Constructed Farm Wetlands (CFW)

Design Manual for Scotland and Northern Ireland

Prepared for the Northern Ireland Environment Agency and the Scottish Environment Protection Agency

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Abbreviations

ASSI: Area of Special Scientific Interest (equivalent in NI to a SSSI)

BMP: Best Management Practice

BOD: Biochemical Oxygen Demand

CBD: Convention on Biodiversity

CFW: Constructed Farm Wetland

COD: Chemical Oxygen Demand

DARD: Department of Agriculture and Rural Development (Northern Ireland)

DOE: Department of Environment (Northern Ireland)

GAEC: Good Agricultural and Environmental Condition

ICW: Integrated Constructed Wetland

NI: Northern Ireland

NIEA: Northern Ireland Environment Agency

NNR: National Nature Reserve

NSA: National Scenic Area (Scotland)

SAC: Special Area of Conservation

SEPA: Scottish Environment Protection Agency

SFP: Single Farm Payment

SPA: Special Protection Area

SSSI: Sites of Specific Scientific Interest

SUDS: Sustainable Urban Drainage Systems

TSS: Total Suspended Solids

UNEP: United Nations Environmental Programme

Foreword

Interest in the use of constructed wetlands has increased significantly during the past few years as a means of treating surface water runoff from farmyards (Old Castles, Scotland, Greenmount, Northern Ireland and Anne Valley, Ireland). This design manual for Constructed Farm Wetlands (CFWs) addresses the ever more apparent requirement for a holistic approach to land and water management. This need has international, European and national support through the European Union Directives (Water Framework, Nitrates, Bathing Water, and Groundwater Directives), United Nations Environmental Programme (UNEP) and it's Convention on Biological Diversity (CBD) and the Ramsar Convention for the protection of wetlands.

This design manual is intended for use by farm advisers, farmers, consulting engineers, landscape architects, environmental regulators, local authorities and any organisations involved in water quality management in rural areas.

The manual provides information and guidance necessary for the design, siting, construction and maintenance of sustainable constructed farm wetlands used to treat lightly contaminated surface water runoff from farm steadings.

This manual focuses on the design of constructed farm wetlands in Scotland and Northern Ireland, however, does not detail the regulatory requirements associated with their implementation. As such it is important that regulatory advice is sought from the relevant agency, SEPA in Scotland or NIEA in Northern Ireland and respective Local Planning Authorities.

There are various design approaches to constructing farm wetlands. The approach used in this manual is largely inspired by the Integrated Constructed Wetland (ICW) concept pioneered in Ireland by the National Parks and Wildlife Service (Department Environment, Heritage and Local Government), and is based upon data on the performance of 13 ICWs constructed within the Anne Valley on the south coast of Ireland over the last twelve years.

The ICW approach on explicit integration facilitates processing synergies, robustness and sustainability that are not generally available in other constructed wetland paradigms. The benefits are primarily due to relatively larger land requirements and the greater biological complexity. The generally relatively larger land area and associated longer hydraulic residence time provides ecological infrastructures that are largely self-managing, biologically self-designing and have social and economic coherence.

1. Agriculture and water quality management

1.1 Main agricultural pollutants and their impacts

The loss of nutrients and contaminants from agricultural land, farmyards, steadings, tracks and roofs to the aquatic environment, has a detrimental impact on water quality. Both point and diffuse sources of pollution from agriculture can contribute to the degradation of water quality and aquatic ecosystems (fish kills, loss of habitats) through eutrophication, siltation, contamination of groundwater, siltation and direct toxicity to organisms. Water pollution can affect fisheries, angling, tourism and public health. It also exposes farmers to fines and possible prosecutions as well as impacting directly on the wider community by the subsequent degradation and loss of water use within the watersheds.

Examples of pollution sources arising from agriculture, and the associated impacts of the pollutants released are shown in Table 1.

Table 1: Main sources of agricultural pollutants and potential impacts.

Sources of pollution	Pollutants	Impacts
Animal housing and farmyard	Nitrogen	Siltation / sedimentation
Slurry store (risk of failure, leakage)	Phosphorus	Eutrophication
Dungstead, midden or manure pit	Ammonia	Acidification
Roofs	Organic matter	Oxygen depletion
Dairy and milking parlour	Sediments	Microbial contamination
Sheep dipper unit	Pesticides	Human health risks
Vegetable washing unit	Faecal pathogens	Cattle and wildlife poisoning, illness and death
Silage (silo, pit), effluent collection tank, soak-away	Fuel / Oil	Disruption and disturbance of aquatic ecosystems
Chemical store, filling area and spraying equipment	Veterinary medicines and hormones	Loss of biodiversity
Fertiliser store, filling area and spreading equipment		
Land runoff (e.g. following land spreading)		
Fuel/Oil: storage tank, filling point		
Farm machinery		

1.2 Legislation, policies and planning

There is a wide range of laws and policies at international, European, and national level, which aim to control and mitigate the risks of water pollution caused by the loss of agricultural contaminants to the water environment. However, it must be noted that agri-environmental legislation and policy is continuously being updated to take account of new practices and challenges. In Scotland the main pieces of legislation, which are relevant to the implementation of CFW include the Control of Pollution (Silage, Slurry and Agricultural Fuel Oil) (Scotland) Regulations 2003, the Water Environment (Controlled Activities) (Scotland) Regulations 2005, and in Northern Ireland the Pollution Prevention and Control Regulations (Northern Ireland) together with local planning laws. It is recommended that guidance and support in this field is sought at the initial stages of development from the local SEPA office (in Scotland) or the NIEA Agricultural Regulations Team (Northern Ireland) prior to works commencing.

In every instance the prevention of pollution to the water environment is very important. The discharge from a CFW must not result in the deterioration of the water environment. The development of a CFW may require planning consent; therefore it is necessary to contact the local authority to determine the authorisation needed. The level of authorisation will depend on the quality of the material conveyed to the CFW and that of the discharge from the CFW. It is recommended that advice be sought from SEPA or NIEA at the initial design stage.

1.3 Best management practices

Pollution from agriculture can be minimised through implementing good farming practices such as those detailed in the "Prevention of Environmental Pollution From Agricultural Activity" (PEPFAA) (Scotland), in the "4 Point Plan" (Scotland) and the ''Code of Good Agricultural Practice for the Prevention of Water Pollution'' (Northern Ireland). Some of these activities are enforced by law (e.g. collection, storage and application of livestock slurries and manure, use of sludge), but many are voluntary measures and actions. Compliance with certain environmental regulations is a minimum requirement for CAP Reform Cross Compliance, which is the requirement for receipt of Single Farm Payment and certain other support schemes.

Contaminated surface water has to be managed and several best management practices (BMPs) can be implemented to reduce the volume of and reduce the risk of contaminated drainage impacting on the environment. Table 2 gives examples of the most common measures, not listed in any order of preference, which can be implemented at farm scale and should be considered before assessing the need for a CFW [(1)].

Table 2: On-farm measures to minimise contaminated runoff and mitigate its impacts on water quality.

Measures for Pollution Source Control	Measures for runoff conveyance and treatment
Improve animal diet to reduce nutrient losses. Roof silage pits, slurry stores and areas of steading where excrements are expected to accumulate. Keep clean roof rainwater separate from the foul drainage and divert to sustainable drainage systems to reduce the volume of contaminated water produced, collected, stored and spread. Upgrade buildings and manure, slurry, fuel or pesticide storages to avoid leaks and spillages. Implement biobeds for pesticide handling and washing areas.	Ditches and swales to convey and store momentarily farmyard runoff. Buffer strips, ponds and constructed farm wetlands to attenuate peak flow and treat farmyard runoff before discharge to watercourses.

Constructed Farm Wetlands provide indeed a means of receiving and treating steading runoff before it is released into watercourses, therefore ensuring the protection of surface and groundwater resources. However, they are located at the end of the treatment train and consequently, Source Control Measures such as those listed in Table 2 should be implemented prior to considering their construction.

The development of a CFW is based on several criteria, such as; 1) sufficient land area, 2) suitable site conditions, 3) discussion with SEPA or NIEA, 4) capacity of the farmer to properly operate and maintain the system. Therefore, CFWs are not suitable for all sites and as such it is essential to determine whether a site is suitable for a CFW well before undertaking any construction.

The use of an existing natural wetland as a CFW, either wholly or in part, is illegal. This is due to the impact this would have on the existing habitat as the various habitats and plant and animal species could be altered, damaged or polluted if used to treat contaminated water from a farmyard. While a CFW is designed to mimic many of the functions and processes of a natural wetland, and may create habitats and increase biodiversity, it is primarily designed and operated for the treatment of contaminated water within a defined and controlled area.

2. Constructed Farm Wetlands

2.1 What are CFWs?

A Constructed Farm Wetland (CFW) is defined as "one or more shallow, free surface flow constructed cells containing emergent vegetation, which is designed to receive and treat lightly contaminated surface water runoff from farm steadings, in such a manner that any discharge from the wetland will not pollute the water environment".

