Constructed farm wetlands - treating agricultural water pollution and enhancing biodiversity

Produced by Wildfowl and Wetlands Trust with Natural England

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This guidance is aimed at farm advisers, primarily Catchment Sensitive Farming Officers, as well as other Natural England and Environment Advisers 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, location, design, costs, permits required and case studies.

Foreword

Rivers, lakes, ponds and coastal waters are important habitats and part of our landscape, as well as providing drinking and bathing water. Water quality and biodiversity have improved dramatically but are still impacted by diffuse water pollution from agriculture.

Constructed wetland systems can be designed to create wetland habitats, reduce pollution on farms, control flooding and enhance public enjoyment of the countryside. In order to be effective their design needs to be appropriate for the site and pollutant issues and this guidance aims to give an introduction to constructed farm wetlands and where to seek further advice and support.

Catchment Sensitive Farming (CSF) provides training and support to farmers on a range of farm practices and infrastructure improvements that reduce diffuse water pollution from agriculture. Constructed wetlands and sustainable drainage systems (SuDS) can be used to trap and treat pollutants, as part of a CSF approach to tackling agricultural pollution.

Wildfowl and Wetlands Trust (WWT) have experience in design, construction and maintenance of constructed wetlands for treating pollutants and creating wetlands and amenity features at sites across the world.

WWT worked with CSF to develop this guidance for advisers, on the role of constructed wetlands and sustainable drainage systems on farms. How and where to use these options, singly or in combination, to reduce the source of a pollutant, break the pathway of pollution and protect water bodies or sensitive habitats is described.

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1 Introduction

The purpose of the guidance is to provide a basic introduction to the benefits and use of farm wetlands to reduce diffuse water pollution from agriculture (DWPA) and enhance biodiversity. The aim is to provide guidance on the options, suitability, placement, design, construction and cost of farm wetlands and sustainable drainage systems.

In this guidance a broad definition of farm wetlands is used to cover rural sustainable drainage systems (Rural SuDS), including sediment ponds and traps, bunds and swales, as well as the creation of artificial wetlands to improve water quality and how these options can be used together. Please refer to Section 3 for more information on each of these features.

The aim is to enable Catchment Sensitive Farming Officers (CSFOs) and other advisers, including Natural England local land management advisers and Environment Agency Officers, to understand how and where to use these options, as part of a suite measures that could be implemented on farms to reduce water pollution.

Farm wetlands can be used to treat and control pathways of agricultural pollutants, provide some attenuation of flood flow and create wildlife habitats and public access opportunities (See Figure 1). They can be used as an additional option to the existing suite of measures available and require careful targeting and design as part of an overall farm water management plan.

Figure 1. Farm swale (WWT) – see section 3.

This guidance will build on existing available information and cover 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 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.

1.1 Why use wetlands?

Wetlands can be used to improve water quality. They can successfully treat a range of pollutants associated with agricultural wastewater including: Biological Oxygen Demand, suspended solids, ammonia, nitrate, phosphate, faecal indicator organisms (FIO's) and some pesticides.

- With careful and specific design wetlands provide many opportunities for wildlife habitat especially if receiving less contaminated water.
- They are a practical, sustainable, environmentally friendly, aesthetically pleasing option to treating contaminated water in rural areas
- They can be designed to provide additional benefits such as biofuels, e.g. using willow coppice systems and for wildlife.

1.2 Type of water that can be treated

Wetlands can be used to treat lightly contaminated water from farmyards or as a result of run-off from roads, tracks and fields. They are one of the best examples of a measure that will provide a wide range of additional benefits to people and wildlife including cleaning and retaining water and creating new habitats. Some of the diffuse pollutants that can be effectively captured from agricultural sources are:

Nitrates and **ammonia:** These are extremely soluble. A proportion of fertiliser or manures not used by crops are lost through the soil profile to groundwater or into rivers through drains or subsurface flow.

Phosphorus: can also be carried in this way, but more commonly binds tightly to soils and is lost through surface run-off, commonly from tramlines, compacted fields and stubbles. The majority of phosphate is delivered via field drain flow and SuDS are an effective mitigation measure for this.

Sediment: results from soil erosion from fields due to inappropriate livestock or soil management, and when livestock damage riverbanks or churn up sediment within the riverbed.

Agrochemicals: such as sheep dip and crop protection pesticides, which can be washed into surface or ground waters even if correctly handled and applied. The design of integrated wetlands systems for treatment of agrochemicals is in its infancy in the UK and the Environment Agency (EA) advocates the use of a biobed, biofilter or total containment and disposal to land.

Microbial pathogens: from manure, can be washed into surface waters by rain or where livestock have direct access to watercourses.

Typically, 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 (See Figure 2).
- 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 CSF measures.

Measures to reduce the sources of pollution should put in place first before considering use of constructed wetlands. For example, alleviation of soil compaction and other improvements in soil management to reduce the risk of soil run off or clean and dirty water separation of farm yard run off. In CSF catchments, soil husbandry and/or infrastructure farm visit combined with use of the Capital Grant Scheme would be a preliminary step to make this improvements in farm practices or infrastructure and a CSF water management plan would help identify if and where a constructed wetland may fit in. Regularly used livestock yards should drain to a slurry store or dirty water systems under current Silage, Slurry and Agricultural Fuel Oil (SSAFO) regulations. These regulations are currently under review.

Figure 2. Runoff into farm track (WWT).

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

- Septic tank discharges - problematic if water tables are high and soakaways are ineffectual or soil conditions do not allow infiltration
- Silage effluent - a high strength organic pollutant which can be produced in significant volumes particularly immediately after ensiling and must be collected and stored, either in a dedicated silage effluent tank or in slurry storage and spread on land in accordance with good agricultural practice.
- Dairy production waste water.
- Abattoir waste water.

There are current regulations to control agricultural waste and water pollution, and wetlands designed to treat these effluents will require a discharge consent from the Environment Agency. For more information see Section 2.2 and the Environment Agency website pages on Water Resources and Agricultural waste.

1.2 How are wetlands used

Wetland design exploits the natural properties of wetlands. A variety of conditions are created to provide storage, uptake by plants and a controlled discharge. Examples include: having deep water areas which can encourage settlement of solids; open water allowing ammonia volatilisation and UV breakdown of pathogens; and encouraging an interface of anaerobic and aerobic zones within marsh areas to facilitate nitrogen removal. The way in which these different wetland habitats are used and combined within a constructed wetland system is dependent on pollutant type and volume of water. Section 2 provides more details on the various wetland options.

Wetland options 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 3).

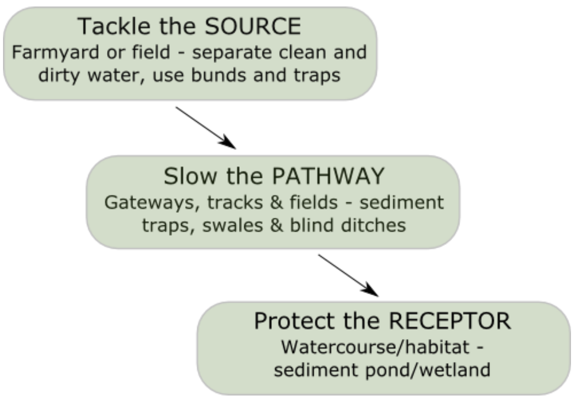


Figure 3. Source, Pathway & Receptor

Wetland options can be used in addition to existing options under Entry Level Stewardship (ELS), Higher Level Stewardship (HLS) and Catchment Sensitive Farming (CSF). The document entitled 'NE230 Farming for cleaner water and soils' outlines some of these, as does the document An Inventory of methods to control DWPA (Newell Price *et al*., 2011).

1.3 Multiple benefits (Ecosystem services)

1.3.1 Benefits

A major advantage of farm constructed wetlands is that they can be designed to provide more than one benefit and, among other things, can play a particular role in:

***Flood control* -** Wetlands deliver a wide array of hydrological services, for instance, swamps, lakes, and marshes can assist with flood mitigation, promote groundwater recharge, and 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 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

***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.

Figure 4. Ragged-Robin Lychnis flos-cuculi

1.3.2 Focus on habitat provision

Constructed wetlands 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 can be easily and cheaply modified in order to maximise the potential benefit for biodiversity, while still providing optimal water treatment. See Box 1 for an example.

