WWT Wetlands for life

Constructed Farm Wetlands

Treating agricultural water pollution and enhancing biodiversity

A guide for farmers and farm advisers in England

Produced by the Wildfowl and Wetlands Trust

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Overview

This guidance is aimed at farm advisers, particularly Catchment Sensitive Farming Officers, as well as other Natural England and Environment Agency staff working with farmers. The aim is to provide further information and examples on the use of constructed wetlands and sustainable drainage systems on farms. These wetland features can reduce diffuse water pollution from agriculture as well as improving biodiversity and other benefits. Different types of constructed wetlands and sustainable drainage systems are described, with guidance on their suitability for different farm situations and pollution issues. Advice is given on the design, costs and permits required. This revised version includes new and updated case studies as well as updated information on sources of funding. The 1st edition was published electronically in May 2013

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Contributing authors

Philippa Mansfield has made an invaluable contribution to the writing of this guidance document, particularly providing information on support to farmers from Catchment Sensitive Farming and Countryside Stewardship. **Fabrice Gouriveau** and **Rory Harrington** have written key case studies on practical examples of constructed wetlands in the environmental landscape. They have all provided extremely useful comments and feedback on the document.

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Foreword

Our freshwater environments – rivers, lakes and other wetlands – are in an alarmingly poor condition. In England and Wales, less that 25% are currently considered to be healthy under the European Water Framework Directive (WFD). The reasons for this are many and varied, but right at the top of the list is pollution. In recent years we have made a great deal of progress in tackling some of the major point-sources of pollution but diffuse pollution, and particularly diffuse water pollution from agriculture, remains one of the most significant issues affecting the ecological status of our freshwater environment.

Because of its diffuse nature, the solutions to the problem are often small and local, but the issue itself is of course considerably larger and national, so the challenge lies in making sure these solutions can be scaled-up and implemented right across the country – all the way from Cumbria to Cornwall. This requires a fundamental change in how we perceive our natural environment, and particularly our wetlands, recognising that, in failing to properly and urgently address this issue, bit-by-bit we are destroying the very systems that support our lives and that many of us hold so dear.

The farming community has a huge and positive role to play in this change. As custodians of much of our rural landscape, few people are closer to the land than farmers, and many have already made big changes to the way they operate to help protect and manage it. However sometimes it is easier to make these big changes than the little ones. There are literally thousands of instances where 'just a bit of dirty water' runs off a farmyard and into a ditch or where field runoff is funnelled out of a misplaced gate or down a country road and into the local river. And cumulatively they are having a seriously damaging impact on our waterbodies and the wider environment.

Constructed wetlands and sustainable drainage systems are a perfect example of the solutions needed to tackle this problem. Not only do they deliver simple, effective, sustainable and robust wastewater treatment but they provide a whole host of other benefits including attenuating rainfall from storms and providing excellent wetland habitat. These multiple benefits make them extremely attractive in terms of delivering value in an increasingly competitive and resource-constrained world.

In recognition of this the Wildfowl and Wetlands Trust has produced this guidance document in partnership with Catchment Sensitive Farming, drawing on both organisations considerable expertise and experience, to promote uptake of these solutions at the scale needed to address the problem. It is my hope that this excellent report will help to demystify the use of these solutions for farm advisors, and indeed farmers themselves, and result in much wider use of wetland-based solutions for real on-farm wastewater issues, and of course in doing so, also create vital new homes for wetland wildlife right across the country.

Martin Spray CBE
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Contents

1 Introduction

This guidance gives an introduction to the use of Constructed Wetlands and Sustainable Drainage Systems (SuDS) on farms and signposts to further sources of advice and support. Descriptions and examples of swales, in ditch wetlands, sediment ponds and traps, and constructed wetlands are included. The focus is on how these options can be used to improve water quality and enhance biodiversity with guidance provided on suitability, placement, design, construction and cost. A range of case studies gives further illustration.

The aim of this document is to enable farm advisers, including Catchment Sensitive Farming Officers (CSFOs), Natural England local advisers and Environment Agency Officers, as well as farmers themselves, to understand how and where to use constructed wetlands and SuDS to reduce water pollution and enhance biodiversity. The document covers a range of wetland options from simple, easily created options to treat lightly contaminated water to multi-stage treatment systems which are designed to treat point source high strength agricultural wastewater. Depending on the nature of the wastewater, designs will vary in complexity from those the farmer can easily create to something which requires more technical support.

Figure 1. Farm wetland at WWT Caerlaverock.

This guidance builds on existing guidance provided in The Scottish and Northern Ireland Design Manual (Carty et al., 2008), the Integrated Constructed Wetlands Guidance document for farmyard soiled water and domestic wastewater applications in Ireland (Department of Environment, Heritage and Local Government, 2010) and examples included in the second Mitigating Options for Phosphorus and Sediment project (MOPS 2, Undated).

2 What are Constructed Farm Wetlands and SuDS?

Constructed Farm Wetlands and SuDS (Sustainable Drainage Systems) are man-made systems which function by mimicking the water treatment properties of natural wetlands. 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 Farm Wetlands range from simple vegetated pond-based systems up to complex, multi-stage systems treating concentrated point-source effluent. SuDS are water holding structures that are used in the rural landscape to slow the flow of surface water, soil runoff and drainage from fields or farmyards. SuDS include a range of structures such as swales, seepage barriers, check dams, earth banks and soil bunds.

3 Why use Constructed Farm Wetlands and SuDS?

One of the main advantages of Constructed Farm Wetlands and SuDS over more conventional wastewater treatment options are the additional benefits they can provide. In addition to treating and controlling pathways of agricultural pollutants, they provide some attenuation of flood flow, create wildlife habitats and, if desired, public access opportunities. They are a practical, sustainable, environmentally friendly, aesthetically pleasing option for treating contaminated water in rural areas.

3.1 Reducing water pollution

One of the primary functions of Constructed Farm Wetlands is to treat wastewater. They can be used to tackle the source of pollution, slow, break or re-direct the pathway of a pollutant or to protect a receptor such as a river, ditch or stream (Figure 2). They can be designed to create a variety of water levels and a mix of vegetated areas and open water to maximise water treatment: areas of deep water encourages settlement of solids, open water allows ammonia volatilisation and UV breakdown of pathogens and marsh areas facilitates nitrogen removal. The way in which these different wetland habitats are used and combined is dependent on pollutant type and volume of water.
Section 5 provides more details on the various wetland options.

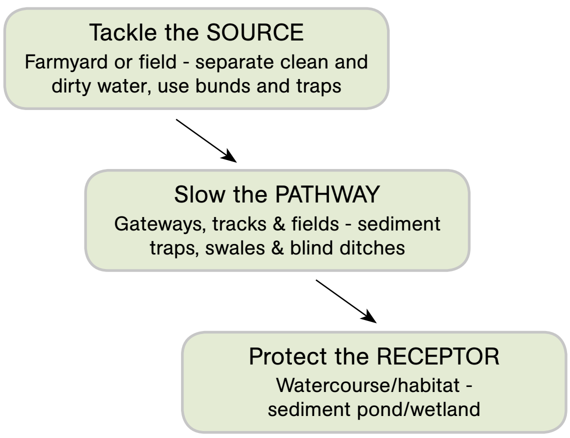


Figure 2. Source, Pathway & Receptor.

Newman *et al.,* (2015) carried out a review into the effectiveness of Constructed Farm Wetlands for treating agricultural wastewater. The review used data from 19 studies to evaluate the impact of these systems on the reduction of Total Nitrogen, ammonium/ammonia, nitrate and nitrite, Total Phosphorus (TP), Soluble Reactive Phosphorus (SRP), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD) and Suspended Sediments (SS). Three Constructed Farm Wetland types were included in the evaluation: engineered, lined constructed wetlands (94 systems), large, unlined pond-based constructed wetlands (90) and wetland buffer zones and other wetlands which didn't fall into either of the two previous categories (3 systems). Overall, the review found that, with the exception of nitrate removal in the open-pond based systems, *"all wetland types are very effective at reducing major nutrients and suspended sediments"* Newman *et al.,* (2015).

3.1.1 Water pollutants treated or captured

Constructed wetlands and SuDS can be used to treat lightly contaminated water from farmyards or as a result of run-off from roads, tracks and fields. Pollutants that can be effectively captured and treated from agricultural sources are:

- Nitrates and ammonia: mainly from fertiliser or manures, extremely soluble and are lost through the soil profile to groundwater or into rivers through drains or subsurface flow.
- Phosphorus: also lost in this way but more commonly binds tightly to soils and is lost through surface run-off, such as from tramlines, compacted fields and stubbles or via field drain flow.
- Sediment: Loss can result from soil erosion and run off from fields under poor livestock or soil management and livestock damage to riverbanks.
- Agrochemicals: including sheep dip and crop protection pesticides lost through drain flow or soil run off, or from overspray and drift. The Environment Agency (EA) advocates treatment of pesticide washings using a biobed or biofilter.
- Microbial pathogens: faecal indicator organisms from manure can be washed into surface waters by rain, or deposition where livestock have direct access to watercourses.

Sources of water that could be treated on the farm using constructed wetlands have been summarised in Carty *et al.* (2008) and include:

- Run-off/washings from livestock handling areas where livestock are held occasionally for less than 24 hours, and which can become heavily contaminated. By scraping these areas and collecting and storing the manure the total level of contamination will be reduced allowing any precipitation driven drainage from these areas to be conveyed to wetland treatment areas.
- Roof drainage from pig and poultry housing (often tainted with ammonia deposition).
- Runoff from lightly contaminated concrete areas as a result of vehicle and occasional livestock movements.
- Machinery washings (unless contaminated with pesticides or veterinary medicines).

- Runoff from baled silage storage areas on farm.
- Run-off from farm tracks carrying sediments and associated pollutants.
- Run-off from fields which cannot be controlled by buffer strips or other measures.

Figure 3. Runoff into farm track.

Measures to reduce sources of pollution should be put in place first before considering the use of constructed wetlands or SuDS. For example, avoidance and alleviation of soil compaction to reduce the risk of field run off or separation of clean water and dirty farmyard run off. In addition, regularly used livestock yards should drain to slurry stores or dirty water systems under current Silage, Slurry and Agricultural Fuel Oil (SSAFO) regulations. In CSF catchments, farmers are offered soil husbandry, water management and infrastructure farm advice visits, which combined with use of the capital grants available through the Countryside Stewardship Scheme, would be a preliminary step to make these improvements in farm practices or infrastructure. A CSF water management plan would help identify if and where a constructed wetland or SuDS may fit in to reduce pollution issues on the farm.

On farms and farmyards there are additional sources of point source pollution that can also be treated through specifically designed wetlands. However these are less likely to be funded through available schemes as it is a legal obligation to prevent pollution from these sources and other treatments may be more appropriate. These include:

- Septic tank discharges
- Dairy parlour waste water.
- Abattoir waste water.

3.2 Multiple benefits

A major advantage of constructed farm wetlands is that they can be designed to provide a range of benefits in addition to water quality improvements. Among other things, they can play a particular role in the ecosystem services below:

Flood control - Wetlands deliver a wide array of hydrological services. Swamps, lakes, and marshes can assist with flood mitigation, promote groundwater recharge, and help regulate river flows, but the nature and value of these services differs across wetland types. The hydrology of the local catchment needs to be accounted for in system design.

Food, fibre and water provision - Wetlands are critically important around the world for their role in food and water provision. Within the farm environment there is the potential to use treated water for crop irrigation and for biofuel production (e.g. using willow coppice systems).

Climate change - Wetlands are critically important for both mitigation (reducing emissions of greenhouse gases to the atmosphere) and adaptation (dealing with the impacts of climate change). They absorb and store carbon in above-ground and below-ground biomass, through photosynthesis and soil formation.

Habitat provision - Wetlands provide valuable habitat for a range of mammals, reptiles, amphibians, fish, birds and invertebrates. There is a great opportunity to adapt system design to improve its attractiveness to local wildlife and play a role in local habitat networks by increasing connectivity.

3.2.1 Focus on habitat provision

Constructed wetlands and SuDS have potential to support a wide range of biodiversity. In the past, wetlands have been created either for the purpose of water quality improvement or for biodiversity conservation but rarely the two objectives together (Hansson *et al.,* 2005). However, this guidance will show that the design of constructed wetlands and SuDS can be easily and cheaply modified in order to maximise the potential benefit for biodiversity, while still providing optimal water treatment. This in turn can provide further benefits to the farmed environment.

Figure 4. Biodiversity in wetland treatment systems.

Box 1. **Case study: treating wastewater and creating wetland habitat**

The Millennium wetland treatment system was commissioned in 1999 and treats all sewage from WWT Slimbridge. It not only remediates effluent, but provides habitat which benefits wildlife and offers amenity and educational value. The reedbeds and the margins around them are cut on a wildlife-friendly regime to maximise biodiversity. The system supports 75 plant species including the Southern Marsh Orchid (*Dactylorhiza praetermissa*) and the Cut-leaved Cranesbill (*Geranium dissectum*), birds such as the Water Rail (*Rallus aquaticus*), mammals such as the Water Vole (*Arvicola amphibius*) and 281 moth species, 9 of which are nationally scarce and 50 species from the UK BAP (Biological Action Plan). The system meets its environmental permit limits of 40mg/l suspended solids and 20mg/l Biochemical Oxygen Demand.

Figure 5. Millennium Wetland Treatment System at WWT Slimbridge.

3.3 Limitations of using wetlands

Wetlands are not always a suitable solution in all locations due to constraints in topography, land availability, cost or pollutant strength. There will be certain circumstances in which more hard engineered solutions may be needed and others where complementary land management solutions should also be considered, such as woodland and buffer strips.

The Scottish and Northern Ireland Design Manual (Carty *et al.*, 2008) provides a useful summary of limitations of the use of constructed farm wetlands which include relatively large land requirements, seasonable variability in pollutant removal and risk to wildlife due to contact with pathogens from farmyards.

4 Opportunities for farm wetlands – an overview

Wetlands and SuDS present a range of options for pollution control from low-cost intervention (e.g. swales) to higher-cost designed, constructed wetlands. Table 1 outlines the main types of system; each has been given a 1-5 star rating (with 1 being the lowest and 5 being the highest) based on their complexity, cost and application for treating low to high strength pollution. Each wetland type is also graded on its potential to provide biological benefits and improvements in water quality. The options can be selected and used together for different situations and types of pollutant. A decision tree has been created to enable a quick assessment of the options available (Figure 6).