It should be recognised that the need for and design of CFWs will be influenced by a number of site-specific factors and while CFWs may be a suitable means of treating lightly contaminated waters from some farms, they will not be suitable for all situations.

CFWs must be sized adequately to provide efficient and effective treatment and retention. They are designed for easy management and should provide the correct level of treatment to meet environmental objectives.

A CFW fit for purpose will be:

- Reliable and efficient in water treatment, especially during high storm events with extreme rainfall and high hydraulic loadings,
- Capable of coping with accidental spillages,
- Flexible and versatile,
- Relatively simple to build,
- Economical to operate and maintain,
- Low in energy consumption,
- Safe for farmers and for the public.

The CFW is also designed to fit the landscape and provide habitat and biodiversity benefits.

Figure 1 over page shows an aerial view of a five year old constructed wetland comprising of a series of five separate, interconnected shallow wetland cells, Anne Valley, Co. Waterford, Ireland.

Figure 1: Aerial view of a five year old constructed wetland, Anne Valley, Co. Waterford, Ireland.

CFWs are used to benefit both the environment and farmers, by reducing the impact of potential pollution incidents, helping to manage lightly contaminated surface water runoff and enhance habitats, biodiversity and landscapes, in a way that is practical, efficient, affordable and cost-effective.

2.2 Processes within CFWs

CFWs are effective in treating different types of contaminated runoff arising from the farm steading, through various physical, chemical and biological processes involving plants, algae, micro-organisms, water, soil, wind and sun. The main processes and factors affecting them are illustrated by Figure 2 and shown in Table 3.

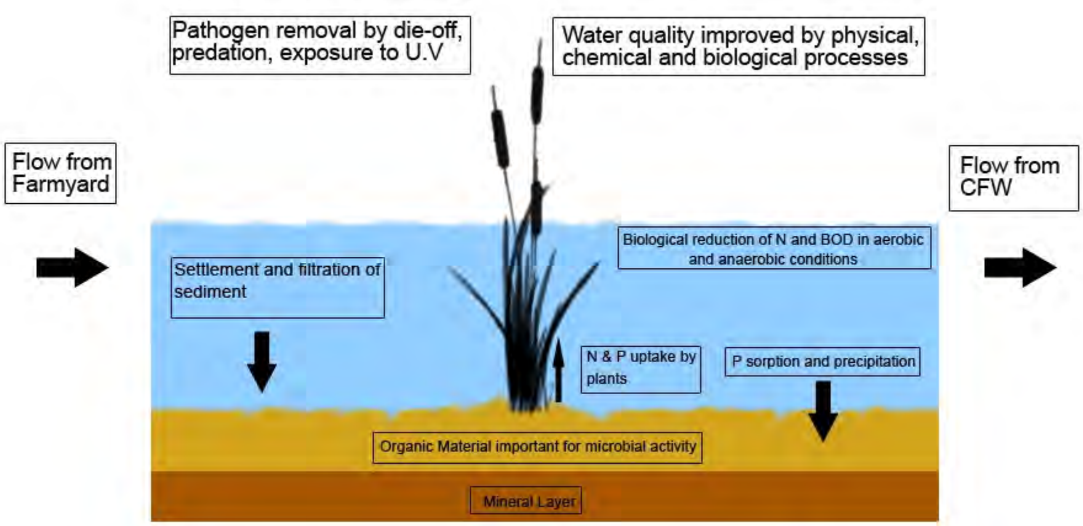


Figure 2: Wetland processes.

Table 3: Main water treatment processes in CFWs and the factors that optimise treatment.

Water treatment process	Factors that optimise process
Settling of suspended particulate matter by gravity	Low flow velocity, low wind speed, low disturbance, long residence time
Physical filtration of suspended solids by wetland biomass acting as a hydrological baffle to incoming flows	High vegetation density, low flow velocity
Uptake and breakdown of nutrients by plants and micro-organisms	Longer residence time, contact with high densities of micro-organisms and plants, readily available organic matter
Accumulation and increase of organic matter, which is important for nutrient cycling	Low flow velocity, availability of adsorption sites
Aerobic and anaerobic microbial mediated processes, such as nitrification and denitrification, important for the cycling of nitrogen and reduction of sulphur	Presence of oxidising and reducing conditions, high density of a variety of micro-organisms, around neutral pH, high temperature
Chemical precipitation of phosphorus in and sorption on soils	Many available sorption sites, pH, redox potential
Predation and natural die-off of pathogens	High diversity and density of natural predators (e.g. protozoan's), exposure to sunlight

2.3 CFW Design

The CFW design has similarity with the broader 'Integrated Constructed Wetland' (ICW) concept pioneered in Ireland by the National Parks and Wildlife Service (Department of Environment Heritage and Local Government).

The ICW concept is based on the following principles (2) (3):

- Containment and treatment of influents within shallow vegetated cells using wherever possible, local soil material.
- Aesthetic placement of the containing wetland structure into the local landscape ('landscape fit') towards enhancing a site's ancillary values.

- Enhancement of habitat and biodiversity.

The design endeavours to optimize natural biological, chemical and physical processes of pollutant removal in a way that is compatible with the local aquatic and terrestrial communities and that does not incur negative impact on adjacent aquatic and terrestrial ecosystems.

2.4 What can CFWs treat?

CFWs may be used to treat a variety of different types of lightly contaminated farm drainage derived from specific areas in and around the farm steading. Regulation will determine the types of drainage that can legally be conveyed to a CFW, as well as drainage types that must be collected. To minimise the amount of contaminated water to be treated or collected there are several measures that can be implemented, such as those already mentioned in section 1.3. Prior consultation with SEPA or NIEA is necessary to agree the regulatory requirements based on the types of drainage to be conveyed to the CFW.

The following list provides examples of the types of areas where lightly contaminated water could be conveyed to a CFW for treatment and may be considered as appropriate by SEPA and NIEA:

- **Livestock handling areas** where livestock are held occasionally for less than 24 hours,
- **Roof drainage** from pig and poultry housing,
- **Lightly contaminated concrete areas** as a result of vehicle and occasional livestock movements,
- **Machinery washings** (unless contaminated with pesticides or veterinary medicines),
- **Winter run–off from silage pits** between 1 November in one year and 30 April in the next,
- **Baled silage storage areas on steading.**

CFWs are NOT designed for:

- The treatment of more nutrient rich effluent types such as slurries, silage effluent and raw milk,
- The treatment of run-off containing veterinary medicines such as sheep dip, or pesticides, such as sprayer or dipping equipment washings.

Silage effluent is 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 land spread in accordance with good agricultural practice.

Areas such as occasional livestock access tracks or where livestock are held for a short period of time 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 the CFW.

Prior to any CFW development the farmer should contact the local SEPA or NIEA office to discuss the type of drainage to be treated through the CFW.

2.5 Benefits of CFWs

The main benefits of CFWs are shown in Table 4.

Table 4: Main benefits of CFWs.

High level of treatment and robustness	Treatment of contaminants such as, phosphorus, nitrogen, BOD, TSS, hydrocarbons and pathogens in lightly contaminated water. CFWs are designed to accommodate run-off from heavy rainfall events.
Relative low cost and simplicity of operation	Little, if any, energy use. Equipment needs are minimal. Water can be transferred by gravity through the system. Simplicity of operation. Cheaper than alternative methods of dealing with farm runoff (if lined using in-situ material).
Odour minimisation	Odour can be an issue when handling and treating agricultural wastes. Odours are minimized in CFWs using dense plant cover, appropriate plant species and water level management**.**
Aesthetically pleasing	CFWs enhance the landscape by adding colours, texture, and by diversifying plants and habitats.
Habitat and biodiversity enhancement	CFWs provide habitats for a wide variety of birds, mammals, reptiles, amphibians, fish and invertebrates.
Contingency measures	CFWs can help to mitigate the impact of accidental spillages, acting as buffer zones and giving time to implement emergency measures.
Flood attenuation	CFWs are designed to manage rainfall events, providing sufficient attenuation for increased volumes during storm events. By acting as buffer zones and attenuating peak flows, they contribute to flood attenuation downstream.

2.6 Limitations of CFWs

It is important to recognise that CFWs will not be suitable for all situations.

- CFWs should be regarded primarily as runoff treatment systems and should be treated accordingly, i.e. not used for bathing, fishing or animal watering due to the risk of pathogens, toxins and parasites.

- CFWs are best suited to farming systems and farms where significant amounts of lightly contaminated water are produced, where the soil types and gradients are appropriate and where a CFW will fit in with the existing drainage system and landscape.

- CFWs are not suitable for the treatment of more concentrated effluent types, such as silage effluent, slurry, raw milk or run-off containing veterinary medicines or pesticides.

- CFWs have some limitations, outlined below, that can be managed by designing and maintaining CFWs for their designed goals, as described in this manual.

