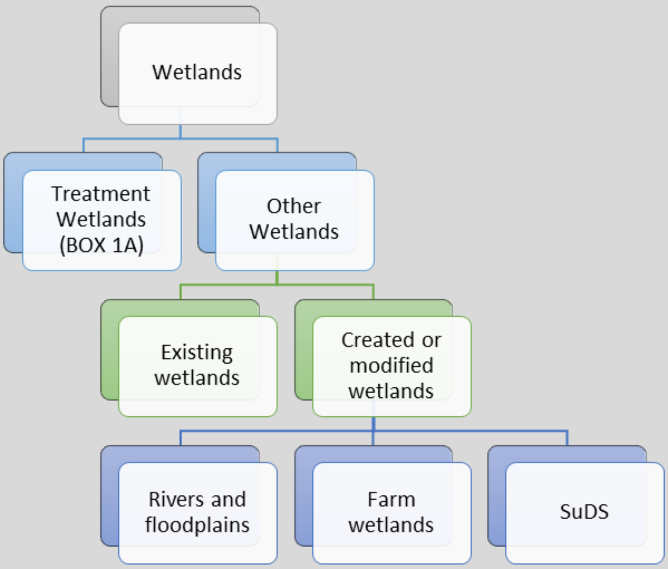

**Figure 1.2 Illustrative examples of Treatment Wetlands and Other Landscape Wetlands (Not Treatment).**

## A.3 Limitations of the Framework

The Framework focusses on how proposals should objectively demonstrate that a wetland will have no adverse effects on Natura 2000 sites within the context of the precautionary principle and the following limitations should be considered when using it.

**BOX 1B: Other Landscape Wetlands – Not Treatment**

**Other Landscape Wetlands differ from Treatment Wetlands insofar as their hydrology is more dynamic and the ability to manage and control water inflows and water levels is considerably more challenging. However, these wetlands can all be designed, created, restored or modified as part of an overall strategy for managing nutrients in the aquatic environment.**



**Confidence in the removal efficiency of *wetlands* should be high** where the influent quality and flows have been well defined and a robust design approach has been applied.

**The precautionary principle should be applied** to the evaluation of wetland proposals where a scientific evaluation of the risks identifies insufficient, inconclusive or imprecise data making it impossible to determine with sufficient certainty that the water quality, and particularly nutrient removal, targets will be achieved (European Commission, 2000).

**Residual uncertainty should be addressed by applying precautionary rates** to variables such as flow rates or concentrations of nutrients, in order that reasonable scientific certainty as to the absence of a predicated adverse outcome in the context of the Habitat Regulations will be achieved.

**Confidence in the removal efficiency of *wetlands* will be lower where** the variability and controllability of influent quality and quantity is high or unknown. In more open systems, a precautionary Approach is required and certainty on removal rates is only likely to be possible through well designed monitoring.

**All wetlands have the potential to provide multiple benefits in addition to water quality improvements.** Whilst every attempt should be made to optimise benefits to society, even if they cannot be used for nutrient neutrality, the Framework does not provide specific guidance on assessing multiple benefits.

**The Framework is intended to support NE's decision-making processes rather than to replace them.** It is assumed that NE staff utilising the Framework will possess different levels of wetland knowledge and experience., therefore, the need to undertake detailed modelling, data manipulation or to become experts in the design of wetlands does not form part of the Framework. Ultimately, the Framework provides a robust, comprehensive and integrated decision-support process that will allow a wetland proposal to be evaluated against industry best practice standards but remains precautionary in its emphasis.

## A.4 Structure of the Framework

The Framework considers all the various interlinked stages of the wetland design process. It is intended to be used by non-technical specialists that are not fully cognisant with the wetland design process but who possess a basic understanding of wetlands and how they function. In Part B, the Framework considers the following seven stages in the wetland design, implementation and monitoring process:

Stage 1. Design objectives
Stage 2. Feasibility
Stage 3. Design process
Stage 4. Design detail
Stage 5. Implementation process
Stage 6. Monitoring and evaluation

Figure 1.5 describes the overall process and the different routes through the Framework depending on the wetland proposal.

## A. 5 Summary tables from the Framework

The tables below summarise the approach developed in the rest of the Framework and supports the delivery of well-designed treatment wetlands. The three key principles are:

- **Confidence in the design and maintenance**. Removal estimates **must be calculated** and good practice followed in the design, commissioning and maintenance of a wetland.
- **Flow into the wetland** must be characterised so that the wetland hydraulics function correctly.
- **Nutrient concentration into the wetland** must be characterised so that the biogeochemical processes that provide the nutrient transformations and removal function correctly.

The tables below summarise how to quantify ***Confidence in the design*** (Table 1.4) which can then be used to select the appropriate treatment efficiency matrices. The treatment efficiency matrices (1.7a – c) are based on the level of knowledge about the ***influent flow*** (Table 1.5) and ***concentration*** (Table 1.6). The better this is characterised the greater the percentage of the calculated nutrient removal that can be credited to the design. Additional nutrient credits can be gained through monitoring performance. These tables provide a simplified summary of the rest of the Framework in sections 3, 4, 5 and 6 which give greater detail and include 'response statements' for Natural England to use on detailed applications.

Some simple sense check parameter values are also summarised from the Framework in Table 1.3 below. Wetland designs which fall outside the ranges indicated could be acceptable but should include a specific narrative to justify why the design is atypical.

**Table 1.3 Typical ranges for parameter values in wetland designs for nutrient removal**

| Parameter | Min | Max | Typical | Comment |
|---|---|---|---|---|
| **Depth (m)** | 0.1 | 0.3 | 0.15 | Water depth should be stable throughout the year |
| **Width to length** | - | - | 1:2 or 1:3 | Ideal range is between 1:2 and 1:3 |
| **Number of cells** | 2 | - | 2-5 | Avoid single cell systems |
| **HRT (hours)** | 8 | - | 12-24 | HRT will be scheme dependent but if less that 12 hours the design could be flawed |
| **P Conc which is too low (mg/l TP)** | 0.1 | | | Unlikely that a wetland will reduce P concentrations further |
| **Substrate N (mg/kg)** | - | 1000 | | If representative soil samples from the site exceed this mitigation may be required to prevent pollution |
| **Substrate TP (mg/kg)** | - | 80 | | As above |

**<u>Table 1.4 Confidence in the design & maintenance:</u>** Evaluate the design based on each of the 6 columns and score based on the lowest confidence. It is worth noting that there is no 'Amber' for the 'Design' confidence. Only designs which use the approved calculation methods have high confidence for nutrient removal.

| | Assessment criteria | | | | | |
|---|---|---|---|---|---|---|
| | **Nutrient removal and wetland area** | **Wetland size - Sentsitivity analysis** | **Wetland size - Constants** | **Water balance** | **Hydrological control** | **Sediment accumulation & maintenance** |
| **L** | Used literature values or used manufacturers data , applied rule of thumb approaches with limited supporting narrative | Did not calculate a range | No sensibleness check for constants | No water balance | No detail on hydraulic performance in drought or flood and interaction with GW; no description of water management within the wetland | No assessment of sediment accumuation; and/or no sediment maintenance regime described |
| **M** | [*No Medium*] | Calculated a range and used the mean | Constants used but no justification | Annual balance; or use of regional climatic data; or no consideration of climate change impacts | Incomplete detail on hydraulic performance in drought or flood and interaction with GW; limited information on water management within the wetland | Maintenace regime identified but no sedimentation calcs |
| **H** | Use at least 1 of the approved design calculation methods (P-k-C* model, k-C* model, regression equation) with supporting narrative | Calculated a range and used the min | Rationale good for all constants used and robust narrative provided | Robust water balance, including seasonal variability and based on local climatic data including climate change forecast | Detailed description of hydraulic function in drought and flood and interaction with GW | Evaluation of sediment accumulation rates; description of a reasonable sediment maintenace regime |

**<u>Table 1.5a Confidence in the flow into the wetland:</u>** This table applies to inflows from River, stream, ditch, surface (yard, buildings, road, field etc.), groundwater and springs. Evaluate the design based on each of the 3 columns and score based on the lowest confidence.

| | **1. Assessment criteria for the following water sources: River, stream, ditch, drain, surface (yard, buildings, road, field etc.), groundwater and springs** | | |
|---|---|---|---|
| | **Flow of primary water source** | **Inflow of other sources of water** | **Variability of flow with time** |
| **L** | Used estimated values from published literature and guidance; or applied rule of thumb with no justification or supporting narrative | No other sources of water considered | No consideration of variability of flows over time (both annual and with respect to climate change) |
| **M** | Used values from standard hydrological modelling but with limited narrative; used site-specific monitoring data (surrogate or actual) with no justification or supporting narrative | Some but not all other sources of water considered | Estimates of annual mean, maximum and minimum but no consideration of climate change |
| **H** | Used values from standard hydrological modelling with robust supporting narrative; used site-specific flow monitoring data with narrative to justify interpretation (catchment scale, sample frequency, statistical comparisons, etc) | The influence of precipitation, groundwater and other surface water inputs are considered | Robust estimate of seasonal variability; application of an industry standard value including a safety factor (e.g. 80%ile) |

**Table 1.5b Confidence in the flow into the wetland:** Wastewater treatment works (private and municipal), package treatment plants, septic tanks. Evaluate the design based on each of the 3 columns and score based on the lowest confidence.

| | **2. Assessment criteria for the following water sources: Wastewater treatment works (private and municpal), package treatment plants, septic tanks** | | |
|---|---|---|---|
| | **Flow of primary water source** | **Inflow of other sources of water** | **Variability of flow with time** |
| **L** | Used estimated values from published literature and guidance; or applied rule of thumb with no justification or supporting narrative | No other sources of water considered | No consideration of variability of flows over time (both annual and with respect to climate change) |
| **M** | Used modelled values using standard methodologies but with limited narrative; used site-specific monitoring data (surrogate or actual) with no justification or supporting narrative | Some but not all other sources of water considered | Estimates of annual mean, maximum and minimum but no consideration of climate change |
| **H** | Used water industry standard modelling with robust supporting narrative; used site-specific flow monitoring data with narrative to justify interpretation (catchment scale, sample frequency, statistical comparisons, etc) | The influence of precipitation, groundwater and other surface water inputs are considered | Robust estimate of seasonal variability; application of an industry standard value including a safety factor (e.g. 80%ile) |

**<u>Table 1.6a Confidence in the characterisation of water quality into the wetland:</u>** River, stream, ditch, surface (yard, buildings, road, field etc.), groundwater and springs. Evaluate the design based on each of the 3 columns and score based on the lowest confidence.

| | **1. Assessment criteria for the following water sources: River, stream, ditch, drain, surface (yard, buildings, road, field etc.), groundwater and springs** | | |
|---|---|---|---|
| | **Quality of primary water source** | **Quality of other sources of water** | **Variability of quality with time** |
| **L** | Used estimated values from published literature and guidance; calculated values from generic leaching rates; or applied rule of thumb with no justification or supporting narrative | No other sources of water considered | No consideration of variability of water quality over time (both annual and with respect to climate change) |
| **M** | Used verifiable values from published literature and guidance; calculated from local leaching rates; used site-specific monitoring data (surrogate or actual) with no justification or supporting narrative | Some but not all other sources of water considered | Estimates of annual mean, maximum and minimum but no consideration of climate change |
| **H** | Used site-specific monitoring data (surrogate or actual) with narrative to justify interpretation (catchment scale, sample frequency, statistical comparisons, etc) | The water quality influence of precipitation, groundwater and other surface water considered | Robust estimate of seasonal variability; application of an industry standard value including a safety factor (e.g. 80%ile) |

**Table 1.6b Confidence in the characterisation of water quality into the wetland:** Wastewater treatment works (private and municipal), package treatment plants, septic tanks. Evaluate the design based on each of the 3 columns and score based on the lowest confidence.

| | **2. Assessment criteria for the following water sources: Wastewater treatment works (private and municpal), package treatment plants, septic tanks** | | |
|---|---|---|---|
| | **Quality of primary water source** | **Quality of other sources of water** | **Variability of quality with time** |
| **L** | Used estimated values from published literature and guidance; or applied rule of thumb with no justification or supporting narrative | No other sources of water considered | No consideration of variability of water quality over time (both annual and with respect to climate change) |
| **M** | Used values from industry standards; or used values from manufacturer's verifiable source; used site-specific monitoring data (surrogate or actual) with no justification or supporting narrative | Some but not all other sources of water considered | Estimates of annual mean, maximum and minimum but no consideration of climate change |
| **H** | Used site-specific monitoring data (surrogate or actual) or industry standars - both will require narrative to justify interpretation (catchment scale, sample frequency, statistical comparisons, etc) | The water quality influence of precipitation, groundwater and other surface water considered | Robust estimate of seasonal variability; application of an industry standard value including a safety factor (e.g. 80%ile) |

**<u>Nutrient removal summary</u>:** Use the Confidence in the Design (Table 1.4) to select one of the three matrices below (Table 1.7a – c). Then use Confidence in the flow (Table 1.5a & b) to estimate the vertical axis and Confidence in the concentration (Table 1.6a & b) to estimate the horizontal axis. There are two tables for flow and concentration, dependent on the source of the inflow. The percentage represents the precautionary proportion of the calculated nutrient removal that can be credited to the design without monitoring, based on the expert opinion of the authors. The remaining nutrient removal can only be credited if it is confirmed through monitoring, see section 6. Nutrient credits can also be claimed for the change in landuse.

**High confidence in design & maintenance**

| | | Concentration | | |
|---|---|---|---|---|
| | | L | M | H |
| **Flow** | L | 0% | 20% | 50% |
| | M | 20% | 50% | 80% |
| | H | 50% | 80% | 100% |

**Table 1.7a Percentage of calculated nutrient removal – high confidence design**

**Medium confidence in design & maintenance**

| | | Concentration | | |
|---|---|---|---|---|
| | | L | M | H |
| **Flow** | L | 0% | 0% | 20% |
| | M | 0% | 20% | 50% |
| | H | 20% | 50% | 80% |

**Table 1.7b Percentage of calculated nutrient removal – medium confidence design**

**Low confidence in design & maintenance**

| | | Concentration | | |
|---|---|---|---|---|
| | | L | M | H |
| **Flow** | L | 0% | 0% | 0% |
| | M | 0% | 0% | 0% |
| | H | 0% | 0% | 20% |

**Table 1.7c Percentage of calculated nutrient removal – low confidence design**

It is worth noting the importance of design when assessing wetlands for nutrient neutrality. Any design that is not based on calculating nutrient removal using an approved, evidence-based approach cannot gain any nutrient credits unless the flow and concentration have been very well characterised. Even under these circumstances only 20% can be claimed if overly simple design approaches are used.

## A.6 References

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**Part A: Introduction**
A general introduction and rationale underpinning the logic within the Framework

**Part B: Framework**

**Stage 1 Design Objectives**
**Stage 1 should be completed for all wetland proposals**
The objective of Stage 1 is to ensure that a clear definition of the design objective has been provided and that there is sufficient, precise and conclusive supporting data and evidence to evaluate the desired water quality and nutrient removal outcome.

**Stage 2 Feasibility Assessment**
**Stage 2 should be completed for all wetland proposals**
The objective of Stage 2 is to ensure that all potential constraints, challenges and limitations on the ability to create or modify a wetland in the chosen location have been considered appropriately.

**Stage 3 Design process**
**Stage 3 should be completed for all wetland proposals**
The first objective of Stage 3 is to defined whether the wetland proposal is for a Treatment Wetland or an Other Wetland. The outcome of this first assessment will determine the progression through the Framework.

**Stage 3A Treatment Wetland Design process**
**Stage 3A should be completed only for Treatment Wetland proposals**
The objective is to ensure that the Treatment Wetland is designed in accordance with industry best-practice standards so that there can be certainty in its performance.

**Stage 4 Detailed Design process**
**Stage 4 should be completed only for Treatment Wetland proposals**
The objective is to ensure that the Treatment Wetland has been designed in accordance with industry best-practice standards so that there can be certainty in its performance.

**Stage 5 Implementation**
**Stage 5 should be completed only for Treatment Wetland proposals**
The objective is to ensure that the Treatment Wetland will be implemented correctly.

**Stage 6 Monitoring**
**Stage 6 should be completed only for all wetland proposals**
The objective is to ensure that all wetlands are monitored appropriately so that their performance and management can be ensured.

**Figure 1.5 Structure of the framework**

# PART B The Framework

*Integrated Constructed Wetland, Ingoldisthorpe, Norfolk. © R.J.McInnes*

# Stage 1. Design objectives

## Introduction

Appropriate wetland design requires clearly defined objectives, i.e. what is the wetland designed to achieve? Usually the design objectives, within the context of nutrient neutrality, will relate to a water quality parameter, such as a reduction in nitrate concentration, removal of total phosphorus or suspended solids content. Often, this will be expressed as a reduction in the overall load of a parameter, such as kilograms of total nitrogen being removed by the wetland. However, there may be other considerations within the objectives, for instance the potential to provide wider benefits to society (sometimes referred to as ecosystem services or natural capital benefits) such as through reducing flood risk, providing a habitat for pollinators or enhancing recreational opportunities.

For all wetland systems that are being considered in the context of the Habitat Regulations, it is necessary to clearly articulate what the wetland intends to achieve in terms of nutrient reduction. ***However, where a wetland is not being considered within the context of the Habitat Regulations or a permit limit, the degree of scientific certainty and the precautionary approach applied can be less rigorous***. It is important to ensure that opportunities to create wetlands which will improve water quality and potentially provide multiple benefits to society are not lost due to the application of unnecessarily stringent controls on their design.

**BOX 1 Understanding loads**

**The load is the total amount of a substance, such as total phosphorus (TP), that will be received by the wetland over a defined period of time. The load is derived from combining the amount of water entering the wetland (the discharge – sometimes incorrectly termed the "flow" and sometimes correctly termed the volumetric flow rate) over a fixed time period and the concentration of the substance in a fixed volume of water, usually a litre (L). Calculating the load is demonstrated in the example below.**

**Discharge** ($m^3 d^{-1}$)
The amount of water (e.g. cubic meters ($m^3$)) over a fixed time interval (e.g. days (d))
*Example*: 15.2 $m^3 d^{-1}$

**Concentration** ($mg\ TP\ L^{-1}$)
The amount in mass (e.g. milligrams (mg)) of a substance (e.g. Total Phosphorus (TP)) in a fixed volume of water (e.g. litres (L))
*Example*: 7.5 $mg\ TP\ L^{-1}$

**Load** ($kgTPd^{-1}$)
The amount of substance (e.g. TP) in mass (e.g. kg) over a fixed time interval
*Example*:
15.2 x 1,000 = 15,200 $L\ d^{-1}$ (convert $m^3$ to L)
7.5 x 15,200 = 114,000 $mg\ TP\ d^{-1}$ (convert concentration into a load in mg per day)
114,000/1,000,000 = 0.114 $kg\ TP\ d^{-1}$ (convert mg to kg per day)

**NB "Discharge" is a technical term in hydrology that refers to the flow rate of water through any line across a hydrological system, (not to be confused with "Final Discharge" or "Final Effluent" from a treatment system". See Glossary*

Defining the objectives in terms of nutrient reductions requires a robust understanding of several factors. Usually within the context of nutrient neutrality and the Habitat Regulations, the focus will be on understanding the amount (as a mass) of a substance (Typically Phosphorus or Nitrogen) removed by a wetland over a year (usually termed the load – see Box 1). Evaluation of this requires information on several factors including the source of the water, how much water will be flowing into the wetland, the concentration of the substance in the inflowing water, how concentrations and flows might vary over time, for instance during different seasons, and the level of confidence there is in the understanding of these factors.

The following sections need to be evaluated for all wetland proposals.