4.1 Summary of wetland options

*Table 1. Wetland options. 1 Star represents the simplest, lower cost option for lower strength pollutants up to 5 Star for the most complex, higher cost system to treat high strength pollutants. * These costs are purely indicative and can vary considerably based on a variety of factors including soil type, location, fencing requirements, etc. ** Adapted from Ockenden et al., 2012.*

Wetland type	Star rating (complexity & cost)	Typical use for sources from	Indication of capital cost *	Permit required	Ecological value and water treatment	Case studies (see annex I)
Swale	★☆	Tracks and fields	£10-15/m2	No	Lower ecological value, poorer water quality treatment.	Powhillon Farm
In-ditch field wetland	★★	Fields	£895 in LEAF case study	Consult	Lower ecological value, poorer water quality treatment.	Green Hall Farm India in-ditch wetland
Sediment traps or ponds	★★★	Fields and tracks in conjunction with swales	£5-100/m2 **	Consult	Moderate ecological value, moderate water quality treatment.	Church Farm River Eye silt traps
Constructed wetlands (low to moderate strength effluent)	★★★★	Lightly contaminated yards	£4/m2 - £25/m2	Possibly	Potential for high ecological value, high water quality treatment	Yew Tree Farm Powhillon Farm Old Castles Farm
Constructed wetlands (moderate to high strength point source)	★★★★★	Farmyards and fields	£5/m2 – £100/m2	Yes	Potential for high ecological value, high water quality treatment	Greenmount Campus Produce World Yaxley Sheepdrove Organic Farm Anne Valley ICWs

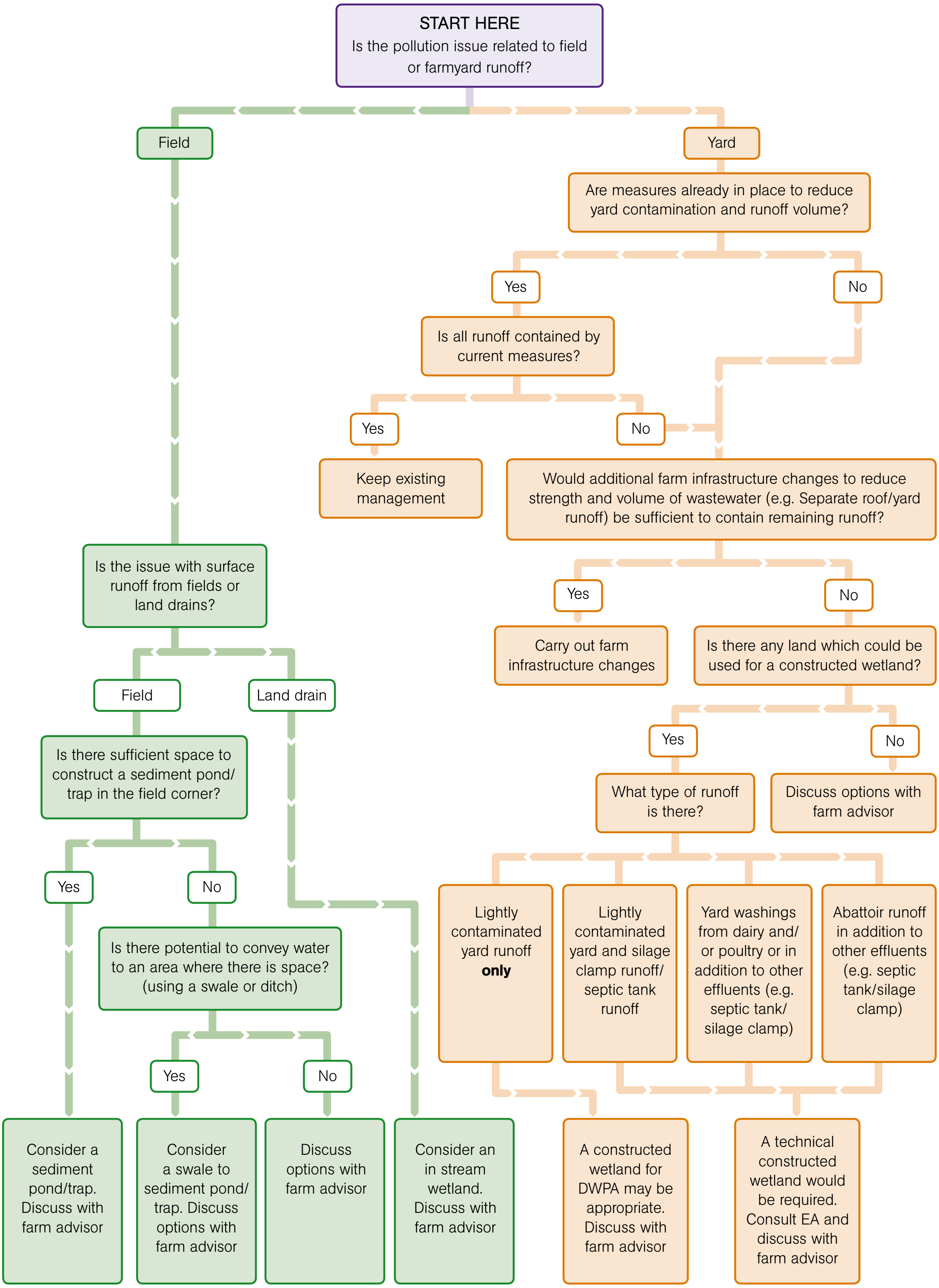


Figure 6. Decision tree to choose the most suitable wetland option.
(Adapted from Carty et al., 2008 Design Manual for Scotland and Northern Ireland).

4.2 General consent issues

Certain activities are likely to require consents, licences or environmental permits from the relevant authorities such as the Environment Agency (EA), as shown in the table below.

Please note that the EA's Flood defence Consenting is proposed to be moving into the Environmental Permitting regime in October 2015. This will affect applications for main river consents to EA but will not affect applications to Internal Drainage Boards and lead local flood authority (Local Authority). Please check for further information on the GOV.UK webpages on Environmental Permitting: https://www.gov.uk/environmental-permit-how-to-apply

Some key considerations to take into account are:

- The source, volume and strength of the effluent.
  - In England, wetlands are currently not an acceptable treatment option for pesticides, silage effluent or slurry.
- Frequency and timing of release.
- Potential impact on receiving watercourse.
- A natural clay or artificial liner will be required in order to ensure there is no discharge to ground. Contact your local EA office to discuss the project from the outset to clarify liner requirements.
- Barriers should not impede the passage of fish such as eels. Guidance can be found on the GOV.UK website: Pollution Prevention Guidelines: Works and maintenance in or near water (PPG5) (SEPA, EA, EHS, 2007) and DEFRA's Codes of Good Agricultural Practice for the Protection of Water, Soil and Air (DEFRA, 2007).

Table 2. Common consents, licences and permits.

Flood Defence Consent – main rivers	▪ A main river is a watercourse that is shown on a main river map and includes any structure or appliance for controlling or regulating the flow of water into, in or out of the channel. ▪ This is administered by the EA if it is a main river. See the GOV.UK webpage on Flood Consents for further information. ▪ Required for working within 10 m (8 m if in Midlands) on, in, over or under a watercourse. ▪ For a consent to be obtained the EA must be assured that the activities will not worsen the flood risk or cause negative impacts on the local environment, wildlife of fisheries.

Flood Defence consents – ordinary watercourses	▪ Ordinary watercourses are defined as rivers and streams which are not classified as main rivers. This will include ditches, drains and sewers (with the exception of public sewers). ▪ To carry out work on an ordinary watercourse the authority responsible for that particular watercourse must be contacted in order to apply for an Ordinary Watercourse Consent. The responsible authority will be either an internal drainage board or lead local flood authority – this is the Local Authority. ▪ Required for works over, under, in or within 10 m of ordinary watercourses (streams and ditches both natural and manmade and culverts etc).
Internal Drainage Board (IDB) Land Drainage Consent	▪ Required for any works that affect watercourses that lie within an IDB district. IDBs need to be consulted on fencing as this can affect their ability to carry out routine maintenance.
Impoundment licence	▪ If impounding a stream or river an impoundment licence will be required. Please see the GOV.UK web pages on Environmental Permitting for further information.
Environmental Permit	▪ Issued by the Environment Agency and required for the discharge of dirty water, to watercourse or to groundwater. Please see the GOV.UK webpages on Environmental Permitting for further information.
EA Waste exemption	▪ Required for import or export of materials. Please see the GOV.UK webpages on Waste Exemption for further information. Spreading of excess spoil from larger wetland creations may not be allowed if in the flood plain – consult flood authority as shown above for Flood Defence Consents. ▪ *"If soil from excavation works is being reused for other works, for example, embankments or soil bunds, this would not be considered a waste provided it is clean and fit for purpose. Material brought onto the farm from elsewhere to build bunds embankments and structures is waste and U1 exemption would be required. Surplus spoil generated by the construction or maintenance of a sediment trap, dredging or widening of existing ditches can be disposed of by spreading it thinly over adjacent land. Any excavated material may be classified as a 'waste' and its use may need a waste exemption (U10) from the Environment Agency."* (TIN099 Natural England, 2011b).
Vegetation and wildlife management	▪ Ensure all permissions are obtained prior to works beginning. These may include consents from the Environment Agency, local authorities or other bodies. Consult Natural England if the site is designated as a Site of Special Scientific Interest, Natura 2000, Ramsar site and if the construction could affect a protected area or species. See the GOV.UK webpages on 'Protected sites and species' for further information.

5 Farm wetland options

The following sections provide guidance on the different types of constructed wetland and Sustainable Drainage Systems (SuDS) and describe their main application, design criteria, cost, consents, management and maintenance. A range of case studies can be found in Annex I which demonstrate the wetland options in practice and highlight good examples. A star classification system has been used as a guide to the different options where a 1 Star system is easy to construct and low cost, while a 5 Star system requires specialist input to design and construct and tend to be higher cost solutions. Different options are appropriate in different situations, depending on the pollution type and land available. The wetland options can be combined to be more effective or to create a farm wetland system.

5.1 **Swales** (1-2 Star systems)

5.1.1 Description

A swale is a broad, shallow vegetation-lined channel or blind ditch which is designed to convey water away from source. Swales can be designed to provide infiltration along the route, reducing volumes of water. They are planted systems so the vegetation plays a role in reducing flow velocity and also in the uptake of nutrients. They are normally planted with grass species but with alterations to the design they can have deeper areas which remain wet and are planted with more wetland vegetation. Wet swales are constructed on poorly draining soil with no under-drains and have the potential to retain water for most of the year, which greatly increases their biodiversity potential. Swales may be used on their own for very lightly contaminated runoff or can be used as part of an integrated system e.g. alongside a track or discharging into a sediment pond. Figure 7 shows the wet swale at WWT Welney which is used as part of a treatment system for wastewater from the centre building. It is planted with a range of wetland plant species to be visually attractive and provide wetland habitat.

Figure 7. WWT Welney - wet conveyance swale.

Table 3. Advantages and disadvantages of swales

Advantages	Disadvantages
Low capital cost – cheaper than piped systems.	Larger land requirement than traditional pipes (minimum 0.6m wide).
Can be constructed by the farmer/landowner.	Unsuitable for high strength effluents (e.g. dairy runoff, septic tank runoff) unless the swale is fully lined and the effluent is being conveyed to additional treatment stages.
Easily and cheaply managed and maintained as blockages can be easily identified and removed.	Not suitable for steep gradients (Greater than 2°).
Ecological value can be enhanced if permanently wet areas are included.	Require regular maintenance such as mowing and de-silting.

5.1.2 Application

Swales can be used to convey sediment rich water from farmyards and fields to constructed wetlands or sediment traps and can also be used to convey rainwater away from hard standing areas to reduce water volumes. Rainwater can then be fed into nearby watercourses or used to create freshwater ponds which are an important resource for wildlife. It is likely that swales will need periodic management to prevent clogging. If lined or constructed on clay rich soil, swales can be effective in removing nitrates. However, in areas with sandy soil, contaminated water may pose a pollution risk if swales are designed as infiltration channels. Swales are best located on gentle slopes, since on steep areas the water velocity is likely to cause erosion. On sandy/gravelly soils it may be difficult to establish a vegetative layer.

5.1.3 Design

Swale design is based on the size of the area being drained and on local rainfall. A worked example of this can be found in the Guidance for Treating Lightly Contaminated Surface Run-off from Pig and Poultry Units (Christian/NIEA, 2006) which can be downloaded by from the Northern Ireland Department of the Environment website: http://www.doeni.gov.uk/. Further design principles can be seen in Table 4.

Table 4. Swale design principles.

Swale Design	▪ A width ranging between 0.6-3.0 m. ▪ The wider the swale the more opportunities there are for edge habitat for wildlife. Additional edge benefit will be gained by maximising the length of the swale using curved sections, rather than straight lines. ▪ Bunds and shallow pools will slow and hold back water, with standing water benefitting species such as water beetles, dragonflies and snails. ▪ Check dams are used to retain water and attenuate flows within the wet swale. They slow water flows and increase sedimentation and infiltration. They can be simple wood structures such as willow hurdles or more substantial, for example made of stone. ▪ Research has indicated that permeable barriers function more effectively, allowing temporary ponding of water behind them but also slow infiltration. At low flows, water ponds behind the structure slowing flow rates. At high flows, water flows through and over the structure, so flows are not as impeded, avoiding excessive backing up and flooding (Environment Agency 2012).
Planting	▪ Plant with native plants taking care not to seriously impede storm water passage. The plants will provide foraging and breeding habitat for a wide range of species. ▪ If a native wildflower mix is used on the drier edges of swales it will provide seeds for birds and mammals and a nectar source for insects.

5.1.4 Cost

Costs are generally low as farmers can create these systems on their own using local planting material and natural regeneration. Capital costs will vary depending on how much excavated material there is and if there is a convenient disposal method. However, CIRIA (2007) estimates capital costs of £10-15/m^2 of swale area and annual operation and maintenance costs of £0.10/m^2 of swale area. Capital grants for swales and check dams are available under Countryside Stewardship.

5.1.5 Consents

Consents are usually not required as long as the swale is not in, on, under, over, near or discharging into a watercourse, or impacting on groundwater.

5.1.6 Operation and maintenance

Table 5. Swale management tasks.

Do	Don't
Cut the swale at least once a year to avoid blockages by decaying organic matter.	Mow wet swales - it is best to mow in dry periods in late summer.
Diversify grassland structure by cutting selected areas to different heights.	Allow access to swale by livestock.
Periodically clean bunded swales between September and March if necessary.	
Periodically reinstate shallow pools in the same location or elsewhere along the channel.	

5.1.7 Further guidance

TIN 099 Protecting water from agricultural run-off - water retention measures (Natural England, 2011b).

The SuDS Manual (Woods-Ballard *et al*,. (CIRIA, 2007).

Guidance on the construction of swales for poultry farms (SAC Environment 2003).

Guidance for Treating Lightly Contaminated Surface Run-off from Pig and Poultry Units (Christian/NIEA, 2006).

Rural SuDS Guidance Document (Environment Agency, 2012).

5.2 In-ditch wetlands (2 Star systems)

5.2.1 Description

In-ditch wetlands are generally formed within existing ditches and function by holding back water flows based on the principle of 'Slowing the Flow'. To create an in–ditch wetland the ditch is widened and the banks are re-graded to create a series of shelves at different water levels. The water is detained within the ditch using barriers which can be solid or permeable. Figure 8 shows an example of how these can look.

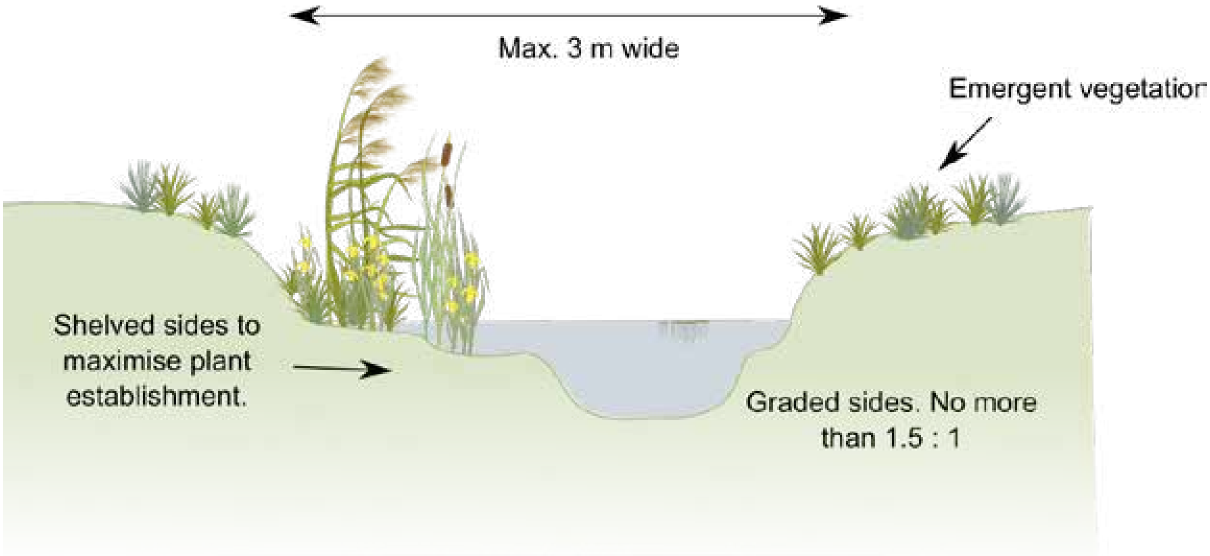


Figure 8. Cross section through an in-ditch wetland.