  - CFWs have a relatively large land requirement compared to other methods of managing surface water runoff.
  - Infiltration of water to groundwater may occur. However, infiltration is reduced by the use of shallow cells, an adequate substrate (clay or an artificial liner) and it decreases over time, as the wetland seals itself by accumulation of organic matter and sediments[4] [5] [6] [7] [8].
  - The removal of pollutants may vary during the year (lower in winter) and in the long-term due to seasonal weather patterns and also 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.
  - CFWs may emit greenhouse gases such as methane, nitrous oxide and ammonia. However, these emissions are estimated to be negligible compared to livestock emissions.
  - Areas of standing water can attract wild birds and therefore any bio-security risks should be discussed with your vet or animal health specialist.
  - Although CFWs 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 sloping sides, marginal vegetation, fencing and by raising public awareness. There should be no access by livestock to the CFW.
  - CFWs may cause wildlife poisoning, but this impact can be mitigated by an appropriate design taking into account ecological aspects and by excluding certain types of drainage from CFW's (e.g. pesticide washings).

3. Assessment of the need for a CFW

Specialist advice from a suitably qualified consultant/engineer is advisable when assessing the need for a CFW and the suitability of a CFW site. A decision tree is included at the end of this section to facilitate the decision making process.

In order to decide if a CFW is needed and is appropriate for a given farm the following steps below should be followed:

1) Determine the need for a CFW by assessing existing on-farm measures and potential alternatives of best management practices for dirty water management.

2) Assess of the type and volume of the runoff to be treated (present and future) and the kind of infrastructure present on the farm (e.g. existing storage, drainage routes, etc).

3) Identify available site for a CFW and determine the characteristics of the site available for CFW construction and assessment of any potential impacts that may result from CFW implementation.

3.1 Farm assessment

Some of the more important factors that the farmer/farm advisor will need to consider prior to making a decision regarding CFW construction are listed below:

- The present surface water runoff management system,
- The types and volumes of material produced,
- Whether there is separation of drainage streams and if this will be required,
- What storage facilities currently exist,
- What additional storage might be necessary if a CFW is not used,
- The cost of developing a CFW,
- If the CFW will improve the existing management of surface water runoff.

When assessing the type and volume of material to be treated, consideration should be given to both present and possible future loading (e.g. increased stock numbers, increased impervious areas and shed roofs).

3.1.1 Run-off type

Examples of the areas from which the lightly contaminated water can be derived from and the types of drainage that a CFW can be designed to treat are listed in section 2.4 of this manual. The types of drainage to be treated must be identified for each particular site, as each site will vary. A short survey of existing farm infrastructures and a map will be helpful to highlight the sources and areas of the waters to be treated and the direction of the flow on the farmyard. The type of drainage to be treated through a CFW must be agreed with SEPA or NIEA prior to any development. In Scotland the Control of Pollution (Silage, Slurry and Agricultural Fuel Oil) (Scotland) Regulations 2003 as amended by the Water Environment (Diffuse Pollution) (Scotland) Regulations 2008 state which areas of the farm steading can be drained to a CFW.

3.1.2 Volumes of run-off to be treated

The volume of rainfall intercepted by the yard is a primary factor affecting design, as it is the main source of flows to be treated, compared to farm wastewaters.

The CFW design takes into account the magnitude of precipitation in Scotland and Northern Ireland and the variable composition of influents in calculating wetland storage and sufficient treatment areas. In order to determine the volumes to be treated through the CFW, the areas of yards, tracks and roofs within the farmyard to be drained and the volumes used in yard washings should be calculated.

Each farmyard will have varying daily water usages, which must be calculated as part of the total volumes of water/runoff produced on site (see procedures for calculating these in the Four Point Plan and the Guidance Book for the Northern Ireland Nitrates Action Programme).

In some cases, for example where the ventilation system has roof outlets, the rainwater coming from the roof may be contaminated and require treatment and should be intercepted. For ventilated piggery and poultry facilities**,** roof runoff may potentially be contaminated with pollutants derived from dust and avian contamination. Where this is the case run-off should be treated through a CFW or stored and spread. CFWs can attract wildlife and as such it may be appropriate to discuss their siting and proximity to poultry buildings with local health officer in order to manage any disease risk.

Field experience suggests that it is often impractical to effectively identify and separate roof runoff from farmyard runoff. However, if roof runoff is considered not to require treatment, it is recommended that farmers ensure there is proper guttering on all buildings and that all clean water is collected and discharged separately.

The volumes to be treated through a CFW will be driven primarily by rainfall. The volumes discharging to the CFW and losses through evapotranspiration and infiltration will determine the residence time. As the source of the lightly contaminated water is predominantly precipitation, there may be very little flow to the wetland for prolonged periods but the CFW must be able to cope with rainfall events. As climate appears to be changing and storm events appear to be more intense with shorter intervals, CFWs should be designed and constructed to cope with possible future increases in runoff.

Figure 3 illustrates the steps to follow when evaluating the need for a CFW.

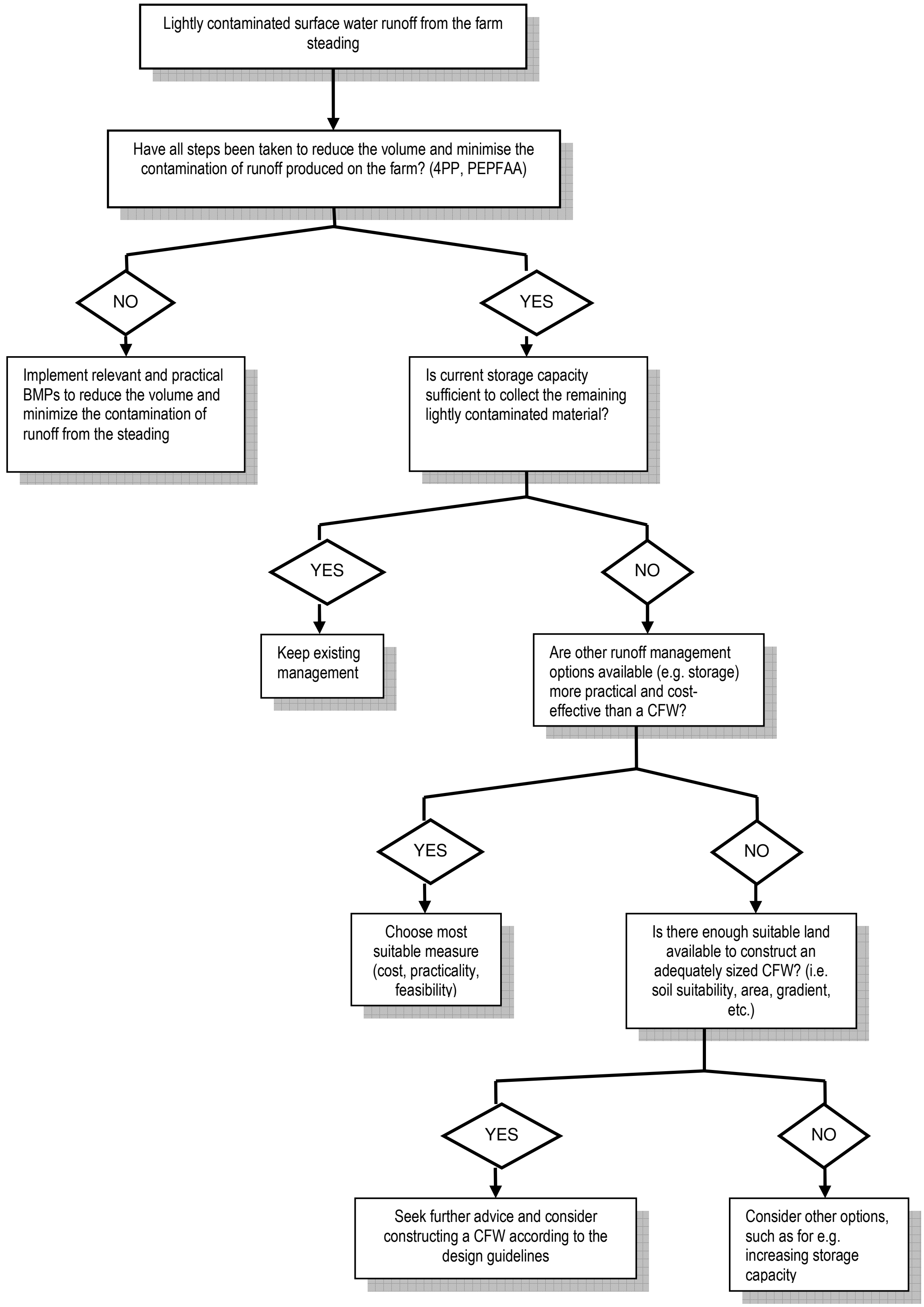


Figure 3: Decision tree to assess the need for a CFW.

4. Site assessment

The site assessment should be undertaken by a person who is professionally qualified, has some experience in all of the required disciplines and can call in experts if necessary to clarify any anomalies that may arise. When assessing the suitability of a site, the relevant bodies and authorities should be consulted in the context of the prevailing legislation.