Box 1. The Millennium Reedbed 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 amphibious*) and 281 moth species, 9 of which are nationally scarce and 50 species from the UK BAP (Biological Action Plan). The system meets its discharge consent limits of 40mg/l suspended solids and 20mg/l BOD.

1.4 Limitations of using wetlands

Wetlands are not always a suitable solution in all locations due to constraints in topography and land availability. The Scottish and Northern Ireland Design Manual (Carty *et al*., 2008) provides a useful summary of limitations:

- Constructed Farm Wetlands (CFWs) have a relatively large land requirement (if an efficient treatment is to be achieved) compared to other methods of mitigating diffuse water pollution and managing surface water runoff. However, due to their potential to provide additional benefits such as biofuel production, low construction and maintenance costs and habitat provision they can be an economically viable solution.

- Removal of pollutants may vary during the year (less efficient in winter, when temperatures and biological activity are lower) and in the long-term due to seasonal weather patterns and variations in the inflow of pollutants. In some circumstances pollutants might even be released, but this can be minimised by the use of individual cells and by designing the system for extreme rainfall events.

- Wetlands may emit greenhouse gases such as methane, nitrous oxide and ammonia but conversely also play a role in carbon dioxide capture.

- Ponds and wetlands may raise safety and health concerns for humans and livestock because they contain standing water. Such concerns can be minimised by the use of shallow ponds, gently sloping sides, marginal vegetation, fencing and by raising public awareness. There should be no access by livestock to any wetland feature to avoid trampling and faecal inputs. Areas of standing water can also attract wild birds and therefore any bio-security risks should be discussed with your vet or animal health specialist.

- A wetland will only function correctly where it receives an appropriate type and volume of waste that it was designed to treat. It is not a magic solution, and serious pollution and potential legal consequences can arise from passing additional waste or volume to such systems.
- Care should be taken to avoid excessive flow volumes of even lightly contaminated water during storm or run off events which can flush pollution into a watercourse and will not allow a residence time sufficient to treat the water adequately.
- A reed bed or constructed wetland is not maintenance free and should be maintained in accordance with its design.

2 Types of farm wetlands

Wetlands present a range of options for pollution control from low cost intervention (e.g. swales) to higher cost designed, constructed and planted wetlands. Table 1 outlines the main constructed wetland types; 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. Cost is an important factor in the decision making process and both capital and maintenance costs are indicated. The decision tree has been created to enable a quick assessment of the options available (Figure 6). Figure 7 illustrates the potential placement of wetland features on a farm.

Figure 5. WWT Slimbridge Millennium reedbed system (WWT).

2.1 Summary table of wetland options

Table 1.Wetland options

Wetland type	Star rating (complexity & cost)	Typical use for sources from	Indication of capital cost *	Permitting required	Case studies (see annex I)
Swale	★☆	Tracks and fields	£10-15/m^2	No	
In-ditch wetland	★★☆	Fields	£895 in LEAF case study	Consult	LEAF Green Hall Farm
Sediment ponds	★★	Fields and tracks in conjunction with swales	£5-100/m^2 **	Consult	MOPS, Powhillon
Constructed wetlands (diffuse effluent)	★★★☆	Lightly contaminated yards	£3.3-3.5/m^2	Possibly	India wetland, Scottish CFW's
Constructed wetlands (point source effluent)	★★★★☆	Farmyards and fields	£5/m^2 – 100/m^2	Yes	Greenmount Campus

Key: 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

Lower ecological value, poorer water quality treatment.

Medium ecological value, moderate water quality treatment.

Potential for high ecological value, high water quality treatment.

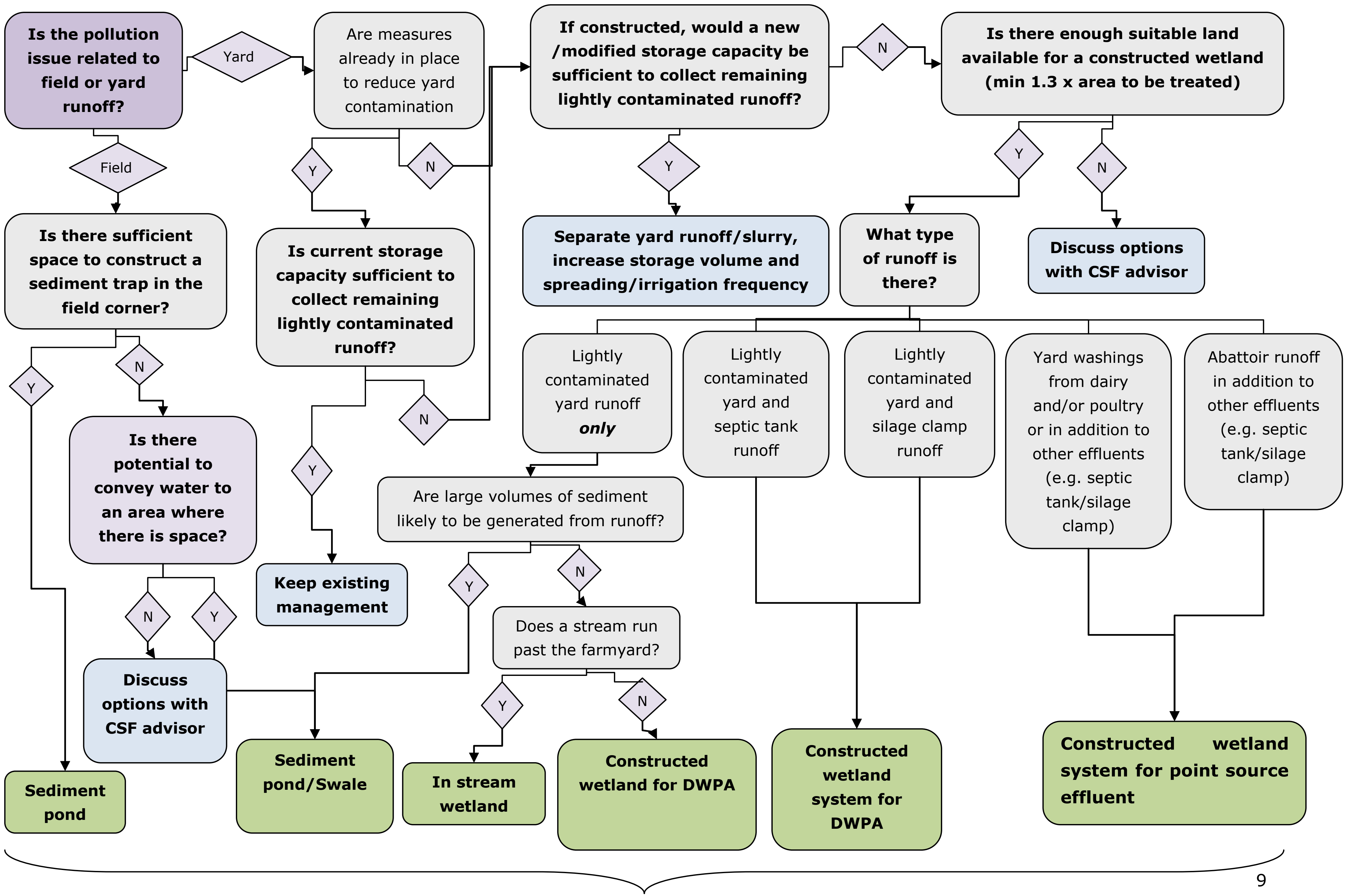


Figure 6. Decision tree to choose suitable wetland option. (Adapted from Carty et al.,2008 Design Manual for Scotland and Northern Ireland).

Figure 7. Potential placement of wetland features on a farm.

2.2 General consent issues

Certain activities are likely to require consents from the relevant authorities such as the environment agency. As a general rule, the following activities are most likely to be subject to EA consents but see the table below for further details:

- Working in, on, under or within 10 m of a watercourse.
- Discharge of dirty water.