Table 6. In-ditch wetlands advantages and disadvantages.

Advantages	Disadvantages
Low capital cost.	Not suitable for high strength effluents – e.g. dairy runoff, septic tank runoff.
Easily implanted, can be constructed by the farmer/ landowner.	Not as effective as a wetland treatment system for breaking down pollutants.
Easily and cheaply managed and maintained.	
Small land requirement as existing ditch is simply widened.	
Can be constructed quickly.	
Opportunity to create additional ecological value.	

5.2.2 Application

- In-ditch wetlands are suitable for the interception, storage and treatment of runoff from fields. They are not suitable for farmyard or point source effluent.
- Normally, new in-ditch wetlands should be created in ditches with shallow gradients and which do not have continuous flow year round. They should not be constructed in ditches which drain large areas, receive heavy storm flows or are located in the floodplain.
- They can be created within a network of seasonal ditches to improve general water quality.

- In-ditch wetlands have great potential to mitigate delivery of phosphate via drains to watercourses.
- In-ditch wetlands can also be used to capture flow from field drains which can carry sediments, pesticides and fertilisers.
- If barriers are used within in-ditch wetlands they will encourage deposition of sediments and increase water detention (See Figure 9). This could contribute to reducing the peak flow in times of high rainfall especially if the approach was scaled up and applied to a large number of field ditches within the catchment.
- The increased wetland area allows for the establishment of wetland plants which contribute to the slowing of water and also play a role in the uptake of nutrients and settlement of sediments. The increased area of wetland habitat can attract a wider range of wetland species such as water vole (*Arvicola amphibius*) and so form valuable wildlife corridors.

Figure 9. In-ditch barrier.

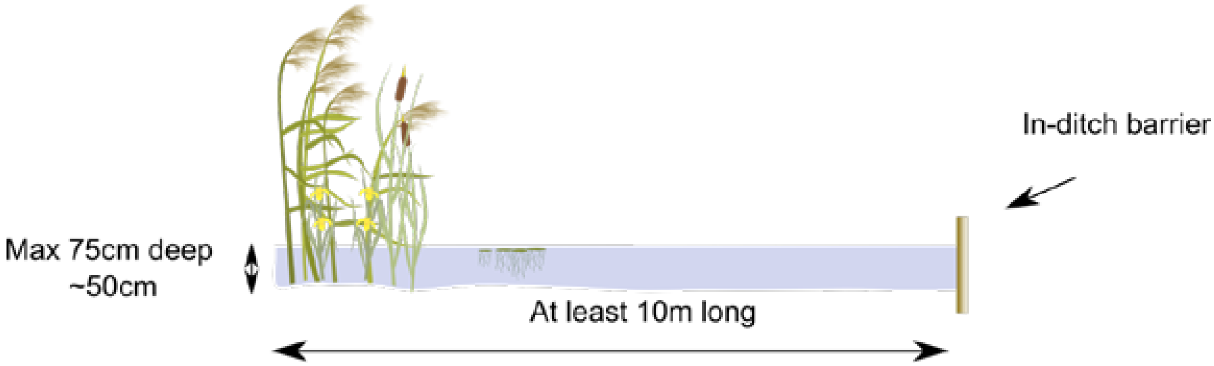


Figure 10. In-ditch wetland barrier.

5.2.3 Design

When considering the creation of in-ditch wetlands, specialist advice should be sought as they will require consents (See section 4.2).

Table 7. In-ditch wetland design principles.

In-ditch wetland design	▪ Modifications of the existing ditch are normally necessary to create suitable topography for wetland creation. Re-profiling of the banks of existing ditches (inserting shelves, etc) will make them more suitable for wetland plant establishment and more accessible to wildlife. ▪ The cross-section of the ditch should be varied to provide wide shelves for the development of emergent plants. ▪ The depth of water across the majority of the ditch should be around 50 cm deep and no more than 75 cm deep. ▪ Ditches should also be widened to enable water flow to slow and allow sediments to settle out. ▪ Barriers can be added to slow the flow of water and allow sediments to settle out. ▪ Barriers can be either solid structures such as earth bunds with a drainage pipe, or simple wooden barriers to slow the flow of water and allow it to seep out slowly, for example willow hurdles have been used. (See Figure 9). Woody debris dams can also be used. ▪ The style of water control structure will need to be selected for each site, but in most cases simple soil bunds with pipes to control water flows should be sufficient. Water control structures need to be carefully designed so that storm flows can be accommodated. ▪ Ensure that the in-ditch water-control structure is not located too close to a field drainage outlet to ensure that water is conducted away. ▪ Work should be carried out during a dry period to avoid any unnecessary soil damage. In some cases, it may be necessary to pump out or divert the water flow to allow 'dry' working at the site. ▪ If water has high sediment loads a trap should be incorporated as part of the design to allow for easy periodic maintenance. ▪ Discharge can be highly erosive and the most appropriate protection should be used e.g. large stones, sleepers or concrete rocks.
Planting	▪ The in-ditch wetlands should be left to colonise naturally with wetland plants. However, natural colonization may take longer if existing wetland communities are not in close proximity or if the ditch experiences high water flows. If planting is considered necessary a list of recommended species is provided in Section 8. ▪ Wherever possible, native wetland species should be used using local sources if feasible.

5.2.4 Cost

The creation of in-ditch wetlands can be a low cost solution to the prevention of pollution incidents due to field runoff. To give an indication of cost, the total expenditure for an in-ditch wetland (approx. area 40m^2) created as part of a joint SuDS project between LEAF and the EA at Green Hall Farm was £895. This project is described in more detail in a Case Study (Annex 1). Capital grants for silt filtration dams/seepage barriers are available through Countryside Stewardship.

5.2.5 Consents

The Local Flood Authority must be informed of any potential works because it will alter flows. A Flood Defence Consent under the terms of section 23 of the Land Drainage Act may have to be obtained (see general consents section). In-ditch wetlands should only be located in either dry or wet ditches and should not be located in streams or rivers. In addition, in-ditch wetlands should not be placed in wet ditches which are subject to heavy storm flows or drainage from large areas (>100ha).

5.2.6 Operation and maintenance

Table 8. In-ditch wetland management tasks.

Do	Don't
Remove sediments periodically to stop the wetlands becoming a source of pollution. Phosphate remobilisation is a potential problem especially during spring when oxygen conditions change.	During annual vegetation management don't clear all the plants from the system at once, since this will reduce performance of the system and take away valuable habitat.
Check for blockages every week and remove as necessary.	
Install debris screens to ease maintenance.	

5.2.7 Further guidance on in-ditch wetlands

TIN 099 Protecting water from agricultural run-off - water retention measures
(Natural England, 2011b).

Rural Sustainable Drainage Systems (EA, 2012).

MOPS 2 Diffuse Pollution in ditch wetlands guidelines (MOPS 2, 2012).

5.3 **Sediment ponds/traps** (3 star systems)

5.3.1 Description

Sediment ponds or sediment/silt traps are designed to trap run-off from fields or farmyards with a high sediment loading. Sediment ponds are built on impermeable substrates and have a permanent pool of water for most of the year, whereas sediment traps are constructed on permeable substrates allowing greater infiltration of water. Ponds will generally hold greater potential value for wildlife. Soil management measures to reduce erosion and run off should be employed before resorting to a sediment pond or trap. These are best used as a network of sediment control measures around the farm rather than a single large feature. It is important not to use existing ponds, as clean water ponds are vital habitats for wetland wildlife and even slight contamination can impact on sensitive species. Areas of existing archaeological or historic value should also not be excavated. Table 9 provides some of the advantages and disadvantages of creating this option.

Research on field wetlands, undertaken through the DEFRA project WQ0127 Mitigation Options for Phosphorus and Sediment 2 (MOPS2), suggests that ultimately any field wetland which can slow and store runoff will be better than no mitigation feature at all, and as a result field wetlands should be considered alongside other mitigation options as part of an integrated approach to catchment management (Silgram *et al*,. 2014). The MOPS2 project involved the field monitoring of ten new field wetlands over three years at four sites with different characteristics and has built up evidence for the effectiveness of wetlands for reducing pollution from agriculture (Ockenden *et al.,* 2014).

Table 9. Advantages and disadvantages of sediment ponds and traps.

Advantages	**Disadvantages**
Trap large volumes of sediments and associated contaminants (pesticides, phosphates, Cryptosporidium spp.) which could otherwise run off into watercourses.	Limited water retention limits opportunities for biodiversity if created on sandy, free draining soils.
Can have high detention times giving appropriate residence times for pathogen or nutrient removal.	May be costly if do not have appropriate soil type and if groundwater contamination is an issue.
Easily implemented, can be constructed by the farmer/landowner in 1-2 days.	Not suitable for high strength effluents i.e. dairy and septic tank runoff.
Easily and cheaply managed and maintained.	Sediment removal will be required to maintain effectiveness.
Small land requirement ~ 0.035-0.1% of catchment area.	
Can fit well aesthetically within the environment and adds some ecological value.	
Low capital cost.	

5.3.2 Application

Sediment ponds and traps can be used in three main situations:

1. In-field as a collection point for field drains.
2. Situated in field corners to capture runoff from fields.
3. As the first stage in a constructed wetland to remove the majority of the sediment load.

Figure 11. Newly created sediment pond with clay lining as part of a constructed farm wetland.

5.3.3 Design

If the area has high sediment loadings it is advisable for runoff to enter a deeper depression before the main basin. This depression should represent around 20% of the total basin area. The idea is that this will trap the majority of the sediment so that maintenance is undertaken on a smaller area. This will be the case for both sediment traps (permeable substrates) and ponds (impermeable substrates). It is not crucial to make this sediment/silt trap attractive to wildlife because it is likely to be disturbed on a regular basis for cleaning out. In the main basin, shallow water can be planted up in the margins so the plants contribute to sediment retention and nutrient reduction. These shallow transitional areas are the best habitats for insects and amphibians.

A simple small-scale sediment trap on permeable soil can be used in an area where runoff is allowed to pond temporarily so that sediment settles out. A shallow excavation of the topsoil should be made to create gently sloping banks without above ground embankments. The excess soil should be spread thinly away from the excavated pond area. For larger-scale sediment ponds advice from a soil and water engineer should be sought before construction.

Table 10. Sediment pond and trap design principles

Size	▪ Size depends on soil type, runoff volumes to be intercepted and desired removal efficiency. Generally, the larger the basin, the greater the removal efficiency. ▪ For field sediment ponds, a specialist should be consulted to calculate likely run-off volumes from the catchment. ▪ The basic design should allow for sufficient headroom for several intensive rainfall events.
Substrate	▪ Sandy substrates allow water to drain freely. ▪ A soil with a clay content of at least 20% will retain water for longer periods. ▪ Ponds that do retain water will be of greater benefit to wildlife.
Form	▪ Pond spoil can be compacted and used to stabilise the structure and to vary levels and the topography of the bed. ▪ Permanent ponds should include zones of both very shallow (<20cm) and moderately shallow (<50 cm) water, using underwater earth berms to create the zones. This design will provide a longer flow path to encourage settling, and it provides two depth zones to encourage plant diversity (Graham et al., 2012). ▪ Gentle slopes (no more than 1:4) ensure that the edges provide valuable wildlife habitat and also act as a safety feature.
Inlets & Outlets	▪ Inlets and outlets should be 200-300mm below mean water level to minimise disturbance and re-suspension of particles in the pond ▪ Vegetated inlets can trap silts and pollutants, as well as reducing nutrient input. ▪ Face overflow outlet channels with stone to prevent erosion. ▪ Create outlets larger than inlets if using pipes to prevent water backing up along the system.
Planting	▪ Excavated topsoil should be spread on top of the embankments and on the outside slopes to allow vegetation to grow and grass can be seeded into this. ▪ The area can be left to colonise naturally with plants or planted using species of local provenance (See Section 8). ▪ Avoid aggressive species such as Greater reed mace (*Typha latifolia*). ▪ If sowing, use a species rich grass and flower mix appropriate to soil conditions and the region (Graham et al., 2012). Selective and careful use of other vegetation around the basins can help enhance or conceal features as desired and stabilise slopes, reducing erosion.

5.3.4 Cost

Construction cost estimates based on existing sediment traps and ponds range between £280 to £3100 depending on pond size, fencing and lining costs, and whether or not the pond is required to store water. For specific costs see the case studies presented in annex I. Grants for sediment traps are available from the Countryside Stewardship Scheme.

5.3.5 Consents

Consult the Environment Agency (see section 4.2 on general consents issues) and for further information see Natural England TIN 98 (Protecting water from agricultural run-off: an introduction) (Natural England, 2011a), TIN 99 (Protecting water from agricultural run-off: water retention measures) (Natural England, 2011b) or TIN 100 (Protecting water from agricultural run-off: buffer strips) (Natural England, 2011c). These can be downloaded from http://publications.naturalengland.org.uk/

5.3.6 Operation and maintenance

The main maintenance activity will be sediment removal. There will also be a requirement for vegetation management once it becomes established, to ensure there are no blockages in the system. Another feature that can help reduce the potential for clogging of the outlet is to incorporate a small pool ("micropool") at the outlet.

Table 11. Sediment pond management tasks.

Management tasks
Remove sediment from inlet sediment traps as required, this may require licensed waste disposal. The local EA officer should be consulted.
Where contamination is not an issue and consent has been obtained, spread and level away from the basin to reduce nutrient leaching and re-seed.
Regular cutting and pruning of shrubs and scrub: timing and frequency depends on the type and nature of the plants.
Maintain a diversity of habitats throughout each basin with variable vegetation structure.
Check for blockages every week and remove them as necessary.

5.3.7 Further guidance

More information on in-field wetland design specifics is available within the MOPS field wetland guidelines MOPS 2 - Sediment ponds in fields (MOPS 2, 2012) which can be downloaded from the Mitigation for Phosphorus and Sediment 2 website: http://mops2.diffusepollution.info/

5.4 Constructed wetlands for low to moderate strength effluents (4 Star systems)

5.4.1 Description

Constructed wetlands for low to moderate strength effluents can range from single celled wetlands to multi-stage systems which incorporate some of the options already described (sediment ponds/ in-ditch wetlands). Due to long residence times, these types of constructed wetlands can be effective in reducing suspended solids, Biochemical Oxygen Demand, nitrogenous compounds, phosphorous, some pesticides and faecal coliforms. Phosphorus removal can vary and these types of wetland can occasionally become a phosphorus source in the long-term due to releases at certain times of year (Clerici, 2013).