Each CFW design is site-specific, therefore a comprehensive site-specific assessment combining site investigation and desk study is required to:

- Determine the site characteristics,
- Assess any potential impacts that may result,
- Decide on the groundwater and surface water protection measures needed,
- Provide data that will be used in the design of the CFW.

4.1 Identifying a suitable site for a CFW

The location, topography, geology, topsoil and subsoil characteristics, surface water and groundwater hydrology, ecology, social and planning aspects, archaeological and architectural features and natural interest need to be considered when assessing the suitability of a site for a CFW. These characteristics are examined in more detail below and a decision tree to assist in selecting a suitable site for a CFW is shown in Figure 4 at the end of the section.

4.2 Location

Ideally, the CFW should be sited so as to allow the lightly contaminated water to flow by gravity from the yard to the CFW and thus remove the need for pumping. The elevations of the cells and embankments should be designed so that the water flows through the CFW by gravity. Elevation differences between cells in existing CFWs vary between 10 cm to greater than 1 m. Distance from the farmyard is also a consideration as there will be additional cost associated with trenching and pipe work.

4.3 Topography and slope

Ideally, a CFW should be constructed on gently sloping land. Areas that are steeply sloping require larger wetland areas, deeper soils and subsoils, more excavation works and increased costs of construction.

A topographical survey of the farm steading and the proposed CFW site is recommended, to a scale of at least 1:500. The information in the survey should include: contours (0.5 m contours), location and use of buildings, boundaries, hydrological, archaeological and architectural features.

4.4 Area

When assessing the proposed site, consideration should be given to the approximate area of land required for the wetland, embankments and access. It is better to over- rather than under-estimate the area needed. As a general rule of thumb the area of the cells in a CFW should be at least twice the area being drained (farmyard plus any other areas, e.g. roofs). Deciding on the area required for the CFW is dealt with in more detail in Section 5.3.

4.5 Geology and soils

A desk study should be undertaken to establish the geological context of the site. Trial holes must be dug on the proposed site to examine the nature, thickness and permeability of the underlying soil and subsoil. Holes should be dug to a depth of 2-3 m (deeper if the land is steeply sloping), with a minimum of four per acre (one per 1000 m^2), distributed randomly. Additional trial holes should be dug where available mapping or ground conditions suggest complex conditions. There should be a minimum of 1.0 m of low permeability unsaturated subsoil beneath the base of the CFW cell.

The water table height should be assessed during the trial hole investigation and should be measured preferably in the spring months when groundwater levels are at a maximum. The distance of the CFW from the high water table will depend on the groundwater vulnerability of the site and/or whether the water table is confined, but must lie at least below the soil liner, thereby providing at least 1m from the bottom of the CFW and the water table.

Due to the importance of groundwater protection and the variability of soils that may be present at a site, it is important that someone who has sufficient knowledge in this area carries out the site assessment. A detailed log of the assessment and photographs should be recorded.

4.6 Lining

The bases of the CFW cells are ideally lined using the in-situ soil material if it is suitable. To provide adequate groundwater protection an adequate geological or artificial liner system for the sides and base of each cell must be provided.

An adequate geological 'liner' consists of a soil layer with a permeability of less than or equal to 1×10^{-8} m s^{-1} throughout the CFW to a thickness of at least 1 metre. This requires a material with a high clay content to provide protection to groundwater, with certain sensitive situations requiring greater depths or reduced permeability rates. Soils used in lining can be reworked by compaction and puddling (using tracked machine and water) to increase the homogeneity and to enhance their sealing quality.

The site assessor should determine the type and depth of the soils and to what degree the permeability of the soils can be improved by carrying out various hand assessment methods on site (BS 5930 - Code of practice for site investigations, British Standards Institute). However, where soil type is not easily determined on site, laboratory testing will be needed to determine soil permeability and particle size distribution.

4.6.1 Alternative lining systems

Where it is not possible to achieve the above conditions from on-site materials, suitable soils may be transported to the CFW from an alternative location on-farm or may have to be brought in from off-farm. It is important to contact SEPA or NIEA and the local authority prior to importing soils onto site.

Alternatively, an artificial liner may be used in conjunction with a soil liner of at least 0.5 metres thickness under the artificial liner (for protection). The artificial liner may be any material providing a similar degree of protection as the geological liner described above. HDPE, as used in non-hazardous landfill liner construction would be considered adequate. Such liners will incur greater costs due to the need for an expert engineer during installation. Artificial liners have a given lifespan and will need to be replaced over time. They may also pose difficulty during sediment removal. Where possible the use of on-site or on-farm soil materials is preferable.

4.7 Hydrology

4.7.1 Surface water

All surface water features in proximity to the proposed CFW site such as rivers, streams, lakes and drains should be noted and located on the survey. In most cases the final discharge from the CFW will be to a local river, stream, ditch or even woodland planted for that purpose. As well as assessing the suitability of the watercourse as a potential discharge point, consideration must be given to high water levels, flooding and whether a floodplain is located within the surrounding wetland landscape. Where a CFW is to be developed in a floodplain the potential effects upstream and downstream must be investigated. In some instances the floodplain may be protected by development control, in which case a CFW may not be permitted unless it can be demonstrated that there will be no loss of flood storage.

Where a discharge is to surface water, the location of any local water abstractions downstream or discharges upstream and downstream must be identified. To minimise the impact of any structural failure of the CFW on nearby watercourses any cell must be located at least 10 m from existing surface waters.

The final discharge should be to surface water with sufficient assimilative capacity, such as a stream or river with flows throughout the year, rather than a field drain which has low assimilative capacity and often dries up. The discharge of the treated waters from the CFW must not cause pollution of the water environment.

Where a discharge to surface water is not possible or not suitable, an option could be to discharge to a wet woodland planted for this purpose or willow bed. These can be used to obtain a zero discharge in certain climatic circumstances but a large area may be required.

4.7.2 Groundwater

Groundwater is an important resource and must be protected from potentially harmful impacts. The following information is considered to be the minimum required to identify any groundwater dependent water features and determine whether the proposed CFW will have negative impacts on them:

- Wells and boreholes - location and use (site investigation)
- Springs - location (site investigation)
- Water table - elevation (site investigation)
- Aquifers - type and importance (this information is available from the NIEA and SEPA)
- Groundwater vulnerability (Aquifer and Groundwater Vulnerability Maps for Scotland and Northern Ireland and site investigation, SNIFFER Report – WFD 28)
- Connectivity with surface water features (geological maps)

The location of groundwater dependent water features should be included in the topographical survey.

Wells - There must be sufficient distancing between a CFW and any water supply features, the minimum distance will depend on the location but must be a minimum of 50 m from any down gradient well.

Springs - The presence of springs within a CFW must be avoided, as they will cause increased volumetric loading to the system, reducing residence time and treatment. Springs also indicate the presence of a shallow water table and will provide a direct link to groundwater.

Water table - The CFW must not be constructed within or below the water table as this will lead to excessive flows to the wetland and possible contamination risks. The distance between the base of the CFW and the water table will depend on the specifics of the site, but where there is a soil liner the groundwater must lie at least 1 m below the bottom of the wetland. Where an artificial liner is installed there should be a minimum of 0.5 m between the base of the liner and the maximum groundwater level. The water table is assessed during the soil investigation by keeping the trial holes open for at least 24 h to measure the depth of the water table below ground level. Water level measurement is best carried out when the water table is likely to be at its highest. Where measurement is made at other times adequate allowance should be made for any seasonal increase, which might be considerable depending on the location.

Groundwater vulnerability - The vulnerability of groundwater to pollution is assessed through combining information of the geological and soil classification together with the character of the superficial strata so that highly vulnerable groundwaters are those where the protecting cover is absent or thin and highly permeable.

The report 'Development of a Groundwater Vulnerability Screening Methodology for the Water Framework Directive SNIFFER WFD 28 (http://www.sniffer.org.uk) describes how groundwater vulnerability assessment can be made and Appendix 1 of the report describes how classification can be decided on the basis of geological and site-specific information. The site assessor should be qualified in assessing groundwater risk and suitability of sites for CFWs. Further information on groundwater vulnerability and risk assessment is available from SEPA (www.sepa.org.uk/groundwater) (for Scotland) and NIEA (www.ni-environment.gov.uk/water/quality/groundwater.htm) (for Northern Ireland) also the British Geological Survey (www.bgs.ac.uk).

Field drains - Field drains (tile or mole) are widely used in agricultural land, especially those that are associated with poor drainage. The location of all field drains must be identified (through local knowledge or through site excavation) to investigate whether they are likely to conduct water to the CFW or create a pathway for wetland waters to leave the system prior to treatment. A trench or drain should be dug around the perimeter of the proposed CFW site to a depth of at least 1 m during construction to intercept any field drains, which can be diverted away to a local surface water.

Careful consideration must be given to on-site and adjacent water supplies and sufficient distance must be kept between a CFW and up gradient and down gradient water supplies.

In some instances there may be a requirement for a detailed hydro-geological assessment, for example where site conditions are more complex. A qualified hydro-geologist will assess in more detail the types of underlying soils and hydrology to determine the suitability of the site and whether the use of a CFW will impact on groundwater.