## 1.6 Has the source of water that the wetland is going to treat been clearly defined?

***What is the issue to be addressed?***

- Wetlands can treat water from a variety of different sources. These include (but are not limited to): Septic tanks and Package treatment plants; Municipal wastewater treatment works; Combined Sewer Overflows (storm water); Rural or Urban drainage; Runoff from fields and polluted water from rivers or streams. The designer of the wetland will need to define the characteristics and quantities of inlet water in order to estimate the incoming load of nutrient, and to ensure the hydrological controls within the wetland are appropriate.
- Some wetland sources such as from septic tanks, and package treatment plant may have a very well defined source of water, which is relatively consistent day-to-day and subject to well-researched industry standards on which to estimate flows and loads. Water derived from more 'open' systems, such as that derived from agricultural run-off from fields, ditches or farmyards, or urban drainage will be influenced by rainfall, so are liable to wider variations in flow and concentration in the wetland influent. It will often be important for the designer to clearly understand the size of the catchment of the drainage system that is to be treated, and the nature of the ground cover (proportion of soft landscaping) and the soil type in that catchment to estimate flows. Runoff quality may be influenced over time by factors such as agricultural practices or long-term land use change. Current Natural England Guidance suggests reviewing land use changes over the past decade to identify whether current land use is likely to increase or decrease monitored concentrations.
- Water from river systems which has been diverted to a wetland, or groundwater discharges will probably require detailed hydrological or hydrogeological modelling, or else an extended monitoring period in order to understand flows and loads sufficiently.
- Municipal wastewater treatment systems and CSOs typically receive water from combined sewers that in turn take domestic effluent, trade effluent, surface water runoff (from rain) and infiltration from groundwater. The population and catchment for surface water will of course vary over time. As such the flow and load variation is likely to be complex, though it is normally fairly well understood by the water company. Flows and loads at any point in the network will generally be forecast using a complex network model, which needs to be calibrated at regular intervals to ensure its accuracy.
- The source of the water being treated by a wetland will influence the choice of wetland, the design process and the final design.
- If the source of water has not been characterised robustly, the overall design process could be undermined.

***Key information required***

- The principal source of water to be treated by the wetland needs to be clearly defined.
- All possible water sources – precipitation, groundwater, surface water and influent flow need to be considered and explained.

## 1.2 Has a robust description been provided of the quality of the water that the wetland is going to treat?

***What is the issue to be addressed?***

- The quality of the water to be received by the wetland is critical to how the wetland will function and the type of wetland used to treat it.
- A clear description of the quality of the water entering the wetland needs to be provided. The description can be based on different information sources including *inter alia*:
    - empirical data which is representative of inflow to the wetland over a time period;
    - surrogate data derived from modelling using best-practice approaches and industry standard methods including published Nutrient Neutrality calculators;
    - surrogate data based on data drawn from relevant peer-reviewed literature sources that are appropriate to characterise the inflow; and
    - surrogate estimates based on generic values derived from a range of sources.
- The description of the water quality should review temporal variation (within year and over a period of several years) to ensure that the range of conditions that the wetland will experience is known.
- The description should consider the most up to date and relevant information on influent water quality.
- For the purposes of nutrient neutrality calculations, it is the nutrient content (primarily nitrogen (N) and phosphorus (P)) that will be of interest, though wetlands may be used to treat other parameters (such as sediment, biological oxygen demand, heavy metals, pathogens, etc.). The appropriate information needs to be provided on each parameter that the wetland is being designed to treat.
- The water quality is usually described as a concentration but other descriptors may be appropriate depending on the parameter being considered.

***Key information required***

- The quality of the water to be treated by the wetland needs to be clearly defined, and the methodology for estimating water quality needs to be explained and justified. For nitrogen and phosphorus removal this definition may typically be presented as a range of loads and concentrations that are expected in different forms of the nutrient (soluble, particulate, reduced or oxidised forms of Nitrogen etc.)
- The quality of all possible water sources – precipitation, groundwater, surface water and influent flow need to be considered and described.
- The potential variation in water quality over time needs to be clearly explained.

## 1.3 How much water will the wetland receive?

***What is the issue to be addressed?***

- The volume of water entering the wetland is a critical consideration. ‘Closed’ systems, such as single dwelling septic tanks will usually have a regular inflow that will demonstrate predictable variation from month to month. However, more ‘open’ systems, such as those from rural or urban surface water drainage may demonstrate a significant variation in volumes entering the wetland, both from month to month and from year to year.
- The flows need to be clearly characterised. The confidence levels applied to the possible variations in flow over time need to be clearly explained.
- A clear description of the quantity of the water entering the wetland needs to be provided. The description can be based on different information sources including *inter alia*:
    - design flows e.g. from pumped or hydraulically controlled inputs;
    - empirical data collected at the point of inflow to the wetland over a time period;
    - surrogate data derived from modelling using best-practice approaches and industry standard methods and estimations;

- surrogate data based on data drawn from relevant peer-reviewed literature sources that are appropriate to characterise the inflow.
- The description of the inflows to the wetland should review temporal variation (within year and over a period of several years) to ensure that the range of conditions that the wetland will experience is known.
- The description should consider the most up to date and relevant information on influent water quantity.

***Key information required***

- The amount of water to be treated by the wetland needs to be clearly defined.
- The methodology for estimating the flow rates and variation needs to be explained and justified.
- All possible water sources – precipitation, groundwater, surface water and influent flow need to be considered and discounted if negligible.
- The potential variation in flows over time needs to be clearly explained.

## 1.4 What is the predicted water quality leaving the wetland?

***What is the issue to be addressed?***

- The wetland should be designed to achieve a consistent quality of water leaving it **or** a known reduction in load. The quality of water leaving the wetland will depend on the quality and quantity of water flowing into the wetland and the design and management of the wetland. This should be derived from a robust design process, and appropriate methodologies are discussed in section 3 of this report.

***Key information required***

- The target concentration of the design parameter in the water leaving the wetland.
- The target load reduction of the design parameter.

## 1.5 What other benefits are part of the design objectives?

***What is the issue to be addressed?***

- Whilst a wetland designed to remove nutrients may be considered by some to represent an end of pipe solutions for water quality treatment, the wetland will still provide other benefits to society (such as pollination, local climate regulation and aesthetics) even if these have not been considered explicitly in the design and development process.
- Wherever possible, efforts should be made to consider a wetland as natural capital which can deliver multiple benefits to people which extend beyond a limited subset of benefits.
- It is understood that some funders of natural capital benefits will release payment for only a single wetland benefit (e.g. they may not be willing to fund both the biodiversity net gain and the nutrient removal benefits that a single wetland offers). The position of Natural England on this issue has not been formally determined at the time of writing this guidance, and advice should be sought from the appropriate internal guidance when determining applications.

***Key information required***

- If additional benefits, beyond achieving nutrient neutrality, are proposed due consideration needs to be given to current guidance and advice provided by Natural England and/or Defra regarding the integration of different compensation or mitigation schemes, such as biodiversity net gain.

## 1.6 Have long-term trends in influent water quality and hydrological flows been considered?

***What is the issue to be addressed?***

- The quantity of nutrient that a wetland can remove is clearly dependent upon the quantity of nutrient that will flow into the wetland over its design life. It is therefore important that the incoming flows and loads are considered not just at the time of the design process, but over the lifetime of the wetland for which nutrient credits are to be claimed. This design life should be clearly set out in the proposal, along with any "end of life" plans for the wetland.
- Future increase or decreases in the design concentration or flow should be accounted for in the design and the forecast of nutrient removal. However, designs can only be based on ***current knowledge***, monitoring and subsequent adaptive management will be used to manage future changes in flow or concentration. ***Designers should not be expected to predict changes in concentrations and loads as part of the design process***.
- A risk-based approach is advocated to evaluate the percentage of the predicted nutrient removal that should be credited, Tables 1.4 a to c.
- Confidence in predicted nutrient removal depends on the design and maintenance approach used and the level of available data on water flow and quality. Designs based on industry standard calculations will have higher confidence than those which use other approaches. The level of data on input water flows and quality will also impact confidence in the calculations. The confidence in the predictions can be increased by using the most conservative estimates.
- Wetlands that receive water and nutrient from a larger catchment will tend to be more robust to changes in land use and hydrology over the lifetime of the wetland than will wetlands that receive water from a very small catchment (such as a small field or runoff from farm buildings)
- Higher confidence may be achieved for wetlands which have been significantly oversized potentially reducing the risks associated with underperformance.

***Key information required***

- The variability of the water quality and hydrological flows to wetland should be clearly described and their implications on the wetland design approach clearly articulated.
- Information provided by the project proponent should be evaluated through the use of the risk assessment matrix (Table 1.1) to ascertain whether the appropriate wetland design process has been applied.

## 1.8 Overall evaluation of design objectives

For the design objectives to be robust in the context of the Habitat Regulations, sufficient information needs to have been provided for all the sections described above.

| | | Yes, all information has been provided | Some information has been provided | No information has been provided |
|---|---|---|---|---|
| 1.1 | **Has the source of water that the wetland is going to treat been clearly defined?** | | | |
| 1.2 | **Has a robust description of the water quality that the wetland is going to treat been provided?** | | | |
| 1.3 | **How much water will the wetland receive?** | | | |
| 1.4 | **Has the designed water quality leaving the wetland been defined?** | | | |
| 1.5 | **Have other benefits been integrated within the design objectives?** | | | |
| 1.6 | **Has the long-term variation in influent water quality and quantity been accounted for in the performance forecasts?** | | | |

| | ***Response statements*** |
|---|---|
| If ALL green | The design objectives are appropriate to proceed to undertaking the feasibility assessment and design process for a Treatment Wetland. Ensure that the information defined in the design objectives is clearly applied throughout the feasibility and design process. |
| If ALL green except 1.6 | The design objectives have failed to demonstrate that the long-term security of the influent quality and quantity has been accounted for and therefore it is unlikely that there will be sufficient scientific certainty necessary to design a Treatment Wetland. Recommend that an estimate of long-term variation, based on ***current knowledge,*** is included e.g. planned for growth. Designers should not be expected to 'predict' landuse change. |
| If SOME green and some amber or red | The design objectives are lacking or absent in key areas. It will be necessary to request further information on the amber and red issues so that the design objectives can be more robustly assessed |
| If SOME red | The design objectives are absent in key areas. It will be necessary to request further information on the red issues so that the design objectives can be more robustly assessed. |
| IF ALL red | The design objectives are not defined and therefore it will not be possible to design a wetland that will deliver on water quality targets to any level of certainty. |

# Stage 2. Feasibility

## Introduction

Before a wetland is created, there are many issues that need to be assessed as part of a feasibility study. Each one of these factors needs to be examined in the feasibility assessment. For many of these factors there may be appropriate mitigation strategies to overcome potential constraints on feasibility. If the risk associated with one of the issues identified below has not been assessed, or if any of the key information including a mitigation strategy is not available, then the application is flawed. There are some scenarios where specific items of key data are not required, these are highlighted in the text. Optional information is also identified which should be incorporated if it is available. The inclusion of optional information indicates a low risk application.

## 2.1 Topography & levels

***What is the issue to be addressed?***

- The topography of the site needs to be understood for a wetland to function properly, allowing water to flow through the system ideally under gravity and runoff from surrounding land does not flow into the wetland and compromise the treatment efficacy of the design.
- Whilst the topography might constrain the ability to move water under gravity, pumped solutions may be possible. However, the feasibility of any pumped system needs to evaluate the type of pumps, their carbon footprint, the long-term management needs, and the viability of operation over the duration of the development.
- All wetland designs will require some earthworks. Balancing the amount of excavation with the amount of fill will minimise the cost of the design. The need for deep excavations should be avoided as these could cause health and safety issues and slope stability problems.
- Key water levels, which act as hydraulic controls for the wetland must be identified. The difference between the inlet and outlet levels determines the hydraulic head available to drive gravity flow through the system.
- The hydraulic head to drive flow through the wetland needs to be sufficient to achieve the design flows. The larger the plan area of the wetland the greater the hydraulic head that is required.
- The shape and layout of the wetland will determine whether flow is evenly distributed across the wetland. Poor design of wetland shape can lead to short circuiting of flow through a wetland cell which reduces the effective residence time in the cell and compromises treatment efficacy.
- Attempts should be made to work with the existing topography and to seek a congruous fit within the existing landscape.

***Key information required (required for Nutrient Neutrality)***

- A map showing the water levels in each of the proposed wetland cells and the ground level in the surrounding landscape. Normal operating water levels in each cell should be lower than the upstream cell.
- The level of the surrounding land should not be such that it can drain into the wetland **unless** the wetland has been designed to treat runoff.
- The invert level of the inlet to the wetland should be explicitly stated along with the upstream water level. This is particularly important for Treatment Wetlands downstream of conventional engineered sewage treatment works. The design should demonstrate that the wetland will not 'back-up' flow into the treatment works which could compromise its treatment efficacy.

- The invert level of the outlet from the wetland, along with the water level in the receiving water, should be explicitly stated. If the water level in the receiving water is too high flow through the wetland will be reduced.

## 2.2 Soils

***What is the issue to be addressed?***

- Naturally functioning peat is an extremely valuable natural resource and should not be disturbed. There is a presumption that wetlands which require significant loss of peatland through excavation should be rejected unless there are specific conservation goals which justify it.
- The hydraulic conductivity of the soil is required to estimate the vertical leakage from the wetland into the shallow sub-surface or deeper aquifer. Leakage can be an issue both in terms of treatment efficacy (if the wetland dries up) and water quality (if the receiving groundwater is sensitive – see 2.4)
- Contamination of surface or groundwater may be an issue if contamination in the soil is mobilised by flows through, or leakage from, the wetland.
- Nutrients in the soil may be mobilised by excavation and removal of vegetation and lost to the wider environment. This will be a temporary issue but should be accounted for in the design or the commissioning of the wetland and in the nutrient balance for the wetland

***Key information required (required for Nutrient Neutrality)***

- A map of the expected soil type for the site. It should be noted that landscapes are highly heterogeneous and as such this map will only give an indication of soil type and properties.
- A simple site investigation identifying the local soil type along with an estimate of hydraulic conductivity **unless** the design includes a liner. The site investigation should also be used to identify if contamination is present so that this can be factored into the design.

## 2.3 Geology and hydrogeology

***What is the issue to be addressed?***

- The shallow geology of the site is important because it provides some (if not all) of the parent material for the soil and determines the vulnerability of any groundwater below the site.
- If the drift or solid geology is also an aquifer it could provide upward discharge of groundwater into the wetland which could compromise the treatment efficacy of the wetland.
- If the drift or solid geology is an aquifer, which is being used to supply potable water or provides inflow to a sensitive natural system (spring or existing wetland), leakage from the wetland could reach the receiving groundwater, and the risk of pollution should be assessed, also see 2.4 below.
- If there is an upwards head gradient in the groundwater, the viability of a liner and/or the ability to maintain hydrological control in the wetland needs to be understood to ensure that the functioning of the wetland is not compromised.
- The design water level in the wetland relative to the hydraulic head in the groundwater determines whether the wetland will receive or discharge water from or into the aquifer.

***Key information required (required for Nutrient Neutrality)***

- A map of the expected drift geology type for the site. It should be noted that drift properties are highly heterogeneous and as such this map will only give an indication of drift type, thickness and properties. The map should also include the stipple layer from the groundwater vulnerability maps, Annex 4

- A map of the expected solid geology below the site. It should be noted that solid geology can only be inferred from boreholes and geophysics and as such this map can only give an indication of the geology.
- In some circumstances, where the geology is complex or highly heterogenous, a site investigation identifying the local drift and solid geology properties and the presence/absence of fissures or fractures may be required. This may be available if there are significant engineering works nearby e.g. a sewage treatment works.

## 2.4 Groundwater protection

***What is the issue to be addressed?***

- If a wetland is receiving a source of water that has higher contaminant levels than are generally prevalent in the surrounding environment (e.g. discharge from a wastewater treatment works) it is important to be sure that the water from the wetland does not harm groundwater resources.
- Groundwater is the lowest carbon source of drinking water. If it is polluted by leakage from a wetland a valuable source of water may be lost for a considerable amount of time. Nitrate, heavy metals and some chemicals are sufficiently mobile in groundwater that they could be a source of pollution. In general phosphorus is not mobile in groundwater and is unlikely to present a drinking water quality issue. Some pesticides breakdown rapidly in a wetland and if so, they are unlikely to cause an issue. However, phosphorus and pesticide pollution are site specific and should always be considered especially if rapid flow paths exist, e.g. in karstic areas
- All groundwater is a potential future resource for drinking water. Groundwater nitrate vulnerable zones (NVZs) identify areas where groundwater is vulnerable to nitrate pollution and should be protected from elevated levels of nitrate leaching either directly via leakage from a wetland or via leaching from the soil during the construction process.

***Key information required (required for Nutrient Neutrality)***

- Groundwater source protection zones identify the catchment for boreholes which supply drinking water and are used by the Environment Agency to regulate surface activities which could cause pollution. Wetlands treating wastewater of a quality that could pose a hazard to groundwater resources (specifically drinking water) - should not be located in zone 1 and should be lined if within zone 2 or 3 to limit the risk of microbial pollution of groundwater **unless** there is hydrogeological evidence that any leakage from the wetland could not be captured by the abstraction.
- Groundwater NVZs identify areas where aquifers are vulnerable to nitrate pollution. Wetlands within groundwater NVZs should ensure that there is an appropriate hydrological seal to prevent losses of high nitrate water into the aquifer **unless** there is hydrogeological evidence that leakage from the wetland into groundwater will be limited. Low permeability drift deposits will protect an aquifer and can be identified by using the EA groundwater vulnerability maps. It is also possible that leakage from a wetland into groundwater will be ‘captured’ by a gaining reach of river – in this situation the ‘leakage’ from the wetland is effectively discharging to surface water and groundwater protection is not an issue.
- Groundwater vulnerability maps should be used to identify additional groundwater protection issues. If these maps identify that groundwater is ‘extremely’ or ‘highly’ vulnerable it is likely that a liner will be required **unless** there is local hydrogeological evidence that the wetland poses a low risk to groundwater.

## 2.5 Hydrology and drainage

- The interaction of the wetland with existing surface water and shallow drainage needs to be characterised so that inputs of water to the wetland, and leakage of water from the wetland, can be identified and mitigated so that flows through the wetland can be estimated accurately.
- Historical field drainage (clay or plastic pipes) can compromise the functioning of a wetland. Therefore, information on sub-surface drainage needs to be considered either from historical drainage maps or from field investigations.
- The flow path of overland flow should be characterised to ensure that additional runoff does not enter the wetland and compromise the design, see 2.1 above.

***Key information required (required for Nutrient Neutrality)***

- Map of surface water within and adjacent to the site.
- Site investigation identifying if land drainage is present and how the impacts of this have been mitigated within the design.

## 2.6 Flood risk

***What is the issue to be addressed?***

- A wetland design which could increase fluvial flood risk will not be permitted by the relevant risk management authority which is normally the Environment Agency on main rivers and Local Authorities for ordinary water courses.
- Changing a flood flow path or reducing storage capacity of the floodplain are unlikely to be permitted in flood zones 2 and 3 (main rivers) without a Flood Risk Assessment (F.R.A). which demonstrates that flood risk has not increased. This will mean that spoil will need to be removed from the flood zone.
- Wetlands which are likely to flood will be at risk of having reduced or unpredictable treatment efficacy at times when they are inundated. They may also require more frequent maintenance.
- Surface water flooding is also an issue. It is unlikely that a wetland could increase surface water flood risk but it is important to consider this risk and whether the wetland is in an area which suffers from surface water flooding.

***Key information required (required for Nutrient Neutrality)***

- A map to show if the wetland is in a flood zone. If the wetland is in Flood zone 2 or 3 (fluvial flooding) it is highly likely that it will require a flood risk assessment including a plan for the removal of spoil. (Wetland Data explorer – coming soon).
- A map to show if the wetland is in a surface water flood risk area. If it is in an area of surface water flood risk, provide a mitigation strategy. (Wetland Data explorer).
- An evaluation of the impact on fluvial and surface water flooding on the functioning of the wetland.
- A flood event on a treatment wetland may cause settled wetland sediments to mobilise, however the high sediment loads that naturally occur in rivers during storm conditions will also tend to settle in the wetland as flood waters recede (this is part of the natural function of flood plain wetlands).
- The sensitivity of a treatment wetland to flooding will be dependent upon the water being treated in that wetland e.g. if a wetland is being used to treat wastewater treatment works final effluent, or high-nutrient runoff from animal manure, then the risk of nutrient release during a flood event is relatively high. Conversely if a wetland is only treating river water in the first place, the impact of the flood event may be low (as long as the water control

structures in the wetland are not damaged), and the effect of the flood event may just be a temporary loss of treatment efficiency.