Table 12. Advantages and disadvantages of constructed wetlands. (summarised from Carty et al., 2008; Christian/NIEA, 2006)

Advantages	Disadvantages
Potentially high ecological value.	Large land requirement
Possibility of amenity use (e.g. public access, educational visits).	Not suitable on permeable or excessively wet soils, unless lined.
High retention time leading to increased treatment efficiency.	Moderate capital cost.
Greater water storage capacity delays the flow peak during flood events.	Moderate maintenance commitment.
Ability to retain fine sediments containing nutrients such as phosphorus. When accumulated this sediment can normally be spread on farmland after consultation with the Environment Agency. Spreading will not be permitted in the floodplain.	Not suitable for high strength effluent such as slurries, silage effluent, raw milk, veterinary medicines such as sheep dip, or pesticides from sprayer or dipping equipment washings.

5.4.2 Application

Constructed wetlands provide an ideal solution for treating low to moderate strength diffuse effluent such as runoff from fields or farmyards, if not heavily contaminated with slurry, silage or pesticides. These types of systems are generally comprised of several stages and can provide excellent wildlife habitat by incorporating varying water depths, landforms and planting.

5.4.3 Design

5.4.3.1 Constructed Farm Wetland- size estimation tool

A tool has been created for Catchment Sensitive Farming (CSF) by the Wildfowl and Wetlands Trust to approximate the size of a constructed wetlands treating lightly contaminated yard runoff. This is based on the design of a 3-stage wetland used for the Countryside Stewardship option for a constructed wetland for the treatment of pollution.

The tool is only suitable for approximating simple constructed wetlands to treat lightly contaminated farm yard runoff. It is **not suitable** for technical constructed wetlands treating high-strength pollution. It is **not suitable** if any of the following effluents are present in the inflow waters: silage effluent, slurry, dairy washings, septic tank outflow.

The tool is intended to give a rough estimate of the area of wetland required but is not a design tool. The actual design should be carried out through a complete farm water management plan which sizes the wetland based on inflow wastewater composition and volume. The tool can be accessed on the WWT Constructed Farm Wetlands webpage: www.wwt.org.uk/farmwetlands.

The tool utilises information generated by the 'Greenfield Runoff Estimation for Sites' website created by HR Wallingford (HR Wallingford, Undated): http://www.uksuds.com/greenfieldrunoff_js.htm

5.4.3.2 Other sizing approaches

The Irish Department of the Environment Heritage and Local Government Guidance Document for Farmyard Soiled Water and Domestic Wastewater (Department of the Environment, Heritage and Local Government, 2010) recommends that a farm wetland should be at least 1.3 times the size of the contributing area and ideally twice the size of the contributing area. This is based on the finding that this is the area required to achieve concentration reductions of phosphate (molybdate reactive phosphorus) to 1.0 mg/l or below (Department of the Environment Heritage and Local Government, 2010). The size is due to the composition of the inflow wastewater and correspondingly to the area required to remove the high phosphate concentrations associated with those wastewater types. Wastewater types included in the Integrated Constructed Wetland approach include *"yard and dairy washings, rainfall on open yard and farmyard roofed areas and silage and manure effluent"* (Scholz, et al., 2007) in addition to domestic wastewater (Department of the Environment Heritage and Local Government, 2010).

5.4.3.3 Lining

In order to prevent any contamination of groundwater or adjacent waterbodies constructed wetlands should either be constructed on an impermeable clay substrate or be lined with an artificial liner. A natural clay liner is preferable due to cost and the comparative difficulties associated with installing plastic liners in non-rectangular wetland cells (Kadlec and Wallace, 2008).

Soils suitable for use as a natural clay liner should consist of *"a soil layer with a permeability of less than or equal to 1 x 10-8 m s-1 throughout the CFW to a thickness of at least 1 metre"* (Carty et al., 2008). If the site substrate does not have these characteristics then the possibility of winning clay from elsewhere on site should be investigated. An alternative solution is to mix imported clay material with the on-site soil to reduce hydraulic conductivity (Wallace & Knight, 2006).

The use of an artificial liner will increase costs due to the expense of labour in addition to materials (Kadlec and Wallace, 2008). A comparison of several constructed wetlands in the USA estimated that the cost of installing a liner is likely to range from £2.68/m^2 to £14.20/m^2 with a median of £6.24 m^2 (Adapted from Kadlec and Wallace (2008) and adjusted to GBP and 2013 prices using the Retail Price Index (Swanlowpark, 2014). In addition, rocky soils may require the installation of a geotextile layer to protect the liner. The use of a geotextile is estimated to add £2.16/m^2 to the total cost of the liner installation (Adapted from Kadlec and Wallace (2008) and adjusted to GBP and 2013 prices).

5.4.3.4 Hydrology

Where constructed wetlands are required to hold water, care must be taken to ensure that they are not constructed near to or below the water table as this could lead to potential groundwater contamination risk. The water table should be no less than 0.5 m below the bottom of the wetland if using an artificial liner and no less than 1 m below the bottom if an in-situ natural liner is used (Carty *et al.*, 2008). Additional potential contamination risks which must be avoided include: proximity to wells and springs and interception of field drains (Carty *et al.*, 2008). For detailed site considerations relating to hydrology please refer to Carty *et al.* (2008).

5.4.3.5 Zero discharge systems – willow

Due to high evapotranspiration rates, willow can be used very effectively to limit the discharge of effluent from a constructed wetland. Willow is also highly effective in nutrient uptake (Ericsson, 1981; Elowson, 1999) and the assimilation of metals, especially Cadmium (Klang-Westin and Eriksson, 2003). The willow can be harvested for biomass every year, thereby effectively converting the nutrients from a potential pollution source into a nutrient source for the willows. These beds can be added at the very end of a multi-cell wetland to take up excess effluent and evapotranspiration rates can be increased by planting the willow trees in a crosswind aspect (Kadlec & Wallace, 2008). The addition of willow beds can provide a source of biomass fuel and valuable wildlife habitat.

Any willow bed would need to be harvested regularly to stimulate growth and remove nutrients and heavy metals (Kadlec & Wallace, 2008). A third of the willows should be harvested every year in order to stimulate new growth and thereby to maintain healthy vegetation (Brix and Arias, 2005). In addition, young willow trees have a high proportion of phosphorus in their bark so it's important to cut them regularly to maintain uptake of this nutrient (Gregersen & Brix, 2001).

Willow is expected to take up a large proportion or all of the waste water during the growing season, but there may be a discharge during the winter months (Kadlec & Wallace, 2008). The use of willow beds may not be appropriate in areas of the country where groundwater recharge is important for water supply.

Table 13. Constructed wetlands for low to moderate strength effluents – design principles

Size	▪ Several methods exist for the sizing of wetlands to treat lightly contaminated farmyard runoff. Sizing recommendations vary considerably depending on the permitted inputs to the system. Please see section 5.4.3.2 for further explanation of other sizing approaches.
Wetland cell arrangement	▪ Stage 1 should be 20% of the total treatment area, max. depth 1.5m. ▪ Stage 1 should have adequate access so that a digger (or similar) can approach and remove accumulated sediment. This may be required every 1-4 years depending on the rate of sediment accumulation. ▪ Stage 2 & 3 are shallow vegetated cells with a maximum depth of 0.5m and 0.4 m respectively. ▪ If gradient and space allow stage 2 and 3 should be split into two to allow better water distribution throughout the cells. ▪ Stage 2 should comprise approximately 30-40% and stage 3 approximately 40-50% of the total treatment area. ▪ Gently sloping sides. No more than a 1:4 gradient, less if possible. ▪ Create undulating edges to provide more edge habitat.
Inlets/Outlets	▪ Plant inlets to trap silts and pollutants and reduce nutrient input. ▪ Face overflow outlet channels with stone to prevent erosion. ▪ If using pipes, create outlets larger than inlet to prevent water backing up. ▪ A two-stage outlet can be installed to allow stormwater overflow, this should be situated at a higher level than the normal outflow level. ▪ Discharge should be to a suitable waterbody only with Environment Agency permission ▪ If of sufficient quality, water can be reused for irrigation or for creating additional clean water wetland habitat.
Planting	▪ The wetland can be left to colonise naturally or be planted up with species of local provenance (See Section 8). ▪ Willow systems can be used for a zero discharge or reduced output flow system. ▪ Use only emergent species of appropriate provenance to the region. Avoid aggressive species such as Greater reed mace (*Typha latifolia*).

Water supply

- Where possible, construct the treatment wetland on a slope so water can move through the system by gravity.
- Pumps may be necessary if there is no fall in the land to provide gravitational flow, but they will significantly increase the cost due to machinery and continuous electricity consumption.
- Wet ditches and swales can be used to convey water to the wetland.
- Minimise the use of pipes to reduce blockages. To facilitate movement of water between wetland stages, have slightly lowered sections at the end of each cell. These lowered sections should be ~ 1 m wide and lined with large stones to prevent erosion (See Figure 12). Swales can transport water over longer distances and pipes may be required if water needs to be directed under tracks or other areas of access.

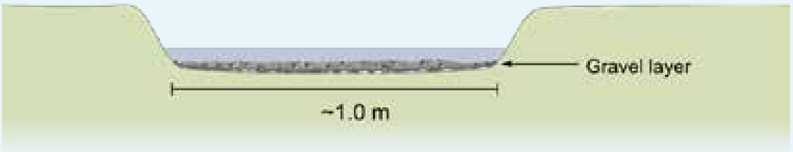
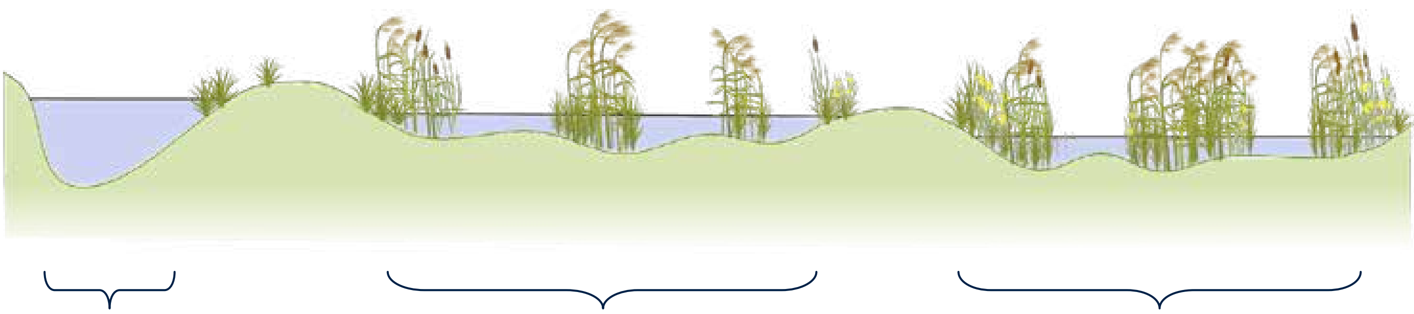


Figure 12. Stone-lined outlet.

- Outlet water control features: range from simple elbow pipes and flashboards for small wetlands, through to adjustable weir gates for larger, more complex systems where a greater degree of control is required over water levels.



Stage 1. This first pond should be ~1.5 m deep to allow sediments to settle out. It should account for ~20% of the total surface area of the wetland.

Stage 2. This section should be shallower (max. 0.5 m) to allow for increased vegetation establishment. It should account for 30-40% of the total surface area of the wetland.

Stage 3. This section should again be shallow (max. 0.4 m) to allow for increased vegetation establishment. It should account for 40-50% of the total surface area of the wetland.

Figure 13. Three-stage constructed wetland.

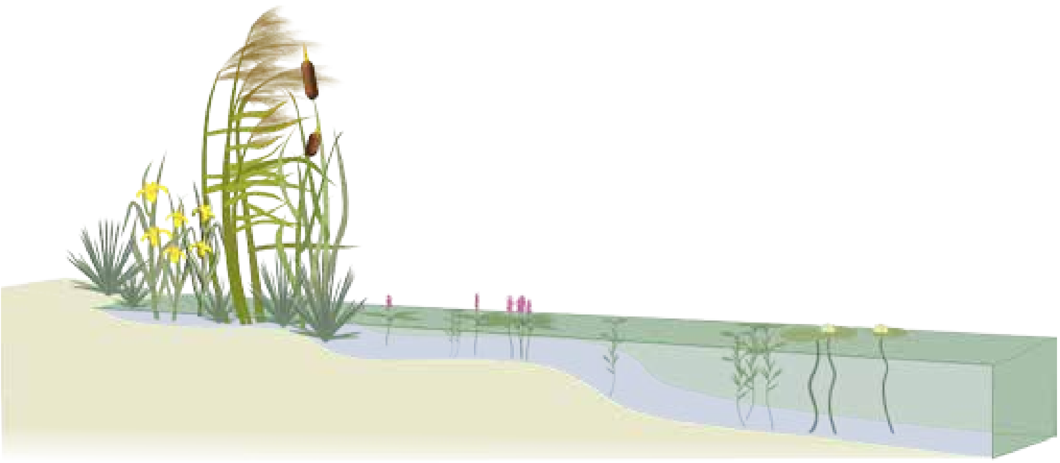


Figure 14. Cross section of an ideal edge, illustrating the benefits of the various water depths for biodiversity (emerging, floating and submerged plants and associated animal communities).

5.4.4 Cost

The overall costs for this type of constructed wetland are extremely varied, depending mostly on their size, whether machinery and labour is available on the farm, land availability and the need for a liner. Known examples range from around £4/m^2 up to £25/m^2 (£1,500 for a 0.4 ha wetland up to £29,500 for a large scale, multi-celled 1.2 ha wetland) (Carty *et al.,* 2008). Capital grants are available for constructed wetlands for treatment of pollution through the Countryside Stewardship scheme.

In a comparison of sixteen Scottish farm wetlands, wetland areas ranged from 1600m^2 – 12,000m^2. Overall costs including construction, design, fencing, planting, land and farmyard modifications ranged from £1,600 - £20,000. The median cost was £3.5/m^2 (Range: £1.6/m^2 -£16.7/m^2) (Gouriveau, 2009). If a large proportion of the construction work is carried out by the landowners/farmers themselves, this can reduce costs by around 30% (Gouriveau, 2009).

5.4.5 Consents

The need for consent to discharge water from a constructed wetland to a watercourse will vary on a case by case basis. This will depend on the types of pollutants entering the wetland and the likely quality of the discharge. The Environment Agency would need to be satisfied that only clean uncontaminated water is allowed into the wider water environment. Please see the Environmental management webpages on - GOV.UK for further information (https://www.gov.uk/environmental-management/water) and contact your local Environment Agency office for more advice.

Surplus spoil generated by the construction or maintenance of a wetland and the dredging or widening of existing ditches may be disposed of by spreading it thinly over adjacent land but check with the relevant Flood Authority if it is within the floodplain. Excavated material may be classified as a 'waste' and its use may need a waste exemption (U10) from the Environment Agency (Natural England, 2011b).

5.4.6 Operation and maintenance

Long-term maintenance is an important consideration for constructed wetlands. This maintenance is often neglected and therefore the treatment efficiency and ecological benefits of the wetland decrease over time. Wetland vegetation, water control structures and pipes all need to be maintained in order to preserve the functionality of the constructed wetland.

Table 14. Constructed wetlands for low to moderate strength effluents – management tasks

Management tasks
Visually inspect inlet and outlets monthly for blockages & damage and remove blockages and repair as required.
Visually inspect water levels monthly within each bed. Adjust water levels using elbow pipe if required.
Cut back vegetation around inflow and outflow pipes twice yearly.
Strim around the edges of the wetland cells but leave a 1 m margin to provide edge wildlife habitat, since these areas can support a wide range of species.
Remove sediment every 1-5 years, depending on sediment inputs and accumulation. This activity can be minimised by constructing a dedicated sediment trap as the first stage of the constructed wetland.