4.8 Ecological characteristics

An assessment of existing ecological characteristics must be undertaken to describe the flora, fauna and habitats on and adjacent to the CFW site. If sites are located either in or adjacent to areas of Conservation or Protected areas (SSSI, ASSI, NNR, NSA, SAC and SPA) the relevant authority and advisory body should be contacted, as there maybe restrictions on the type of development that can carried out on or close to these sites.

In some instances the proposed CFW site will be an area that is unproductive to the farmer, but may be very valuable in terms of biodiversity and habitat. In Northern Ireland, for example, 37 priority habitats are listed, which are not suitable for siting CFWs.

The existing environment must be assessed to determine whether the development of a CFW will have any negative impacts such as loss of habitats (e.g. removal of hedgerows, nesting grounds, trees). The positive contribution of the CFW for creating new habitat areas and/or enhancing the existing habitats and biodiversity should be considered. Hedgerows are often found on the boundary of agricultural fields; they prevent soil erosion, create habitats for wildlife and increase landscape connectivity. Therefore, their removal or disturbance should be avoided during CFW construction. In both Scotland and Northern Ireland the removal of hedges and boundary features is not permitted under GAEC (measure 15) and requires written permission from the Scottish Government Rural Payments and Inspections Directorate or in Northern Ireland, DARD.

The site assessor should be able to carry out an ecological survey of the site and determine whether there will be any negative impact on the ecological characteristics of the site.

4.9 Social and planning considerations

For reasons of security, health and safety a CFW should not be located too close to dwelling houses. Appropriate fencing or hedging in keeping with the local landscape should be used to restrict access to humans and livestock. However, this may only be required around the initial CFW cell. The local planning authority should be contacted to determine if any planning issues or restrictions apply for these issues.

The local authority must be contacted prior to the development of a CFW to ascertain whether planning permission is required.

4.10 Archaeological and architectural features

The location and type of any archaeological or architectural feature on or adjacent to the site must be assessed. This can be carried out through a combination of site investigation and desk study. Sources of reference are the Royal Commission on the Ancient and Historical Monuments of Scotland, Historic Scotland and the Northern Ireland Environment Agency.

The assessment should consider any potential negative impacts on archaeological or architectural features. Archaeological sites must not be removed or disturbed during CFW construction (GAEC 6 in Northern Ireland and GAEC 17 in Scotland). Consideration should also be given to potential for damage to architectural sites or archaeological material by changes to local hydrology caused by the construction of the CFW.

4.11 Decision process

An assessment of the above characteristics will determine whether a site is suitable for a CFW. The decision tree in Figure 4 provides guidance on the suitability of a site for a CFW.

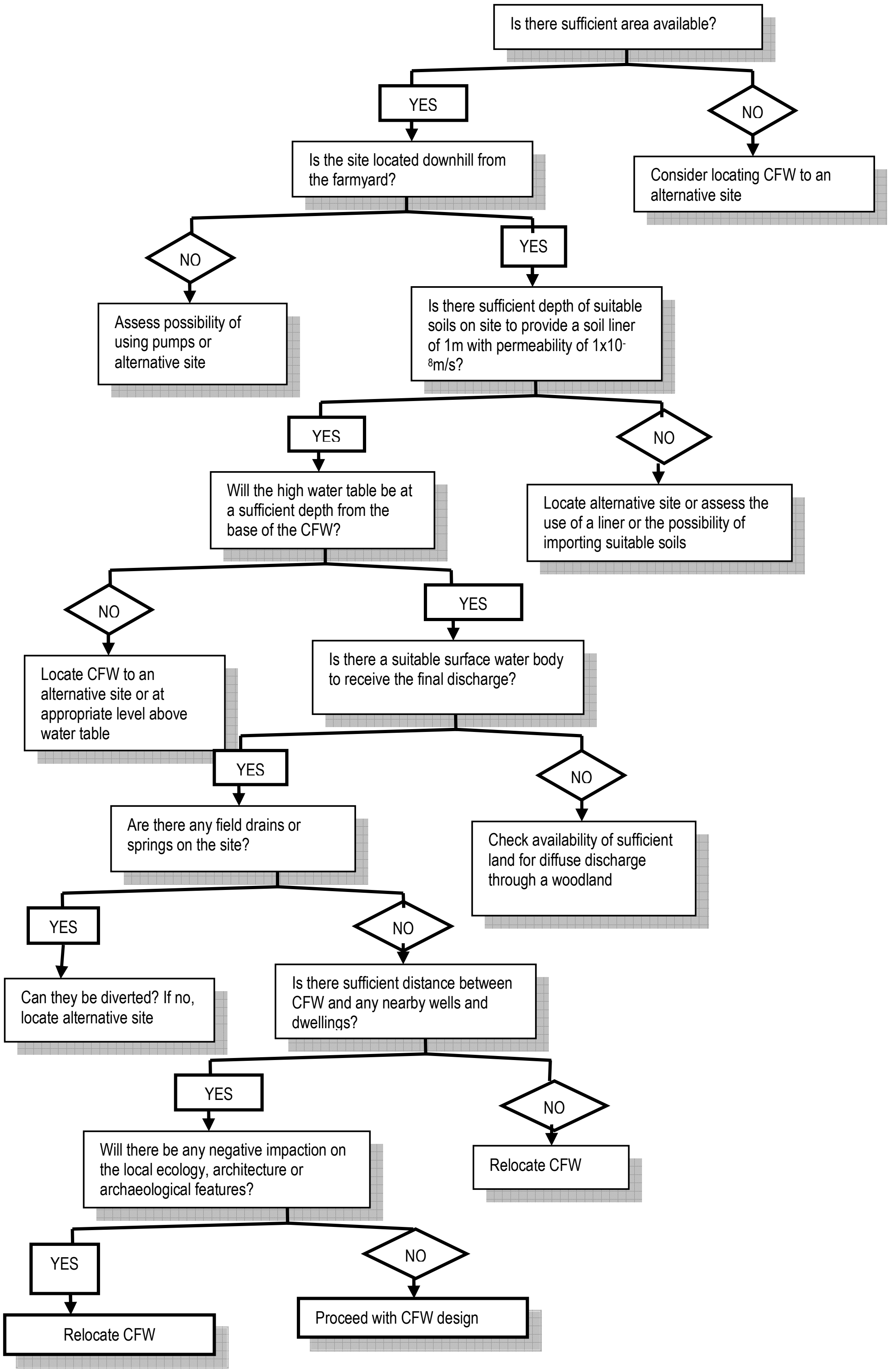


Figure 4: Decision tree for assessing the suitability of a site for a CFW.

5. CFW Design

When designing CFWs, the variation in farm and farmyard structure and behaviour needs to be recognised. Ideally the overall infrastructure should be self-managing, robust and sustainable, and appropriate to meet legal and regulatory needs.

When designing CFWs, the following aspects are of major importance:

- The characteristics of the farmyard runoff to be treated (volume/quality),
- The objectives behind the construction of the CFW,
- The water quality targets to be achieved,
- The availability of suitable land.

5.1 Runoff capture and conveyance

The conveyance of water to, within and from the CFW must consider the following:

- Collection of water from the farm,
- Conveyance of that water to the CFW,
- Water movement within the CFW,
- Water movement out of the CFW.

The type of runoff to be collected will have been identified when assessing the need for a CFW (section 3). Ideally, the lightly contaminated water to be treated from various areas of the farm should be conveyed to one point prior to entering the CFW. Various conveyance methods can be used, from traditional hard piping to more sustainable green drainage (swales), if these are constructed to prevent infiltration. Where possible, the lightly contaminated water to be treated should flow by gravity to minimize maintenance and energy costs. Whichever system is chosen it must be of sufficient capacity to be capable of conveying peak flows. Runoff from adjacent land should not be allowed to enter the CFW. A receiving layer of large chippings or small stones placed below the inlet of each cell will prevent scouring. Larger stones should be used where inlet velocities are high.

It is essential that any containment is secure and that only water free from polluting contaminants is discharged to watercourses. The containment of influents within a CFW and its segmented structure, with each sequential segment having its own contamination gradient, will progressively lead to improved water quality, which should ultimately meet the needs of the receiving environment. The wetland's embankments retaining the water flowing through the system must be sufficiently high to allow for the accumulation of sediments and detritus. Side embankments and the base of wetland cells must be adequately lined to impede water transfer between cells and infiltration to protect groundwater [9] [10] [11].

5.2 Water movement in cells

Uptake of water by emergent vegetation, evapotranspiration and infiltration reduces the amount of water in the individual cells of a CFW, creating a freeboard between the level of the water in an individual wetland cell and the outlet level. Hence, each wetland cell has the capacity to handle rainfall events and to increase hydraulic residence time [9] [11] so that peak flows are attenuated and delayed and contaminants treated before discharge to the receiving watercourse. This configuration also minimises the risk of the system drying out which could lead to loss of diversity and habitat and reduce wetland performance.