Key considerations to take into account are:

- The source and strength of the effluent. Wetlands are currently not an option for pesticides, silage effluent and slurry.
- Volume.
- Frequency and timing of release.
- Potential impact on receiving watercourse.
- Where wetland systems are collecting low strength pollutants and are not likely to have an impact on a receiving watercourse or groundwater, a permit should not be required.

An additional consideration to be taken into account is that barriers should not impede the passage of fish such as eels. Eels can travel over land and around some barriers, but the risk of obstructing their free passage will need to be considered as part of the application. Guidance can be found at Pollution Prevention Guidelines: Works and maintenance in or near water (PPG5) (SEPA, EA, EHS) and DEFRA's Codes of Good Agricultural Practice for the Protection of Water, Soil and Air. In addition, one or more of the following consents are likely to be required:

Flood Defence Consent – main rivers	• This is administered by the EA if it is a main river. • *"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"* (Environment Agency 2013). • 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 *"activities do not cause or make existing flood risk worse, interfere with* [the EA's] *work, and do not adversely affect the local environment, fisheries or wildlife"*. • Please click here for further details on how to apply.
Flood Defence consents – ordinary	• 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

watercourses	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). • "*An ordinary watercourse can be all rivers and streams (other than main rivers) and all ditches, drains, cuts, culverts, dikes, sewers (other than public sewers) and passages, through which water flows*" (EA 2013).
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. • If impounding a stream or river an impoundment licence will be required. Click here for more details.
Impoundment licence	• Required if impounding a stream or river. Click here for details.
Environmental Permit	• Issued by the Environment Agency and required for the discharge of dirty water, to watercourse or to groundwater. Please click here for details of how to apply.
EA Waste exemption license	• Required for import or export of materials • "*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. If silt spreading – Spread under an exemption (D1 deposit of dredgings) there is no charge for this exemption*" (TIN099 Natural England, 2011). • "*Any excavated material may be classified as a 'waste' and its use may need a waste exemption (U10 and/or U11) from the Environment Agency*." (TIN099 Natural England, 2011).

2.3 Lining

If the wetland is to be constructed in a source protection zone for groundwater a liner will be required to ensure there is no discharge to ground. Artificial liners will also be required on soils with less than a 20% clay content. Contact your local EA office to discuss the project from the outset to clarify liner requirements.

3 Farm wetland options

The following sections provide guidance on each wetland type describing 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 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.

3.1 Swales *(1-2 Star systems)*

3.1.1 Description of swales

A swale is a broad vegetation lined channel or shallow 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 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 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
- Swales can be used as part of an integrated system e.g. alongside a track, discharging into a sediment pond

Figure 8 shows the wet swale at WWT Welney which is used as part of a treatment system for the centre building wastewater. It is planted with a range of wetland plant species to be visually attractive and provide habitat.

Figure 8. WWT Welney - wet conveyance swale

Table 2. Advantages and disadvantages of swales

Advantages	Disadvantages
Low capital cost – cheaper than piped system,	Larger land requirement than traditional pipes (minimum 0.6m wide).
Can be constructed by the farmer/landowner (1-2 days).	Not suitable for high strength effluents. i.e. dairy runoff, septic tank runoff, unless the swale is lined.
Easily and cheaply managed and maintained as blockages can be easily identified and removed.	Not suitable for steep gradients (Greater than 2 ^{o}).
Added ecological value – further enhanced if permanently wet areas are included.	Require regular maintenance such as mowing and de-silting.

3.1.2 Application of swales

Swales, if lined or constructed on clay rich soil, can be used for the removal of nitrates. However, in areas with sandy substrates, contaminated water may pose a pollution risk if swales are designed as infiltration channels. Swales can be used to convey sediment rich water from farmyards and fields to sediment traps, and they may need periodic management to prevent clogging. Swales 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.

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.

*Figure 9. Rock check dam in a swale reducing water flows (*Photo Dam Pendegali*)*

3.1.3 Design of swales and check dams

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 Christian/NIEA (2006).

Table 3. Swale design principles

Swale Design	• A width ranging between 0.6-3.0 m. • The wider the swale the more opportunities 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 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 concrete. Research has indicated that permeable barriers function more effectively, allowing temporary ponding of water behind them but also slow infiltration (EA, 2012). At low flows, water ponds behind the structure slowing flow rates. At high flows, water flows over or through the structure, so flows are not impeded causing backing up and flooding.
Planting	• Plant with native plants taking care not to seriously impede storm water passage. The plants will provide foraging and breeding habitat for invertebrates, amphibians, birds, reptiles and mammals. • 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.

3.1.4 Cost of swales

Costs are generally low as farmers can create these systems on their own using local planting material and natural regeneration. Water retention can be improved if check dams are used. Low cost options include the use of wooden structures. Table 4 provides an outline of capital and maintenance costs. Capital costs will vary depending on how much excavated material there is and if there is a convenient disposal method.

Table 4 Capital and O&M costs, Swales (CIRIA, 2007)

Capital costs	Annual operation and maintenance costs
£10-15/m^2 of swale area.	£0.10/m^2 of swale area.

3.1.5 Consents

Consents are usually not required if the swale is not in, on, under, within 10m or discharging into a watercourse, or impacting on groundwater.

3.1.6 Management & Maintenance of swales

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
Bunded swales may require periodic cleaning between September and March. Undertaken every two or three years for small traps or a third each year for larger traps	
Periodically reinstate shallow pools in the same location or elsewhere along the channel.	

3.1.7 Further guidance

TIN 099 Protecting water from agricultural run-off - water retention measures

CIRIA 2004 Sustainable drainage systems: hydraulic structure and water quality advice, CIRIA C609

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

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

Environment Agency (2012) Rural SuDS Guidance Document gives a useful summary of the attributes of a good check dams

3.2 In-ditch wetlands *(2-3 Star systems)*

3.2.1 In-ditch wetland 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 10 shows an example of how these can look.

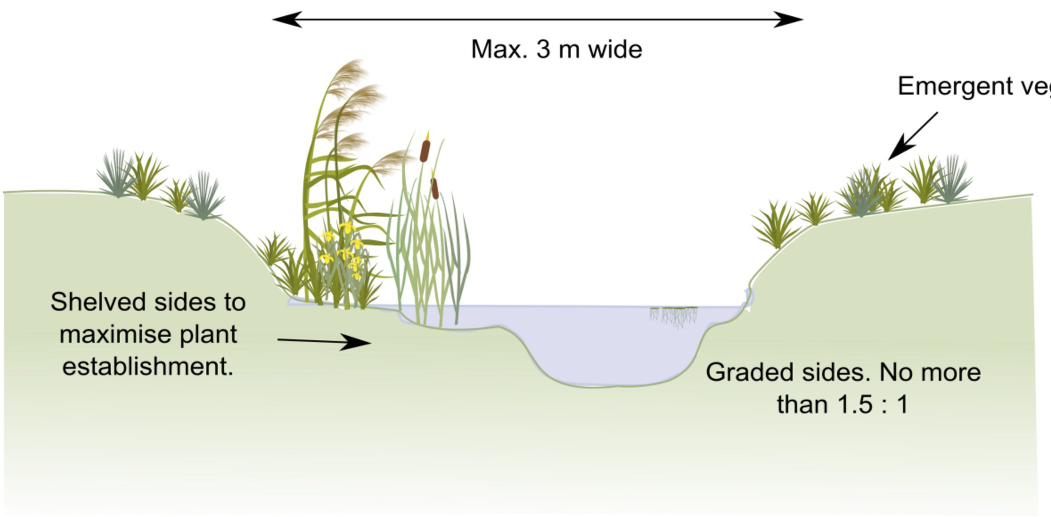


Figure 10. Cross section through an in-ditch wetland

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.	
Easily and cheaply managed and maintained.	
Small land requirement as existing ditch is simply widened.	
Can be constructed quickly (1-2 days).	
Opportunity to create additional ecological value.	

3.2.2 Application of in-ditch wetlands

- 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 11). 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 amphibious*) and so form valuable wildlife corridors.