5.4.7 Further Guidance

Further design guidance and information can be obtained from:

Integrated Constructed Wetlands: Guidance document for farmyard soiled water and domestic wastewater applications (Department of the Environment, Heritage and Local Government, 2010).

Constructed Farm Wetlands (CFW) - Design Manual for Scotland and Northern Ireland (Carty *et al*., 2008).

Guidance for Treating Lightly Contaminated Surface Run-off from Pig and Poultry Units. NIEA Christian/NIEA (2006)

5.5 Constructed wetlands for treating moderate to high strength effluent (5 Star systems)

5.5.1 Description

Constructed wetlands can be used for treating moderate to high strength point source effluent which includes septic tank discharge, abattoir effluent and dairy parlour wastewater or heavily contaminated yard washings. Constructed wetlands should not be used for slurry treatment or slurry liquor as this is a valuable nutrient resource and can be spread on the land in accordance with good practice. As these systems treat high strength, point-source pollution they need to be lined. The liner can either be a natural clay-rich substrate or an artificial liner which is more costly and has a limited life span. There are three main types of constructed wetland cell which can be used independently or in combination depending on the wastewater composition to be treated and the land area available. Please see Table 15 for further details.

Table 15. Descriptions of the three types of constructed wetlands cells.

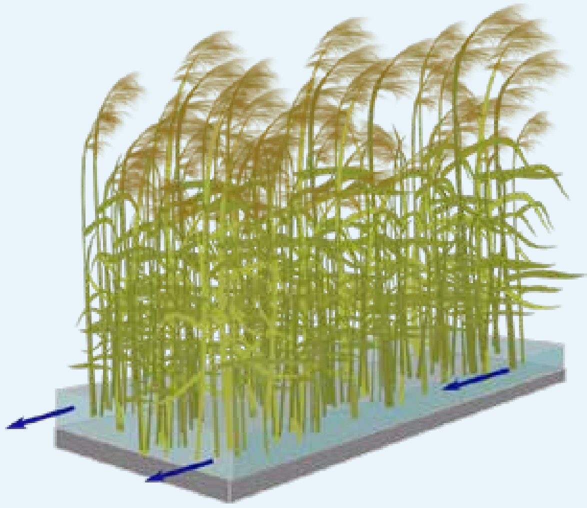
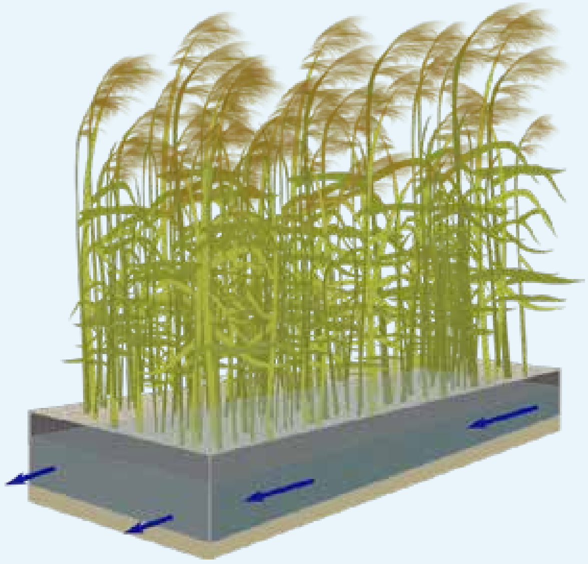
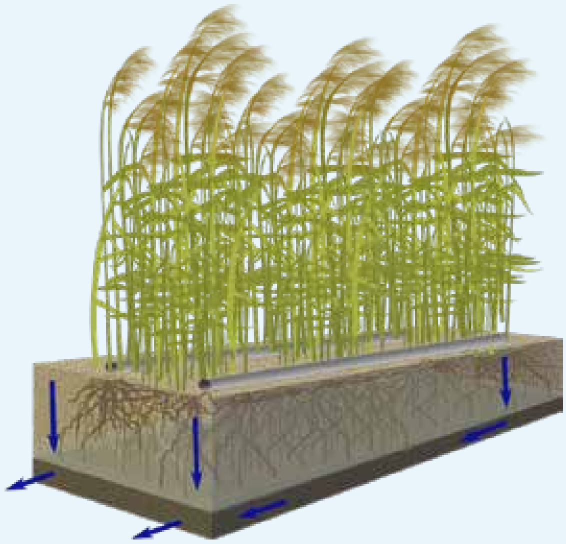
Surface-flow constructed wetland cell	In surface flow wetlands water is distributed across the inlet area but flows horizontally over the surface of the media, which is usually soil, to the outlet. The water depth ranges from 10 to 30 cm. This bed type is particularly effective in reducing pathogens and nitrate.	
Sub-surface flow constructed wetland cell	Water is distributed across the inlet area and moves horizontally through the media which is soil or gravel to the outlet. The water level is ideally 20-50 mm below the substrate surface. This bed type is particularly effective in reducing nitrate, phosphate, BOD and pathogens.	
Vertical flow constructed wetland cell	Water is distributed over the surface of the wetland and percolates down through the media which is sand or gravel. This bed type is particularly effective in reducing ammonia and BOD and can be used to remove phosphate.	

Table 16. Advantages and disadvantages of constructed wetlands for moderate to high strength effluents.

Advantages	**Disadvantages**
Potentially high ecological value.	If clay is not available on site to line the system, an expensive artificial liner will be required.
Opportunity to treat extremely high strength effluent (e.g. abattoir waste).	Higher capital costs including additional pipe work.
Possibility of amenity use (e.g. public access, educational visits).	High maintenance commitment (checking pipes, pumps, etc. every week/two weeks).
High retention time leading to increased treatment efficiency.	May require electricity source/solar power for pumps

Figure 15. Contaminated farmyard runoff.

5.5.2 Application

Constructed wetlands have been used effectively to treat a range of high strength wastewaters including septic tank effluent (Vymazal, 2011), dairy wastewater (Healy *et al.,* 2007; Knight *et al.,* 2000) and abattoir effluent (Finlayson *et al.,* 1990). In order to treat high strength effluents effectively, more complex and expensive systems may be required.

5.5.3 Design

These types of systems have to be designed specifically for the organic loading (based on BOD & TSS) and the hydraulic loading (volume of water). There are design equations specific to these parameters. Detail is not given on the design of constructed wetlands for high strength effluent as this requires specialist advice.

General design principles include:

- Designs, including system sizing, are normally based on organic (BOD) and hydraulic loadings.
- If ammonia, nitrate and phosphate are targets for reduction, there are additional design calculations to be performed.
- As a first stage, water samples should be taken and analysed for BOD, suspended solids, ammonia, nitrate and phosphate to provide an indication of water quality.
- It is advisable to have the samples also analysed for total coliforms, to assess loading and calculate required residence time.

Specialist advice should be taken for design of these systems. They will require professional installation of an impervious liner, which could be clay if available on site or a synthetic liner. See section 5.4.3.3 for further details on lining and section 5.4.3.4 for considerations relating to hydrology. The correct construction is critical to ensure that the wetland performs well, therefore it is advised to contact and employ a specialist contractor.

5.5.4 Cost

Costs will vary depending on the complexity of the system and may be as low as £5,000-10,000 for a system to treat low volumes of water from a single septic tank, to over £100,000 to treat complex high volume wastewater. Please refer to the case studies in Annex 1 for further details.

As the control of point source pollution is a landowner obligation, any system targeting this type of pollution would not be eligible for any of the funding options presented in this document.

5.5.5 Consents

These systems will require approval from the Environment Agency and possibly the Local Planning Authority. Therefore, it is recommended that the local office is contacted at the planning phase.

The following consents may be required:

- A discharge consent.
- Waste management exemption for spoil.
- Ground water permit.

5.5.6 Operation and maintenance

These systems require maintenance for effective functioning.

Table 17. Constructed wetlands for medium to high strength effluent – management tasks

Management tasks
Monthly visual inspection of inlets and outlets for blockages & damage. May require removal of blockages to pipes.
Monthly visual inspection of water levels. Adjustment of water levels if required.
Cut back vegetation around inflow and outflow pipes.
Strim around the edges of the wetland cells but leave a 1m margin to provide edge wildlife habitat: these areas can support a wide range of species.
Removal of sediment. This activity can be minimised by constructing a dedicated sediment pond/trap prior to runoff entering the constructed wetland.

5.5.3 Further guidance

Integrated Constructed Wetlands: Guidance document for farmyard soiled water and domestic wastewater applications (Department of the Environment, Heritage and Local Government, 2010).

Constructed Farm Wetlands (CFW) - Design Manual for Scotland and Northern Ireland (Carty *et al.*, 2008).

Treatment Wetlands (Kadlec & Wallace, CRC, 2008).

6 Funding and support

6.1 Advice and support

Before building a farm wetland or SuDS, it is recommended that advice is taken from a farm adviser and/or agricultural soil and water engineer to assess the sources of pollution and to reduce pollutant levels at source first. For example by separating clean and dirty water in the farmyard, roofing or concreting livestock yards/buildings and soil management to reduce erosion and run off. Further specialist advice to assess surface water flow volume and direction, identify the best options and location and then to design the wetland or SuDS may be required.

Specialist advice to address diffuse water pollution from agriculture is available to farmers in target catchments of England via the Catchment Sensitive Farming (CSF) project. CSF provides tailored farm advice on soil, water, pesticides, infrastructure, livestock, manure and nutrient management to protect water. Advice to support specific Countryside Stewardship options and capital items is also available via CSF or as a scheme option.

6.2 Funding

Constructed farm wetlands and SuDS may be constructed without funding support. For example, low cost options can be installed with farm labour and machinery. Return on farm investment is more likely for options which replace alternative treatment systems e.g. for abattoir or septic tank waste or for flood control or options which generate wider benefits, e.g. creation of a recreational feature. High construction cost and loss of productive farmland can be a deterrent to farm investment in constructed wetlands, however the potential benefits such as floodwater attenuation and habitat provision should be considered alongside the capital investment.

Potential sources of funding available for advice and construction or maintenance of farm SuDS and constructed wetlands include the Countryside Stewardship scheme, funded by the Rural Development Programme for England (RDPE), and similar schemes exist in Wales, Scotland and Northern Ireland. Other funding may be available through specific projects such as Water Framework Directive (WFD), Catchment Restoration Fund or other projects. The availability of and criteria for funding varies between sources.

6.2.1 Countryside Stewardship

Targeted support is available to farmers, land managers, land owners and tenants through the Countryside Stewardship scheme for a range of land management options and the construction and maintenance of capital items. These options may be supported with advice from CSF or via Countryside Stewardship options for management or feasibility plans.

Countryside Stewardship has 3 main elements:

- Higher Tier – land management options and capital items for the most important environmental and woodland sites requiring complex management
- Mid Tier – a more limited range of land management options and capital items targeted and scored for environmental benefit
- Lower tier - capital grants mainly for hedgerows and boundaries, woodland creation, woodland management plans, feasibility and implementation plans

Water quality capital grants for infrastructure work will be available as part of Mid Tier and Higher Tier agreements, or standalone capital agreements. All applications will be assessed and scored against local priorities and those that score highest will be more likely to be accepted. Farmers and land managers applying for these grants should speak to a Catchment Sensitive Farming (CSF) adviser to get advice about choosing options and carrying out any infrastructure work. Otherwise, they may not be eligible to choose some water quality options.

Countryside Stewardship includes capital items for constructed wetlands for the treatment of pollution and for a range of SuDS items including swales, check dams, earth banks and soil bunds, silt filtration traps and seepage barriers. The most relevant options available for constructed farm wetlands and SuDS are highlighted in the tables below. Capital grants are available under Countryside Stewardship for yardworks for clean and dirty water separation, roofing, rainwater harvesting, gateway relocation and resurfacing, tracks and cross drains. Such works can be used as mitigation measures to reduce the source and pathway of water pollution prior to installing constructed wetland or SuDS options. Options for woodland and scrub creation, hedgerow and soil bank boundaries and buffers are also available and may also be used for controlling the flow of soil and surface water or trapping run off as part of a wetland system. Some of the options aimed at natural or high environmental value wetlands may also be appropriate for constructed wetlands as long as the biodiversity objectives for the option are not compromised, for example ditch management and sluices, wetland cutting supplement, reedbed creation/management and water penning structures. The more complex items such as 'Making space for water' will only be available through the higher tier Countryside Stewardship agreements on priority sites.

6.2.1.1 Countryside Stewardship option: Constructed wetland for treatment of pollution

A new capital item for constructed wetlands for the treatment of lightly fouled field and farm yard run off is expected to be available through the higher tier of Countryside Stewardship in priority sites targeted for the reduction of water pollution from agriculture. It is not available for treatment of slurry, silage liquor, concentrated pesticide spillage/washings or heavily fouled water, as defined under the Nitrate Action Plan regulations or Slurry, Silage and Agricultural Fuel Oil regulations or the Health and Safety Executive. This will require a bespoke management plan funded through Countryside Stewardship or CSF but the likely design specification follows the advice given in section 5.4.3 (Design of constructed wetlands for low to moderate strength effluent)[1].

[1] Please note that this is subject to final approval of the scheme by the European Union so details may change. See www.gov.uk

Table 18. Countryside Stewardship: selected options relating to farm wetlands and SuDS (as published by Defra December 2014 – subject to final approval by EU)

Option code	Option title	Proposed (Dec 2014) payment rate
RP5	Cross drains	£245/unit
RP6	Installation of piped culverts in ditches	£340/unit
RP7	Sediment ponds and traps	£10/sq m
RP8	Constructed wetlands for the treatment of pollution	Actual costs
RP9	Earth banks and soil bunds	£155/unit
RP10	Silt filtration dams/seepage barriers	£75/unit
RP11	Swales	£5.95/sq m
RP12	Check dams	£42/unit
RP19	First flush rainwater diverters/downpipe filters	£125/unit

Table 19. Countryside Stewardship: selected options relating to payment for advice.

Option/capital item code	Option/Capital item title	Proposed (Dec 2014) payment rate
PA1	Implementation plan	£1,100/unit
PA2	Feasibility study	Actual costs
PA3	Woodland management plan	£10-20/ha

7 Management of wildlife during creation & management

Creating wetlands on farms has the potential to provide valuable habitat. An ecological survey should be undertaken prior to commencing construction works and any consents or permits required applied for. If protected species start using the wetlands, specialist advice should be sought and the appropriate care should be undertaken during management activities.

Table 20. Wildlife management considerations. Adapted from: Sustainable Drainage Systems: Maximising the potential for people and wildlife (Graham et al., 2012).

Consents and permits	▪ Ensure all permissions are obtained prior to works beginning. These may include consents from the Environment Agency, local authorities or other bodies (See Section 4.2). Consult Natural England if the site is designated as a Site of Special Scientific Interest, Natura 2000 or Ramsar site or if a protected species is affected.
Vegetation management	▪ Avoid vegetation management between mid March and mid August to avoid disturbing wildlife. ▪ Certain species, including water Voles, can be significantly affected by vegetation management at all times of year. If they are known or thought to be present seek specialist advice before undertaking management. ▪ Consider the possible presence of bats if work is required on mature or veteran trees, including pollards. Birds may nest in holes and cavities. ▪ Where maintenance for safety reasons is required between mid March and mid August, it is essential to consider nesting birds and the likely presence of other protected species. ▪ Be aware that birds may breed outside of these times and it is essential that preliminary inspections are undertaken before proceeding with work which may disturb protected species.
Birds	▪ The nests of all wild birds are legally protected under the Wildlife and Countryside Act 1981. ▪ It is also an offence to intentionally or recklessly disturb any wild bird listed on Schedule 1 of the Act, while it is nest building, or at a nest containing eggs or young, or disturb the dependent young of such a bird.
Amphibians	▪ Amphibians and their spawn are protected under the Wildlife and Countryside Act 1981 from sale or trade. ▪ The Great Crested Newt is specially protected under Schedule 2 of the Wildlife and Countryside Act 1981 and under European law Annexes 2 and 4 of the EU Habitats and Species Directive, the Bern Convention and the Conservation (Natural Habitats, etc.) Regulations 1994.