The hydraulic effectiveness of the CFW depends on:

- Segmentation of the wetland into a number of wetland cells of appropriate configuration,
- Avoidance of preferential flow,
- Dense vegetation stand,
- Management of water depth to ensure optimal functioning.

The velocity of the water flow through the CFW is determined by the volumetric flow and the cross-sectional area of the water channel. Taking predominantly surface flow within the CFW into account, this equates to volumetric flow across the width of each wetland segment. Minimising the velocity enhances the precipitation of suspended solids and promotes a longer contact time with emergent vegetation whose surfaces support water-cleansing biofilms [11].

Wind and temperature differences have the potential to generate water movement between the different aquatic strata within a wetland segment. Emergent vegetation minimises mixing, thus allowing the cleaner water to flow preferentially along the surface, especially during periods of large precipitation-generated flow. In the initial receiving wetland segment, floating vegetation may develop (typically *Glyceria maxima* and *Agrostis stolonifera*) and water flow will be partially sub-surface, thus having the additional advantage of reducing odours [9] [11].

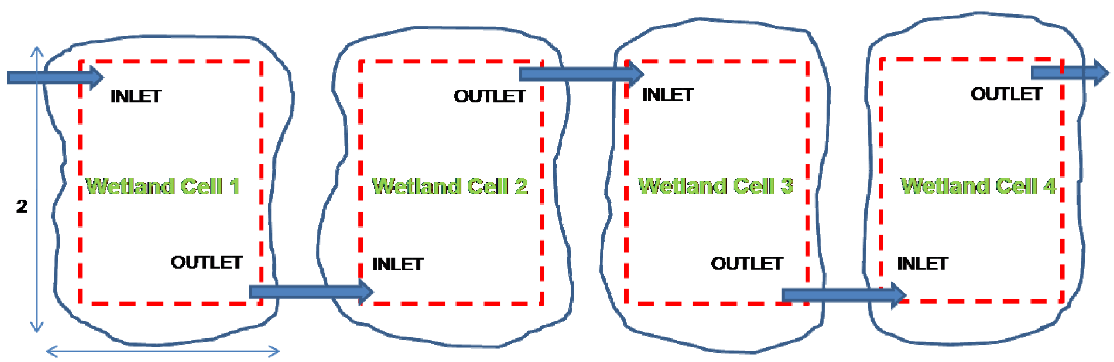
5.3 Calculating CFW area

The design and sizing of CFWs has focused on the most limiting factor, that of phosphorus, which is recognised as one of the most difficult nutrients to remove from water and a limiting factor in freshwater ecosystems. A study of the treatment performance of 13 wetland systems (ICWs) in Ireland analysed the relationship between wetland design and mean molybdate reactive phosphorus (MRP) concentration at the outlet, which showed that a system with four cells and a CFW aspect ratio of less than 2.2 (ideally closer to 1) is required to obtain an outlet mean MRP concentration of 1 mg l^{-1} or less. The aspect ratio is defined as the mean length of the wetland system divided by the mean width. The study has also shown that the wetland area required can be related to the farmyard area; the former should be twice the area of the latter. Also by increasing wetland area there is greater capacity to further remove MRP levels.

5.4 Wetland layout

Using the above guidelines and a wetland area of twice the farmyard area, it is very simple to design the geometry of a CFW. For example, a farm with an effective yard runoff area of 10,000 m^2 requires a CFW system size of 20,000 m^2. If the CFW system is to have (at least) four CFW cells in it, with a 1:1 ratio (round or square), then each cell requires an area of 5,000 m^2 with dimensions of 71 m by 71 m, or a 2:1 aspect ratio requires a 100 m by 50 m.

However, curvilinear CFW would be preferable in practice, see drawing below in Figure 5. Increasing the number of wetland cells decreases the required size of any single cell. It also facilitates effective transport (for nutrient and contaminant retention) of water within the wetland system. This, combined with remaining design guidelines (i.e. providing adequate groundwater protection and adequate freeboard), is sufficient to adequately design a CFW system comprising of four cells (11) (14).



Each wetland pond should have a width:length ratio of at least 1:2. Inlet and outlet pipes should be located at maximum distances from each other.

Figure 5: Example of layout for a CFW.

As illustrated in Figure 5, the aspect ratio, which is defined as the mean length of the wetland cell divided by the mean width, should be at least 2:1 or ideally circular or square. The embankment height should be at least 1 m, with upper embankments a minimum 2-3 m wide. The slopes of the embankments where land availability allows should be 1:4, but no less than 1:2. The embankments must provide stability and easy access for maintenance and monitoring. Water levels are managed using adjustable bends on the outlet pipe of each cell. Water levels should be maintained at no greater than 300 mm. Figure 6 shows the cross section through a wetland cell in a CFW.

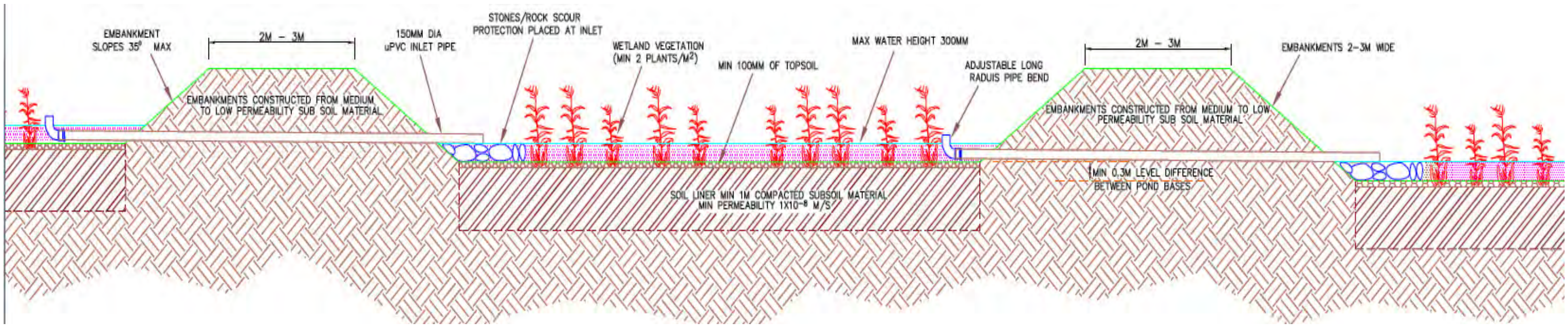


Figure 6: Cross section of CFW.

5.5 Flows within the CFW

Pipes with a diameter of at least 150 mm to avoid clogging are placed at the inlet and outlet of each cell to convey the flows through the system. Inlets and outlets should be kept as simple as possible avoiding the use of concrete and over- engineered structures. The pipes should be placed on the base of the cell and the distance between inlet and outlet pipes within each cell should be maximised to increase retention time and reduce short-circuiting of flow in the cell. At the outlet from each cell, elbow PVC pipes fitted to linear PVC pipes (Figure 8) are used to control water level and outflow from each cell.

Figure 7: Inlet pipe to CFW cell

(The picture on the left shows a 150 mm diameter inlet pipe and chippings below to reduce scouring. Picture to the right shows recently installed inlet pipe and picture to the left shows inlet pipe in use.)

Figure 8. Outlet pipe with an adjustable bend.

5.6 Final outlet and discharge from the CFW

The final discharge from the CFW will require a suitable surface water to discharge to. The discharge of water to a surface water will need to comply with the relevant regulations and legislation as outlined in Section 1.2 of this manual. At the early stages of developing a CFW, the local SEPA or NIEA will need to be contacted to discuss discharge to a given watercourse. The level of authorisation will depend on the quality of the material conveyed to the CFW and that of the discharge from the CFW.

5.7 Habitat, biodiversity and landscape enhancement

The opportunities for habitat restoration and biodiversity enhancement require attention at the design stage, particularly the development of transitional habitats between the terrestrial embankment and wetland zones (13). Wide, shallow and low elevated edges at the embankments will promote floral and faunal diversity. Local vegetation is best incorporated wherever possible. Care should be taken when locating CFWs immediately adjacent to woodlands as problems may arise from shading and seepage of water via root systems. CFWs can be dynamic ecosystems and their habitats may be transient unless managed and maintained. The management of water depth to facilitate optimal water treatment is particularly important in this regard (9) (11) (15).

5.8 Aesthetics and amenity

CFWs can have considerable aesthetic appeal. The combination of water, vegetation and associated wildlife, as shown in Figures 9 and 10 are the principal elements of visual enhancement, and there are many examples of this throughout the world.

Figure 9: Old Castles Constructed Wetland, Scotland - Final Cell of the CFW.

Figure 10: ICW in Carlow, Ireland.