Figure 11. In-ditch barrier (LEAF & EA, 2009)

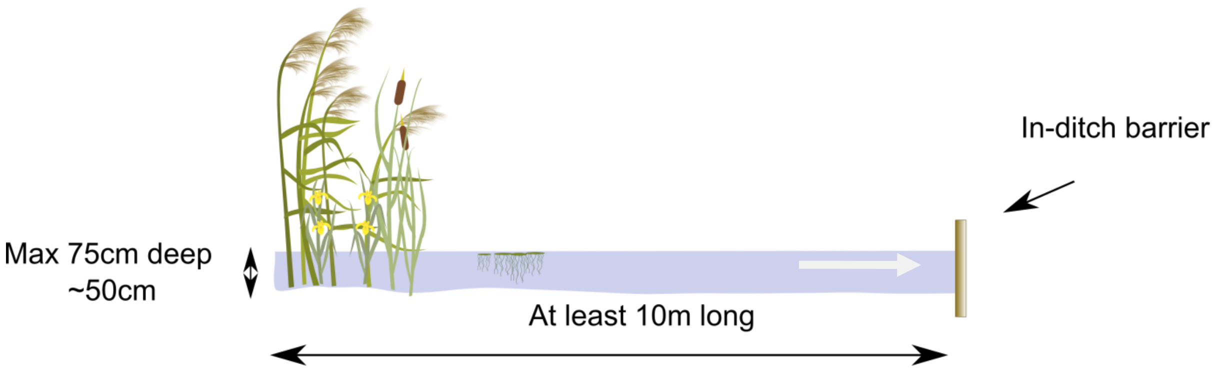


Figure 12. In-ditch wetland barrier

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 11). 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 a long time depending on proximity of local plants and seed stock. In areas of higher flow natural colonisation will be slower. If planting is considered necessary a list of recommended species is provided in Section 7. • Wherever possible, native wetland species should be used using local sources if feasible.

3.2.3 Design of in-ditch wetlands

When considering the creation of in-ditch wetlands, specialist advice should be sought as they will require consent from the Local Flood Authority in case they significantly alter local hydrology.

3.2.4 Cost of in-ditch wetlands

The creation of in-ditch wetlands can be a low cost solution to the prevention of pollution incidents due to runoff. Total costs for the 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).

3.2.5 Consent for in-ditch wetlands

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 and assistance for this can be provided by the local Environment Agency Officer. 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).

3.2.6 Management of in-ditch wetlands

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 (Clerici, 2012).	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 them as necessary.	
Install debris screens to ease maintenance.	

3.2.7 Further guidance on in-ditch wetlands

TIN 099 Protecting water from agricultural run-off - water retention measures
Rural Sustainable Drainage Systems, EA 2012
MOPS 2 Diffuse Pollution in ditch wetlands guidelines

3.3 Sediment ponds (*2 star systems*)

3.3.1 Description of sediment ponds and traps

Sediment ponds or sediment traps are designed to trap run-off from fields or farmyards with a high sediment loading. They can be built on impermeable substrates and have a permanent pool of water for most of the year, or be constructed on permeable substrates allowing infiltration of water while sediment is trapped. The latter will not hold water for long periods and will have less value for wildlife. Figure 14 shows a section through a pond edge which allows plenty of opportunity for planting or encouraging colonisation of marginal plant species and so provides good wildlife habitat. Conversely, a sediment trap constructed on a permeable substrate which retains no water will have limited capacity to provide habitat. 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. Areas of existing wildlife, archaeological or historic value should not be excavated. Table 9 provides some of the advantages and disadvantages of creating these features.

Figure 13. Sediment trap with clay lining, recently constructed so vegetation is not yet established (WWT)

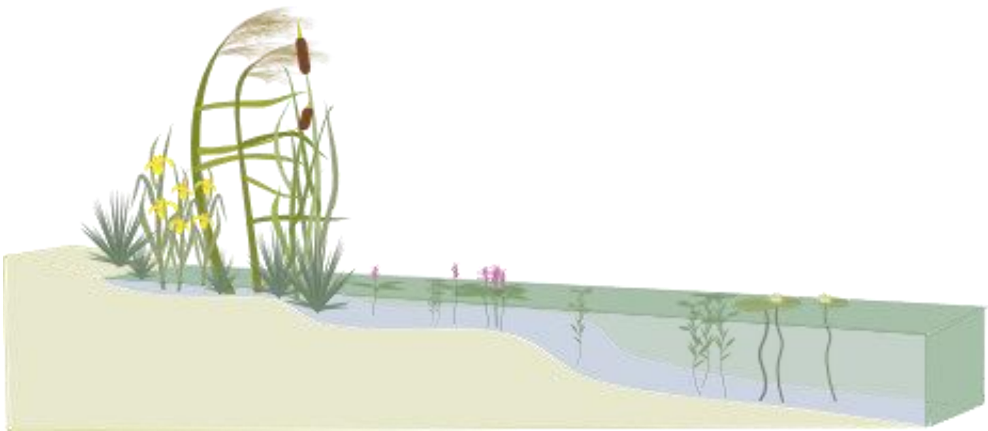


Figure 14. Cross section of an ideal pond edge, illustrating the benefits of the various water depths for biodiversity (emerging, floating and submerged plants and associated animal communities).

Table 9. Advantages and disadvantages of sediment ponds and traps

Advantages	Disadvantages
They trap large volumes of sediments and associated contaminants (pesticides, phosphates) which would otherwise be lost.	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 implanted, 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.	
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.	

3.3.2 Application of sediment ponds and traps

Sediment ponds can be used in three situations:

1. In-field as a collection point for field drains.
2. Situated in field corners to capture runoff from fields.
3. Capturing run-off from farmyards if forming part of a larger constructed wetland system.

They give maximum benefit if they are placed early on in the system to reduce sediment loading, and can also provide buffering against storm flows (Christian/NIEA, 2006). Ideally ponds come after swales and, if lined, they will retain water. They will also trap sediments and their associated pesticides, phosphates and pathogens such as *Cryptosporidia* (EA, 2012). It is important not to use existing ponds, as clean water ponds are vital habitats for wetland wildlife and even slight contamination can deter sensitive species such as some species of water beetle and dragonfly.

3.3.3 Design of sediment ponds and traps

If the area has high sediment loadings it is advisable to have a silt trap before water enters the main basin. This silt trap should represent around 20% of the total basin area. The idea is that this will trap the majority of the silt so that maintenance is undertaken on a smaller area. This will be the case for sediment traps constructed on permeable and impermeable substrates. It is not crucial to make this 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 muddy run off 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.

Figure 15.Sediment trap on permeable soil.

For larger-scale sediment ponds advice from a soil and water engineer should be sought before construction. Work can include excavation the topsoil and sub-soil. The sub-soil should be used for building up embankments around the pond, which should be compacted well to stabilise the structure. An outfall pipe into a ditch should be inserted 750mm below the top of the embankment. The 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.

Table 10. Sediment pond and trap design principles

Dimensions	• 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. • For farmyard runoff the pond should form part of the whole treatment system calculation. • The basic design should allow for sufficient headroom for the next intensive rainfall event.
Substrate	• Sandy substrates allow water to drain freely. Generally, a soil with a clay content of at least 20% will retain water for longer periods and therefore, this needs to be designed for if sediment ponds are to form part of the storm water management system on the farm. • Ponds that do retain water will be of greater benefit to wildlife.
Form	• Pond spoil can be used 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 through the wetland to encourage settling, and it provides two depth zones to encourage plant diversity (WWT & RSPB, 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 outlets channels with stone to prevent erosion. • Providing dead wood as a substrate increases wildlife potential. It could also be used as a form of inlet trap and flow control. • Create outlets larger than inlets if using pipes to prevent water backing up along the system.
Planting	• The area can be left to colonise naturally with plants planted using species of local provenance (See Section 7). • Avoid aggressive species such as Greater reedmace, *Typha latifolia.* • If sowing, use a species rich grass and flower mix appropriate to soil conditions and the region (WWT & RSPB, 2012). Selective and careful use of other vegetation around the basins can help enhance or conceal features as desired and stabilise slopes, reducing erosion.

3.3.4 Cost of sediment ponds

Construction costs based on existing sediment ponds range between £280 to £3100 depending on pond's size, fencing and lining costs, and also whether or not the pond is required to store water. For specific costs see the case studies presented in annex I. Grants are currently available from the CSF Capital Grant Scheme.