Mammals	▪ The Water Vole is fully protected under Schedule 5 (Section 9) of the Wildlife & Countryside Act 1981. ▪ Otters receive protection under the Wildlife and Countryside Act 1981 (as amended) and the Conservation (Natural Habitats, etc.) Regulations 1994. ▪ All bat species are protected under schedule 5 of the Wildlife & Countryside Act 1981 and under European law Annexes 2 & 4 of the EU Habitats and Species Directive, the Bern Convention and the Conservation (Natural Habitats, etc.) Regulations 1994. ▪ Badgers and their setts are protected under the Protection of Badgers Act 1992. Consult Natural England wildlife Section if required.
Plants	▪ The following plants are European Protected Species and are protected by law. Many other plants are also protected under Schedule 8 of the Wildlife and Countryside Act 1981. — Creeping Marshwort — Early Gentian — Fen Orchid — Floating Water-plantain — Killarney Fern — Lady's Slipper — Marsh Saxifrage — Shore Dock — Slender Naiad
Invertebrates	▪ Many species of invertebrates are protected by law. See Schedule 5 for the Wildlife and Countryside Act (1981) for details. ▪ Three species with a high level of European protection are the Large Blue Butterfly, Fisher's Estuarine Moth and the Lesser Ramshorn Whirlpool Snail.

8 Suitable Planting Schemes

Where possible, natural colonisation is encouraged but where planting is used then species native to the area and habitat created should be selected. Suggestions for suitable meadow species, marginal wetland species and floating and submerged pond species have been given in the tables below. Plants can be transplanted from the surrounding area as long as it is not a sensitive habitat or if the removal of plants causes significant disturbance. Otherwise, native plants can be sourced from a reliable nursery which does not stock non-native species and be as close to local provenance as possible. The following websites can be used to check native distributions of plants within the UK:

- Ecological Flora of the British Isles http://ecoflora.co.uk/
- Online Atlas of the British and Irish flora http://www.brc.ac.uk/plantatlas/
- National Biodiversity Network http://www.nbn.org.uk/

Table 21. Meadow flower species.

Meadow flower species		**Meadow flower species**	
Scientific name	Common name	*Scientific name*	Common name
Achillea millefolium	Yarrow	*Alopecurus pratensis*	Meadow Foxtail
Agrostis spp.	Bents spp.	*Filipendula ulmaria*	Meadowsweet
Centaurea nigra	Black Knapweed	*Lychnis flos-cuculi*	Ragged-Robin
Cynosurus cristatus	Crested Dog's-tail	*Silaum silaus*	Pepper-saxifrage
Festuca spp.	Fescue spp	*Succisa pratensis*	Devils-bit Scabious
Galium verum	Lady's Bedstraw		
Hypochaeris radicata	Cat's-ear		
Leucanthemum vulgare	Oxeye Daisy		
Lotus corniculatus	Common Bird's-foot-trefoil		
Plantago lanceolata	Ribwort Plantain		
Prunella vulgaris	Selfheal		
Rumex acetosa	Common Sorrel		

Table 22. Marginal, submerged and floating species.

Marginal species		Submerged and floating species	
Scientific name	Common name	*Scientific name*	Common name
Carex riparia	Greater Pond-sedge*	*Persicaria amphibia*	Amphibious Bistort
Sparganium erectum	Branched Bur-reed*	*Nuphar lutea*	Yellow Water Lily
Iris pseudacorus	Yellow Iris	*Ceratophyllum demersum*	Rigid Hornwort
Stachys palustris	Marsh Woundwort	*Potamogeton natans*	Broad-leaved Pond Weed
Lythrum salicaria	Purple Loosestrife	*Myriophyllum spicatum*	Spiked Water-milfoil
Glyceria maxima	Reed Sweet-grass*		
Phalaris arundinacea	Reed Canary-grass*		
Alisma plantago-aquatica	Water Plantain		
Mentha aquatica	Water Mint		
Phragmites australis	Common Reed*		
Scrophularia auriculata	Water Figwort		
Caltha palustris	Marsh Marigold		
Eupatorium cannabinum	Hemp Agrimony		

* These species are vigorous and can dominate if not managed.

9 Case studies

Swales

CASE STUDY - WWT Caerlaverock

A swale is used on a farm on the WWT reserve at Caerlaverock to direct water from the farm yard down into a simple constructed wetland. The movement of the water is aided by the presence of a concrete bund which prevents any runoff from flowing down a track and then into the ditch which flows out onto the WWT reserve. Vegetation has established well in the swale, which will help slow the flow of the water before it reaches the treatment wetland and increase infiltration into the ground. The swale was created using the small digger which was also used for the creation of the main treatment wetland. The concrete bund was added the following day and involved roughly an hour of work to smooth and adjust the concrete to the correct level. The swales should be scraped and maintained on a regular basis to keep them functioning and guiding water down into the two-stage sediment pond.

Figure 16. Swale creation.

Table 23. Caerlaverock swale costs.

Items	Cost
Lorry load of hardcore	£550
6 m² Concrete & £87/m²	£522
Total cost of materials (this excludes labour and fuel/machinery use)	**£1072** (ex VAT)

In ditch wetlands

CASE STUDY - Green Hall Farm in ditch wetland

The in-ditch wetland at Green Hall Farm in Wales was created in 2010 through a collaboration between LEAF (Linking Environment and Farming) and the Environment Agency. The wetland treats the water in a ditch that sometimes receives farmyard runoff. This ditch eventually flows into the Afon Cain via a tributary which has occasionally suffered from the presence of sewage fungus in the past.

In terms of planning and design, the application included a location plan of the works and a typical cross section showing height of bund in relation to top of the bank. No flow calculations were required but the application did include a projection of the consequence of high flows. As the creation of the in-ditch wetland will change flows in the ditch, a Flood Defence Consent was required.

Very little alteration of the ditch topography was required at the time and since installation small improvements, including the creation of some surrounding bunds to guide water, have been added. This feature had a low overall cost, with a total cost to the farmer of £895 (See Table 24).

Figure 17. Fully vegetated in-ditch wetland.

Source: Generated from SUDS – Sustainable Drainage Systems. To explore the effectiveness of different pathway options in slowing down the flow of surface run-off and trapping sediment from different farm and field locations (LEAF & EA, 2010).

Table 24. Capital costs – Green Hall Farm In-ditch Wetland.

Item	Cost
Flood Defence Consent Application	£50
Hire and operation of digger (4hrs)	£225
Pipe	£200
Common reed (*Phragmites australis*)	£220
Stone as substrate	£200
Total cost to farmer	**£895**

CASE STUDY - India in-ditch wetland

The India in-ditch wetland was created in 2010 as part of the MOPS 2 (Mitigation Options for Phosphorus & Sediments) project. This project has been studying the role of ponds and constructed wetlands as potential mechanisms to limit sediment and nutrient losses from farm landscapes into streams and rivers. A large amount of sediment within runoff was transported though the original stream and so widening the stream and re-profiling the banks gave an opportunity for suspended solids to settle out and for the wetland to act as an effective sediment trap. The wetland is 125 m^2 in area (25 m x 5 m) and is approximately 0.5m in depth. The wetland is built on a clay soil but is unlined. The construction cost was approximately £2,700 which included the removal of soil and fencing (MOPS2, 2012).

Accumulation and concentration of sediment and nutrients in the wetland has been monitored and lower concentrations of these pollutants have been found in the outlet compared to the inlet. Results so far show that 0.3-0.4 tonnes/hectare/year sediment, 0.1-0.2 kg/ha/year total phosphorus (TP), 0.4-0.6 kg/ha/year total nitrogen (TN) and 4-8 t/ha/year total carbon (TC) was trapped. However heavy rainfall led to re-suspension of fine sediment (Ockenden *et al.* 2014)

Further information on the India in-ditch wetland can be found on the MOPS 2 website:
http://mops2.diffusepollution.info/

Figure 18. MOPS2 (2012) India: A Shallow Single-Cell Field Wetland.

Sediment traps

CASE STUDY - Church Farm field corner sediment trap, Somerset

In partnership with the Environment Agency, LEAF (Linking Environment and Farming) has been trialling different types of sustainable drainage systems (SuDS) to slow and intercept field run-off. Their study has focussed on low-cost measures that can be implemented easily and quickly by agricultural landowners.

A sediment trap was created at Church Farm at the foot of a steep 8 ha field. Sediment loss from this field was a regular occurrence and, prior to the construction of the sediment trap, runoff containing sediment would flow off the field through a gate at the corner of the field, across a road and into a nearby watercourse. The existing gate was relocated and a sediment trap was dug in the corner of the field. The initial intention was to gently grade the sides of the sediment trap and sow grass seed in order to stabilise the banks but this was not possible due to bad weather (LEAF & Environment Agency, 2010).

The created sediment trap measures 8m x 8m x 1m deep. It was created on permeable soils so does not retain water for long periods of time. It was estimated that several cubic metres of soil could be retained over the course of one season (LEAF & Environment Agency, 2010). The total cost to the

Figure 19. Church farm sediment trap.

farmer was £658 (See Table 25). However, as this also included the creation of an offline ditch at another site on the farm, the actual costs associated with the sediment trap would be less than this. There is also a 6 m grass margin around the sediment trap. The biodiversity benefit of this sediment trap could be enhanced by the implementation of the planned graded banks and the sowing of a mix of native wildflower and grasses.

Table 25. Church Farm sediment trap. Total cost to the farmer of both options (Sediment trap & Off line ditch)

	Cost
JCB digger hire 12 hrs @ £ 25/ hr	£ 300
Tractor and dump trailer 10 hrs @ £ 20/ hr	£ 200
6 m 225 mm diameter pipe	£ 40
10 m 102 mm perforated land drain	£ 9.50
1 t of clean stone	£ 10.50
Total cost	£560 + VAT £658

CASE STUDY - River Eye Silt Traps

The River Eye is a Site of Special Scientific Interest. High levels of phosphate entering the river mean that it is currently classed as "Unfavourable" condition by Natural England. It was estimated that around half of the phosphate loading in the catchment is from agricultural sources and by trapping the sediment to which the phosphate binds, it should be possible to reduce the concentration of phosphate entering the River Eye SSSI. A large silt trap built by the Environment Agency captures sediment catchment-wide but requires regular expensive de-silting. Five further small-scale in-field and in-stream silt traps were constructed later to trap sediment at source, with varying sizes and designs to be simple enough for landowners to construct and easily maintain. The restoration of a 'wetland area' at one of the sites provides further wildlife benefits and is already attracting short eared owls. The smaller traps took around five weeks to complete and cost £1890 for 1 silt trap and £7225 for 4 silt traps.

Figure 21. Simple in-field sediment trap.

Constructed wetlands for low to medium strength effluents

In light of the wide variety of constructed wetlands in terms of cost, design and application, three case studies have been included within this section. The first of the case studies features a feasibility study for a proposed system while the other two case studies provide an overview of existing systems.

CASE STUDY - Yew Tree Farm. Proposed constructed wetland designed by WWT Consulting for Catchment Sensitive Farming

A clear solution for farmers
CATCHMENT SENSITIVE FARMING

Site background

Natural England contracted WWT Consulting to carry out a feasibility study to assess the potential for using an agricultural Sustainable Drainage System (SuDS) to process surface runoff from a proposed new 100 capacity cattle barn and hay store at Yew Tree Farm, Harlton, Cambridge. A spring fed stream and ditch is located along the western boundary of the site and would be the receiving water course for any discharges.

Proposed design

It is recommended that clean and dirty drainage and yard water from the barn should be managed separately; roof water should be separated from inside and outside yard drainage. This would allow for lower level treatment of the less contaminated roof water with higher level treatment of yard runoff. The majority of runoff would be generated by the roof area but as it would be less contaminated it could be processed with a simpler swale arrangement (See Figure 20).

It is recommended that a series of primary treatment cells should be created adjacent to the swale to process the yard runoff. These would consist of four vegetated ponds connected using earth weirs and planted with marginal vegetation (Figure 20). The total capacity of the proposed system would be 150 m^3.

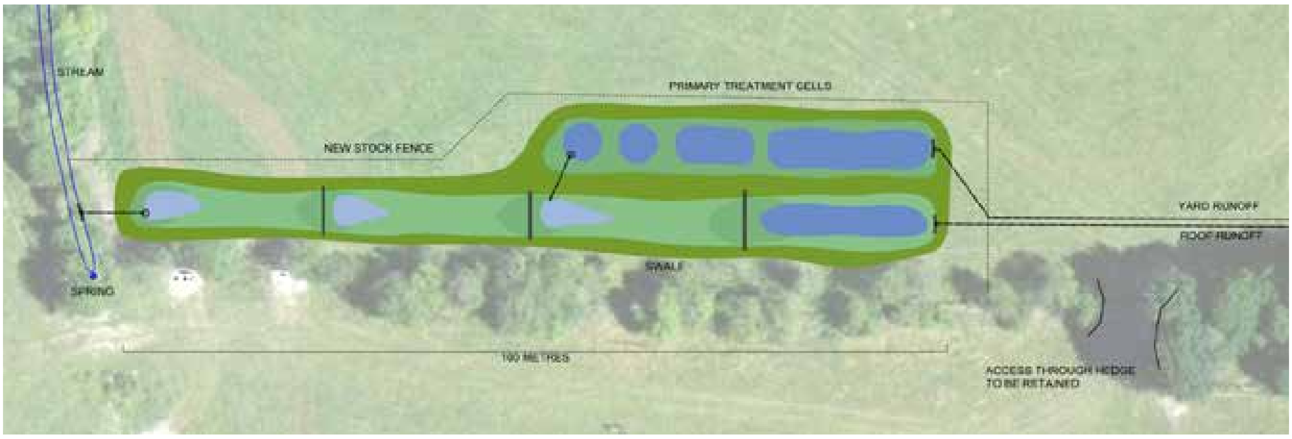


Figure 20. Proposed design.

The first two cells of the primary treatment stream have been designed to provide good residence time to increase suspended solid removal and treatment. The primary treatment system outfall would discharge midway down the swale providing additional polishing treatment and attenuation. The features could be left to colonise naturally or could be given a head start with seeding and planting. Marginal plants could possibly be sourced locally from elsewhere on the farm or bought in.

The clay content of the soils indicates very low permeability so that losses of processed water from the SUDS would not occur via infiltration and therefore, the primary treatment cells and initial suspended solid removal section of the swale would not require lining. An adequate seal could be achieved through puddling of the clay subsoil during construction.

Phosphorus removal

It may be necessary to insert a specific phosphate removal stage to improve the system's capacity for the removal of this nutrient. Modelling using the current proposed design configuration suggests that it would be difficult to reduce phosphate levels to below 15-25mg/l. This is significantly higher than the ideal final effluent target of 1mg/l. The addition of a crushed stone treatment cell of around 25m^2 by 0.5m depth could provide the additional removal required. This could be incorporated into the tail end of the swale or added to the end of the primary treatment cell series without compromising overall performance or attenuation capacity. Phosphate removal beds work well for a finite period of time; once the adsorption media becomes saturated the bed media will require renewal.