- It is important for the designer to recognise the frequency at which flooding of the treatment wetland may occur, and where to account for any loss of nutrient or temporary loss of removal efficiency in the Nutrient Credits that they are claiming where this loss may be significant. It is also important that the wetland be designed to withstand foreseeable floods over the lifetime of the project, and where necessary to have a contingency for making repairs in the event of flood damage.

## 2.7 Protected sites and species

***What is the issue to be addressed?***

- If the location is in, or near, a protected site, and could impact the conservation objectives of the site, a permit will be required from Natural England.
- If protected species are present at or near the site and could be impacted by the project, a consent will be required from Natural England.
- What is the 'ideal' habitat at the location? Natural England currently publish Habitat Network Opportunity maps and priority habitat maps (Wetland Data Explorer). These enable the designer to see what the 'ideal' habitat would be and if a wetland will compliment or conflict with this usage. These maps will be progressively replaced by the Local Nature Recovery Plans (LNRS).

***Key information required (required for Nutrient Neutrality)***

- Map of international and national protected sites for nature conservation (SAC, SPA, SSSI, Ramsar sites and MCZs).
- Map of locally protected sites (Local nature reserves, Local wildlife sites and local geological sites).
- Map of other protected areas (National Parks, AONBs and Heritage Coast).
- List of protected species (presence near the site location).
- Map of Habitat Network Opportunities and Priority habitats including priority river restoration sites. Ultimately the LNRS will be required.
- In some locations, a full ecological assessment may be required to provide maximum confidence that protected sites or species will not be impacted.

## 2.8 Land use

***What is the issue to be addressed?***

- It is important to understand the current and historical land use of the site because this could indicate historic industrial contamination or nutrient enrichment. Construction of a wetland could mobilise this historic pollution and impact receiving waters.
- If the land is currently under an agri-environment scheme, payments may be lost if the scheme is delivered.

***Key information required (required for Nutrient Neutrality)***

- Map of current land use and commentary on any previous land use that might cause an elevated risk of pollution from the wetland either during construction or operation.
- Map of active agri-environment schemes.

## 2.9 Ownership

***What is the issue to be addressed?***

- A project can only be delivered with the agreement of the landowner.

***Key information required (Required for wider feasibility of project)***

- Details of the landowner and, if possible, their attitude towards the potential development.
- Outline details of any legal or management agreements in order to secure the long-term future of the wetland.

## 2.10 Archaeology and heritage

***What is the issue to be addressed?***

- Archaeological remains and landscape features may need to be protected so that they are not lost. The best way to minimise the risk that archaeological remains will delay construction and increase costs is to identify the issue early on and plan for it.
- Scheduled monuments have additional protection and should not be impacted by development.
- Peat soils will also preserve environmental records in situ and should be protected.
- The heritage value of the site and its landscape can be important. The feasibility of the wetland design needs to consider how to accommodate landscape and heritage issues.

***Key information required (Required for wider feasibility of project)***

- Archaeological or heritage value risk assessment based on advice from the Local Authority.
- Map of scheduled monuments.
- In areas of high archaeological or heritage risk, a bespoke archaeological risk assessment and any planned mitigation may be required. This will minimise the risk of costly delays during construction and shows that the design is managing risk proactively.

## 2.11 Rights of way and public access

***What is the issue to be addressed?***

- Public rights of way cannot be closed or diverted, even temporarily, without permission from the local authority.
- Public access to the completed wetland will improve its amenity value, however, it may also increase H&S or vandalism concerns.
- Conversely, public access provides an opportunity to integrate the wetland design with wider communication and public awareness raising opportunities. Such opportunities can add value to the over wetland scheme.

***Key information required (Required for wider feasibility of project)***

- Map of the nearest public rights of way and any planned mitigation if required.
  Consideration of public awareness raising opportunities.

## 2.12 Birdstrike risk

***What is the issue to be addressed?***

- Wetlands can attract birds which maybe an issue if the site is near an airfield. This is especially an issue for large wetland birds such as geese and swans and also large flocks of birds such as starlings.
- The risk of birdstrike will depend on the type of airport and its associated usage by planes. An evaluation of risk needs to be within the context of the type of airport.

- Airports may have their own birdstrike risk management programmes or plans. These should be consulted and any mitigation of birdstrike risk should be derived through consultation and the development of a mutually agreed strategy.

***Key information required (Optional)***

- Map showing the nearest airfields and the type of airfield (commercial, military etc) along with any proposed mitigation strategy.

## 2.13 Historic landfill, coal mining and contaminated ground

***What is the issue to be addressed?***

- Historic contamination from landfills or industry can be remobilised and released into the environment if there are excavation works. This could cause increased pollution.
- Areas with historic coal mining pose a potential risks to a new wetland.
- Depending on the buried materials, historic landfill may pose a threat to the efficacy of the project depending on the material present. For instance, the potential removal of large volumes of buried asbestos may contribute significantly to the overall project costs.

***Key information required (Required for wider feasibility of project)***

- Map of historic landfills and contaminated land.
- Risk assessment based on local knowledge and readily available data.
- A site investigation report provides the greatest certainty that historic contamination is not an issue. This may be available for wetlands near to existing sewage treatment works or other significant engineering works.

## 2.14 Unexploded ordnance

***What is the issue to be addressed?***

- Uncovering unexploded ordinance will delay project construction and increase costs.

***Key information required (Optional)***

- Identify presence or absence of unexploded ordinance.

## 2.15 Services and infrastructure

***What is the issue to be addressed?***

- Buried and overhead services (telecon, electricity, gas and water) could all be impacted by the creation of a wetland. Moving services is expensive and time consuming and requires the involvement of the service provider.

***Key information required (Required for wider feasibility of project)***

- A full service search along with maps of any services identified. The locations should be plotted on the design drawings for the wetland to show their relative position.
- A mitigation strategy for any services identified.

## 2.16 Proximity to housing

***What is the issue to be addressed?***

- Where wetlands are close to housing, the opportunity for maximising the benefit of the wetland as an amenity should be particularly closely considered.
- If wetlands are treating odorous effluents, smell can be an issue, however, it is important to compare the potential odour issue from a wetland with the engineered alternative.

- Open water and human health issues associated with sewage are a potential health and safety risk, however, it is important to compare this with the engineered alternative and the fact that wetlands occur naturally within the environment.

***Key information required (Optional)***

- Map showing location and distance to nearest housing.
- Assessment of the potential for amenity use.
- Mitigation strategy for health and safety and odour if it is an issue.

## 2.17 Nature recovery

***What is the issue to be addressed?***

- Wetlands have the potential to be a very important part of a habitat network which will allow nature to recover and thrive. However, there are locations where wetlands would not be appropriate as they could displace a more valuable habitat type.

***Key information required (Required for wider feasibility of project)***

- Map of the habitat opportunity network identifying that the location is suitable for a wetland. In time the Local Nature Recovery Strategy (LNRS) should be used to minimise the risk that a constructed wetland habitat will compromise the local habitat network.
- **Optional.** Identification of potential biodiversity net gain credits using The Defra BNGNE Biodiversity Metric V3.0. This could provide a significant additional source of funding to optimise the habitat benefit of the wetland.

## 2.18 Decommissioning

***What is the issue to be addressed?***

- As part of the Construction Design and Management (CDM) regulations 2015 a decommissioning plan should be included in the design stage risk assessment.

***Key information required (Required for wider feasibility of project)***

- Be clear about the design life of the wetland, and what will happen to the site after decommissioning.
- Consider the fate of the nutrient captured in the wetland during the decommissioning process.
- Consider the fate of other captured pollutants if appropriate, for instance heavy metals and microplastics.

## 2.19 Regulatory considerations

***What is the issue to be addressed?***

- Environmental permits are likely to be required for many constructed wetland projects, especially near Main Rivers. Early dialogue with the Environment Agency is recommended to identify potential permitting requirements. These are likely to vary from project to project.

***Key information required (Required for wider feasibility of project)***

- A list of the permits that the developer considers will be required along with an assessment of the likelihood that they will be granted.
- **Optional.** A narrative on each permit identifying any engagement with the relevant regulator and advice already received.

## 2.20 Constraints and options assessment

***What is the issue to be addressed?***

- A summary table which describes the constraints identified for each factor; any further information needs/gaps and the preferred wetland type and location (option) provides a sound audit trial to justify why the option submitted is the best one. Although this step is not mandatory it does show that the applicant has formally considered other wetlands options which increases the likelihood that the design will be sustainable in the long term.
- Ideally, the constraints should also be offset by a summary description of the potential benefits that the preferred scheme can provide.

***Key information required***

- **Optional.** A summary table of options and constraints.
- **Optional.** A narrative justifying the preferred option and highlighting why it is better than other possibilities.

## 2.22 Evaluation of feasibility assessment

The feasibility assessment should include the key pieces of information that are identified in the table below to show that the wetland will work effectively and not cause worse pollution or damage to existing natural systems. Most items of information are readily available in mapped from within the 'Wetland Explorer' which has been developed in parallel with this project, although funded through alternative resources provide by the CWA/RT partnership. This means that it is easy to produce a high-quality feasibility assessment with maps which demonstrate that the developer understands the spatial context of the wetland within its catchment and is therefore far more likely to deliver a wetland that will be a sustainable component of improved water quality and habitat in the long term. For a number of pieces of information mapped data is unlikely to be possible and tabulated data is perfectly acceptable. The Green response statement is appropriate.

It is also acceptable for developers to use this guidance as a checklist and produce a simple table that demonstrates that each component of the feasibility assessment has been considered and only produce maps of the topography and services, making the 'Amber' response statement appropriate. It is envisaged that this checklist type approach would be appropriate for most smaller wetland proposals, simply showing that the information has been considered, a tick would indicate that there are no concerns or it is not relevant. If any of the key items of information are missing the 'Red' response statement below can be used so that the applicant understands precisely what is required.

| | **Comment** | All information has been provided in mapped form where possible | All information has been provided in tabular form | No information has been provided | Unlikely to be applicable for small wetlands |
|---|---|---|---|---|---|
| 2.1 | Topography | | NA | | |
| 2.2 | Soil | | | | |
| 2.3 | Geology & Hydrogeology | | | | |
| 2.4 | Groundwater protection | | | | |
| 2.5 | Hydrology & drainage | | | | |
| 2.6 | Flood risk | | | | |
| 2.7 | Protected sites & species | | | | |
| 2.8 | Landuse | | | | |
| 2.13 | Historic landfill & Con. land | NA | | | NA |
| 2.18 | Decommissioning | NA | | | |
| 2.20 | Constraints and options assessment | NA | | | |

| | ***Response statements*** |
|---|---|
| If ALL information green or amber where green NA | This is a well-structured feasibility assessment that maximises the likelihood that this ***Treatment Wetland*** will be a sustainable natural asset within this catchment. |
| If SOME information is amber instead of green | This feasibility assessment has considered all the mandatory information and is acceptable. |
| If SOME red | The application is missing mandatory information on 2.# and 2.#. Please provide this information so that the feasibility assessment can be evaluated. |

# Stage 3. Design process

## Introduction

To meet the objectives of the Habitat Regulations, a wetland scheme must provide effective mitigation for nutrient loads to avoid any adverse effects on international important nature conservation sites over the duration of the project. Consequently, any wetland system proposed for neutralising nutrients must be designed using best scientific knowledge in the field so that no reasonable scientific doubt of its treatment efficacy remains. This is consistent with the precautionary approach.

When using a wetland to mitigate nutrient impacts, it is essential to assess the sensitivity of the design to key assumptions (e.g. about loading, flow rates etc.) and to account for the likely variability of performance over the lifetime of the wetland by applying precautionary rates to variables. Such an approach will provide reasonable scientific certainty that an adverse outcome can be avoided.

There are four core principles that, when combined, allow the nutrient removal efficiency of any wetland design to be estimated with confidence:

1. The variability of the ***inflow quality*** must be clearly defined for a **Nutrient Treatment Wetland**. Uncertainty in nutrient concentrations and other physical and chemical characteristics of the water source over the lifetime of the wetland need to be transparent, and the sensitivity of the nutrient removal calculations to uncertain parameters need to be assessed and accounted for. (This should be addressed in Section 1.1)

2. The variability of the ***inflow quantity*** must be clearly defined for a **Nutrient Treatment wetland** and the ability to manage and maintain desired water levels should be robust. Uncertainty in flow rates over the lifetime of the wetland need to be transparent, and the sensitivity of the nutrient removal calculations to uncertain parameters needs to be assessed and accounted for. (This should be addressed in Section 1.2).

3. **Design of Nutrient Treatment Wetland** should use well-established and appropriately calibrated best-practice design equations and models. There are methods available that have been recognised for decades and are supported by a considerable body of peer-reviewed literature and published research. Consequently, the level of reasonable scientific certainty associated with the robust application of these design approaches to **Nutrient Treatment Wetlands** is considered to be relatively high.

4. **Most wetlands are effective at removing nutrients**. However, the lower the confidence in the input data (1) & (2) and the lower the relevance of the design assumptions (3) the more precautionary nutrient removal predictions should be. Additional nutrients may be removed however, this can only be proven through monitoring

The objective of Stage 3 of the Framework is to assess the quality and pedigree of the wetland design.

# Stage 3. Treatment Wetland Design Process

## Introduction

The design of a Treatment Wetland should be an iterative process that considers the objectives but also responds to the constraints imposed by a specific site as identified in the feasibility assessment. It is for this reason that it is rare that any two wetlands will be identical.

The design process is about considering the way incoming nutrients will behave in the wetlands, and the overall area of wetland required to ensure the desired nutrient reductions. The flows of water into the wetland and the associated nutrient concentrations should be described under sections 1.1 and 1.2. This part of the process should address:

- what is the mean flow rate of water entering the wetland, and what concentration and types of nutrient will it contain?
- How much variation will there be of flow rate and concentration around the mean, on a daily basis, and on a seasonal basis and over the lifetime of the wetland?
- How much uncertainty is there in the assumptions you have made around flow rates, concentrations, and the variations of these?

It is also necessary to determine how the incoming water and nutrient will behave once it is in the proposed wetland system.

- What is required to ensure the water levels in the wetland will be suitable throughout its life?
- Is there a need to "balance" peak flow by providing storage in part of the wetland? Would this be desirable (e.g. to mitigate downstream flood risk?)
- How will water flow through the system? What is the effective 'treatment area' and will there potentially be 'dead areas' with limited throughflow?
- Will the water velocity always be low enough to allow sediments to settle?
- Is it possible to diversify habitat niches in the wetland? Are the needs of wildlife met?
- What will be the fate of sediment-bound nutrient? (A proportion will normally be released into water).
- Is a 'background concentration' of nutrients likely in the wetland due to internal turnover of nutrients?
- Will the appropriate physical and chemical conditions be consistent in the wetland for all the required chemical transformations to occur at the rates you have proposed, especially when considering the seasonal and long-term variation in flows and concentrations?

There may be other conditions that are relevant on a site-by-site basis.

Once a location for the wetland has been confirmed as being feasible, the required functional area for the desired nutrient load removal must be calculated. This will be based upon accepted design approaches. The sensitivity of the forecast removal rate to variation and uncertainty in incoming flows and loads, and uncertainty in performance and other model parameters should be explored and explained.

## 3.1 Calculating nutrient removal and associated wetland area

***What is the issue to be addressed?***

- The review of the literature and the knowledge of industry best-practices recommends the application of the following approaches to calculate nutrient reductions and to estimate wetland area:
  - The *P-K-C** approach.
  - A 'plug flow' model termed the *k-C** approach; or
  - Regression (or exponential decay) equations;
- The P-K-C* model described in Kadlec and Wallace (2009) is considered to be the most robust approach and is strongly recommended. This model is a 'First Order' reaction model. That is to say, the rate of reaction (the nutrient removal processes) assumed is dependent upon the concentration of the parameter in question. Such a model may be used either to derive a treatment area based upon target performance (load removal or outlet concentration), or else to derive the expected nutrient removal from a wetland with a particular treatment area (where the area of land where wetland feasibility has been proven).
- The P-K-C* model considers the area of a wetland and within the hydraulic loading rate (HLR). The parameters P, K and C* describe the way the contaminant of interest is processed within the wetland. C* is the 'background concentration of a particular parameter, such as Total Nitrogen. The background concentration is a parameter that represents an irreducible concentration that will exist in the water in a wetland that results from internal biogeochemical processes i.e. the contaminant would be present without the addition of the influent. Therefore, it represents a concentration below which further removal of contaminant is impossible. K is the reaction rate, which describes the speed with which contaminants at any particular concentration (above C*) are removed from incoming water by the wetland. P is a parameter that describes both the hydraulic efficiency of the wetland, and the way in which contaminants 'weather' or breakdown as they pass through the wetland (if contaminants are actually a mix of chemicals (e.g. Total Nitrogen), some of those chemicals that go to make up Total Nitrogen will break down more readily than others).
- The *k-C** model has been widely applied to the design of treatment wetlands. As with the P-k-C* model, the *k-C** model is a first order reaction model that similarly incorporates a background concentration value below which further nutrient removal is not possible.
- There are numerous regression equations proposed in the literature to calculate the removal rates of different parameters, including Total Nitrogen and Total Phosphorus. Different equations will have limitations on their input and output range and the hydrological parameters used.
- Any method of estimating nutrient removal that does not consider inlet concentration should be treated with caution, and should be rejected unless the approach is very carefully and robustly justified. Some potential pitfalls are considered below.

  - Percentage treatment efficiencies (for instance, the use of values derived from the literature such as 37% TN reduction, 46% TP reduction) should not be used to design a treatment wetland. These take no account of inlet concentration, flow rate or the size of the wetland so it is very rare that such estimates will be reliable. They may be a reliable way of predicting future performance of a wetland for which there is a lot of existing data, or for a wetland of the same size treating identical flows and loads.

   - Assumed areal removal rates (such as 1.2 gTP $m^{-2}$ $yr^{-1}$, 93 gTN $m^{-2}$ $yr^{-1}$) or similar hydraulic loading rates (HLR) as found in the literature (for instance in Land *et al.*, 2016) should not be used. These take no account of inlet concentration, which will strongly influence the load removal in most wetland treatment systems. Such an approach can only work if the removal rates are derived from very similar situations with very similar inlet concentrations, in a directly comparable geographic location.

- Many wetland designers consider the mean nominal Hydraulic Retention Time as a sense-check for the design of treatment wetlands. Generally something in the range 8-24 hours is considered a 'sensible' or appropriate value. However, these values should be used only as a sense-check and not as the primary design approach.
- The choice of parameters used in all the model is extremely important. These need to be clearly articulated and described in relation to the context of the design site. Parameter choice should reflect uncertainty regarding effective treatment area, temperature or wetland performance (where calibration data is poor).
- It is good practice to conduct sensitivity analysis on the choice of parameters chosen when calculating nutrient load removal using performance models. Greater scientific certainty can be applied to designs that have conducted sensitivity analysis and used conservative parameter values.
- Design calculations should be conducted for different seasons and potentially different influent conditions to understand and evaluate temporal variability in performance and to provide greater scientific certainty.
- Over time, more real-world data from nutrient removal wetlands in UK conditions will become available. When they become available these data should be used to validate and calibrate design parameters for future wetland proposals.
- Calculations may estimate wetland area (in hectares or $m^2$) based on a desired target concentration in the water leaving the wetland (where the goal may be to comply with a discharge permit), or the sizing calculations may estimate a target concentration based on a given size of wetland (i.e. where the goal is to create the largest wetland possible on a given site, for the purposes of maximising load reduction).
- Treatment area of a wetland should not be confused with the overall site area. The overall area that the wetland covers will include the Treatment Area (the functional area which will treat the water flowing through the wetland) and the larger area required to fit the wetland within its landscape.