A CFW incorporates aesthetic appeal and amenity value through appropriate land forming design implemented during construction. The process of design ensures that the final CFW structure 'fits' well into the landscape; e.g. by making the enclosing embankments curvilinear and conforming them to the site's topography. Subsequent vegetation development will further enhance the visual natural appearance of the system. Appropriate land forming of the structure to fit the landscape also reduces CFW maintenance, thus enhancing a variety of amenity values and improving its sustained functionality [9] [11]. The placement of an island can add to the aesthetic appeal of a CFW while also providing additional habitat and nesting areas for wildlife. The use of an island or floating island can be developed as an additional feature to the CFW design; however, it would require additional area and ideally would need to be located in an additional cell. The use of islands within the first four required cells is not recommended as it will disrupt the configuration of the cells width to length ratio of 1:2.

Figure 11: Island within the final cell of a wetland in Co. Waterford.

Farmers involved in CFW projects have expressed their appreciation of having an area of visual beauty, tranquillity and wildlife interest that was not previously present adjacent to their farmyard. This often resulted in the wider appreciation of CFWs within the community leading to curiosity and interest in the nature of wetlands in general. The encouragement of the farmer to participate in building the CFW has been helped by the acquisition of these new values for their land [9] [11].

6. CFW construction and planting

6.1 Construction

The construction of a CFW should be undertaken by a competent machine operator and the work supervised by a qualified engineer who will sign off as fit for use on its completion. A tracked excavator and bulldozer will be required for the construction and a vibrating roller may be needed for soil compaction.

Figure 12: Construction phase.

It is recommended that the construction of CFWs be undertaken during late spring and summer. The involvement of the farmer is encouraged throughout the construction of the CFW. The main stages of construction are given in Table 5 and are described in more detail below.

Table 5: Main stages in the construction of a CFW.

Stage 1	Topsoil stripped from the CFW area and retained for later use
Stage 2	Excavation of subsoil
Stage 3	Liner preparation
Stage 4	Creation of bunds and embankments
Stage 5	Pipe laying between the cells
Stage 6	Redistribution of topsoil over the base of the cells
Stage 7	Placement of stones/chippings beneath the inlet pipes
Stage 8	Planting the cells

Stage 1: The depth of excavation will vary depending on the depth of the overlying topsoil, but is usually between 10-30 cm.

Stage 2: The depth of excavation will depend on the topography and elevations required between each cell. The typical excavation depth for flat sites is c. 0.5 m below ground level. Where a CFW is located adjacent to lands sloping toward the system a drain or an embankment should be constructed around the cells to prevent/divert potentially large volumes of runoff entering the system.

Stage 3: The amount of compacting and layering will depend on the type of material being used to construct the cells and banks of the CFW and should be determined in the site assessment of the soils. Medium to low permeability soils will require layering and compaction to ensure a permeability of 1×10^{-8} m s^{-1}. Where there is sufficient low permeability soil layering may not be needed.

A soil liner should be at least 1.0 m thick, ideally using in-situ material, with a permeability of 1×10^{-8} m s^{-1}. Where an artificial liner is used there should be at least 0.5 m of low permeability soil beneath the liner. The top of the wetland liner in each cell should ideally be puddled using the tracked machine and water to further impede infiltration.

The banks and base of the wetland cells should be compacted and smoothed-off using a tracked excavator which is suitable for use of difficult terrain, has the capacity to work in wet conditions and may in some cases be suitable for compaction of the wetland soil liner. Where a greater degree of compaction is required rollers or other suitable machinery should be used.

Stage 4: Embankments/bunds are created to form the cells and should be:

- Gently sloping (ideally 1:4 if space allows) for safety,
- At least 1 m in height to ensure containment of water and allow for accumulation of sediments, and
- 2-3 m wide at the top to provide for structural stability and allow access to the wetland.

Baffles (smaller embankments within the pond) if needed, can be created to alter flow paths or the direction of flow to ensure the flow of water is over the maximum distance of the pond. These can vary in length, but will usually only need to be 300 mm in width and 400 mm height.

Stage 5: Basic pipe work should be incorporated in the construction of the cells and embankments. 150 mm diameter ducting and elbows should be placed at the inlet and outlet point for each cell. Piping should be positioned in places that are accessible and as close as possible to the cell base of the exit point to ensure that complete drainage is possible if required in the future. Piping should be placed so as to ensure that the movement of water in each segment is across the maximum distance from inflowing point to exit, as illustrated in Figure 6 section 5. CFWs discharging to surface waters prone to flooding/increased water height should have a non-return valve placed on the outlet pipe to prevent any water entering the CFW.

To prevent flow from the CFW to the receiving waters in the event of pollution the final outlet pipe has an adjustable right-angled pipe, which can be turned up, to prevent any discharge. The outlet pipe should have a manhole/inspection chamber to allow for easy and safe monitoring.

Stage 6: When the soil liner and embankments have been constructed and pipe work installed, topsoil material is distributed over the bottom and sides of the wetland. The topsoil material contains the finest soil particles and organic matter, providing a better growing medium for planting. Topsoil also increases hydrological sealing of the wetland cell base.

Stage 7: Stones or chippings should be placed beneath the inlet pipes to prevent scouring of the wetland floor and to provide access for monitoring.

Stage 8: Species planted should include a variety of suitable native & ideally locally sourced plants (see Section 6.2). Use of faster growing species gives rapid cover and early treatment. Smaller plants may need a longer time period to become established.

6.1.1 Risk mitigation during construction

Measures should be employed during the construction of a CFW to limit the impact on the surface water (runoff and siltation) and groundwater environments. Where a CFW is being developed near a water body it is recommended that any runoff from the site is not directly discharged, therefore a settlement cell may be required. In Scotland operators should be aware of and adhere to General Binding Rules for work in or close to watercourses. In Northern Ireland operators should be aware of and adhere to Pollution Prevention Guidelines for works and maintenance in or near water (PPG5)

6.1.2 Access and fencing

Depending on the location of the site there may be a need for fencing to restrict access to humans and livestock, with adequate gates to allow access by machinery. In most cases fencing similar to that already used on the farm will be suitable, such as 600 mm high electric fencing or 1.5 m post and rail fencing.

6.2 Planting and landscaping

6.2.1 Suitable plant species

The advisor preparing the CFW design should assist the farmer in selecting the appropriate plant species and their source. CFWs should only be planted with native species, which occur in the local area. Table 6 below includes some of those recommended, although not all of these are widespread in Scotland and Northern Ireland. The species listed have shown to be successful in existing CFWs, with *Carex riparia* being widely used due to its year-round growth. Other species such as *Glyceria maxima* and *Typha latifolia* are also tolerant to contaminated influents and establish quickly.

Table 6: Suitable plants for use in CFWs.

Common name	Latin name
Greater pond sedge	*Carex riparia*
Reed sweet grass	*Glyceria maxima*
Reedmace or Cattail	*Typha latifolia*
Bulrush	*Scirpus lacustris*
Lesser bulrush	*Typha angustifolia*
Common reed	*Phragmites australis*
Branched burreed	*Sparganium erectum*
Yellow flag iris	*Iris pseudacorus*

6.2.2 Sourcing the right plants

Plants should be sourced from accredited plant nurseries or from small-scale collections from existing wetlands (constructed or natural) where permission has been given by the landowner. Protected areas such as SSSI, ASSI, NNR, NSA, SAC and SPA are not suitable for sourcing plants. The unauthorised picking, cutting, destruction, selling and transportation of material from European protected sites is prohibited under the Conservation (Natural Habitats) (Amendments) Regulations (Northern Ireland) 2007. Care must be taken to ensure that plants are of Scottish or Irish provenance, as appropriate, and that non-native species are not introduced. Some non-native species (which can also be found in the wild) can be very invasive and problematic. The recommended sourcing of plants is detailed in Table 7.

Table 7: Sources and size/maturity of plants for planting CFWs.

Source	Size
Nursery stock	Mature plants (1-2 years) Bare root No seedlings*
Natural/Constructed wetlands Rivers	Harvested stock

*Seedlings are not generally recommended as they are juvenile plants and are more vulnerable to pollution and water level variations, and take longer to establish. Discharge of the lightly contaminated water to the cells may not be possible for several months until the plants have established.

Figure 13: Planting bare root vegetation.

Small-scale harvesting from existing natural/constructed wetlands is the most economical means of sourcing suitable plants. Sufficient root material should be collected to allow the plant to establish, while also ensuring that the root system of the original plant is not entirely removed. Ideally the harvesting should be carried out by hand to minimise disturbance to the plants and its environment. Scottish Natural Heritage (SNH) or the Northern Ireland Environment Agency (NI) should be notified prior to sourcing plants in this manner, as a licence to harvest plants may be required.

6.2.3 Planting density and procedure

Planting should be carried out by hand into water or suitably saturated soils, ideally with 50 and 100 mm of water above the topsoil. Figure 14 shows a recently planted cell. Water levels should be maintained between 100 and 200 mm for at least the first six weeks after planting, and the cells should not be allowed to dry out below the soil surface. Shallow water (<100 mm) will encourage establishment of grasses and weeds, which can restrict the growth of the wetland vegetation. Water may need to be sourced from nearby surface water features during summer time planting, as the lightly contaminated water from the farmyard may only provide sufficient cover for the first cell. The local SEPA or NIEA office should be contacted before abstracting from any surface water.