Construction

Construction of the system would not be technically demanding or require specialist equipment. It is therefore feasible that the excavation and land forming work could be carried out by the landowner using agricultural machinery such as a back actor. For indicative purposes an outline bill of quantities is presented in Table 26.

Table 26 – Indicative bill of quantities

Item	Description	Unit	Quantity
Conveyance pipe	150mm dia. pipe from roof drainage	m	60
Conveyance pipe	150mm dia. pipe from yard drainage	m	60
Pipe bedding	Granular fill	m^3	24
Sandbags	Sand bags in black UV stable polypropylene	n/a	115
Concrete	ST4/GEN3 concrete for sandbag fill	m^3	1.4
Manhole	Polypropylene manholes to protect throttle pipes	n/a	2
Fencing	Stock fencing to enclose system	m	140
Excavation	Material excavated to form features	m^3	740

Estimated costs

If the works were to be carried out by a contractor it is recommended to allow £5,000 to £8,000 for construction and materials. The major costs would be excavation and landscaping of the features and trenching of the 150mm pipe work from the barn to the system. If the landscaping works were carried out by the landowner this would reduce costs. In addition if plants for kick-starting were sourced from the farm this would provide further savings. For materials with landscaping and planting of farm sourced plants carried out by the landowner, it is recommended to allow £3,000-£5,000 for construction. Detailed design plus site supervision and support from a reputable consultant is recommended prior to undertaking the works. It is expected that this would cost between £3,000 and £5,000.

CASE STUDY - Powhillon Farm

At Powhillon farm on the WWT Caerlaverock Reserve in Dumfries and Galloway, a system was constructed to treat farmyard run-off and prevent nutrients reaching sensitive wetland habitats and a nearby water course. A feasibility study was conducted to determine soil types and topography and informal discussions with the regulatory authority, SEPA, took place to ensure their agreement with the wetland proposal. Construction of the farm wetland took place in November 2012 over the course of two and a half days and at a cost of £1,302, excluding the farmer's labour, fuel and use of his digger.

Dirty water is directed from the farmyard via a mixture of bunds and swales into a two-stage sediment trap and then into a newly planted, species poor, nutrient rich wet woodland. Run-off from an adjacent field is also captured in the woodland using a swale.

The profile of the sediment ponds maximises the collection of sediment. An initial sharp drop encourages sediment to settle out followed by a gradual slope to a vegetated strip. Each sediment pond measures 5 m x 4 m with a maximum depth of 1.1 m. The wet woodland element of the system covers an area of approximately 2,000 m^2. Emptying of the sediment ponds is expected to be required every three to five years, with the first of the ponds emptied more regularly than the second.

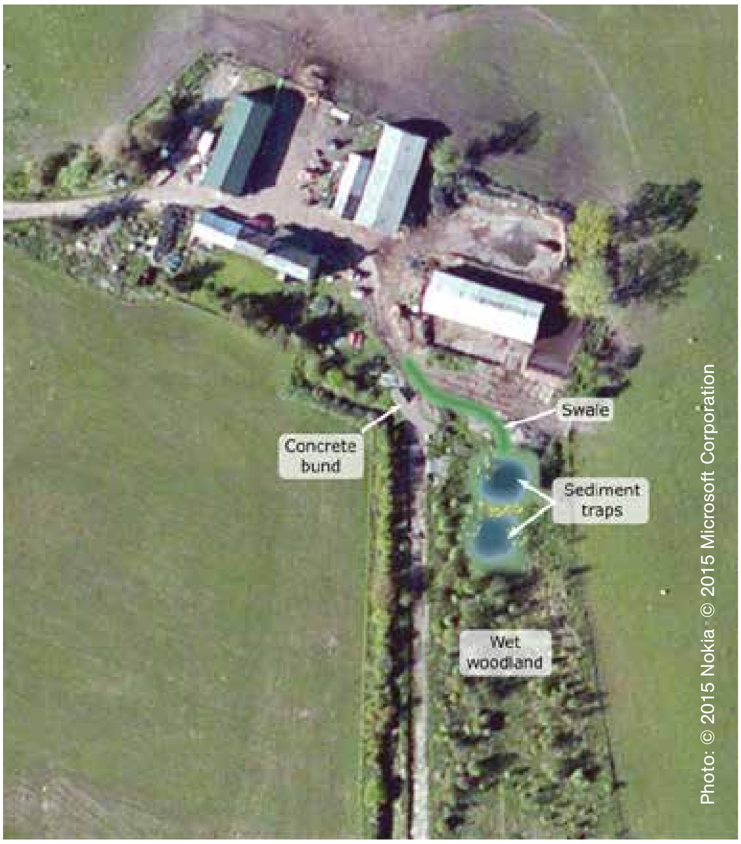


Figure 22. System diagram of Powhillon Constructed Farm Wetland.

The quality of the water has been regularly analysed to assess the efficiency of the system. The system is sampled at two points, the first where water enters the first sediment pond and the second at the end of the second sediment pond. The system has reduced total phosphorus concentrations between the inflow and second sample point by around 20% on average, however, the main reduction will occur as the water passes through the wet woodland. The system is working very well as a zero discharge system as any remaining effluent is reduced through evaporation and uptake by trees in the wet woodland.

A CSF/WWT video featuring the creation of the constructed wetland on the WWT Caerlaverock reserve can be accessed on the WWT Constructed Farm Wetlands webpage: www.wwt.org.uk/farmwetlands.

Table 27. Capital costs- Powhillon farm wetland (Includes cost of guiding swale).

Items	Cost
New gate Fitted	£130
Lorry load of hardcore	£550
6 m2 Concrete @ £87/m2	£522
Fencing materials	£100
Total cost of materials (this excludes labour and fuel/machinery use)	**£1302** (ex VAT)

Figure 23. Newly created Powhillon Wetland Treatment System.

Figure 24. Powhillon Wetland Treatment System - eight months after construction.

CASE STUDY - Old Castles wetland

The following case study has been provided by Fabrice Gouriveau.

Old Castles Farm in Berwickshire, Scotland is a mixed beef and arable farm. There is no separation between roof water and farmyard runoff. A wetland was constructed in 2004 to control pollution from the farm (farmyard, tracks, and septic tanks). It was constructed as part of a demonstration project by SEPA to investigate the effectiveness of ponds in treating diffuse pollution from farm yard runoff. The total cost was £5,000. The main pollutants were expected to be faecal pathogens, nitrogen, phosphates, organic matter, suspended solids and pesticides.

The wetland is located 0.5 miles from the farm, at the foot of the hill and occupies ca. 1 ha of land. It is composed of 5 ponds and shallow vegetated areas submerged at certain times of the year. The total impermeable area expected to contribute to the input to the wetland is 16,230 m and the catchment area draining into the wetland is 33 ha. It is fenced and surrounded by pastures (grazed by sheep in winter) from which runoff is expected to occur carrying suspended solids and nutrients. The wetland treats 90% of annual runoff from the steading and some field drainage. It also treats effluents coming from three septic tanks serving the farm house and farm cottages (design population: 24 people).

The first small pond, which is a former cattle watering area, acts as silt trap. This pond is up to 1.6 m deep. Field drainage also enters this through two pipes. Water leaves the first small pond through a pipe, runs through a long shallow vegetated area (20 m long, 15 m wide) and through a series of 3 small ponds (up to 1m deep) separated by short shallow vegetated areas. Logs have been placed between the ponds to create a serpentine flow path and increase sediment retention and treatment performance. Water then enters a large and deep pond (2,500 m^2 – 3,000 m^2, up to 1.70 m deep, planted with reeds) through a pipe passing under a bund (track).

Under normal conditions, water discharges from this largest final pond through a pipe back into an existing main drain and to a small burn. Under higher flows, when the level has risen sufficiently, water leaves the pond by a large vertical “stormwater outflow pipe” located at the northern part of the pond. This pipe controls the maximum level and maximum volume of the pond.

Figure 25. Old Castles Constructed Farm Wetland.

The wetland was planted with several species (e.g. *Phragmites australis, Typha latifolia*) at a density of 1 plant/m^2 and regeneration occurred. It is now fully vegetated with *Glyceria fluitans, Holcus lanatus, Lemna minor, etc*). It hosts a variety of wildlife including ducks, swifts and moorhen.

Reference: Frost, A. (2004). Old Castle steading runoff system design. Soil and Water, Scotland.

Table 28. Costs: Old Castles wetland

	Amount	Cost
Earth movements and pipe laying		
Moving machine to site:		£250
Four days work @ £25/hour		£800
Materials, labour (except for digger) etc.		
160mm perforated plastic pipe	200m	£570
160mm unperforated plastic pipe	80m	£230
200mm unperforated plastic pipe	110m	£670
300mm unperforated twinwall plastic pipe	13m	£150
300mm concrete pipe	30m	£200
Sleepers or similar	7	£140
Headwalls	3	£210
Headwalls with trash guard	1	£120
Manhole	1	£600
Fencing	180m	£630
Bulrushes (supply and plant)	800	£800
Planting Reed Canary Grass clumps	200	£300
Sowing grass	500m	£300
Total		**£5,970**

Constructed wetlands for high strength point source effluent

CASE STUDY - Produce World Yaxley

Produce World Yaxley is an organic vegetable processing site in Cambridgeshire. In 2007 a constructed wetland was built to treat the water produced by the vegetable washings on site. The farm produces ~ 170 m3 of vegetable washings per day (ARM, Undated) which was treated by chemical dosing prior to the construction of the wetland treatment system. This chemical approach had substantial labour requirements in terms of both operation and maintenance and was also considered to be out of line with the ethics of the operation (Froglife, 2011). As such, the less labour intensive, more environmentally friendly solution of a wetland treatment system was proposed. The original system designed by ARM consisted of a soil-based surface flow bed planted with *Typha latifolia* followed by a gravel-based sub-surface flow bed planted with *Phragmites australis*. Additions to this original design included the construction of a large lagoon at the beginning of the system and a smaller one after the second reedbed. Floating reedbeds were also added to the last section of the lagoon. Due to higher than expected loadings from the vegetable washings, further treatment stages were added, in the form of another reedbed and some aeration within the existing lagoon (ARM, personal communication). After a residence time of approximately ten days, the effluent is discharged into a nearby stream (Froglife, 2011). The system meets the EA effluent discharge consent limits of 30 mg/l suspended solids and 50 mg/l Biochemical Oxygen Demand.).

Figure 26. Wetland cell at Produce World Yaxley.

In addition to the benefits of water treatment, the system at Produce World Yaxley also supports a range of species. In 2009 two ponds were created adjacent to the reedbed system as part of a Froglife project which aimed to create amphibian habitat by creating ponds on agricultural land. As part of the project, Buglife carried out surveys in 2009 and 2010 to assess their provision for invertebrates. The study found a total of 657 invertebrate species over the two survey periods, 21 of which are either in the Red Data Book or Nationally Scarce. 82 other species were found to be uncommon (Froglife, 2011).

Further information on the original design of this constructed wetland can be found on the ARM website: http://www.armreedbeds.co.uk/. Information on the study carried out by Froglife can be found on their website: http://www.froglife.org/.

CASE STUDY - Integrated Constructed Wetlands (ICW) in the Anne Valley: effective rural water management through the reanimation of shallow emergent vegetated wetlands.

Dr. Rory Harrington, VESI Environmental Ltd. Euro Business Park, Little Island, Cork www.vesienviro.com

In 1987/88 the reanimation of a range of wetland types was undertaken in the 25km^2 Dunhill–Annestown catchment of coastal County Waterford, Ireland. The objective was to improve the water quality and ecology of the catchment through landowner participation towards recreating conditions associated with natural wetlands that had been lost over time, such as ponds, marshes and mires.

The project used local soil material for lining and water retention and the establishment of a range of aquatic vegetation types. It was further developed in 1994/96 to treat point-sources of polluted water which had compromised water quality of the receiving main water channel, its tributary streams, and contiguous coastal waters. These Integrated Constructed Wetlands have proven extremely effective in treating wastewater, as can be seen from the results displayed in Figure 27. They can also accumulate about 13t DM of reusable organic matter per ha per year, along with the retention of nearly all influent phosphorus and organic nitrogen. Whilst initially applied to treat farmyard soiled water and dairy washings, the approach - which evolved into what is known as the Integrated Constructed Wetland (ICW) concept - has subsequently proven effective in the treatment of a much wider range of polluted water sources, including domestic dwelling and municipal waste water, landfill leachate, mine drainage and waste waters from food and other industries.

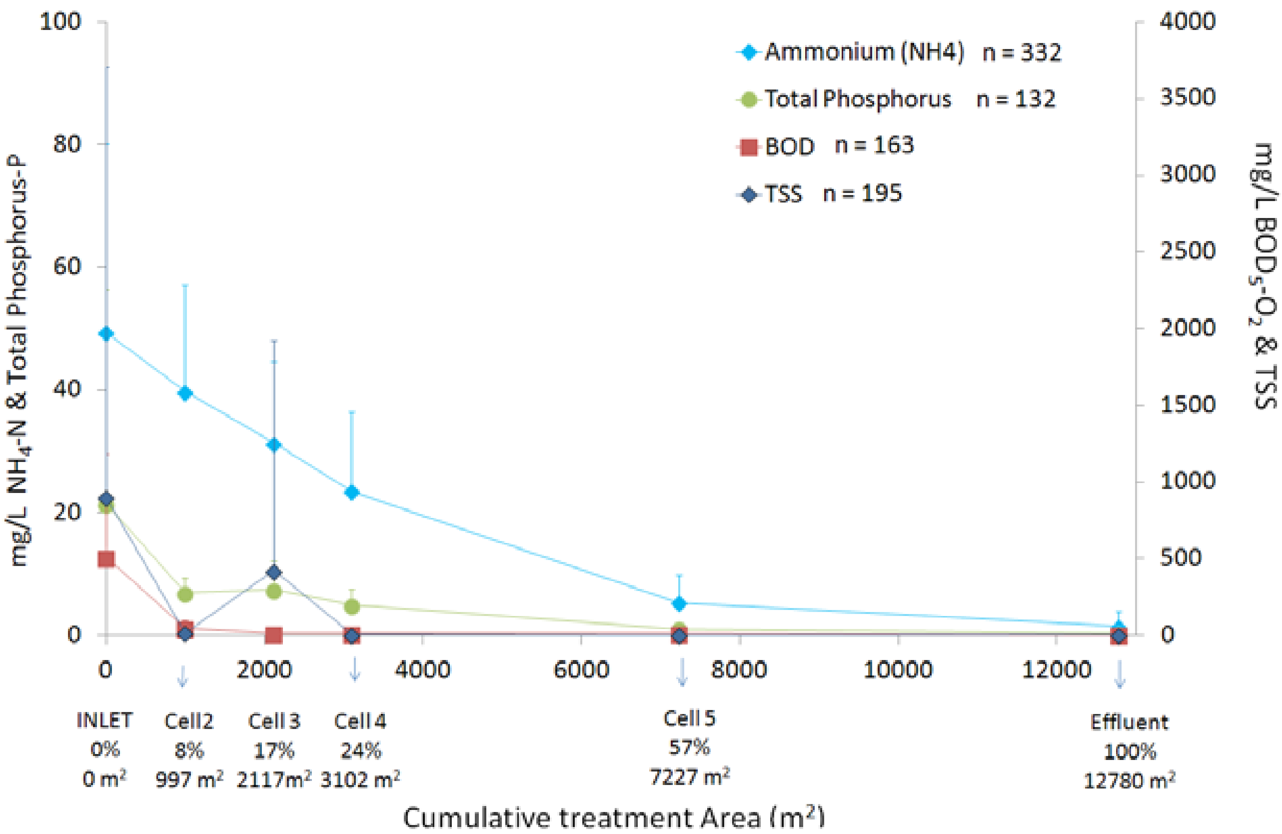


Figure 27. Figure showing decreasing nutrient concentrations with increasing cumulative wetland area.