***Key information required***

- The design equation used along with the assumptions that make this approach applicable to the wetland. The approach should consider the likely concentration and quantity of nutrient in the inlet water. Rule of thumb checks can be used to cross check the results.
- Treatment performance should consider a target concentration (mg $L^{-1}$) and be stated as a load reductions (kg $yr^{-1}$) for the relevant contaminants (TN, TP, etc).
- Design calculations should include the flow coming into the wetland (usually expressed as $m^3$ $yr^{-1}$ or $m^3$ $d^{-1}$) and the contaminant concentration (usually expressed as mg $L^{-1}$) of the influent (to be treated) as well as the area and hydraulic loading rate (q, cm $d^{-1}$ or m $yr^{-1}$).
- Seasonal variations in performance may be expected, particularly for phosphorus removal. These should be accounted for and clearly described and explained.
- Certain design models and equations use rate constants ($k$, m $d^{-1}$ or m $yr^{-1}$). The rate constants will vary for different contaminants, different climates and also for different Treatment

Wetland types (FWS, VF, HSSF). The use of any constant needs to be clearly justified and the value selected clearly explained.

- The background concentration of the contaminants of interest should be selected, appropriate to the wetland being considered. It must be noted that the modelled outlet concentration from a Treatment Wetland will never be lower than the background concentrations applied in the model.
- The size, or area, of the wetland used in the calculations should be the functional or active area (net of earthworks, berms and flow control structures which although necessary for function, do not contribute to the actual treatment processes).

## 3.2 Water balance

***What is the issue to be addressed?***

- Design of a Treatment Wetland requires a thorough understanding of hydrological inputs, outputs, stores and how these may change seasonally. Understanding these fluctuations and incorporating these variables into a design will ensure the Treatment Wetland functions correctly and provides the treatment required.
- Significant changes in the hydrological conditions in a Treatment Wetland, such as from inundation by major storm inputs or drying out due to summer drought conditions can seriously compromise the performance of the wetland. .

***Key information required***

- The design process must identify and quantify all hydrological inputs to the Treatment Wetland. These may include the following, but it should be noted that not all these inputs occur in every situation:
    - Precipitation (always an input) – daily or monthly rainfall data from a nearby weather station (average mm per day or month and converted to $m^3$ for area of the ***Treatment Wetland*** per month) and storm data ).
    - Groundwater (not always an input) – daily or monthly groundwater data (average $m^3$ per day or month).
    - Influent flows - water to be treated (always an input) – influent daily discharge data (average $m^3$ per day and converted to $m^3$ per month).
    - Surface water – water from the wider catchment (not always an input) – daily or monthly surface water discharge ($m^3$ per day or month) and storm data
- Identification and quantification of all hydrological outputs to the ***Treatment Wetland***. These may include the following, but it should be noted that not all these outputs occur in every situation:
    - Evapotranspiration (always an output) – daily or monthly evapotranspiration data relevant to the plant types proposed within the ***Treatment Wetland***. These data are normally found from published data from a nearby weather recording station or calculated from climate data using equations such as the FAO Penman-Monteith equation (Allen et al. 1998) or Hargreaves equation (Hargreaves 1981; Hargreaves et al. 1985). It is important that these data are derived from climate data located near the site (expressed as mm per day or month and converted to $m^3$ for area of the ***Treatment Wetland*** per month).
    - Infiltration to ground (not always an output) – daily or monthly infiltration data often calculated by carrying out an infiltration test on site ($m^3$ per day or month) or estimating the flow rates with material of a proven hydraulic conductivity.
    - Surface water – water leaving the ***Treatment Wetland*** (not always an output as the final stage of a ***Treatment Wetland*** may rely on evapotranspiration as the only output) – daily discharge data ($m^3$ per day and converted to $m^3$ per month).

- The identification and quantification of all hydrological inputs and outputs needs to be transparent and all data sources need to be clearly defined and their quality evaluated.
- Water balance. A water balance should be produced showing the average monthly fluctuations (surpluses or deficits) between the hydrological inputs and outputs to the system. It is important that the wetland does not dry out, as this is likely to cause nutrient release once it is re-wet.
- The performance forecast of a wetland should consider the potential effects of extreme storms, and of potential effect of climate change on hydrological inputs over the lifetime of the wetland.

## 3.3 Hydrological control and management

***What is the issue to be addressed?***

- Design of a ***Treatment Wetland*** requires a thorough understanding of the hydrological dynamics of the system to ensure the ***Treatment Wetland*** functions correctly and provides the treatment required.
- The Treatment Wetland needs to operate in drought and flood conditions so understanding these fluctuations is crucial to developing a robust design.
- The Treatment Wetland also needs to a predicted interaction with groundwater so as to ensure both robust hydrological control within the wetland and to protect sensitive receptors from any discernible uncontrolled discharge from the system.

***Key information required***

- Water balance and storm water balance implications. The water balance and storm water balances calculated as part of the feasibility and design process should have demonstrated the hydrological dynamics of the proposed ***Treatment Wetland***. An assessment should be made of any implications in terms of water deficit and surpluses. The effect of these factors on nutrient removal should be considered. Key factors to consider include the following:
    - Plant species and plant community maintenance. Have the implications of periods of drought or prolonged inundation been evaluated for proposed plant species or plant communities?
    - Hydrological functioning. Do water control structures or ***Treatment Wetland*** beds become overtopped during periods of surplus?
    - Uncontrolled groundwater interactions. Will either inputs of groundwater or seepage losses to ground impact on the overall water balance and hydrological functioning of the wetland?
    - Treatment functioning. Will the wetland dry out and potentially release nutrient?
    - Ecosystem services beyond water quality treatment. Will periods of deficit or surplus impact on the delivery of additional ecosystem services? For example, does flood retention still occur during periods of water balance surplus.
- Variability of influent flows. If influent flow is interrupted for extended periods of time this can compromise treatment as biological processes can become dormant. This is a particularly relevant consideration for wastewater treatment systems (e.g., for holiday homes that are occupied only part of the year) and is true of conventional wastewater treatment systems as well as wetlands. Reductions in performance immediately after a dormant period should be considered where relevant.
- Strategies to mitigate extreme deficits or surpluses to the ***Treatment Wetland*** should be proposed. These may include the following:

- Influent flow interruptions. To maintain the treatment ability of the system during periods of influent flow interruption then a sweetening flow, from another source, may be used to sustain treatment biological processes during the influent flow interruption, or water can be managed within the wetland to maintain appropriate hydrological conditions.
- Water level management. To maintain suitable water depths for plant species and plant communities and for robust treatment, water level management measures need to be considered. These include, for example, water level control structure operation to hold back or release water, use of additional water inputs during drought conditions and the design of spillways and additional flood storage areas for high rainfall or flood events.

- Maintaining hydrological integrity and predictable interaction with groundwater. The design process needs to clearly describe the potential risk of water loss to, or ingress from, groundwater. The relationship between the Treatment Wetland and its substrate needs to be clearly described and methods to avoid undue water loss (or gain) via the ground should be described. In some cases a lining system may be needed to reduce or eliminate water loss to ground.

## 3.4 Sediment loads and accumulation rates

- Accumulation of sediment will affect the way the hydrology of the wetland works. If wetlands are to receive a high sediment load, the design needs to provide places for the sediment to settle while allowing the water to continue to flow through the wetland as intended. All wetlands will fill up with sediment and organic material eventually, and if this is likely to occur within the design lifetime of a treatment wetland, a mechanism and schedule for removing accumulated sediment will need to be provided within the maintenance plan.
- Sediment would be expected to settle out and accumulate in the wetland at very low flow velocities and to potentially become remobilised into the water at relatively high flow velocities. The range of flow velocities that may be experienced within a wetland, and the effect of these on sediment transport need to be considered in the design.
- The fate of the nutrient that is removed in the sediment needs to be considered as a part of the nutrient balance for the wetland system as a whole (e.g. sediment that is allowed to dry out on bunds or adjacent land is likely to release Phosphorus back into the environment).

***Key information required***

- The amount of sediment in the Treatment Wetland influent should be described. Variations in the sediment loads, such as seasonal or event-driven, being received by the wetland need to be clearly described.
- The rate of sediment accumulation within the Treatment Wetland should be calculated and clearly described.
- The provenance and pedigree of the data used to evaluate the sediment loads should be clearly explained.
- Potential long-term changes in the sediment loads should be evaluated.
- Sediment can accumulate in Treatment Wetlands without compromising the performance. However, the implications of sediment accumulation over time and the necessary management measures required to adapt to this should be clearly articulated and evaluated.
- Sufficient freeboard should be provided in the design of treatment wetlands to allow the flow of water to be controlled by the surrounding elevated ground levels (or commonly used bunds), even accounting for the build-up of sediment and organic matter on the base of the wetland over its design life.

## 3.5 Evaluation of the design process

For **Treatment Wetlands** the design process needs to address the four sections identified above in 3.1 to 3.4 to show that construction and operation risks of the ***Treatment Wetland*** have been reduced as far as possible and any remaining risks can be managed and mitigated. Full compliance to the information requirements identified in these sections will ensure that the design process has been conducted with reasonable scientific certainty and to best-practice standards.

| | **Comment** | All information has been provided | All information has been provided in tabular form | No information has been provided |
|---|---|---|---|---|
| 3.1 | Calculating nutrient removal and the associated wetland area | | - | |
| 3.2 | Water balance | | | |
| 3.3 | Hydrological control and management | | | |
| 3.4 | Sediment loads and accumulation rates | | | |

| | ***Response statements*** |
|---|---|
| If ALL information green | This represents a Treatment Wetland design process that provides reasonable scientific certainty and maximises the likelihood that the wetland will be a sustainable natural asset within this catchment. |
| If ALL green but 3.1 is red | The Treatment Wetland design process does not use an acceptable design approach and is not robust. It will not provide reasonable scientific certainty with regards to its performance. Significant additional information will be required. |
| If SOME information is amber (3.2-4_ instead of green | This ***Treatment Wetland*** design process has considered all the mandatory information and is acceptable. |
| If SOME red | The application is missing mandatory information on 3A.# and 3A.#. Please provide this information so that the feasibility assessment can be evaluated. |

## References

Allen R.G., Pereira L.S., Raes D., Smith M. (1998). *Crop evapotranspiration — guidelines for computing crop water requirements.* FAO Irrigation & Drainage Paper 56. FAO, Rome

Hargraves, G.H. and Samani Z.A. (1982). Estimating Potential Evapotranspiration, Tech Note, J. *Irrig. Drain Eng*., vo. 108, no. 3 pp. 225-230.

Hargraves, G.H. and Z.A. Samani, (1985) Reference Crop Evapotranspiration from Temperature, *Appl. Eng. Agric*., vol 1, no. 2, pp. 96-99.

Kadlec R.H. and Wallace S.D. (2009) *Treatment Wetlands*, Second Edition. Boca Raton, Florida: CRC Press.

Land M., Graneli W., Grimvall A., Hoffmann C. C., Mitsch W. J., Tonderski K. S. and Verhoeven J. T. A. (2016) How effective are created or restored freshwater wetlands for nitrogen and phosphorus removal? A systematic review. *Environmental Evidence* 5:9

# Stage 4. Treatment Wetlands detailed design

## 4.1 Overall design

***What is the issue to be addressed?***

- There are any number of potential configurations for the layout of ***Nutrient Treatment Wetlands.*** In order for any quantitative forecast of water quality improvement to be robust, inlets, outlets, and intended flow paths across the wetland need to be well defined.
- It is also important to consider how access will be achieved for the maintenance activities that are essential for the efficient operation of the wetland. What sort of access is needed to what part of the wetland? Is vehicular access needed? Are access tracks provided? Are turning areas for vehicles needed?
- In general, most wetlands ought to be able to deliver multiple benefits to the landscape, amenity and wildlife, and many will be able to be designed to reduce flood risk in addition to performing a treatment function. Designs that consider only treatment efficiency are not good designs unless there is a compelling argument against offering additional benefits.
- Experienced designers will consider how the wetland fits into the landscape of the area. Can the shape be made to mirror features such as nearby waterways? Arbitrary curvilinear features set within an open patchwork field system can look just as out of place as a rectangular wetland within the curves of a "natural" landscape.
- Bunded areas around the margins of wetlands don't have to be amenity grassland. Flowering grassland mixes and lawn are widely available, but will still need mowing once or twice a year.

***Key Information Required***

- The inlet point and discharge point should be well defined.
- There should be a clear method for holding water within the treatment area.
- Sufficient access to carry out the required maintenance activities should be included.
- The potential for additional benefits (other than water quality) should be considered.
- Is public access allowed and if not, is there a good reason for this. Could controlled access be permitted? This information is not required for the Habitats regulations but is good practice as it maximises the public goods that are delivered by the wetland.

## 4.2 Hydraulic performance

***What is the issue to be addressed?***

- Robust ***Nutrient Treatment Wetland*** performance models will normally involve a factor that is the "Treatment Area" of the wetland. The Treatment Area is simply the area of wetland that is available for treating the incoming water.
- When water flows over the surface of a wetland, it will not naturally flow over the whole of that wetland area in an even way. By nature, water will tend to form channels, and will flow preferentially through areas that have a high local "hydraulic gradient" (e.g. directly towards the outfall) and/or the lowest resistance to flow (e.g. where plant growth is less dense). If the velocity of flow becomes too high in particular areas, this may cause erosion of the base of the wetland, suppressing plant growth and increasing the tendency for channels to form locally and short circuiting to occur.
- If water passes through the wetland with very low velocity it will have a lower momentum, and so the flow path is more likely to spread out owing to interaction with emergent plant stems etc, improving hydraulic efficiency.
- It is necessary to account for natural hydraulic inefficiencies in the design of wetlands in two ways:

  - Design the ***Nutrient Treatment Wetland*** to deliver hydraulic efficiency. Where appropriate in the wider context, preferential flow paths and "dead areas" in wetlands should be avoided. This will include consideration of the overall layout of the wetland, the velocity of the water, and the way in which wetland plants will affect the wetland hydraulics, particularly during establishment.
  - Anticipate and account for the hydraulic inefficiencies when forecasting the removal rates that will be achieved by the wetlands (e.g. by correcting the treatment area, or adjusting another parameter in the performance model, the parameter "P" in the P-K-C* Model deals with hydraulic efficiency for instance).
- It is not always necessary or appropriate for a wetland designer to optimise hydraulic efficiency above other design objectives. Improving hydraulic efficiency by introducing berms or additional treatment cells will normally add cost and reduce the overall treatment area for instance, so these trade-offs are carefully considered by an experienced designer. In other cases, water quality improvement will only be one of a number of benefits delivered by the wetland, so it is legitimate for the wetland to be optimised for habitat improvement, amenity or flood risk reduction etc. This is a perfectly valid approach, as long as the hydraulic inefficiency is accounted for in the forecast of water quality performance.
- Particular considerations regarding hydraulic performance include:
  - A length to width ratio of 3:1 or greater is generally considered to be sufficient to allow reasonable hydraulic efficiency. Some designers prefer to achieve efficiency by optimising cell shape for low velocities (see below) as this will cause water to "spread out" more between the inlet and outlet point.
  - It is allowable for the wetland to be inefficient hydraulically, as long as this has been allowed for when estimating treatment performance. One approach might be to reduce the value of the parameter P in the P K C* model used to estimate treatment performance. Another might be to reduce the effective treatment area in performance calculations.
  - The width and depth of a wetland will control the velocity of water in a wetland for a given flow rate. Low velocities will tend to cause more even distribution of water in the wetland. Mean velocities up to around 0.03m $s^{-1}$ are considered good practice for nutrient control and may be expected to avoid re-suspension of sediments even in unvegetated areas, though good plant populations can be sustained at higher velocities up to around 0.4 m $s^{-1}$.

***Key Information Required***

- The route that the water is expected to take through the wetland or sequence of wetlands.
- The shortest route from inlet to outlet and what (if anything) stops the water taking this route.
- The effect that the length to width ratio of the wetland has on the distribution of flow through the wetland.
- The maximum velocity of the water. This needs to be low enough to ensure that wetland plants will effectively distribute the flow of water. This is particularly true during the period before the plants are mature.
- The areas within the layout which have been used as the "treatment area" in calculations. If there are likely to be hydraulic inefficiencies in the wetland, these areas should not be included in the calculations of treatment area, or else they should be accounted for elsewhere in the performance estimate

## 4.3 Water depth

***What is the issue to be addressed?***

- It is important for the designer to consider what is the design depth of water in a wetland and the effects of this.
- The standard depth of water within a ***Nutrient Treatment Wetland*** will typically be around 0.1-0.3m. Larger depths within this range will tend to correspond with lower velocities (good for hydraulic efficiency) and higher residence times (good for flow and load balancing) but a greater risk of hydraulic mixing which can have negative impacts on certain nutrient removal processes.
- It has been demonstrated that treatment efficiency of a wetland correlates much more readily with treatment <u>area</u> rather than the <u>volumetric</u> capacity of a wetland. Though nominal hydraulic retention time (HRT) is a common and valuable check on the sizing of a wetland, designs which rely heavily on this parameter will need to be carefully justified and will warrant some scrutiny if water depths are significantly greater than 0.3m.
- Water depth will generally be controlled by setting a range of levels for the base of the wetland, and controlling the level at which water can leave the wetland by use of a weir or outlet pipe.
- To design for amenity, consideration should be given to safe egress from the wetland for humans and animals.
- Fences greatly detract from amenity and should be avoided unless there is no other practicable way of reducing risk to an acceptable level. Wetlands are a part of the natural landscape, if well designed they will present a lower risk of drowning than (for example) rivers, lakes or canals, and there is generally no need to restrict access on safety grounds unless the water being treated is particularly noxious. Fences will be needed in some instances to prevent livestock or other herbivores damaging the wetlands.
- If high sediment loads are expected in the water to be treated, allowance needs to be made in the wetland design for the reduction in water depth that will occur owing to the settlement of this sediment and how this will be managed over time.
- Over the years and decades of operation, wetland plants will grow, die back and decay, forming sediment and litter layers which will gradually build up as new wetland soils. This process will cause the base of the wetland to gradually increase over time. The water containment structures of the wetland need to account for this accretion of plant matter and incoming sediment or precipitates by providing sufficient freeboard to accommodate water level rises over the life of the wetland. Consideration should be given to providing the facility for outlet control (weirs etc) to be adjusted to maintain a suitable water depth over the life of the wetland.
- For larger wetlands, where path length from inlet to exit is 100 metres or more, in higher flow rates the mature wetland plants may offer sufficient resistance to water flow that the water depth may not be constant over the length of the wetland cell. In such instances, it is possible for water to "back up" at the inlet end, and the wetland should be designed to accommodate this.
- Some considerations relating to water depth are as follows:
    - Wetland vegetation will not tolerate water depths much in excess of 1 metre, 0.1 to 0.3 metres is a common target water depth but this is dependent on the plant communities chosen.
    - Where sediment loads are anticipated to be high, a deeper "forebay" area may be used adjacent to the inlet of the wetland to capture the initial fallout of sediment when water velocity drops.
    - If a variable water depth is specified (normally by specifying an undulating base level) this will provide a wider range of ecological niches which favour a variety of plants

and animals. As well as biodiversity gains from this approach, a varied botany within a wetland will provide better resilience against long term changes in the water availability, and against the effect of plant pests and diseases.
  - Consideration should also be given to providing extremely shallow gradients (1 in 10 or less) either side of the waters' edge, to make the wetland more suited to use by amphibians.
  - Where amenity use is planned, a common safety feature is to provide gradual slopes at the edge of a wetland that can be easily navigated (1 in 3 or 1 in 4 slope gradients is common) along with a "flat but wet" shallow area around the edge of the wetland.
  - Some designers deliberately specify deeper areas within wetlands, either to increase the variety of ecological niches, or to improve hydraulic efficiency by locally reducing water velocity in a "trench" perpendicular to the direction of flow. There is insufficient evidence to confirm that this is good practice but conceptually it is sensible.

***Key Information Required***

- The design depth of water.
- The method used for water level control.
- Descriptions of how the needs of biodiversity and amenity have been incorporated into the wetland design.
- The allowance that has been made in the design for accretion of sediments from wetland plants (freeboard in the bunds, ability to adjust outlet level).
- If the design relies on removal of sediment, the accumulation rate should be calculated and allowed for in the maintenance schedule including adequate access to remove material.