3.3.5 Consents for sediment ponds

There may be a requirement for a waste exemption, Consult the Environment Agency and see Natural England TIN 98 (Protecting water from agricultural run-off: an introduction), 99 (Protecting water from agricultural run-off: water retention measures) or 100 (Protecting water from agricultural run-off: buffer strips).

3.3.6 Management & maintenance of sediment ponds

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 every three to five years, this may require licensed waste disposal. The local EA officer should be consulted.
Where contamination is not an issue, 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.

3.3.7 Further guidance

More information on in-field wetland design specifics is available within the MOPS field wetland guidelines MOPS 2 - Sediment ponds in fields

3.4 Constructed wetlands *(3-5 Star systems)*

3.4.1 Description of constructed wetland systems

Constructed wetlands designs can range from single celled wetlands to multi-stage systems which incorporate some of the features already described (sediment ponds/ in-ditch wetlands). They can be used successfully to treat low strength diffuse effluent such as yard and field run-off or designed to treat higher strength point sources such as septic tank outflows and some pesticides. In addition, they can offer great wildlife habitat as they tend to incorporate many different wetland types with varying water depths, landform and planting.

A constructed wetland will range in complexity depending on the type and volume of effluent it is designed to treat. In farm situations they will generally come after a sediment pond with swales or wet ditches being used to convey water to them. For effluents high in suspended solids a pre-settlement stage should be used to prevent clogging of the bed media, which could be a septic tank, settlement pond or a dedicated sludge reedbed. Case studies are provided in Annex I to illustrate several examples of constructed wetlands.

Due to long residence times, constructed wetlands can be effective in reducing suspended solids, Biochemical Oxygen Demand, nitrogenous compounds, phosphorous, pyrethoid 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, 2012).

Figure 16. WWT constructed wetland (Photo WWT)

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 (at least 1.3 times the farmyard area for treating yard run off).
Possibility of amenity use (e.g. public access, educational visits).	Not suitable on soils with less than 20% clay content or excessively wet soils, unless lined.
High retention time therefore increased treatment efficiency.	Medium capital cost.
Greater water storage capacity allows delaying the flow peak during flood events.	Medium maintenance commitment.
Ability to retain fine sediments which pass through initial sediment stages.	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.

3.4.2 Constructed wetlands for diffuse effluent *(3 and 4 Star systems)*

For treating lightly contaminated run-off, constructed wetland systems provide an ideal solution. The system generally comprises at least three stages. When treating DWPA high in sediments the first stage should be a settlement pond to remove most of the solids loading. The sediment pond can incorporate a silt trap for ease of maintenance as discussed in Section 3.2. If stage 1 is adequate for sediment removal stage 2 should be a shallow vegetated surface flow wetland and stage 3 could be a further shallow vegetated surface flow wetland or an area of wet woodland. An example of a farm system treating DWPA is shown in Figure 17 and

Figure 17. Constructed farm wetland treating farmyard runoff in Scotland (Photo, Fabrice Gouriveau).

Figure 19 shows an idealised profile of how a farm constructed wetland may look.

3.4.2.1 Design of constructed wetlands for diffuse effluent

Table 13. Constructed wetlands for diffuse effluent – design principles

Size	• To effectively remove phosphorous from farmyard runoff, the recommended constructed wetland area is twice the area to be treated (**minimum 1.3 times**) (DEHLG, 2010). i.e. a 1500 m^2 farmyard (including 500 m^2 of roofs from which clean water is collected and not permitted to mix with dirty water) would require a wetland with a total area of at least 1300 m^2 to adequately treat the farmyard runoff. The quick calculation would be: Wetland area = (1500 – 500)*1.3. • Guidance for Treating Lightly Contaminated Surface Run-off from Pig and Poultry Units (Christian/NIEA, 2006) provides calculations for sizing smaller constructed wetlands.
Wetland cell creation	• 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 0.6m • 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 outlets channels with stone to prevent erosion. • Provide dead wood as a substrate to increase wildlife potential. It could also be constructively used as a form of inlet trap and flow control. • Create outlets larger than inlet if using pipes to prevent water backing up along the system. • 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 with Environment Agency agreement or water can be reused for water livestock or irrigation or for creating additional wetland clean water habitat.
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

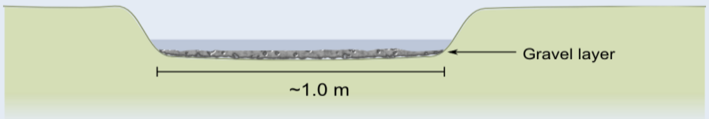
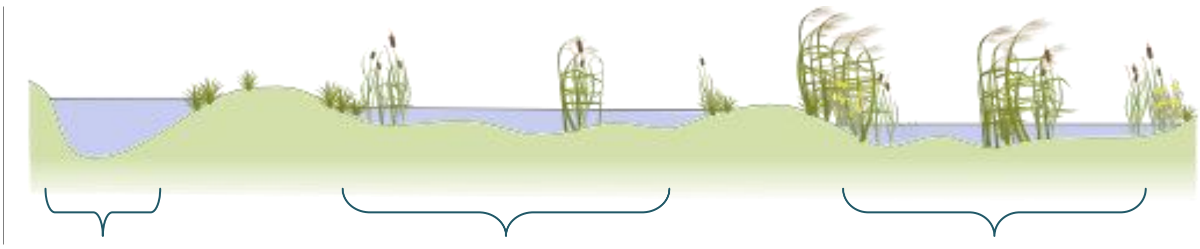
	machinery and continuous electricity consumption. • Wet ditches and swales can be used to convey water to the wetland. • Minimise the use of pipes to reduce blockages. To facilitate movement of water between wetland stages have slightly lowered sections at the end of each cell. These lowered sections should be ~ 1 m wide and lined with large stones to prevent erosion (See Figure 18). Swales can transport water over longer distances and pipes will be required if water needs to be directed under tracks or other areas of access.  *Figure 18. Stone-lined outlet*
Planting	• The wetland can be left to colonise naturally with plants or given a helping hand using plant species of local provenance (See Section 7). • Willow systems are used for a zero discharge or reduced flow outputs. • Use only emergent species of appropriate provenance to the region. Avoid aggressive species such as Greater reed mace (*Typha latifolia*).
Further Guidance	• Constructed wetlands for farms: Design Manual for Scotland and Northern Ireland, Carty *et al*., 2008. Available from SEPA Publications • Integrated Constructed Wetlands: Guidance Document for Farmyard Soiled Water and Domestic Wastewater Applications. Available from Department of the Environment, Heritage and Local Government.

Figure 19 below illustrates the ideal profile of a farm wetland treating diffuse effluent from farmyards.



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 volume of the wetland.

Stage 2. This section should be shallower (max. 0.6 m) to allow for increased vegetation establishment. It should account for 30-40% of the total volume of the wetland.

Stage 3. This section should again be shallow (max. 0.6 m) to allow for increased vegetation establishment. It should account for 40-50% of the total volume of the wetland.

Figure 19. Three-stage constructed wetland.

3.4.2.2 Cost of constructed wetlands for diffuse effluent

The overall costs for this type of constructed wetland are extremely varied, depending mostly on their size, machinery and labour available on farm, land availability and price, and 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).

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). In Ireland Integrated Constructed Wetlands cost £2/m^2, a system at Greenwood College in Northern Ireland was 12,000m^2 costing £4.9/m^2 and at Glenstal Abbey a wetland of 20,000m^2 cost £2.9/m^2 (Gouriveau, 2009). A large proportion of the construction work can be carried out by the landowners/farmers themselves, and can reduce costs by around 30% (Gouriveau, 2009).

3.4.2.3 Consents for constructed wetlands for diffuse effluent

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 chemicals entering the wetland and the likely discharges to water. The Environment Agency would need to be satisfied that only clean uncontaminated water is allowed into the wider water environment. Please contact your local Environment Agency for more advice.