The main elements in ICW design are: having adequate functional area relative to influent flow, soils that hold water and limit seepage (typically < 0.8mm/day) and configuration (several interconnected wetland cells – typically, but not exclusively 4, with a length to width ratio of about 4 to 1). Water is allowed to flow from one cell to the next through an adjustable weir that allows for the accumulation of organic matter at their base. The vegetation comprises emergent plant species that are rooted in the wetland soil and associated detritus, and grow tall above the through-flowing water.

In applying the ICW concept it is recognised that land is a limited resource for which different uses may compete. The development of this *integrated* concept arose from the limitations associated with addressing just one aspect alone - water treatment itself, which ignores the links that wetlands have with nature in the wider landscape, not to mention the needs of human society. As a result, there is often pressure to restrict, even to the point of under-sizing, the land area required for treatment, maintenance and operation. Other important considerations are the ways the wetland infrastructure fits into the landscape. Here, most importantly, principles of optimal-design apply: functionality, durability and aesthetics. These principles apply at all scales of application, from a single dwelling to large-field situations treating agricultural, domestic, municipal or industrial waste water.

Figure 28. Aerial view of Integrated Constructed Wetlands (ICW) in the Dunhill – Annestown Valley, Co. Waterford treating land runoff and diffuse pollution from agriculture.

The ICW concept that evolved in the Anne Valley catchment since 1994/96, with its focus on the explicit integration of water management-needs with that of landscape-fit and enhanced biodiversity, has been particularly effective in not only addressing water quality requirements but also for its social, economic and environmental coherencies. Whereas the acquisition or even leasing of the necessary land area required for ICWs continues to be a challenge, it is not insurmountable. It is especially achievable on the basis of comparative cost when contrasted with other treatments (ICW systems typically cost > 60% less to construct and >90% less to maintain and operate than conventional treatments and practice methods (Culleton *et al.,* 2005; Doody *et al.,* 2009)). When considered in conjunction with the multiple benefits delivered, ICW can constitute one of the most economically, social and environmentally effective approaches possible to land and water management (Harrington *et al.,* 2009).

Figure 29. Integrated Constructed Wetlands (ICW) for treating farmyard waste waters in the Anne Valley catchment area, Co. Waterford.

CASE STUDY - Greenmount Campus

Thanks to Martin Mulholland and Greg Forbes for their information on the Greenmount Campus Constructed Wetland and their help in putting this case study together. This case study has been updated to reflect changes to the farm system constructed wetland.

Design

In 2004 a constructed wetland was created at the Greenmount Campus in Northern Ireland to treat effluent arising from the dairy farm on site. The waste water effluent was composed of farmyard runoff, winter runoff from unroofed silage clamps and parlour washings from the dairy unit (Forbes *et al.,* 2009).

The system is on a particularly large scale, with five ponds covering a combined area of 1.2 ha (Forbes *et al.,* 2009), which is roughly double the size of the runoff area. These dimensions are in line with the NIEA/SEPA constructed farm wetland design guide sizing recommendations (Carty *et al.,* 2008). The size of the constructed wetland is necessary to cope with the extremely high concentrations of both BOD and phosphorus present in dairy washings. Due to the topography of the site, the ponds were arranged so that the water could flow through the system through gravity. The high clay content of the soil on site meant that lining was unnecessary after the soil had been sufficiently compacted (Forbes *et al.,* 2009).

Owing to the size of the wetland and the relatively small volume of effluent entering the system (~3 m^3/day), there is no outflow from the wetland between May and September each year. In the winter, there is discharge from the wetland due to increased rainfall over both the wetland and its catchment area (Forbes, 2014).

Figure 30. Greenmount Campus constructed wetland diagram. Modified from diagram in Forbes (2014).

Subsequent alterations/modifications

Farm Infrastructure modifications

Of the three original sources of wastewater (dairy milking parlour washings, dirty water runoff from livestock yards and winter runoff from unroofed grass silage pits), volumes from the first two wastewater sources were reduced in 2013 as a result of several modifications to the farm infrastructure. These modifications were made purely to update the farm buildings and accommodate the complete herd at milking time within one building rather than a move to improve the constructed wetland performance (*Pers. comm.* Martin Mulholland).

As the modifications removed the need for cows to stand outdoors waiting to be milked and to walk across concrete yards from the cubicle shed to the milking parlour, it is probable that the water quality of runoff from this area will have improved. Winter runoff from unroofed grass silage pits was also eliminated when new, roofed silage pits were installed. This was done to allow the covered sheds to be used for additional purposes when not full of silage. The runoff from the silage pits now goes to a slurry store where it is contained until it can be spread on the land. (*Pers. comm.* Martin Mulholland). In addition, the volume of water requiring treatment by the constructed wetland is further reduced as a result of a rainwater harvesting system having been installed on the 4,500sq metre roof of the new dairy unit (DARDNI, 2014). Roof runoff is stored in a tank underground and, after passing through a UV filter, is used for the volume wash header tanks and for livestock drinking water (DARDNI, 2014). Although inputs from several sources are reduced, washings from the parlour have increased by ~ 50% as a result of an increase in capacity of the milking parlour which now serves a dairy herd numbering 180 (CAFRE, 2013).

Recent outlet BOD concentrations average ~ 2 mg/l (*Pers. comm.* Martin Mulholland) which is lower than the average of 8 mg/l seen in the past. However, there have been other changes in the management of the farm and natural alterations in the ICW due to natural succession; therefore it is not possible to assume that this reduction in BOD is linked to the changes in effluent input (*Pers. comm.* Martin Mulholland).

Constructed wetland alterations

Alterations have occurred in the constructed wetland as the system has matured. These are mainly changes in vegetation due to natural species dominance. The main changes in vegetation composition are that *P. australis* has encroached heavily into the first pond and into the area of *T. latifolia* in the second pond. In addition, due to a build up of sediment in the initial pond in the system, this has been transformed from a relatively large area of open water to being completed grassed over (Forbes, 2014). This is possibly due to large volumes of deposited sediment from the farmyard before the improvements were made to the farm infrastructure. Very little maintenance work has been carrried out to date on the wetland, however it is expected that the first pond will require de-silting in the next 4-5 years (*Pers. comm.* Martin Mulholland).

Water quality

As the treated water is discharged into a water body, discharge consents for the system of 40 mg/l for BOD and 60 mg/l for Suspended Solids were issued by the Northern Ireland Environment Agency. The water quality of the system was intensively monitored and high levels of treatment were achieved, with BOD concentrations well within the discharge consent limit (See Table 29). This level of treatment is likely due to the high hydraulic retention time of the constructed wetland (60-100 days) (Forbes *et al.,* 2009).

Table 29. Water quality results. – Mean values. DARDNI (2013).

Indicator Measured	Inlet	Outlet	% Reduction
BOD5 (mg/litre)	1080	7.6 *	99
Total P (mg P/litre)	46	1.2	97
NH4 (mg N/litre)	5.6	0.02	99
Total Coliform ('000 cfu/100ml)	830	<0.1	>99

* NIEA Discharge Consent: BOD 40 mg/litre.

Wildlife value

The system attracts a range of wildlife. Snipe have been observed in winter, damselflies and dragonflies in summer and sticklebacks have been found in the final, deeper pond. The plants, including Common Reed (*Phragmites australis*), Yellow Flag Iris (*Iris pseudacorus*) and Bur-reed *Sparganium erectum*, have established well (Forbes *et al.,* 2009).

Economics

Extensive financial information is available for the construction of the constructed wetland at Greenmount Campus (See Table 30). Costs calculated in 2007 estimated a total capital cost of £29,296 - £39,707/ha (Gouriveau, 2009). The cost per square metre was around 35% higher than smaller, simpler constructed farm wetlands in Scotland at £5/m^2 rather than £3.3-3.5/m^2 (Gouriveau, 2009).

The Northern Ireland Environment Agency (NIEA) discharge consent application fee was £120 with an annual sampling fee of £467 for 2 years monthly sampling (Mulholland, 2014). However, as the consent criteria was met during this period, sampling is now conducted annually (Mulholland, 2014).

Table 30. Details of the capital costs associated with the construction of the CFW at Greenmount College (Source: DARD; Costs estimated in February 2007). (Table taken from Gouriveau, 2009).

Activity	Cost
Bulldozing	£2/m^3
Loading, transporting and levelling soil	£3.5/m^3
Shaping banks	£0.4/m^2
Pipe work	£17/m
Earth movement per pond	£1,983
Total earthworks (5 ponds, 50 m x 24 m)	£9,916 (£16,527/ ha) *1
Connecting pipe work between cells: 250 m at £17 m^{-1}	£4,250
Connecting dirty water to CFW: 350 m at £17 m^{-1}	£5,950
Overall pipe work	£10,200 / ha *2
Inspection chambers: 6 chambers at £50 each	£300 / ha *2
Plants	£4,500
Planting labour	£3,000
Overall planting	£7,500 - £12,500 ha
Fencing*3	£1,380/ha
Total estimated cost*4	**£ 29,296 - £ 39,707/ha**
Estimated land cost (1.2 ha lost in total, at £250 ha-1)	**£300 / year**

*1 Earthworks costs are assumed to increase linearly with increasing area for simplification (in reality, a large part of the cost is independent of the size incurred initially by machinery renting).
*2 Pipework and inspection chamber costs depend on the number of cells and distance between them.
*3 Fencing cost is not available (fencing might not have been implemented), but was estimated for 460 m fence (160 m x 70 m; 1.12 ha area) at £3 m^{-1}.
*4 Excluding land cost and maintenance.

CASE STUDY - Sheepdrove Organic Farm

This system was designed to take all the wastewater from the conference centre, the on-site abattoir and also on-site cottages. It consists of a vertical flow bed, settlement pond, aeration cascade, overland flow reedbed and a wildlife pond. The final stage is a fishing pond. For more information on this system please see the Sheepdrove Organic Farm website: http://www.sheepdrove.com/.

Figure 31. Sheepdrove WTS diagram.

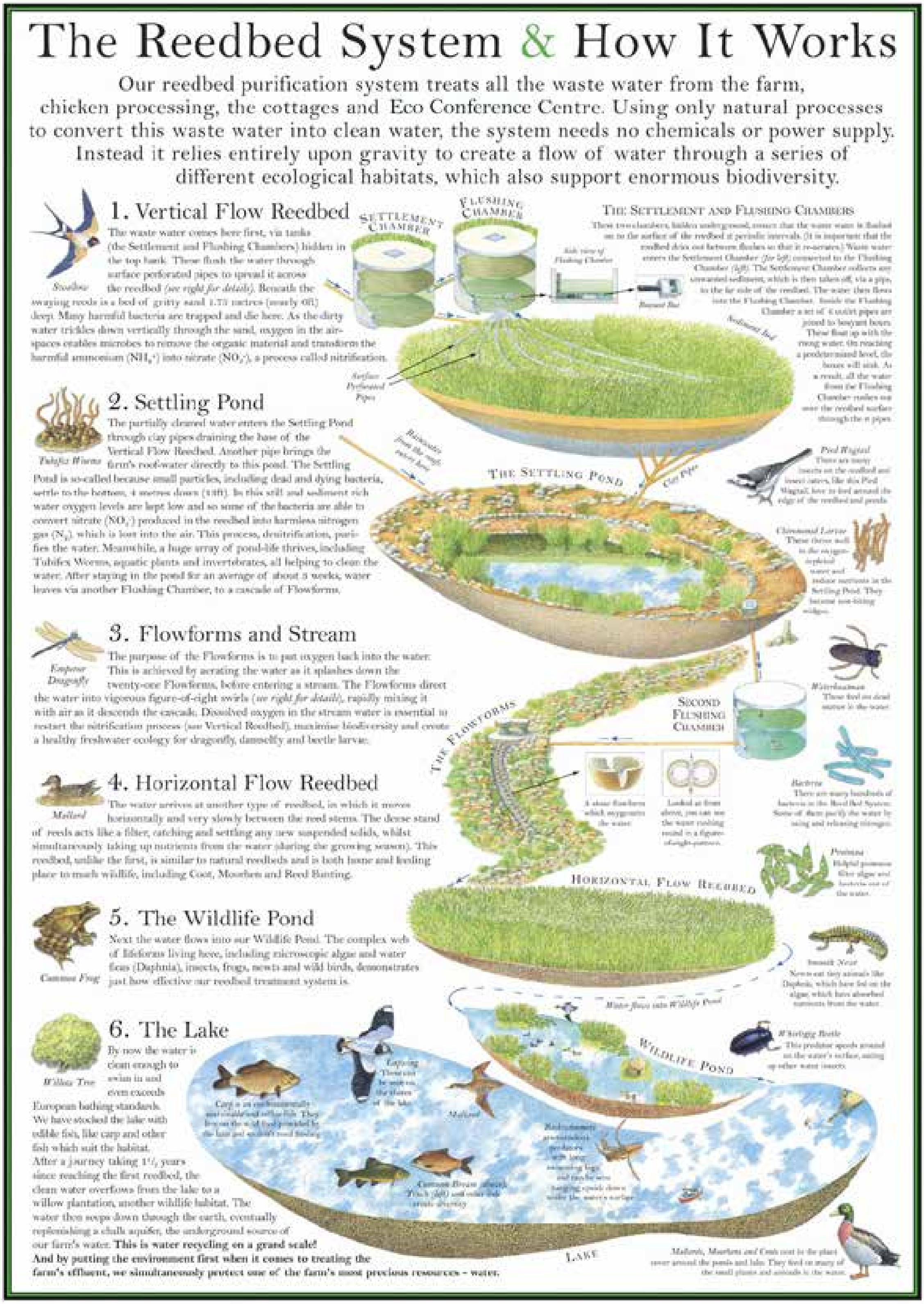


Image reproduced with permission from Jez Elkin, Sheepdrove Organic Farm.

10 Further sources of information

Organisation	Website
Catchment Sensitive Farming	https://www.gov.uk/catchment-sensitive-farming-reduce-agricultural-water-pollution
CIRIA	http://www.ciria.org
Constructed Wetlands Association	http://www.constructedwetland.co.uk/
Environment Agency	https://www.gov.uk/government/organisations/environment-agency
MOPS Project	http://mops2.diffusepollution.info/
Natural England	https://www.gov.uk/government/organisations/natural-england
Susdrain – The community for sustainable drainage	http://www.susdrain.org/
Scottish Environmental Protection Agency	www.sepa.org.uk
Wildfowl and Wetlands Trust (WWT)	www.wwt.org.uk/farmwetlands

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The Wildfowl & Wetlands Trust (WWT) is one of the world's largest and most respected wetland conservation organisations working globally to safeguard and improve wetlands for wildlife and people. Founded in 1946 by the late Sir Peter Scott, WWT also operates a unique UK-wide network of specialist wetland centres that protect over 2,800 hectares of important wetland habitat and inspire people to connect with and value wetlands and their wildlife.

Catchment Sensitive Farming (CSF) is a partnership project between Defra, Natural England and the Environment Agency to help meet the objectives of the Water Framework Directive. CSF provides training and support to farmers in priority catchments in England on a range of farm practices and infrastructure improvements that reduce diffuse water pollution from agriculture. Evaluation of the CSF project since 2006 provides clear evidence that CSF is encouraging action from farmers that is delivering improvements in water quality to help achieve Water Framework Directive (WFD) and Sites of Special Scientific Interest (SSSI) objectives.

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WWT Wetlands for life