## 4.4 Consideration of constraints

***What is the issue to be addressed?***

- Design needs to account for the findings of the surveys and feasibility study (Stage 2). Wetland vegetation will probably not become well established if the wetland is unduly overshadowed by trees, and the leaf fall may add to the nutrient load to a problematic degree.
- Design of wetlands around retained individual standard trees can add landscape character and are unlikely to be problematic for the wetland development. Care needs to be taken not to damage the retained trees by excavation or inundation within the tree protection radii.

***Key information required***

- How have the recommendations of the survey reports been accounted for in the design?
- How does the design account for the presence of underground services and appropriate wayleaves and have the owners of underground services been consulted?
- How does the design account for existing archaeological and ecological value of the site?
- If groundwater will be encountered during construction, how will this be managed?

## 4.5 Water management infrastructure and civil engineering

***What is the issue to be addressed?***

- Water levels and flows must be controlled to ensure good performance and longevity of the wetland.
- There are numerous methods to control flow including penstocks (sluice gates), valves, pumps, lateral spreader/collector channels or perforated pipes.
- Levels control devices include simple swivel pipe for smaller wetlands or stop logs or weir penstocks for larger.

- Treatment wetlands may need to be isolated from flow or their internal cells may need to be isolated. This can be achieved by simple piped connections or outfall from an upstream source or more complicated diversions including channels, weirs and/or sluices
- If a pump is critical to operation or safety, two pumps should be installed ("duty and "standby" pumps) and their operation range able to accommodate both max and min flows
- Any installed head walls must have a scour apron to reduce erosion.
- Any berms used as overflow weirs must Appropriately consider the risk of scour during operation.

***Key Information Required***

- How the flow of water into the wetland is controlled and are the flow control devices labelled on the layout drawing.
- If pumps are required, has information been provided regarding their operation along with head loss calculations demonstrating that the head/discharge performance of the pumps can meet the required flow rates.
- How is the water level of each cell is controlled and are the level control devices clearly labelled on the layout drawings. The control devices should be fully adjustable from full to empty.
- The slopes of the berms should be clearly shown on the drawings. If they are steeper 33% for slope stability reinforcement should specified, depending on soil type.
- The flow of water through the wetland should be controlled, including the transitions between sheet flow and piped / channelled flow. If more than one flow path is specified, the necessary flow control devices should be labelled on the drawings.
- Provisions should be made to prevent erosion around intake / outfall areas, and where berms are used as weirs or overflows.
- How is the designer sure that pipes re large enough to cope with design flows?
- What happens if flow exceeds the design flow? Or if there is a blockage? Or if the level of water gets too high? Or too low? The designer should consider these things and design for exceedance.
- What maintenance is required for the control structures? Is there sufficient access provided for vehicles and pedestrians to conduct this maintenance?

## 4.6 Vegetation communities

***What is the issue to be addressed?***

- Plants play an important role in free-water surface Treatment Wetlands for nutrient control. A dense growth of wetland plants will help to distribute water over the surface of the wetland and will protect the wetland soils from erosion.
- Uptake of nutrients into the vegetation (and microbiology), and the subsequent accretion of dead plant and microbial matter into the wetland soils is an important mechanism for sustainable nutrient removal from water in wetlands. Generally speaking, uptake of nutrients will be greatest in spring and early summer, then a proportion of those nutrients will be released by decay later in the season.
- Plants with complementary growing cycles will help to maintain a consistent phosphorus uptake across the growing season. Plants that are highly invasive and form a monoculture (e.g. Phragmites) do not lend themselves well to a diverse botanical mix (though may have advantages in terms of rapid establishment and high stem density). The inclusion of flowering plants will attract invertebrate pollinators. Not only is this good for biodiversity, but invertebrate movements are thought by some designers to have a beneficial effect in removing phosphorus from the wetland system. A varied plant mix will give the wetland

greater resilience against changing environmental conditions, and against plant pests and diseases.

- It is important when planting wetlands that invasive non- native species are avoided. These can be brought into site inadvertently as seeds in imported plants from nurseries that handle non-native species. The plants selected should complement the regional ecology as well as being native to the UK. Harvesting and re-use of existing plant stock reclaimed from the wetland site where appropriate is often a good solution though the method of harvest should avoid long term damage to existing ecosystems.
- Some practitioners recommend regular harvesting of wetland vegetation to enhance nutrient removal (particularly phosphorus removal). This activity will also reduce the rate of sedimentation in the wetlands so may help to reduce some longer term maintenance activities. Kadlec (2019) argued that the phosphorus content of the harvested vegetation is generally not a particularly high proportion of the overall phosphorus flux in the wetlands, so this activity will only be worthwhile in lightly loaded wetlands. If it is considered, it should always be done in a rotation, to allow refuges for disturbed wildlife, and care must be taken with the method to avoid undue damage to the health of plants, and to avoid large scale disturbance of wetland sediments which could undermine the overall aim. The fate of the nutrient content in harvested plant material also needs to be accounted for in the nutrient balancing calculations.

***Key Information Required.***

- The establishment of vegetation - is it proposed to plant the wetland, or let it establish naturally.
- A planting plan stating the plants that are proposed; the rational and compatibility with the local ecology.
- A commissioning plan stating how long the vegetation be left to establish before a throughput of water is proposed and when design treatment efficacy can be expected. The plan should also state how preferential flow paths will be avoided when water is first introduced to the wetland and the assumptions that have been made about treatment efficiency from the immature wetland.
- A vegetation management plan stating if regular harvesting of vegetation proposed; what the objective of the harvesting is and what measures are in place to prevent wider damage to the wetland while doing this. The plan should also identify the risk of non-native or ecologically inappropriate species being accidentally introduced and what will be done to mitigate this risk?

## 4.7 Substrate

***What is the issue to be addressed?***

- Wetland substrate is important for two main reasons:
  - It is important that the substrate can support the growth of vegetation that is proposed for the wetland. Wetland plants are unlikely to establish well if they are planted in heavily compacted ground, or if the soil does not offer the opportunity for the roots to anchor themselves (e.g. if it has a high fraction of large gravel or cobbles). It is preferable to use site won subsoil as a planting medium if suitable. This can be applied over an impermeable or low-permeability substrate.
  - When a newly created wetland is first flooded, there will be a period of time before the chemistry of the soils and waters equilibrate. There is a risk, particularly in former arable land, that the nutrient content of soils will be high and that these nutrients will enter the water column, causing the new wetland to be a net source of nutrients, rather than

removing nutrients from incoming water. Similarly, it is important that risk of any other soil contamination is considered in the design. In some settings it may be appropriate to provide an artificial liner to isolate the incoming water from potential contaminant sources. Proposed wetland soils may be tested for nutrient content. Total Nitrogen (TN) Content: <1000 mg/kg and Total Phosphorus (TP) content : <80 mg $kg^{-1}$. Are often considered appropriate.

***Key information required***

- A method statement on how to manage water quality risks during construction including:
  - Forming the wetland cells and placing the planting medium without causing undue compaction of the substrate.
  - Reducing the risk of nutrient release from soils.
  - If a ground or groundwater contamination was identified during feasibility Stage 2, how has this risk been investigated and mitigated?

## 4.8 Design stage risk assessment

***What is the issue to be addressed?***

- The Design Stage Risk Assessment should include all measures taken to eliminate or reduce exposure of possible hazards. These hazards are found during construction, operation and maintenance of the wetland. Risk removal must be in line with legal obligations under The Construction, Design & Management Regulations (CDM 2015).
- Evaluation of the design requires cross referencing between calculations, supporting evidence and design drawings. These must be provided in a single easy to use document with revision and date.
- All drawings should be clearly named, numbered (including latest revision no.), dated and their status indicated (e.g. advisory, or, detailed design, or for construction). This is essential for the reviewer to understand what stage of the design and construction process the drawings are intended for, and to make sure the relevant parties / stakeholders all have the correct and current drawing(s).

***Key Information Required***

- A clear statement that the wetland designer understands and acknowledges responsibilities under CDM 2015, and a Design Stage Risk Assessment is included.
- The design and specification should be collated into one document, with all pertinent information appended. The document should have a date and revision number.
- Design drawings should have unique reference numbers, with dates and revision numbers. Their status should be clearly indicated e.g. For Construction.
- All aspects of the design detail (slope and dimensions of berms, flow and level control, erosion protection, vegetation etc) should be cross referenced between the drawings and the design and specification document.

## 4.9 Evaluation of the design detail

For ***Nutrient* Treatment Wetlands** the design process needs to address the seven sections identified above in 4.1 to 4.8 to show that construction, operation risks and treatment risks have been reduced as far as possible and any remaining risks can be managed and mitigated. Full compliance to the information requirements identified in these sections will ensure that the design process has been conducted with reasonable scientific certainty and to best-practice standards

| | | Yes, all information has been provided | Some information has been provided | No information has been provided | Not relevant |
|---|---|---|---|---|---|
| 4.1 | Overall Design | | | | |
| 4.2 | Hydraulic Performance | | | | |
| 4.3 | Water Depth | | | | |
| 4.4 | Consideration of constraints | | | | |
| 4.5 | Water Management Infrastructure | | | | |
| 4.6 | Vegetation communities | | | | |
| 4.7 | Substrate | | | | |
| 4.8 | Design stage risk assessment | | | | |

| | ***Response statements*** |
|---|---|
| If ALL green or grey | The information provided regarding the design detail is appropriate and sufficient |
| If SOME or ALL amber | More information is required on [SPECIFY] to evaluate some of the details of the wetland design. |
| If SOME red | No information has been provided on [SPECIFY]. Without this information it is not possible to determine whether the wetland will perform as specified. |
| IF ALL red or a combination of only red and grey | No information has been provided regarding the design detail proposed for the wetlands. Additional information is required regarding [SPECIFY]. Without this information the wetland designs cannot be evaluated. |

## References

Biofiltration Filter Media Guidelines (Version 3.01), prepared by the Facility for Advancing Water Biofiltration (FAWB), 2009
Construction (Design and Management) Regulations 2015 (UK legislation*)*

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Kadlec, Robert H (2019). Treatment Marshes for Runoff and Polishing. CRC Press Boca Raton. ISBN 978-1-138-32262-2

Yang et al (2010). Yang Deng, Helena M. Solo-Gabriele, Michael Laas, Lynn Leonard, Daniel L. Childers, Guoqing H,Victor Engel. "Impacts of hurricanes on surface water flow within a wetland" Journal of Hydrology 392 (2010) 164–173

Freshater Habitats Trust (2013). "Creating Ponds for Amphibians and Reptiles". Million Ponds Project Species Dossier. https://freshwaterhabitats.org.uk/wp-content/uploads/2013/09/Amphibians-_Common-Toad-Great-Crested-Newt-and-Grass-Snake_-new-logo.pdf

Facility for advancing Water Biofiltreation (FAWB) (2009). Biofiltration Filter Media Guidelines (Version 3.01). FAWB, Melbourne, Australia.
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# Stage 5. Implementation process for Treatment Wetlands

## Introduction

Using the Treatment Wetland detailed design (stage 4) information, a technical specification and environment management plan would usually be produced that provides all necessary information for a contractor to undertake construction of the Treatment Wetland. Typically, this would include site safety, health and environment information outlining the site-specific risks in terms of safety and health, the environment, waste management and incident management. It should also provide information regarding site clearance, earthworks, infrastructure and planting and appropriate method statements.

For the purposes of this decision support assessment framework a full technical specification is not required however key implementation issues should be addressed within a submission and these are detailed in sections 5.1 to 5.4 below.

In addition, an outline management plan is required to assess the requirements for operating and maintaining a robust and effective ***Treatment Wetland*** into the future. This is considered in section 5.5.

## 5.1 Site clearance, earthworks and infrastructure construction

***What is the issue to be addressed?***

- Site clearance can result in unnecessary environmental damage impacting existing biodiversity.
- Excavating, handling of and filling using soil and aggregate material, during the construction of a ***Nutrient Treatment Wetland***, can result in unnecessary environmental damage such as damage to tree roots, compaction of soil or fuel spills.
- Spoil material disposal can result in environmental damage and reduction of flood storage.
- Infrastructure construction can result in environmental damage through pollution incidents and inappropriate waste disposal.

***Key information required***

- Construction environmental management plan and corresponding method statements. Suitable methods and an environmental management plan should be identified for site clearance and earthworks, spoil disposal, infrastructure construction and waste disposal to ensure:
  - biodiversity features are not detrimentally impacted,
  - trees are protected,
  - soil compaction is minimised,
  - potential pollution incidents are avoided,
  - buried services are protected,
  - topsoil and subsoil are handled separately (where needed) and for the suitable disposal of any surplus spoil.
- If spoil is to be generated, then it should be identified how this will be handled and where it will be placed at the site or taken offsite. For this assessment, the following information is needed.
  - an indication of likely site clearance, earthworks and spoil disposal
  - suitable outline mitigation method statements In addition,

  - information regarding incident management (spillages, flooding, services damage, damage to habitats and species or poor waste disposal and storage) and waste management should be provided.
- **Optional.** Full technical specification and environmental management plan outlining safety, health and environment information, construction specifications and proposed method statements, and bill of quantities.

## 5.2 Hydrological commissioning

***What is the issue to be addressed?***

- It is essential that the ***Nutrient Treatment Wetland*** holds water to provide full treatment before water is discharged into the environment.

***Key information required***

- A commissioning plan. Information should be provided regarding how hydrological commissioning would be undertaken for the ***Nutrient Treatment Wetland*** to demonstrate that the wetland holds water before full operation is undertaken. This may include, for example, pressure testing of seals around pipework, permeability substrate tests or liner testing by gradual filling to determine whether there are any leaks, or the installation of lysimeters under the wetland, etc.

## 5.3 Vegetation establishment

***What is the issue to be addressed?***

- Treatment wetland vegetation can be established through planting, introduction of wetland turfs from donor sites and through natural colonisation. Planting and the introduction of wetland turfs results in an operational ***Nutrient Treatment Wetland*** over a shorter time frame (one growing season) than if the system is reliant on natural colonisation.
- The water levels and maintenance of hydrological inputs has implications for the successful establishment of the wetland plant communities and their future management. Once established, emergent vegetation can withstand the natural seasonal fluctuations in water level. However, young plants are less tolerant of flooding and drought. Some young wetland plants installed at the extremes of their range of life are likely to be lost. If the vegetation communities are not well established after the first year's growing season, supplementary planting would be required. This should mirror the initial planting plan and focus on any particular plant species that has suffered from high losses.

***Key information required***

- Vegetation establishment method. It should be clearly stated how vegetation establishment will occur (planting, wetland turfs from a donor site or natural colonisation) and the timeframe required for suitable plant establishment.
- Planting plan. A planting plan should be provided if natural colonisation vegetation establishment is not adopted, identifying the location and planting density of different plant species or plant communities to be used and an indication of the typical water level range required for each species.
- Protection measures. Plants can be eaten or damaged by bird and mammal species during establishment so suitable protection measures, if required, should be identified such as barrier fencing.
- Plant die-back and disease loss. Plants can naturally die-back or be lost through disease. Regular checks are required to monitor plant establishment.

- Supplementary planting plan. Losses of some plants is inevitable so a plan for regular checking and supplementary planting should be provided.
- Water levels. Water levels vary for the vegetation establishment phase to the operation phase of the ***Nutrient Treatment Wetland***. Explanation for how these differences in water level regime will be managed should be given.

## 5.4 Consideration of constraints

***What is the issue to be addressed?***

- The constraints identified during feasibility and desk study will continue to apply during construction. These are discussed in detail in section 2 of this report.

## 5.5 Outline management plan

***What is the issue to be addressed?***

- For a ***Nutrient Treatment Wetland*** to provide effective treatment into the future there needs to be a robust management plan in place that fully covers the routine operation and maintenance of the ***Nutrient Treatment Wetland*** and identifies accident emergency measures if required. For the purposes of an application an outline management plan covering the main topics as detailed below should be provided.

***Key information required***

- Operator's roles and responsibilities. The management plan should clearly identify the roles and responsibilities of the operator and other stakeholders. It should provide contact information, particularly with respect to emergency procedures, if they are required. The outline management plan should identify the key roles and responsibilities related to the ***Nutrient Treatment Wetland***.
- Routine operation and maintenance. All routine operation and maintenance tasks required for safe and effective operation of the ***Nutrient Treatment Wetland*** should be included within the management plan. These include, for example, the following:
    - Silt management – regular checks should take place to determine silt built up within ***Nutrient Treatment Wetland*** cells. If silt levels reach a pre-determined level then measures should be identified for how silt should be removed from the cells.
    - Water control structures – if water control structures are used within the ***Nutrient Treatment Wetland*** these need to have operation guidance routine operation including for drought and storm event management. They also require regular maintenance checks to ensure effective operation.
    - Pipework and connector ditches and swales – pipework and connector features that deliver water from one ***Nutrient Treatment Wetland*** area to another require regular maintenance checks to ensure they are flowing correctly.
    - Bed and bank maintenance – bed substrates and banks vary in the material used for construction from soil to clay to artificial materials. Depending on the type of material used they may require regular maintenance checks. A particular issue is burrowing animals so regular checks are needed to ensure the system does not leak and if a leak is identified remedial work is actioned.
    - Vegetation establishment – the operation and maintenance measures for establishing vegetation within the ***Nutrient Treatment Wetland***, see section 5.3, for monitoring vegetation loss and providing supplementary planting is required.
    - Vegetation management - vegetation management is crucial to establishing the habitats and achieving the objectives. Treatment wetlands often undergo natural succession as the communities become established. It is important to maintain the

necessary water storage capacity and the desired plant communities so some regular management is often required. To hold succession at a given stage a vegetation maintenance programme should be presented. This should include the following typical management activities: removal by hand (saplings), cutting and grazing. It is important, for biodiversity management, that the cutting and grazing activities are done on a rotational basis rather than complete removal of all vegetation. Typically, only a third of a bed is cut in any year. Vegetation management is often required of the beds themselves and the banks of a system. It is important that the removal methods are stated and that the vegetation disposal location is identified so that material does not fall back into the treatment cells.

- Invasive plant management - invasive plants can be a problem as they can quickly dominate a habitat at the expense of other plant species and compromise treatment performance. They include aggressive native species as well as non-native invasive species. Maintenance activities for the identification and removal of any invasive/highly competitive native species and non-native species should be stated. Suitable methods for removal of native invasive/highly competitive species such as Willow spp. saplings includes manual removal whilst winter flooding, cutting back or topping is effective at controlling flood-intolerant plants, such as Willowherb *Epilobium* spp., Nettle *Urtica dioica* and Thistle *Cirsium* spp. For highly invasive non-native species, such as New Zealand Pigmyweed *Crassula helmsii*, Floating Pennywort *Hydrocotyle ranunculoides*, Parrots Feather *Myriophyllum aquaticum*, Water Fern *Azolla filiculoides*, Japanese Knotweed *Polygonum cuspidatum* and Himalayan Balsam *Impatiens glandulifera* manual removal is often the preferred method as the use of herbicides can easily be washed into watercourses and may kill native aquatic flora and fauna.

- Emergency maintenance - All environmental hazards, the risks associated with these and an accident management plan setting out how to prevent accidents but also what to do if they occur, should be provided within the management plan. Typical accidents include the following:
  - Spillages - where wetlands are overloaded, as a result of routine maintenance such as silt removal or as a result of slow seepage leaks.
  - Flood – storm events greater than the design storm and flooding from adjacent waterbodies or overland.
  - Bank failure – failure of ***Nutrient Treatment Wetland*** bed infrastructure due to land movement, impact, corrosion etc.
- Monitoring of the system. See section 6
- **Optional.** For the outline management plan a detailed checklist of routine operation and maintenance tasks, emergency procedures and the frequency of delivery is not required. However, for the final management plan an indication of the frequency of operation is required. If a checklist with frequency of operation is submitted within the outline management plan, at this stage, it would provide additional confidence of a robust management plan for the ***Nutrient Treatment Wetland***.