Surplus spoil generated by the construction or maintenance of a wetland, dredging or widening of existing ditches may be disposed of by spreading it thinly over adjacent land if it is not within the floodplain. Excavated material may be classified as a 'waste' and its use may need a waste exemption (U10 and /or U11) from the Environment Agency (TIN 99).

3.4.2.4 Management & maintenance of wetlands for diffuse effluent

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.

Due to the presence of pipes, vegetation and multiple water levels, there is a management and maintenance commitment associated with constructed wetlands. Equipment such as elbow pipes can be used to adjust the water levels within the beds. Elbow pipes keep things very simple, yet allow for easy inspection and clearing should blockages occur. The following maintenance activities should be carried out:

Table 14. Constructed wetlands for diffuse effluent – 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.
Dredge sediment every 1-5 years, depending on sediment inputs and accumulation. This activity can be minimised by constructing a dedicated sediment trap prior to runoff entering the constructed wetland.

3.4.2.5 Further Guidance

Further design guidance and information can be obtained from:

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

Constructed Farm Wetlands (CFW) - Design Manual for Scotland and Northern Ireland (2008) Constructed Farm wetland design manual

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

Figure 20. Constructed wetland margins at WWT Slimbridge (WWT)

3.4.3 Constructed wetlands for point source effluent *(4 - 5 Star systems)*

3.4.3.1 Description of constructed wetlands for point source effluent

Constructed wetlands can be used for treating high strength point source effluent which includes septic tank discharge, abattoir effluent and dairy wastewater. 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.

For an effluent high in suspended solids, a pre settlement stage should be used to prevent clogging of the bed media. This could be a septic tank, settlement pond or a dedicated sludge reedbed.

As these systems treat high strength, point-source pollution they need to be lined. The liner can either be a natural clay-rich substrate (minimum 20% clay content) or an artificial liner which is more costly and has a limited life span.

There are three main types of wetlands which could be used depending on pollutant to be treated. Please see Table 15 for further details.

Figure 21. WWT vertical flow constructed wetland (Photo WWT)

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

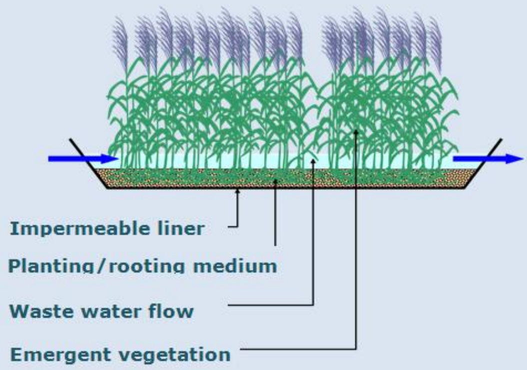
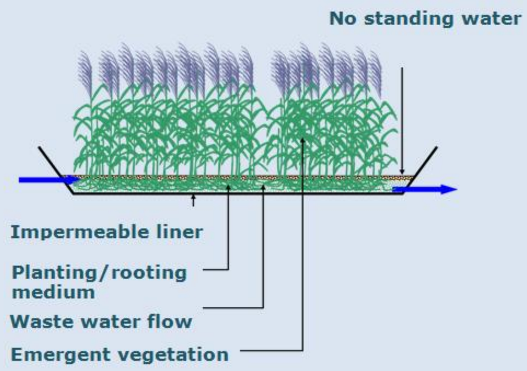
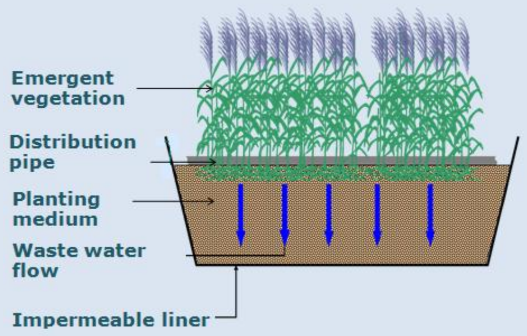
Surface -flow Constructed Wetland	In surface flow wetlands water is distributed across the inlet area but flows horizontally over the surface of the media, which is usually soil, to the outlet. The water depth ranges from 10 to 30 cm. These are used to reduce pathogens and nitrates.	
Sub-surface Flow Constructed Wetland	Water is distributed across the inlet area and moves horizontally through the media which is soil or gravel to the outlet. These are used to reduce nitrate, phosphate, BOD and pathogens.	
Vertical Flow Constructed Wetland	Water is distributed over the surface of the wetland and percolates down through the media which is sand or gravel. These are used to reduce ammonia and BOD and can be used to remove phosphate.	

Table 16. Advantages and disadvantages of a constructed wetland for point source effluent

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, therefore increased treatment efficiency.	

Figure 22. Contaminated farmyard runoff (Photo WWT).

3.4.3.2 Application of a constructed wetland for point source effluent

Constructed wetlands have been used effectively to treat septic tank effluent (Vymazal, 2011) dairy wastewater (Healy *et al*., 2007, Knight *et al*., 2000) and abattoir effluent (Phillips *et al*. Unpublished). In most farm situations there will already be a dedicated treatment system in place, but constructed wetlands could still be used as an option for final polishing before discharge. Septic tank effluent is common to farms and requires adequate secondary treatment before discharge. An exception is where an aerated package plant has been installed and treats effluent to a high enough standard for discharge.

3.4.3.3 Design of constructed wetlands for point source effluent

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.

3.4.3.4 Construction

These systems require professional installation of an impervious liner, which could be clay if available on site or a synthetic liner. The correct construction is critical to ensure that the wetland performs well, for example using the required grade of sand or gravel within the wetland.

3.4.3.5 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 for example 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 previously.

3.4.3.6 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 will be required:

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

3.4.3.7 Management & Maintenance

These systems require maintenance as effective functioning will form part of the discharge consent.

Table 17. Constructed wetlands for point source 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.
Dredging of sediment. This activity can be minimised by constructing a dedicated sediment pond/trap prior to runoff entering the constructed wetland.

3.4.3.8 Further guidance

Specialist advice should be taken for design of these systems. For more detailed information see 'Treatment Wetlands, Kadlec & Wallace, CRC, 2008. Information can also be found in the following publications:

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

Constructed Farm Wetlands (CFW) - Design Manual for Scotland and Northern Ireland (2008) Constructed Farm wetland design manual.

4 Complementary Measures – Woodlands

Woodlands have great potential to improve water quality. If integrated into agricultural landscapes they can provide the dual functions of acting as barriers and interceptors by trapping nutrients and sediments before they reach watercourses. Their implementation can be used as a tool to work towards meeting the Water Framework Directive chemical and ecological objectives.

Short rotation coppice can be grown leading to a number of benefits. Fast growing trees take up excess phosphate and nitrate in the water while high 'hydraulic roughness' slows the flow of water leading to increased deposition of sediment and associated pollutants. In addition, one of the major potential benefits of using woodland to improve water quality is the potential to supplement farm income by utilising short rotation coppice for biofuel. Deciduous or mixed planting schemes can also be very effective in intercepting the pathways of DWPA.

Uptake of the use of woodlands as a method to improve water quality has been limited in the UK by lack of financial incentives and constraints in land use. However, by increasing financial incentives, woodland planting schemes for "water-related forest services" have had successful uptake in Europe.

It is thought that, in the future, there is a potential for water-related woodland schemes to play a heightened role in River Basin Management Plans and also to be included within best management practice documents for agricultural landowners. The creation of demonstration sites would also help to show how woodlands can be used in an agricultural context. Further research is required into the extent to which woodland can offer benefits in water quality and also into any "water trade-offs" where the water requirements of woodlands may impact upon other water users (Nisbet *et al*., 2011).

More information can be found on the Forestry Commission Woodland for Water website. Information on funding for the establishment, improvement and management of woodland in England can be found on the Forestry Commission English Woodland Grant Scheme website.

5 Funding sources

Catchment Sensitive Farming (CSF) provides tailored farm advice on soil, water, pesticides, pathogens and nutrient management. CSF advice is supplemented by a Capital Grant Scheme, available in CSF priority and partnership CSF catchments, which currently includes standard items for sediment control including sediment ponds, grass swales, tracks and check drains and re-location or re-surfacing of gateways. Higher Level Stewardship also includes potential funding for feasibility studies and capital works. This can include the creation and management of wetlands and ditches, temporary ponds, silt traps, bunds, sluices and culverts. Other potential funding streams for deploying wetlands include grants from charities (e.g. Rivers Trusts), Government Agencies (e.g. Environment Agency) and the private sector (e.g. Water Companies).