## 5.6 Evaluation of the implementation process

For evaluation of the proposed implementation process all six pieces of key information that are identified in 5.1 to 5.6 need to be presented to show that construction risks have been reduced as far as possible and any remaining risks can be managed and mitigated. If any of the six items of information are missing the appropriate response statement below can be used so that the applicant understands precisely what is required.

| | **Comment** | All information has been provided including a full technical specification, environmental management plan and full operation and maintenance management plan | All information has been provided | No information has been provided |
|---|---|---|---|---|
| 5.1 | Site clearance, earthworks and infrastructure construction | | | |
| 5.2 | Hydrological commissioning | | | |
| 5.3 | Vegetation establishment | | | |
| 5.4 | Consideration of constraints | | | |
| 5.5 | Outline management plan | | | |

| | ***Response statements*** |
|---|---|
| If ALL information green or amber where green NA | This provides comprehensive information regarding the implementation process for the ***Treatment Wetland*** and maximises the likelihood that this ***Treatment Wetland*** will be constructed appropriately and managed effectively. |
| If SOME information is amber instead of green | The implementation information provided has considered all the mandatory information and is acceptable. |
| If SOME red | The application is missing mandatory information on 5.# and 5.#. Please provide this information so that the implementation process assessment can be evaluated. |

# Stage 6. Monitoring & Evaluation

## Introduction

This section considers three types of monitoring:

- Baseline monitoring of the wetland should be undertaken to ensure that they are well designed, known risks are mitigated and the load reductions and any nutrient credits can be quantified. This is discussed in section 6.1.
- Performance monitoring once the wetland is operational can quantify any additional nutrient load reduction and therefore credits that are actually being provided by the wetland which could not be relied upon at the design stage due to the lack of scientific certainty. This is discussed in section 6.2
- Longer term monitoring is also required to support the maintenance and the adaptive management of the wetlands once they are fully operational. This is discussed in section 6.3

In addition, in order for benefits from the wetland to be realised over its lifetime, the ownership model for the wetland needs to be carefully considered at project inception. This is discussed in section 6.4

## 6.1 Baseline Monitoring to inform design and quantify nutrient credits

***What is the issue to be addressed?***

- Monitoring of wetland proposals through this framework uses a precautionary approach whilst recognising that it is not possible to have absolute certainty in any Treatment Wetlands However reasonable scientific certainty in wetland function may be achieved through structured and case-specific baseline monitoring.
- Baseline monitoring should be designed to improve the characterisation of the existing water quality before the wetland is built. This means setting up a working hypothesis, based on the local situation and the known water quality and quantity processes, which determine the variability of flow, load and therefore concentration. This hypothesis should be used to identify the baseline monitoring that is required.
- Chronic sources of pollution are typically less variable than event-based acute pollution. Chronic pollution from a point or diffuse source should be monitored at regular intervals using a rolling average e.g. effluent from a sewage treatment works or nitrate leaching from agricultural land.
- Event-based pollution can be highly variable and should be monitored on a case-specific basis. For point sources a typical event would be an increase in population due to seasonal tourism. For diffuse sources heavy rainfall may trigger a phosphorus event by mobilising pollution from surrounding land. In both cases baseline monitoring data should include a number of these events if the influent concentration is to be characterised accurately.
- Discharge (flow rate) *and* concentration are intimately linked. Concentration data without associated flow data is unlikely to allow meaningful characterisation of the influent and prevents the load from being estimated. A lack of correlation between discharge and concentration implies that other causal factors may be involved. Failing to collect discharge data will not allow these signals to be spotted and interpreted.
- Proportionality. The precautionary principle under the Habitats Regulations states that decision-making must be proportionate to the project or plan under assessment. Minor projects, where low impact is predicted will require less robust baseline data than those where significant risk is identified. The decision to apply proportionality lies with the competent authority, however guidance is provided here in order to determine the quality of data submitted with wetland proposals.
- Surrogate data. Surrogate data may be used in place of monitoring:

- Where industry standard approaches have been developed e.g. the use of population equivalents (PE) and other features of the wastewater catchment to estimate flow and load from sewage treatment works.
- Where the scenario is sufficiently analogous to another project for which data has been collected i.e. similar by, climate, sizing, treatment objectives, rainfall patterns etc.

- Baseline monitoring is of paramount importance in relation to the allocation of nutrient credits. This baseline data, combined with the design specification, will help quantify the nutrient reduction and therefore nutrient credits that can be assigned.
- If water quality in the future improves the wetland may remove less nutrients but this will not adversely affect the nutrient status of the catchment.
- If water quality gets worse the wetland should continue to provide the same or even enhanced nutrient removal. See 6.3 on adaptive management.

***Key information required***

- The location of sampling points and a justification explaining why they are relevant to the wetland design.
- The correct water quality parameters (NH4, TN, TP, etc.) must be included depending on the objective of the wetland; the sampling frequency is appropriate and the information is of a known data quality.
- Flow data is available which can be used to understand the variations in concentration and estimate loads.
- For surrogate data:
  - The industry standard assumptions that have been used should be stated.
  - Identify why the surrogate water quality baseline from another project is relevant to this design.

## 6.2 Monitoring at equilibrium

***What is the issue to be addressed?***

- After commissioning, when stasis in biogeochemical performance is reached a ***Treatment Wetland*** is at equilibrium. If a sufficiently precautionary design process has been followed, reasonable scientific certainty has been achieved that the design effluent load/concentration will not be exceeded, therefore "compliance monitoring" is not warranted.
- In many cases the **Nutrient Treatment Wetland** will remove more nutrient than was forecast at design, owing to the precautionary approach to uncertainty in the design parameters and variability of inlet waters.

***Key information required***

- No monitoring is required to demonstrate achievement of the nutrient reductions taking into account the confidence in the design, maintenance, flow and concentration. Additional nutrient credits over and above this can be gained through monitoring performance. However, no monitoring is required to demonstrate performance at equilibrium, it is good practice to have a monitoring plan with suitable monitoring frequency, Fig 6.1.

**Figure 6.1. Long term monitoring frequency based on sedimentation predictions**

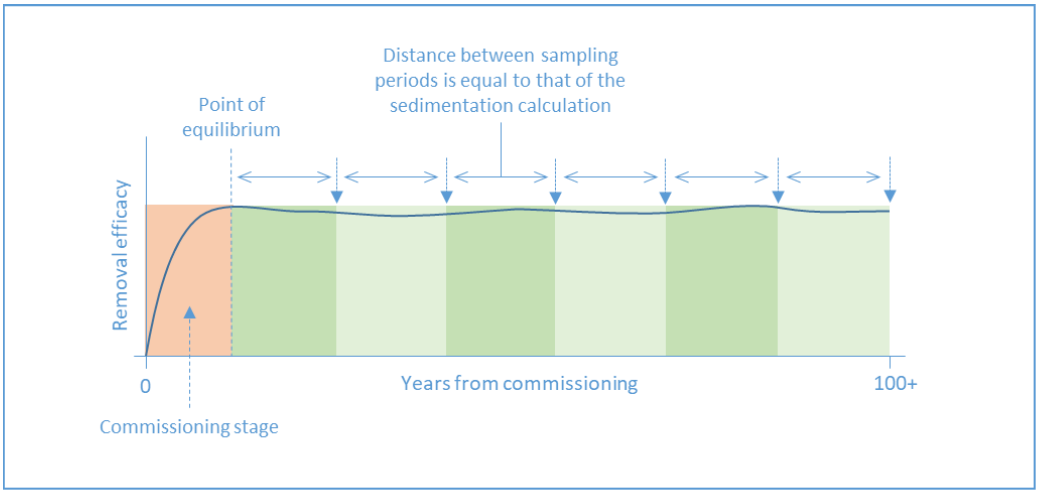


***Diagram__**. A representation of long-term monitoring frequency under for a closed-system treatment wetland to monitor and evaluate performance.*

- Monitoring plan.
    - Monitoring frequency and duration for ***Nutrient Treatment Wetlands***. This will be dependent upon the variability of inlet and outlet concentrations and loads.
    - Sedimentation monitoring will ensure that the wetland continues to function as designed and maintenance is carried out when required.
    - Methodology for capturing influent “events” where this is intermittent.
    - Tracer tests may be used to establish mean detention time and hydraulic efficiency, which may help to interpret inlet and outlet time series data.
    - Visual monitoring will be more frequent (see 6.5)

## 6.3 Adaptive Management

***What is the issue to be addressed?***

- Adaptive management may be required where there are changes to the long-term water quality of the influent to the wetland which were not predicted at the design stage. Poor performance should not be permitted to continue over prolonged periods, figure 6.3, however ***<u>this poor performance is not a result of poor design or evidence that wetlands do not work</u>***.
- Figure 6.2. Long-term monitoring to pick up adaptive management issues

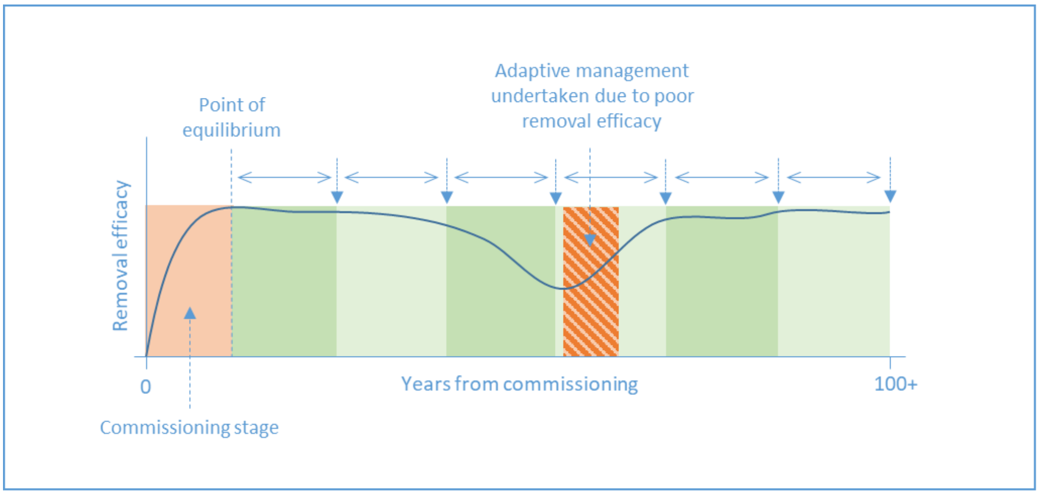


***Diagram__**. A representation of long-term monitoring and the use of adaptive management for a closed-system treatment wetland with a loss of function.*

**Figure 6.2. Long-term monitoring to pick up adaptive management issues**

***Key information required***

- Operation and management plan.
  - Identification of a mitigation plan in the event of underperformance including actions to be taken and parties responsible for undertaking those actions.

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## 6.5 Operation & Maintenance (Intrinsic Risk Management)

***What is the issue to be addressed?***

- Regular visual monitoring of wetland ensures that the wetland continues to function as designed and the lifespan of blue-green infrastructure is maximised (see Section 5).
- Risks arising from blockages, short-circuiting of flow paths, vegetative imbalance and sedimentation may be carried out frequently using a visual assessment and lead to reactive management to rectify the issue at before wetland performance is reduced (see Section 5).
- Anecdotal evidence shows that nature-based solutions are often not managed optimally in the context of development and therefore do not meet intended targets or objectives due to neglect or improper management. In order to mitigate this risk, responsible and accountable individuals or bodies should be identified at the proposal stage to ensure these tasks are assigned and managed correctly.

***Key information required***

- All wetlands: An operation and maintenance plan should be submitted alongside the proposal stating:
  - the frequency of visual checks
  - the entity responsible for carrying out the activities
  - the entity accountable for the wetland function should the plan not be implemented
  - the routine vegetative management around inlets and outlets
  - the actions to be taken should issues arise
  - the removal of sediment on a stated timeframe

## 6.6 Ownership Models (Extrinsic Risk Management)

***What is the issue to be addressed?***

- Although risk management within the wetland system is controlled through the operation and maintenance plan, external risks, such as land ownership, are more complex to manage.
- It is unlikely that the owner of the land at the time of the proposal will own the parcel at the end of the wetlands lifespan.

***Key information required***

- The operational and maintenance plan should include the ownership model relevant to the wetland. There should be some form of guarantee that the treatment benefits from the wetland will not be compromised by a change in ownership. A number of eNGOS use long term covenants to secure environmental gains from blue green infrastructure. These covenants are associated with the land and are passed to the new owner.

## 6.7 Summary Evaluation

For evaluation of the proposed monitoring all six pieces of key information that are identified in 6.1 to 6.6 need to be presented to show that risk has been managed for long-term function of the proposal. If any of the six items of information are missing the appropriate response statement below can be used so that the applicant understands precisely what is required.

| | **Comment** | All information has been provided | All information has been provided | No information has been provided |
|---|---|---|---|---|
| 6.1 | Baseline monitoring | | | |
| 6.2 | **Not required** | - | - | - |
| 6.3 | Additional credits | | | |
| 6.4 | Adaptive management | | | |
| 6.5 | Operation & Maintenance | | | |
| 6.6 | Ownership models | | | |

| | ***Response statements*** |
|---|---|
| If ALL information green or amber where green NA | This provides comprehensive information regarding the monitoring and evaluation process for the ***Treatment Wetland*** and maximises the likelihood that this ***Treatment Wetland*** will be designed appropriately, function as intended and be managed effectively. |
| If SOME information is amber instead of green | The monitoring and evaluation information provided has considered all the mandatory information and is acceptable, however more information may be required dependent on the situation. |
| If SOME red | The application is missing mandatory information on 6.# and 6.#. Please provide this information so that the implementation process assessment can be evaluated. |

# Appendix 1 Glossary of Terms

In order to follow this framework, it is essential to understand the following list of key wetland terms.

| Term | Description |
|---|---|
| Wetland | "*Wetlands are land areas that are wet during part of all of the year because of their location in the landscape*" [1] They are usually characterised by the presence of water, either at the surface or in the root zone; possess unique soils different form adjacent 'uplands'; and support vegetation adapted to wet conditions.[2] |
| Constructed Wetland/ Treatment Wetland/Wetland treatment system | A constructed or treatment wetland is an "*engineered systems designed to optimise processes found in natural environments and are therefore considered environmentally friendly and sustainable options for water treatment*" [3]<br>Wastewater is treated through a complex range of processes which occur within the wetland which include sedimentation, uptake of nutrients by plants and reduction of pathogens through exposure to UV. Constructed Wetlands range from simple vegetated pond-based systems up to complex, multi-stage systems treating concentrated point-source effluent. |
| Free water surface (FWS) wetlands | "*Resemble natural wetlands in appearance.*<br>• *Require large surface area, are generally lightly loaded.*<br>• *Various plant genus can be used…*<br>• *…Are mainly used for tertiary treatment.*" [3] |
| Horizonal subsurface flow (HSSF) | "*Wastewater flows horizontally through a sand or gravel based filter whereby the water level is kept below the surface.*<br>• *Due to the water-saturated condition mainly anaerobic degradation processes occur.*<br>• *Effective primary treatment is required to remove*<br>• *particulate matter to prevent clogging of the filter.*<br>• *Emergent plants (macrophytes) are used.*<br>• *Are used for secondary or tertiary treatment*". [3] |
| Vertical flow (VF) | "*Wastewater is intermittently loaded on the surface of the filter and percolates vertically through the filter.*<br>• *Between two loadings air re-enters the pores and aerates the filter so that mainly aerobic degradation processes occur.*<br>• *Effective primary treatment is required to remove particulate matter to prevent clogging of the filter.*<br>• *Emergent macrophytes are used*". [3] |
| Reedbed | A reedbed (in the context of water treatment) is one of many types of constructed wetland. It is a type of simple free water surface wetland in which the plant species composition is dominated by Common reed *Phragmites australis*. |
| Integrated Constructed Wetland | An Integrated Constructed Wetland (ICW) is another type of free water surface wetland characterised by large biodiverse surface flow wetlands. They are typically found in rural areas and are unlined. |
| Influent | (Waste) water entering a system (such as a wetland) |

[1] Kadlec, R. H., & Wallace, S. (2008). Treatment wetlands. CRC press.
[2] Mitsch, W. J., & Gosselink, J. G. (2015). *Wetlands*. John Wiley & Sons.
[3] Dotro, G., Langergraber, G., Molle, P., Nivala, J., Puigagut, J., Stein, O., & Von Sperling, M. (2017). Treatment wetlands (p. 172). IWA publishing.

| | |
|---|---|
| Effluent | (Waste) water leaving a discharge point (such as a sewage treatment works) and entering a (wetland) system |
| Concentration | The mass of a parameter in a defined volume of water (for example, milligrams of total phosphorus per litre (mgTP/l or $mgTPl^{-1}$) or PPM) |
| Load | The amount (mass) of a parameter that is discharged into a water body over a set period of time (for example, kilograms of total nitrogen per year (kgTN/yr or $kgTNyr^{-1}$)) |
| HLR | Hydraulic loading rate - rate at which water is discharged to a wetland treatment system, expressed in volume per unit area per unit time or depth of water per unit area per unit |
| HRT | Hydraulic Retention Time – the average time taken for water to pass through a wetland. The HRT is calculated by dividing the volume by the flow (usually in days) |

Additional terms used in the framework

| | |
|---|---|
| C* | Background concentration of a parameter found in wetlands below which further reduction in concentration is not possible |
| g | Gram |
| k | Reaction rate constant used in design equations |
| Kg | Kilogram |
| ha | Hectare |
| L or L | Litre |
| m | Metre |
| mg | Milligram |
| N | Chemical symbol for nitrogen |
| P | Chemical symbol for phosphorus |
| pe | Population Equivalent – the average amount of water, or another component, produced by one person during one day |
| PPM | Parts per million |
| SS | Suspended solids – usually defined as the concentration of particulate material in a volume of water |
| TN | Total nitrogen |
| TP | Total phosphorus. |
| yr | Year |
| Karstic | Limestone or similar fractured rock geology. Groundwater pollution can travel rapidly through these systems and pollute drinking water abstractions. |

# Appendix 2 Literature review

## Introduction

This literature review provides an introduction to the pollutants nitrogen and phosphorus and the way they are transformed or transferred through biological, physical and chemical processes within ***Treatment Wetlands***.

The literature review also considers the current Stodmarsh Guidance developed by Natural England (NE) to assess the impact of new development within the catchments of sensitive areas ('designated sites', within the context of the Habitats Regs) whose aquatic levels of phosphorus and nitrogen have become 'unfavourable' and draws conclusions regarding the appropriateness for informing ***Treatment Wetland*** design.

A section then examines published design guidance to discuss current industry approaches to ***Treatment Wetland*** design before finally considering questions raised by NE staff as part of this project.

## Nitrogen and phosphorus

Nitrogen and phosphorus are essential nutrients for plants and animals within the aquatic food web. However, human activities and the built environment can result in excess nutrient pollution of waterbodies whether as diffuse pollution, such as surface runoff from agriculture, urban areas or roads, or as point-source pollution from a specific outlet, such as from industry or a wastewater treatment plant. Pollution leads to the enrichment of waters with nutrients, particularly phosphorus and nitrogen, causing an accelerated growth of algae (and higher forms of plant life), a deterioration in water quality (Carpenter *et al.* 1998; Crockford 2015) and can prove toxic to aquatic invertebrate and vertebrate species (Kadlec & Wallace 2009).

### Nitrogen

Nitrogen is found in different forms within waterbodies and polluted water. These include inorganic and organic nitrogen in dissolved or particulate forms. Inorganic nitrogen forms include ammonia ($NH_4^+$), nitrite ($NO_2^-$), nitrate ($NO_3^-$), nitrous oxide ($N_2O$) and dissolved elemental nitrogen or dinitrogen gas ($N_2$) whilst organic nitrogen consists of amino acids, urea and uric acid, and purines and pyrimidines (Kadlec & Wallace 2009).

As nitrogen is present in various forms there are different ways of analysing and reporting it, but the list below includes the common parameters or derived concentrations that can be computed from water quality analysis.

- Ammoniacal Nitrogen = The sum of un-ionized (free) Ammonia (NH3) and ionized Ammonium (NH4+) expressed as NH3-N;
- Nitrite-Nitrogen = Oxidised Nitrite as Nitrogen (NO2--N);
- Nitrate-Nitrogen = Oxidised Nitrate as Nitrogen (NO3--N);
- Inorganic Nitrogen = NH3 + NH4+ + NO2- + NO3-;
- Organic Nitrogen = Urea, uric acid, amino acids, purines, pyrimidines (TKN-Ammonia N);
- Total Oxidised Nitrogen (TON) = NO2- + NO3-;
- Total Kjeldhal Nitrogen (TKN) = Organic N + Ammonia N;
- Total Nitrogen (TN) = TKN+TON

### Nitrogen cycling

There are many different physical, chemical and biological processes that occur within wetlands that transfer and transform nitrogen.

An understanding of these key processes enables designers of treatment wetlands to develop habitat conditions suitable for nitrogen transfer and transformation to reduce nitrogen load in the water environment. The processes controlling retention and removal of nitrogen within a constructed wetland include ammonia volatilization, nitrification, denitrification, nitrogen fixation, plant and microbial uptake, mineralization (ammonification), nitrate reduction to ammonium (nitrate-ammonification), anaerobic ammonia oxidation (ANAMMOX), fragmentation, sorption, desorption, burial, and leaching (Vymazal, 2007). However, ammonification and subsequent nitrification and denitrification, plant uptake and export through biomass harvesting are the key mechanisms for nitrogen removal from water within a treatment wetland (Dotro et al. 2017).

The chemical transformations by two of these key processes, which are often utilised to reduce the nitrogen load within polluted water by conventional wastewater treatment works, are:

- Nitrification (conversion of NH3-N => NO2-N => NO3-N); and
- Denitrification (conversion of NO3-N => N2).

Nitrification requires an aerobic environment, alkalinity in the form CaCO3 and an optimum pH of 7.2-9 (Kadlec & Wallace, 2009). Denitrification is an anaerobic process that requires a carbon source and is carried out by facultative heterotrophs.

### Phosphorus

Phosphorus in waterbodies can be found in inorganic and organic forms, and in particulate and dissolved forms (Johannesson 2011) and is usually present in natural waters as phosphates. The following list (taken from Kadlec & Wallace 2009) provides the different categories of phosphorus compounds, related to treatment wetlands, that are defined by methods of analysis:

**Dissolved forms (filtered (0.45 µm) samples)**:

- Orthophosphate (PO4–P)
- Condensed phosphates. These consist primarily of pyro-phosphate, meta-phosphate, and poly-phosphates.
- Soluble reactive phosphorus (SRP). PO4–P, together with some condensed phosphates.
- Total dissolved phosphorus (TDP). Phosphorus that is convertible to PO4–P upon oxidative digestion. Dissolved organic phosphorus (DOP). Phosphorus, in forms other than SRP, that is convertible to PO4–P upon oxidative digestion (= TDP–SRP).

**Dissolved plus associated with suspended solids.** The procedures above performed on unfiltered samples yield, by analogy:

- Total reactive phosphorus (TRP)
- Total acid hyrolyzable phosphorus (TAHP)
- Total phosphorus (TP)
- Total organic phosphorus (TOP) (= TP–TAHP)
- Particulate phosphorus (PP) (= TP–TDP)

**Sorbed to the surface of soil particles:**

- Sorbed phosphorus is removed using extractants such as water, or solutions of KCl or bicarbonate.

**Contained in the structure of biomass:**

- Total phosphorus may be found by analysing for PO4–P in digests of biomass samples. Digestion may involve dry or wet ashing, followed by re-dissolution.

**Contained in the structure of soil particles:**

- Structural, internal forms of phosphorus in the solid are removed (solubilized) using harsh extracts of wet soil samples. Typical extractants include:
    - Sodium hydroxide (0.1 M). The SRP in the extract is representative of iron and aluminium bound phosphorus. The balance of the TP in the extract (TP–SRP) is representative of organic phosphorus associated with humic and fulvic acids.
    - Hydrochloric acid (0.5 M). The SRP in the extract is representative of calcium bound phosphorus.
- Total soil phosphorus may be found by analysing for PO4–P in digests of soil samples. Digestion may involve dry or wet ashing, followed by re-dissolution.

### Phosphorous cycling

There are many different phosphorus storages and transfers within the wetland environment (Kadlec & Wallace, 2009). Orthophosphate and particulate phosphorus can enter the wetland water column through rainfall and dryfall (atmospheric deposition), then orthophosphate can become chemically precipitated in the root zone whilst particulate phosphorous undergoes sedimentation into the leaf litter and sediments. Chemically bound phosphorus can then undergo solubilization to become soil porewater dissolved phosphorus. Dissolved phosphorus, within the soil porewater, can then be subject to sorption, diffusion, mass transfer or uptake by plants. Orthophosphate can also be taken up by plants and microbiota. Dissolved inorganic phosphorus is considered bioavailable, whereas organic and particulate phosphorus forms generally must undergo transformations to inorganic forms to be considered bioavailable (Reddy et al. 1999). Decomposition of plants and microbiota can result in structurally bound phosphorus within the sediment and transfer to porewater dissolved phosphorus. Finally, volatilization can result in chemical transformation to phosphine (gaseous form of phosphorus) and combustion can result in orthophosphate release to the atmosphere.

Important phosphorus processing mechanisms that occur within ***Treatment Wetlands*** include chemical precipitation, sedimentation, sorption and plant and microbial uptake (Dotro 2017). Of these, sedimentation of particulate phosphorus is a key process designers use within ***Treatment Wetlands***. This occurs as the water velocity drops when flowing water enters a ***Treatment Wetland*** and particles can settle on the bottom and become stored in a non-bioavailable form in the sediment (Johannesson 2011). Dissolved phosphorus can be retained within a ***Treatment Wetland*** by being adsorbed onto particles, form chemical precipitates with aluminium and iron metal cations and through uptake by plants and microbes (Reddy et al. 1999). It should be noted, that unlike nitrogen transformations within a ***Treatment Wetland***, all the processes, related to phosphorus cycling, are reversible. For example, phosphorus can re-enter the water column when sediment stored particles are resuspended during scouring by high flows or released during the breakdown of dead organic matter. Treatment wetland designers require a complete understanding of the balance between sedimentation and resuspension, adsorption and desorption, and biological uptake and decomposition to ensure the ***Treatment Wetland*** is a sink rather than a source of phosphorus (Johannesson 2011).

## Review of Stodmarsh Guidance –& Cited Literature

The Stodmarsh Guidance was developed by NE as a means of assessing the impact of new development within the catchments of sensitive areas (‘designated sites’, within the context of the

Habitats Regs) whose aquatic levels of phosphorus and nitrogen have become 'unfavourable'. The guidance is predominantly focussed on the methodology for assessing the 'nutrient budget' for new developments, although the subject of mitigation is also covered with an overview of what measures may be taken to 'offset' the impact of new development. Wetlands are identified as a means of nutrient mitigation, and the findings of NE's own research on the subject is summarised in Appendix 7 of the Stodmarsh guidance.

NE cite a number of publications throughout Appendix 7, but it is the data taken from the Land et al. (2016) study (presented in section A7.3) which has subsequently been used by a number of environmental consultants as a basis for designing new wetlands.

The Land et al. (2016) study aimed to quantify observed removal rates of nutrients in created or restored wetlands, specifically to answer the question '*how effective are created or restored freshwater wetlands for nitrogen removal and phosphorus retention?*'. The study involved the search for published literature both from literature databases and also the general internet. The search was conducted in March 2014. Only literature relating to wetlands treating secondary or tertiary treated domestic wastewater, urban stormwater, stream / river water, freshwater aquaculture effluents and runoff from agricultural fields were considered. The study evaluated wetland performance in terms of TN and TP removal rates (g/m$^2$/year) and in treatment efficiency (percentage of incoming TN and TP load removed). Performance was compared between groups of wetlands according to climate, type of wetland, application and flow regime (from continuous to precipitation driven). The study also considered the effect of inlet concentration and hydraulic loading rate (HLR) on removal rates.

The results of Land et al. (2016) showed median removal rates of TN and TP of 93 and 1.2 g m$^{-2}$ y$^{-1}$, respectively. Removal efficiency for TN was significantly correlated with HLR and temperature (T), and the median was 37% with a 95% confidence interval of 29-44%. Removal efficiency for TP was significantly correlated with inlet TP concentration, HLR, T and area (A). Median TP removal efficiency was 46% with a 95% confidence interval of 37-55%. The study concluded that, on average, created and restored wetlands significantly reduce the transport of TN and TP in treated wastewater and urban and agricultural runoff, and may therefore be effective in efforts to counteract eutrophication. However, there was also a cautionary note that restored wetlands on former farmland were significantly less efficient than other wetlands at TP removal.

The results of Land et al. (2016), as reproduced in section A7.3, are derived from such a wide range of applications that they **should not** be used for the purposes of design. The study examined different types of wetlands – created and restored, as well as different treatment types (free water surface and horizontal sub-surface flow). The principle treatment mechanisms are inherently different between such types of wetlands and therefore it is not appropriate to consider averages taken from the study to predict the performance of new wetlands with any degree of confidence.

It should also be noted that Land et al. (2016) reported median wetland age at the start of study periods was 1 year for the included wetlands, whereas the median age at the end of the studies was 3 years. The systematic review may therefore be biased towards short-term nutrient removal rates.

Land et al. (2016) reported that TP removal rate was negatively correlated with area, especially at areas < 2 x 10$^4$ m$^2$ (2 ha). This essentially means that as the area of a wetland increases, the amount of TP removed per unit area decreases. However, in reference to this part of the report, NE have incorrectly concluded that *'inconsistency of TP reduction was particularly acute at wetlands below 2 ha in size, with wetlands below this size more likely to be net exporters of TP especially if they were created on former extensive farmed agricultural land'*. This conclusion is not reflected in Land et al. (2016). Whilst the study does indeed report that wetlands created or restored on former drained cropland have less efficient TP removal, there is no correlation with size given for wetlands in this category.

NE also refer to Treatment Wetlands, 2nd Edition, (Kadlec & Wallace, 2009) in Appendix 7 of the Stodmarsh Guidance. This publication is widely accepted as a comprehensive aresource for the design, construction and operation of wetland treatment systems. The original 1st edition was published in 1995, when there was limited long term performance data available for wetlands (about 90% of the data used in the 2nd edition was not available at the time of the 1st edition). Performance data from over 950 ***Treatment Wetlands*** around the world have been used to establish the design tools and data analysis provided in the 2nd edition.

Kadlec & Wallace (2009) devoted entire chapters to individual water quality parameters such as biochemical oxygen demand (BOD), as well as contaminants such as suspended solids, nitrogen and phosphorus in terms of their fate within various types of wetlands. The complexities of the nitrogen and phosphorus cycles, and the dependence of the former on the availability of a carbon source, are also explained. The publication provides a comprehensive evolution of wetland design models, from the overly simplified 'zero order' model where contaminant removal is constant per unit area ($g/m^2/yr$), through to the more appropriate 'relaxed tanks in series' model, also known as the 'P-k-C*' model, whereby the wetland is assumed to behave like a treatment plant with a number of completely mixed tanks connected in series. The contaminant is 'weathered' incrementally as it passes through the wetland (*P*TIS = 'apparent' number of tanks in series), with overall concentration reduced at a rate constant 'k', but not becoming less than the inherent background concentration of the contaminant within the wetland (C*). Kadlec & Wallace (2009) stated that the apparent number of tanks in series, *P*TIS, depends upon the hydraulic efficiency of the wetland, which in turn is affected by the length (L) to width (W) aspect ratio and the uniformity of distribution of flow across the wetland. Wetlands with cells arranged to accommodate two or more parallel flow paths, and/or more than one stage (i.e. two or more cells in series), and/or with internal berms to promote flow sinuosity will have higher values of *P*, as the hydraulic efficiency will be greater. Wetlands consisting of one stage (one cell per flow path) with a W:L aspect ratio of at least 1:3 will have a *P* value of 2 to 3. The P-k-C* model also utilises the variable 'q', which is the hydraulic loading rate (calculated by dividing the annual discharge by the wetland area) expressed in m/yr.

The P-k-C* model is used to calculate the average estimated percentage of remaining contaminant (after treatment) for a given area and hydraulic loading rate. The treatment efficiency (in terms of percentage of contaminant removed) is then calculated as 1 - % remaining of contaminant.

The annual rate constant k (m/yr) is specific for each contaminant and is selected according to the type of wetland and the climate. For total nitrogen (TN) there is a significant temperature dependence upon the k value. Kadlec & Wallace (2009) reported a median $k_{20}$ value of 21.5 m/yr and a median temperature coefficient, Θ, of 1.056 for a range of FWS wetlands in various climates for entire periods of record. The rate constant for a given temperature, T, is calculated as follows:

$$k_T = k_{20}\ \Theta^{T-20}$$

For total phosphorus (TP) reduction, Kadlec & Wallace (2009) reported that adjustment of the rate constant using a temperature coefficient is not a good model. Studies of Free Water Surface (FWS) wetlands in cold climates gave a median Θ value of 0.986, meaning that the rate constant decreased with increasing temperature (Kadlec & Wallace 2009). It is therefore more appropriate to look at actual rate constants from existing FWS wetlands. Kadlec & Wallace (2009) reported that the median rate constant for 282 studied wetlands was 10.0 m/yr.

Regarding background concentrations, Kadlec & Wallace (2009) reported the following ranges for FWS wetlands:

$C^*_{TN}$ = 0.5 – 2.5 mg/l For all types of ***Treatment Wetlands***
$C^*_{TP}$ = 0.010 – 0.040 mg/l (10 – 40 µg/l) For rainfall driven systems
$C^*_{TP}$ = 0.060 – 0.090 mg/l (60 – 90 µg/l) For systems where the feed water contains phytoplankton

NE explore stormwater / flood wetlands in appendix A7 of the Stodmarsh Guidance. These are classed as 'event driven' wetlands by Kadlec & Wallace (2009) with a whole chapter dedicated to their application. A discrete event, such as a storm within a given catchment, will generate a discrete volume which will arrive at the wetland relatively instantaneously. It is stated that the physical design of event driven wetlands differs in some respects from continuous flow wetlands, because they are focused on capture rather than efficient flow hydraulics. However, Kadlec & Wallace (2009) also pointed out that it should be apparent that the general concepts of continuous flow wetlands mostly carry over to event driven systems. They established that long-term pollutant removals could be described in terms of the same kinds of first-order, steady-flow design equations currently employed for wastewater ***Treatment Wetlands***.

Kadlec & Wallace (2009) described the typical arrangement of an event driven wetland as consisting of a sediment forebay at the inlet, followed by zones of shallow and deep emergent marsh. The sediment forebay, which is an area of deeper water, provides a repository for suspended solids to prevent them from clogging the subsequent zones. It is stated that the area of the deep inlet pool should take up 10 – 45% of the overall wetland footprint.

Kadlec & Wallace (2009) stated that event driven wetlands may require a supplemental source of water as they are prone to drying out in prolonged inter-event periods. There are two different ways that this can be accomplished: firstly by positioning the bottom of the wetland correctly with regards to the regional water table; secondly by providing a source of irrigation water. There are many varieties of wetland vegetation that can withstand, or even prefer, that hydropattern so the existence of that wetland is not threatened. However, there are small penalties for water quality improvement as a result.

Regarding the long-term prospects for FWS wetlands, Kadlec & Wallace (2009) reported that sedimentation eventually compromises the operation of the system in two ways. Firstly, the sediment forebay or deep inlet zone can become filled and no longer provide the required vertical settling depth. Secondly, solids accrete within the vegetated areas (regardless of the effectiveness of the sediment forebay) due to the generation of solids by the various wetland processes. The rate of accretion may be in the order of 1 or 2 cm/yr. The reported solution is to shut down the wetland and excavate and dispose of the excess material. Such rejuvenation is suggested after an operational timescale of 15 – 18 years.

A study by Qualls & Heyvaert (2017) investigated the accretion of nutrients and sediment within a constructed stormwater ***Treatment Wetland*** in the Lake Tahoe Basin (USA). Using sediment cores, they found that 16 years of sedimentation and organic matter production proved the following results and pollutant removal efficiencies: combined sediment and organic layers accreted 3.2 cm/yr; N accreted at 17.7 $g/m^2/yr$; P accreted at 3.74 $g/m^2/yr$

NE note that other critical aspects of wetland design include the water control structures (inflow and outflow arrangements, water level control), and the consideration of whether a liner is required. Kadlec & Wallace (2009) stated that wetland cells may need to be lined with clay or plastic if regulatory requirements prohibit mixing with groundwater, or if natural infiltration rates will make it difficult to maintain surface water wetland conditions. Available plastic materials include polyvinyl chloride (PVC), low density polyethylene (LDPE), high density polyethylene (HDPE) and polypropylene (PP). Of these, PP is the most puncture resistant but it is also the most expensive. Natural materials, such as clays or bentonite, may also be used. Puddled clay installed at a thickness of 30cm (with compaction) is generally required to provide a permeability of less than $10^{-6}$ – $10^{-7}$ cm/s. This makes clay a relatively costly alternative to the plastic materials.

The decision on whether natural infiltration rates will hinder the operation of a proposed wetland can be made with reference to a 'water budget'. A water budget is used to consider all of the flows in and out of a wetland including precipitation, infiltration and evapotranspiration (Kadlec & Wallace, 2009). It should be noted that, where wetlands are intended to extract and treat a proportion of the flow from a 'main' watercourse, before discharging the treated water back to the same watercourse, the Environment Agency considers infiltration and evapotranspiration losses to be 'consumptive' (even though they are returned to the 'environment'). This is of most concern in summer months when river flows are at their lowest and evapotranspiration rates are at their highest. Higher levels of infiltration, which imply a higher overall level of consumption, may therefore prevent the Environment Agency from granting an abstraction or transfer licences.

Water control structures are also important in the operation and maintenance of ***Treatment Wetlands*** (Kadlec & Wallace, 2009). Inlet devices, such as spreader channels, perforated pipe, large rock zone or castellated weir are required to spread the water out as uniform sheet flow over the width of the wetland cell(s). Outlet devices include collection systems and weirs. Collection of water from the cell(s) can also feature spreader channels and perforated pipes etc to ensure uniform sheet flow is maintained over the entirety of the cell(s). Adjustable weirs are used to set the water level of the upstream cell(s), as well as to drain the cells down to the bed level for maintenance.

The vegetation within a wetland is absolutely critical to performance. Kao, Titus and Zhu (2003) reported on the different N and P retentions by five wetland plant species. They found that, in a riparian wetland receiving large inputs of agricultural runoff, American Bur-reed (*Sparganium americanum*) had the greatest aboveground accumulation of N and P but had the lowest belowground accumulation values. In contrast, Woolgrass (*Scirpus cyperinus*) had the lowest aboveground values for N and P accumulation but had the highest belowground value for P. Whilst the differences in uptake and retention of nutrients between different species of plants is of interest, Kadlec & Wallace (2009) reported that to the extent that vegetation is directly involved in removals, it is the entire biogeochemical cycle that matters, not initial uptake. Emergent wetland plants provide a wide range of treatment mechanisms in FWS wetlands, including: increased sedimentation by reducing wind induced mixing; additional surface area for increased biofilm growth and uptake of soluble pollutants; increased surface area for particle interception; shade from the plant canopy over the water column to reduce algae growth; induced flocculation of smaller colloidal particles into larger, settleable particles. Most of these mechanisms are structural in nature, and therefore performance results often show little difference among species mixes of the same general structure. Consequently, selecting the 'perfect' plant species is not nearly as important as establishing a functional plant canopy. Kadlec & Wallace (2009) also explained that whilst the selection of any one particular species is not important, selecting a diverse range of species as opposed to raising a monoculture should be a goal for ***Treatment Wetlands***. As the new wetland experiences fluctuations such as water level, temperature and herbivory, in various environmental conditions over time, some plants or species will not survive, but others may thrive. A more diverse mix of plant species will be more able to tolerate changes in water quality and flow.

In appendix 7 of the Stodmarsh Guidance, NE highlighted concerns over former land use when siting new wetlands. Kadlec & Wallace (2009) reported that antecedent conditions of the soils used to create wetlands must be assessed to determine 'treatment liability'. If water flow is immediately commenced without any treatment liability being accommodated in the commissioning plan, the wetland can temporarily serve as a source of contaminants.