There are potential sources of funding currently available for Sustainable Drainage Systems (SuDS) and constructed wetlands options, including Environmental Stewardship (primarily HLS), the CSF Capital Grant Scheme, England Woodland Grant Scheme (EWGS), Water Framework Directive (WFD) and Catchment Restoration Fund projects. Funding sources availability and criteria vary. Other and new sources of funding may be/become available, e.g. under specific WFD or Environment Agency projects.

Constructed farm wetlands and SuDS may also be constructed without funding, for example low cost options where farm labour and machinery can be used, 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.

5.1 The CSF Capital Grant Scheme

The CSF Capital Grant Scheme is available to farmers in CSF priority catchments for a range of standard items including sediment ponds/traps and grass swales and there is potential for funding special projects.

For more information on the CSF Capital Grant Scheme:

http://www.naturalengland.org.uk/ourwork/farming/csf/cgs/default.aspx

5.2 Environmental Stewardship

Environmental Stewardship is open for applications until November 2013, funded through the Rural Development Programme for England. Existing agreements can be amended, potentially to add in suitable items on constructed wetlands and SuDS, during the lifetime of the agreement. Under the current scheme, funding for these items is mainly via Higher Level Stewardship (HLS) with supporting resource protection options in Entry Level Stewardship (ELS). Negotiations are underway for developing a successor programme.

5.2.1 Entry Level Stewardship

For more information on resource protection options:

Entry Level Stewardship: Environmental Stewardship Handbook 4th Edition. Natural England (2012).

5.2.2 Higher Level Stewardship

A range of HLS options are available for management of runoff, sustainable drainage systems and creation and management of wetlands. These options would be incorporated into a wider HLS agreement, normally as a part of a capital works plan. As well as protecting soils and watercourses these HLS options should benefit wildlife and strengthen the local landscape.

Table 18. HLS options.

HLS capital code	Option description	Resource protection value	Funding (£)
GR	Wooden river gate	To control stock access to rivers and streams where there is a clear environmental gain. For example, to prevent browsing or grazing of vegetation regrowth inside a fenced out stretch of river from a livestock crossing point or drinking bay	£117 each
RDP	Cross drains under farm tracks	To intercept and conduct surface run-off to reduce flow rates and the erosive power of surface water further down the slope. It should also prevent erosion of farm track surfaces. Should act as a cut-off to take water draining down a sloping track. In addition, it can be used to catch water draining from surrounding land on the upper side of the track and either disperse it away from the track on the lower side, or lead water into a stable outlet such as a diversion ditch etc.	£139 each
RPG	Relocation of gates	Used where gateways act as a conduit for water movement on to tracks or other fields and to sensitive features. It is likely that this option will be used in conjunction with resource protection options; however it may be that the relocation of the gate itself may solve the problem.	£136 each
STP	Silt trap provision	Guidance for the use of this option suggests that it is used to improve or protect water quality of an online existing or newly created pond. Use of this item should therefore also, in most cases, be linked to the capital item Ditch Restoration below. This does not, however, prevent it from being used in other situations to protect a specific feature.	Up to 60% of the costs
DR	Ditch Restoration	This item is aimed at enhancing the environmental quality of wetland boundaries and adjacent Agreement land, not at improving the quality of agricultural land. However, there may be occasions when using the item in more intensively managed landscapes is appropriate, if there are specific features on the site identified in the FEP that would benefit from sensitive ditch restoration.	£2.90/m
WPS	Construction of water penning structures	The item may be used in the construction of artificial wetlands for resource protection. The agreement holder must maintain installed structures in good condition during the life of	The payment rate for this item is up to 100% of costs but it is

		the agreement. The item can also be used to pay for feasibility and/or hydrological implementation plans	more likely that constructed wetlands would be funded at a similar rate to silt traps - 60%
SCR	Creation of Temporary ponds first 100m^2	Temporary ponds and grassed waterways should be located in areas where additional capacity is required to reduce concentrated runoff and control erosion in either arable or grass fields. Management of surface water can often be best achieved by using a combination of conservation practices such as silt traps; temporary ponds, grassed waterways or artificial wetlands. They may need to be built together with bunds to provide water storage of an appropriate size (see option below). Other resource protection measures may also be required, for example grass swales to direct water into the pond.	£1.42/m^2
SCP	Creation of Temporary ponds more than 100m^2	As above	£0.90/m^2
S1, S2, S3	Soil bund	May be used to support resource protection objectives or options	£191/unit
	Timber sluice		£314/unit
	Brick stone or concrete sluice		£960/unit

6 Management of wildlife during creation & management of wetlands

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 the appropriate care and advice should be undertaken during management activities. The following advice has been adapted from: Sustainable Drainage Systems: Maximising the potential for people and wildlife (Graham *et al*., 2012).

Table 19. Wildlife management considerations

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. Consult Natural England if the site is designated as a Site of Special Scientific Interest, Natura 2000 or Ramsar site.
Vegetation management	• Avoid vegetation management between mid March and mid August to avoid disturbing wildlife. • Water voles can be 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.

7 Suitable Planting Schemes

We have included an indication of suitable plants for different planting schemes which include meadow species, marginal wetland species and floating and submerged pond species. All native plants should be sourced from a reliable nursery which does not stock alien species and be as close to local provenance as possible.

If additional information on native species is required, the Natural History Museum and Flora for Fauna have created the 'Postcode Plants Database', a site which allows users to input the first half of their postcode and generates a list of native plants and trees based on information from *New Flora of the British Isles*, 2nd edition (1997), by Clive Stace at a 10x10 km resolution.

Table 20. Meadow flower species.

Meadow flower species		**Meadow flower species**	
Botanic name	**Common name**	***Botanic 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 dogs tail	*Silaum silaus*	Pepper saxifrage
Festuca spp.	Fescue spp	*Succisa pratensis*	Devils bit scabious
Galium verum	Lady's bedstraw		
Hypochaeris radicata	Common cat's-ear		
Leucanthemum vulgare	Ox-eye daisy		
Lotus corniculatus	Common birds-foot trefoil		
Plantago lanceolata	Ribwort plantain		
Prunella vulgaris	Common self heal		
Rumex acetosa	Common sorrel		

Table 21. Marginal, submerged and floating species.

Marginal species		Submerged and floating species	
Botanic name	**Common name**	***Botanic name***	**Common name**
Carex riparia	Great Pond-sedge *	*Hydrocharis morsus-ranae*	Frogbit
Sparganium erectum	Branched Bur-reed *	*Persicaria amphibia*	Amphibious Bistort
Iris pseudacorus	Yellow Iris	*Nymphaea alba*	White Water-lily
Stachys palustris	Marsh Woundwort	*Hottonia palustris*	Water-violet
Lythrum salicaria	Purple Loosestrife		
Glyceria maxima	Reed Sweet-grass *		
Phalaris arundinacea	Reed Canary-grass *		
Persicaria amphibia	Amphibious Bistort		
Alisma plantago-aquatica	Water plantain		
Mentha aquatica	Water mint		
Phragmites spp.	Common reed*		
Scrophularia auriculata	Water figwort		
Caltha palustris	Marsh marigold		
Eupatorium cannabinum	Hemp agrimony		

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

8 Further sources of information

Organisation	Website
Catchment Sensitive Farming	www.naturalengland.org.uk/csf
CIRIA	http://www.ciria.org
Constructed Wetlands Association	http://www.constructedwetland.co.uk/
Environmental Stewardship	www.naturalengland.org.uk/es
MOPS Project	http://mops2.diffusepollution.info/
Natural England	www.naturalengland.org.uk
Susdrain – The community for sustainable drainage	http://www.susdrain.org/
UK Environment Agency	www.environmentagency.gov.uk
Wildfowl and Wetlands Trust (WWT)	www.wwt.org.uk/

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10 Annex I Case studies

10.1 In ditch wetlands

10.1.1 Green Hall Farm in ditch wetlands

The in-ditch wetland at Green Hall Farm was created in 2010 as part of a collaboration between LEAF (Linking Environment and Farming) and the Environment Agency. It treats yard runoff in a ditch occasionally contaminated with dirty water, slurries and, very rarely, silage effluents. Figure 23 shows the ditch before in-ditch wetland construction. The ditch flows into the Afon Cain via a tributary and the tributary has had sewage fungus on occasion.