Biofiltration Filter Media Guidelines (Version 3.01), prepared by the Facility for Advancing Water Biofiltration (FAWB), 2009, are recommended within the CIRIA SuDS Manual for the specification of soils for biofiltration systems. The guidelines specify the following limits:

- Total Nitrogen (TN) Content: <1000 mg/kg
- Orthophosphate ($PO_4^{3-}$) Content : <80 mg/kg. Soils with total phosphorus >100 mg/kg should be tested for potential leaching.

It is reasonable to apply these thresholds when assessing the antecedent conditions of soils to be used for creating wetlands. Soils that have nutrient levels exceeding these thresholds can be assumed to pose a risk of treatment liability.

Kadlec & Wallace (2009) reported a framework for the start-up of new FWS wetlands that mitigates the risk of treatment liability. Three periods in the early life of a ***Treatment Wetland*** were identified:

1. Start-up Phase: Water levels are managed to facilitate the recruitment of vegetation. This may include recirculation of water within the system. Start-up is complete once monitoring demonstrates, over a four week period, a net reduction in the target pollutants for an individual flow-way (allowing flow-through discharges to commence).
2. Stabilisation Phase: Once flow-through discharges begin, water quality monitoring of the target pollutants continues. Performance during this phase is not expected to be optimal as the wetland is not fully developed. Stabilisation is complete once the long-term mitigation targets are achieved.
3. Routine Operations Phase: The wetland is fully established and deemed to be achieving mitigation targets.

NE referred to a number of other publications within appendix 7 of the Stodmarsh Guidance, which provide general studies on the ability of wetlands to reduce nutrient loads of various source waters. The consensus is that wetlands do indeed have a proven ability to reduce levels of TN and TP from point source pollution (such as outflows of sewage treatment works) and diffuse pollution from urban and agricultural runoff.

## Review of wider literature and *Treatment Wetland* guidance

### Treatment wetland nutrient removal

In addition to the Land et al. (2016) study, discussed in section 3.0, there have been several studies undertaken to determine the removal efficiency of ***Treatment Wetlands*** and a summary of these, for nitrogen removal, are presented in the table below. Most studies indicate that the total nitrogen removal efficiency is between 40 to 55% removal. Sayadi et al. (2012) identified higher removal efficiencies from systems that had multi-stages, including surface flow and sub-surface flow beds, and therefore providing both aerobic and anaerobic conditions.

Greater than 90% total nitrogen removal efficiencies have also been reported in well designed, free surface wetlands that are densely planted with emergent vegetation (Doody et al., 2009; Abrahams et al., 2017). Evidence from ***Treatment Wetlands*** in Ireland and Norfolk have indicated very stable total nitrogen and phosphorus removal over long time periods with total nitrogen removal efficiencies greater than 60% (Hickey et al., 2018; van Biervliet et al., 2020). Dotro et al. (2021) reported total phosphorus removal rates of between 55% and 75% and that 80% of the 44 tertiary wetlands reviewed, without upstream phosphorus removal, produced an annual average effluent with total phosphorus ≤ 3 mg/l.

Table 5.1 – TN % removal efficiency achieved by constructed ***Treatment Wetlands*** from published studies

| Study | TN % removal efficiency |
|---|---|
| Haberl et al., 1995 | 40 |
| Vymazal, 2007 | 40-55 |
| Lee et al., 2009 | 40-55 |
| Frazer-Williams, 2010 | 40-51 |
| Vymazal, 2010 | 41-58 |
| Sayadi et al., 2012 | 45-93 |

This review has demonstrated that although effective at removing phosphorus and nitrogen there is variability in treatment removal efficiency rates across published data on ***Treatment Wetlands***. This is due to the variability in the geographical location of the original study, temperature, wetland type and size, wetland morphology, substrate, hydraulic loading or plant types used. As discussed in the previous section, the use of removal efficiency rates for design is not recommended because of the variability in wetland characteristics associated with them. For sizing of a ***Treatment Wetland*** and determining likely performance, it is prudent to pursue specialist design input and use industry accepted design principles rather than using a blanket removal efficiency rate.

## Design guidance

Review of published literature and industry guidance has indicated several different methods employed to design ***Treatment Wetlands***. Whichever method is chosen, it is essential that a design approach should only be used in the design of a ***Treatment Wetland*** if the new design falls within the dataset range from which the approach was derived (Kadlec & Wallace, 2009; Dotro et al., 2017 andKadlec, 2019 in terms of:

- Type of ***Treatment Wetland***
- Inlet and outlet concentrations
- Hydraulic and mass loadings
- Size, aspect ratio and depth
- Climate
- Plant community
- Percentage of open water

The most used design approaches include the following (Dotro et al., 2017):

- Rule-of-thumb and treatment stages
- Regression equations
- Plug-flow *k-C**
- Loading charts
- *P-k-C**

### ***Rule-of-thumb and treatment stage***

Rule-of-thumb design guidance is usually based on the area of ***Treatment Wetland*** required per wastewater type or person equivalent. Person equivalents are provided in national or geographical region-specific guidance. For the United Kingdom, British Water (2013) provides the population equivalent for different pollutant and hydrological loadings for wastewater treatment. Rule-of-thumb guidance is usually developed from datasets and the experience of operating ***Treatment Wetlands*** over long time periods.

In the United Kingdom, Cooper (2016) produced rule-of-thumb guidance which was used for many years to design ***Treatment Wetlands*** and this guidance is still used as a sense check for more complicated design approaches used in recent years. There are numerous other national or regional rule-of-thumb guidance approaches that are used around the world for specific locations and types of ***Treatment Wetlands*** (Brix and Johansen, 2004; DEHLG, 2010; DWA, 2017; ÖNORM, 2009; UN-HABITAT, 2008). However, it should be noted that rule-of-thumb guidance should only be used in the location and with the type of system it was developed for.

Treatment stage approaches rely on an assessment of the surface runoff type, for example whether it is runoff from agricultural fields, from farmyards or from urban areas and then the selection of the correct ***Treatment Wetland***, or train of different treatment features, that are required to treat that type of runoff (McKenzie & McIlwraith, 2015; Woods Ballard et al., 2015). The area requirement is often based on hydrologic loading rather than influent concentration.

The advantages of rule-of-thumb and treatment stage design approaches is that they are very simple to use but they do not account for influent concentrations and there is limited understanding of how treatment process factors such as wetland depth, substrate or plant type impact final treatment.

**Regression equations**

Regression equations, developed from collected datasets from monitored real-world operated ***Treatment Wetlands***, have also been used to design ***Treatment Wetlands***. They normally provide a wetland area / effluent concentration relationship that allows sizing of a similar system. Examples of regression equations for ***Treatment Wetlands*** can be found in Harrington and McInnes (2009) and Rousseau et al. (2004).

Similar to rule-of-thumb approaches they are simple to use but they often take into account influent concentrations. However, they are only appropriate if the design parameters and size of the new wetland falls within the data range of the original dataset (Dotro et al., 2017).

**Plug-flow k-*C****

First-order plug-flow models for wetland performance such as the Kickuth equation and the *k*-*C** approach were widely used for wetland design in the 1990s and early 2000s though have now largely been superseded by the first order P-k-C* model first proposed in Kadlec and Wallis (2009) (discussed below). These approaches account for first-order effects relating to influent concentrations, and the presence of a recalcitrant "background concentration (C*)" that is observed for some contaminants in wetland treatment systems. These models assume perfect wetland hydraulics (plug-flow) no "contaminant weathering" so performance forecasts using these methods will need to be revised to account for these imperfections in the model.

**Mass loading charts**

Wallace and Knight (2006) produced mass loading scatter plots of influent mass loading rates against effluent concentrations using water quality data collected from over 1,500 small-scale ***Treatment Wetlands*** from around the world. Using the scatter plots, the design of small-scale ***Treatment Wetlands*** can be undertaken from influent mass loading rate, desired effluent concentration, and risk tolerance making this manual the first design guidance to consider risk tolerance in wetland design (Dotro et al., 2017). Although risk tolerance is considered, this approach does not have any temperature correction and the morphology of the wetland cell is not considered so is not appropriate for all ***Treatment Wetland*** scenarios.

***P-k-C**** **approach**

As discussed in section 3.0 of this literature review, the P-k-C* approach, first proposed by Kadlec & Wallace (2009) and considered the current state-of-the-art approach for ***Treatment Wetland*** design (Langergraber et al., 2019), is now widely used by wetland treatment designers as one of the most robust design approaches as it considers influent, effluent and background concentrations, hydraulic loading rate, area reaction rate coefficients and temperature correction factors (Dotro et al., 2017). The methodology for free-water surface wetlands (Treatment Marshes) was updated by more recent data in Kadlec (2019).

**Multiple design approaches**

As discussed, it is essential that the design approach adopted, particularly rule-of-thumb, regression equations and mass loading charts, are only used if the characteristics of the proposed ***Treatment Wetland*** design fall within the data ranges of the original datasets used to derive the approaches. It is also good practice to use a number of different methods when designing a ***Treatment Wetland*** so they provide a sense-check against each other. This results in a more overall robust approach to ***Treatment Wetland*** design.

## Questions raised regarding ***Treatment Wetland*** design

**Questions raised by Natural England staff:**

*Q1 Applicants often argue over our application of the 37% efficiency rate from the Land et al. review. Some will send literature papers claiming 90+% TN removal etc. Some standard wording about why we use this precautionary figure would be great.*

As explained in the review of the Land et al. study, it is not appropriate to apply the arbitrary 37% efficiency rate for TN (or 46% for TP) when designing wetlands. Rather than using precautionary efficiency rates, the precautionary approach should be to state that wetland designs must consider the hydraulic loading rate, retention time, inlet concentration and treatment area when assessing the efficiencies. . When using the P-k-C* design model (as described in the review of Kadlec & Wallace, 2009), treatment efficiencies of 90% are highly unlikely. This is because there is a logarithmic relationship between efficiency and treatment area and there are ever diminishing returns when trying to achieve a high efficiency by increasing area.

*Q2 Ongoing question mark relating to future land use change - if agricultural practice de-intensifies (common on land where a landowner might be looking to create wetland) how does this affect nutrient budget, credits sold, appropriate assessment, etc.*

This question is not really related to wetland design, however it should be clear that the performance of any wetland depends on the concentration of the nutrients (TN and TP) of the feed water. If, over time, the concentrations in the feed water are reduced, then the loads mitigated by the wetland (in terms of kg/yr) will also reduce. However, this cannot be predicted so nutrient credits can only be calculated based on current knowledge.

*Q3 What is the appropriate time period, after a wetland is created, for monitoring the TN removal and adjusting the number of credits a wetland owner can sell? 2 years? 5 years? 10 years?*

Newly created wetlands take time to become established and are extremely unlikely to perform as designed from the very beginning. Kadlec & Wallace (2009) reported that the key processes during wetland start-up are: the increase of plant density and areal coverage; formation of a litter layer; and the balancing of the soils used to create the wetland (which either release nutrients if initially loaded, or absorb constituents until they are fully loaded). The same publication states that, in cold climates, a grow-in period of approximately two growing seasons may be anticipated, depending on the planting density and rate of vegetation propagation. Monitoring is critical for gauging wetland performance and optimising maintenance activities. Guidance is provided in section 6.

*Q4 Is modelling hydraulic load in a water course, based on estimated rainfall catchments appropriate? Or should calculations only be based on real flow data?*

Real flow data is always preferable, but this is only usually available for ‘main’ watercourses. Where wetlands are intended to intercept and treat surface water from an ordinary watercourse with a defined catchment (i.e. ‘event-driven’ wetlands), annual runoff estimates can be obtained from the UKSUDS (HR Wallingford) web-based tool which provides greenfield runoff rates based on using the IH124 method (applicable for catchments <25 $km^2$). This technique is usually approved by Lead Local Flood Authorities (LLFAs) and planning authorities. The UKSUDS greenfield runoff estimation tool provides the standard annual average rainfall (SAAR, mm/yr) and standard percentage runoff coefficient (SPR, dimensionless) which can be used to calculate the total annual average runoff from the intercepted catchment area (Area, ha):

(SAAR / 1000) x SPR x (Area x 10,000) = Total annual average runoff ($m^3$/yr)

It’s important to add that, whilst the annual average runoff can be used to determine the daily average flow, the more critical design criteria for an event-driven wetland is the ability to capture and treat the 1 in 1 year rainfall event which accounts for all runoff events up to and including events that occur, on average, about once a year. This is consistent with the design guidance for bioretention systems given in the CIRIA SuDS Manual C753, which provide good nutrient removal performance.

*Q5 What is an appropriate concentration and hydraulic load? It would be good to have some example reference tables to sense-check whether or not applicants are in the correct ballpark. In the AT we've learned these over time, but it would be good to show new AT's what ballpark these figures are in. i.e. 4-10mg/l TN.*

Concentration and hydraulic load, that a ***Treatment Wetland*** can receive and still provide adequate treatment, are dependent on the size and type of wetland proposed. An appropriate sizing and design approach, outlined in section 4.0. should be used. Guidance is provided within the overall framework on how assess whether the wetland has been designed correctly for specific concentrations and hydraulic loads.

*Q6 Where a small scale local treatment is implemented, say a reed-bed to treat runoff from a PTP, should we be applying the usual FSW methodology? Is 37% appropriate?*

As discussed in section 3.0, it is not appropriate to use a removal efficiency rate for ***Treatment Wetland*** design as it does not consider hydraulic loading, wetland size, wetland type, bed substrate etc. which all influence removal efficiency and overall wetland performance. An industry recognised wetland design approach, discussed in section 4.0, should be used. Guidance is provided within the overall framework on how assess whether the wetland has been designed correctly.

*Q7 Is it a strict requirement that every **Treatment Wetland** monitors TN/P concentration in and TN/P concentration out? Is this an enforceable planning condition? Are we comfortable advising mitigation is suitable without monitoring and double checking this?*

Ongoing monitoring is advisable for *all* operational ***Treatment Wetlands***, if the intent is for the wetland to perform as designed 'in perpetuity'. It may be possible for the frequency of monitoring to be relaxed after a number of years if the performance is demonstrated to be stable. It would be unadvisable to approve a mitigation wetland without a plan for monitoring and delegation of an appropriate monitoring 'agent', responsible for the monitoring. As a general note, the 'enforceability' of planning conditions is a matter for the LPAs and the Planning Inspectorate. See section 6 for guidance.

*Q8 Post construction monitoring and reporting to regulator and regulatory provision for adjustment and maintenance to provide design performance*

Continuing from Q7 above, copies of periodic monitoring reports could be made available to the LPA (which presumably can be a planning condition). Such reports should inform of any remedial maintenance activities that may be required, so there is an opportunity for the regulator to follow up and check that such maintenance is undertaken.

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# Appendix 4 Data & tools

## Site and catchment characterisation and risk data

This section of the framework provides guidance on how to access to all the non-water quality data required to support a wetland design and how to get at any data that is not open. A Wetland Web explorer is being produced as part of the detailed design work but a Beta version has been created for this project so that LPA and NE officers and designers can easily access as much data as possible in one place to support the framework. The web map will be included in the Wetland Hub which will include guidance on other sources of data and the detailed design process. For each dataset required for the feasibility assessment the following sections identify what data is available and will be included in the Wetland Data Explorer or guidance provided to facilitate access.

**2.1 Topography:** A significant amount of England already has great coverage of DTM data
The Wetland Web Explorer includes:

- LIDAR Composite 2020 1m DTM (Elevation)
- LIDAR Composite 2020 1m DTM (Hillshade)
- LIDAR Composite 2020 2m DTM (Elevation)
- LIDAR Composite 2020 2m DTM (Hillshade)
- Elevation coverage map

Freely available LiDAR data is available to download and can be used with the tools developed by the CaBA technical team to estimate dig and fill volumes (see next section)

In general LiDAR data is reliable however, recent experience, particularly in upland and heavily wooded areas has shown that the accuracy of satellite data should not be relied upon for Treatment Wetlands without some local validation either using drones or bespoke surveys.

**2.2 Soil**
The Wetland Web Explorer includes:

- Soilscapes (England and Wales). This gives a good indication of the type of soils and therefore their properties. However, soil properties and highly heterogeneous and site surveys including soil permeability testing will be required for detailed design
- Lowland peaty soils (England). This is a constraints layer identifying locations where excavations for wetlands may be discouraged due to the loss of an already degraded habitat.

Additional soils data is available from NSRi. Details of how to access this information will be included in the Wetland Hub.

**2.3 Geology and hydrogeology** a great deal of UK geology data is incorporated into the wetland explorer
The Wetland Explorer includes:

- BGS 50k drift geology
- BGS 50k superficial deposits
- Groundwater bodies layer from the Environment Agency
- BGS 650k hydrogeology

Additional data can be accessed from BGS if more detail is required.

**2.4 Groundwater protection** is a key consideration when deciding whether a wetland needs to be lined or not. The layers below allow designers to understand the sensitivity of the groundwater receptor and whether there are already identified groundwater quality issues.
The Wetland Explorer includes:

- Groundwater WFD status
- Groundwater NVZs
- Groundwater SPZs
- Groundwater SgZs

Additional data can be accessed from

- GW vulnerability maps. CaBA data package (Offline)

**2.5 Hydrology and drainage** data is available but is mainly focused on water quality
The Wetland Explorer includes:

- SW NVZs
- Eutrophic NVZs
- SAGIS Phosphorus source apportionment [various]
- Surface water WFD status

Additional data can be accessed locally and inferred from the DTM data see topography. Data about land drainage is available but unreliable. Local site investigations will be required

**2.6 Flood risk** data is easily accessible and
The Wetland Explorer includes:

- Flood zones
- Risk of flooding from rivers and seas
- Surface water flooding

**2.7 Protected sites and species**
The Wetland Explorer includes:

- National protected sites (SSSIs, SACs and SPAs)
- Local protected sites (LNS )

Additional data can be accessed from:

- Biodiversity explorer published by CaBA
- Natural England layers within Data.Gov

**2.8 Landuse**
The Wetland Explorer includes:

- Agricultural land class
- LCM Landcover map

**2.9 Ownership**

Additional data can be accessed from LandApp which provides an SBI number for each land holding

**2.10 Archaeology and heritage**
The Wetland Explorer includes:

- Historic England Heritage at risk

Additional data can be accessed from the local authority archaeology service.

**2.11 Public right of way**
Data can be accessed from OS website

**2.12 Bird strike**
Data can be accessed from Airport finder website

**2.13 Historic landfill & Con. Land**
The Wetland Explorer includes:

- Historic landfill sites

Additional data can be accessed from:

- Local authorities

**2.14 Unexploded ordinance**
Data can be accessed from [TBC]

**2.15 Services**
Data can be accessed from Linesearch

**2.16 Proximity to housing**
Data can be accessed from OS data

**2.17 Nature recovery & priority habitats**
The Wetland Explorer includes:

- Habitat opportunity network map
- Priority Habitat Inventory

**2.18 Multiple benefits**
The Wetland Explorer includes:

- Wetland vision
- WWNP flood plain reconnection
- WWNP flood storage ponds

**Tools:** There are number of tools listed below along with their accessibility. A full guide will be provided along with the detailed wetland design guide.

- GIS workflow for excavations (useful for design and costing)
  - Working with LiDAR: Estimating pond storage volumes using contours: https://youtu.be/PYb7nUapXbM
  - Working with LiDAR: Estimating pond storage volumes modifying your DTM: https://youtu.be/ceGi360jzI0
- SCALGO Live (Payment required)
  - Online terrain editing software
  - Very useful for feasibility stage of wetland design
- HR Wallingford greenfield runoff (Green)
  - Industry standard way of estimating runoff
  - https://www.uksuds.com/tools/greenfield-runoff-rate-estimation
  - QA'd approach
- Constructed Wetland Association Guidelines
  - Constructed Wetlands to Treat Domestic Septic Tank Effluent: https://www.constructedwetland.co.uk/media/file_uploads/CWA_Design_Guidelines_v10.pdf
- Landis Soils Site reporter (Payment required)
  - Can be used to purchase a full or basic soil report for a site.