Figure 23. In-ditch wetland before plant establishment. Photograph courtesy of LEAF.

Very little alteration of the ditch topography was required and since installation small improvements including the creation of some surrounding bunds to guide water have been added. This feature was low cost, with a total cost to the farmer of £895 (See Table 22).

Figure 23 shows the new in-ditch wetland before planting. The habitat value of this wetland could be maximised by planting with a diversity of species and ensuring that the topography of the wetland was varied, with very shallow edge habitat.

Figure 24. Fully vegetated in-ditch wetland. Photograph courtesy of LEAF.

Consent was obtained and 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.

Table 22. Capital costs – Green Hall Farm In-ditch Wetland

	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

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).

10.1.2 India in-ditch wetland 2*

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 wide (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).

Further information on the India in-ditch wetland can be found on the MOPS website.

Figure 25. MOPS2 (2012) India: A Shallow Single-Cell Field Wetland. (Photograph, MOPS 2011).

10.2 Sediment ponds

10.2.1 Church Farm field corner sediment pond, 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 farmer was £658 (See Table 23). 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 23. 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**

10.2.2 River Eye Silt traps

The River Eye is a Site of Special Scientific Interest. However, high levels of phosphate entering the watercourse mean that it is currently classed as "Unfavourable" by Natural England due to it exceeding its 0.06 mg/l phosphate target (Natural England, 2012).

A large scale sediment trap is currently in use in the River Eye. It traps huge volumes of sediment from the surrounding catchment but needs to be de-silted every 10 years at a cost of £150,000. Initially it was thought that the sediment could be recovered from these traps and re-spread on agricultural land. This was achieved but the volume of material removed from an installation of this size was considerable. This required a waste licensing permit to be obtained which would not apply with a smaller scale silt trap where the sediment was applied to adjoining land within certain limits.

In order to reduce costs and de-silting frequency and increase the operational lifespan of this large, catchment-wide sediment trap, a smaller-scale approach was proposed which would trap sediment closer to source. It was estimated that around half of the phosphate loading in the catchment is from agricultural sources. It was hoped that by trapping the sediment to which the phosphate binds, it would be possible to reduce the concentration of phosphate entering the River Eye SSSI.

Figure 26. Figure 5 Burton brook silt trap after de-silting in spring 2007 (Des Kay, CSF/NE).

Five silt traps with varying sizes and designs were constructed by the Environment Agency. These constructions were all relatively small-scale and inexpensive. They were also designed to be simple enough for landowners to self construct and to be easily maintained. In addition, the restoration of a 'wetland area' at one of the sites has the potential to provide further wildlife benefits and is already attracting short eared owls. The project took around five weeks to complete and cost £1890 for 1 silt trap and £7225 for 4 silt traps.

(Kay/CSF, Unpublished case study).

10.3 Constructed wetlands for diffuse effluent

In light of the wide variety of terms of cost, design and application within this wetland type, separate case studies have been included within the section:

Case study 1: Powhillon focuses on a relatively low cost, multi-stage system with swales, sediment ponds, wetland and wet woodland treating lightly contaminated yard runoff.

Case study 2: Old Castles is a larger constructed wetland in Scotland treating yard runoff and septic tank effluent.

10.3.1 Powhillon Farm

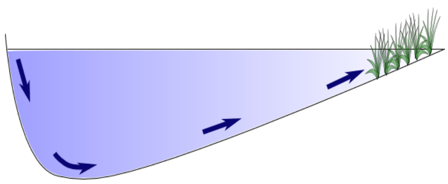
At Powhillon Farm on the WWT Caerlaverock Reserve in Dumfries and Galloway, Scotland a system was constructed to treat farm yard run-off and prevent nutrients reaching sensitive wetland habitats and a nearby water course.

Figure 27 Two stage sediment pond 1 week after construction

A feasibility study was conducted to determine soil types and topography and informal discussions with the regulatory authority, SEPA took place to ensure they were happy with our proposals.

Previous to construction of the farm wetland measures were put in place to separate clean and dirty water. Actual construction of the farm wetland took place in November 2012 over the course of two and a half days and cost a total of £1402, excluding labour, digger hire and fuel.

Work was carried out by the farmer and involved directing dirty water from the farm yard via a mixture of bunds and swales firstly into a two-stage sediment trap and then into an existing species poor, nutrient rich recently planted wet woodland. Field edge run-off was also directed to a swale and then into the wet woodland. 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 (See figure on the right). Each sediment pond measured 5 m x 4 m with a maximum depth of 1.1 m.



Emptying of the sediment ponds is expected to be every three to five years, with the first of the ponds emptied more regularly than the second. The guiding swales should be scraped and maintained on a regular basis to keep them functioning and guiding water down into the two-stage sediment pond. Finally, the quality of the water will be analysed on a monthly basis to assess the efficiency of the system.

Table 24. Capital costs- Powhillon farm wetland

	Cost
New gate Fitted	£130
Lorry load of hardcore	£550
6 m^2 Concrete & £87/m^2	£522
Fencing materials	£100
Dipwells to monitor water quality	£100
Total	**£1402 (ex VAT)**

10.3.2 Old Castle 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 £5000. The main pollutants were expected to be faecal pathogens, nitrogen, phosphates, organic matter, suspended solids, pesticides, etc.

The wetland is located 0.5 mile 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 in the wetland is 16230 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 latter this through two pipes. Water leaves the first small pond through a pipe, runs through a rather long shallow vegetated areas (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 (2500 m^2 – 3000 m^2, up to 1.70 m deep, planted with reeds) through a pipe passing under a bund (track).

Figure 28. Old Castles Constructed Wetland (Photo, Fabrice Gouriveau)

Finally, 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.

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 (*Glyceria fluitans, Holcus lanatus, Lemna minor, etc.*). It hosts ducks, swifts and moorhen and has been surveyed by FWAG.

Reference: Frost, A. (2004). Old Castle steading runoff system design. Soil and Water, Scotland. Table 4. Estimated costs at Old Castles.

Table 25. 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		**£5970**

10.4 Constructed wetlands for high strength point source effluent

10.4.1 Greenmount Campus – (*4 *system*)

In 2004 a constructed wetland was created at the Greenmount Campus in Northern Ireland to treat the following effluents arising from the 180 cow dairy farm on site: farmyard runoff, winter runoff from unroofed silage clamps and parlour washings from the dairy unit.

The system is on a particularly large scale, with five ponds covering a combined area of 1.2 ha, roughly double the size of the runoff area. 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).

As the treated water is being discharged into a water body, discharge consents for the system of 40 mg L^{-1} for BOD and 60 mg L^{-1} for Suspended Solids were issued by the Northern Ireland Environment. Water quality of the system was intensively monitored and showed high levels of treatment with reductions of 94.9 to 97.1% in total phosphate 92.9 to 99% in ammonia nitrogen (NH4-N) and 99.0% in BOD5 (Forbes *et al*., 2009). This level of treatment is likely due to the high hydraulic retention time of the constructed wetland (60-100 days).

The system attracts a range of wildlife. Snipes have been observed in winter, damselflies and dragonflies in summer and stickleback fish have been found in the final, deeper pond. The plants, including Common Reed, Yellow Flag-iris and Bur reed, have established well and other grass species have naturally colonised available space. Particular species dominance has not occurred and high plant diversity is still present.

Extensive financial information is available for the construction of the CW at Greenmount Campus. Costs calculated in 2007 indicated a total capital cost of £29,500. 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). It is estimated that the first pond will have to be dredged and replanted every five years at a cost of £7,500 (Carty *et al*., 2008).

Table 5. 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	£1983
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.

10.4.2 Sheepdrove Organic Farm 5*

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.