Figure 14: Wetland recently planted with bare root Carex riparia.

Vegetation cover of at least 80% after two years is desirable. The first wetland cell will receive a higher pollution load, therefore a minimum of three plants per m^2 is recommended to increase plant success. Subsequent cells will have reduced nutrient loadings and a minimum of two plants per m^2 is sufficient. Provided that planting is carried out at the beginning of the growing season (April-May) and water levels are maintained between 100 and 200 mm for the initial months, there should be full cover within the wetland after two years. To establish a dense cover in a shorter period the initial planting densities should be doubled. Once plants are established water depth can be increased to a maximum of 300 mm.

6.3 Landscape fit and biodiversity

Whilst not essential for efficient operation, the potential visual aspect of the CFW design is important for achieving empathy from both farm dwellers and the local community. There are several measures that can improve the landscape fit and biodiversity of the CFW. CFWs with harmonious and curvilinear shaping and virtually level embankments have a more 'natural' appearance. The use of locally occurring wetland plant species for establishing habitats and enhancing biodiversity appropriate to the locality is likely to increase the robustness and sustainability of the system [11].

When possible the CFW should be located near (but not in connection with) existing wetlands, ponds, lakes etc, to allow for natural colonization of plants and animals. The shape of the cells is important in how the CFW fits into the landscape; whilst retaining their optimum aspect ratio, they should be irregular in shape, have gently sloping embankments and contain areas of deeper water and may include small islands. The area surrounding the CFW can be planted with trees and shrubs, but trees are not recommended on the CFW embankments, due to the risk of water infiltration via roots and destabilisation during high winds. If possible, small pools around the main system should be created, collecting runoff water from adjacent fields.

7. CFW operation and maintenance

7.1 CFW commissioning

Prior to the commissioning of the CFW the system must be signed-off by a competent engineer (construction works) and have all monitoring and maintenance features and fencing (where necessary) in place. During the first few months water levels within the wetland cells should be approximately 100-200 mm, to provide favourable conditions for plant establishment. It is possible that some of the lightly contaminated water from the farm yard may need to be diverted away from the CFW during the start up stage, e.g. stored and/or land spread. Once the plants are established water levels can be maintained at a **maximum depth of 300 mm**.

7.2 CFW life span

Wetland embankment height, in-flowing solids and accumulating detritus determine the functional life span of each cell of the CFW. Given proper construction, a minimum embankment height of 1 m and detritus accumulation rates similar to those measured in ICWs in Ireland, life spans of decades can be expected. However, the life span can virtually be indefinite if maintenance takes place regularly [11].

The success of a CFW will depend on the maintenance and operation of the system. While a CFW is designed to be as self-maintaining as possible, it is crucial that a maintenance programme is adopted to ensure continued effective water treatment and "rejuvenation" of the system.

7.3 Checking and maintenance of inlet and outlet pipes

All inlet and outlet pipes within the CFW should be visually inspected weekly and any blockages and sediment or debris accumulations should be cleared. Blockages will affect the hydraulics of the CFW, whilst sediment accumulation may indicate inadequate solids separation further up in the system.

7.4 Flow maintenance and control

During prolonged dry periods, water depth within the cells will decrease, especially in down gradient areas of the wetland. It is essential that soils are covered with at least 50 mm of water, particularly in the first two cells, as cracks may form, which could cause higher infiltration rates between the soils in the short-term when water re-enters the cell. Plants should not be a concern as they are able to cope with reduced water depths and drying out for periods lasting several months once estabished.

The unnecessary adjustment of pipes should be avoided. If any down turn adjustments are required, they must be carried out in small steps, as moving pipes may cause huge surges of water to subsequent cells, the receiving surface water or groundwater and also reducing residence time and treatment within the system.

7.5 Vegetation maintenance

To ensure good plant growth water depth must be kept less than 300 mm. However, it may temporarily rise higher (up to 500 mm) during high rainfall events, or decrease during dry weather. Any differences in the composition or cover of the vegetation should be noted as an indicator of wetland performance.

7.6 Removal and monitoring of sediments

Over time sediment comprising organic material from the influent and dead plant matter (detritus) will accumulate in the wetland cells. Existing constructed wetlands have shown varying accumulation rates, depending on the influent loading (quantity and type of pollutant) and vegetation cover of the wetland. Mean sediment accumulation rates of 3 cm per annum have been measured after five years in operation in CFWs receiving moderate loadings in the Anne Valley, southern Ireland [11].

From previous wetland monitoring, the general trend is that the sediment will settle in the first cell of the CFW (see Figure 15). For a heavily loaded system the inclusion of an open water cell (0.5 m deep) at the initial stage of the CFW to act as a sediment trap may extend the operational life of subsequent cells before removal of material is required. Such an initial wetland cell might require relatively frequent material removal (possibly annually), but could be configured to be as accessible as a standard slurry storage tank [16]. Where an artificial liner such as a HDPE liner has been used a detailed assessment (e.g. liner location, depth) is necessary prior to sediment removal, since if the liner is damaged it will require replacement.

Figure 15: Sediment accumulation in the initial cell of a CFW.

The most appropriate way of managing the material removed is likely to be land spreading on the farm in accordance with good agricultural practice. Information on the solid content and nutrient content composition, particularly in relation to phosphorus, is required to assess usage options to ensure compliance with farm nutrient management requirements and current regulations.

Some replanting maybe required after the sediment has been removed from the cell. However, an established wetland will have mature vegetation cover and plants deeply rooted in the underlying soils, which is not removed during sediment excavation.

7.7 Inspection of cell embankments

The farmer should undertake a monthly visual inspection of the internal and external faces of the cell embankments to check for any water leakage, slippage or distortion. Any defects such as leakages, slippages or distorted areas should be addressed immediately, with the help of the contractor who initially constructed the wetland if necessary.

7.8 Access and security checking and maintenance

Access around the wetland should be maintained by assessing the vegetation growth on the embankments. Under normal operating conditions growth on the cell crests will need to be cut at least once a year using a mower or topper.

Security/safety considerations for both humans and livestock are required and should be incorporated into the design of the CFW. Access to the influent-receiving segment of the CFW may have to be limited through fencing. Generally the context of the siting of the CFW will determine to what degree exclusion is imposed; this may suggest that the entire area of the wetland is fenced or appropriate hedging. Typically CFWs are fenced using similar fencing with that already used on the farm. Existing hedgerows around the CFW may be sufficient in securing the wetland. All fencing and hedging should be checked to ensure that their purpose (restricting access) is maintained.

7.9 Monitoring of final discharge and receiving watercourse

The monitoring of the final discharge from the CFW and the receiving watercourse will allow the farmer to assess the performance of the CFW and detect any malfunction. Monitoring at times of low stream flow and following high rainfall events is particularly important. An inspection chamber or manhole on the outfall pipe from the wetland will allow the farmer to assess the final discharge (also discussed in section 6.1)

The general appearance of the final discharge should be noted, paying particular attention to water colour, smell and any evidence of plant vegetation in the discharge (plant establishment in adjacent waters is not generally recommended). If the final discharge water appears to be heavily discoloured, polluted or contains plant material then the outlet pipe should be isolated immediately by turning up the adjustable outlet pipe (see also section 6.1) and the appropriate pollution response agency alerted (SEPA or NIEA). However, water that is visibly clear may also have a high nutrient concentration, which can only be determined by laboratory analysis.

The condition and appearance of the receiving waters at the point of discharge should be checked on a weekly basis and following periods of extreme events, such as high rainfall. The farmer should assess the condition and appearance of water, both upstream and downstream of the discharge location. Heavily discoloured water or the appearance of sludge type material may indicate an upstream pollution source. Foaming immediately downstream of the discharge point may indicate pollution in the final discharge. In the event of any pollution incident the outlet pipe from the CFW should be isolated immediately by closing the outlet and the appropriate pollution response agency alerted (SEPA or NIEA). The farmer should obtain advice from a suitable agricultural advisor.

7.10 Decommissioning of the CFW

In some circumstances the use of a CFW will cease. However the system is designed so that its functions are not permanently lost. Should farming practices change or discontinue, the cells can either be filled in or in some cases be maintained as a wetland system continuing to provide habitats. While the maintenance of the CFW is preferred, either of these options can be carried out on either the entire wetland area or part of the site. Where the CFW is filled in, the sediments and organic matter that have accumulated can be excavated or left in the system. The plants in the cells can be harvested or removed for use in another wetland system. Likewise pipe work should also be reused or disposed of appropriately. The material excavated to form the embankments can then be used to fill in cells thus returning the land to its original form.

Where the system is to be maintained as a wetland habitat it will require a supply of water to the system. The source of water will depend on the site, but diversion of clean water drainage to the CFW may be suitable.

Appendix 1: Case Study - CFW at Greenmount Campus, N. Ireland.

A large scale Constructed Wetland was established at Greenmount Campus, CAFRE during 2004. The system provides a research facility in partnership with the Agri-Food and Biosciences Institute and the Environment & Heritage Service to determine if large scale constructed wetlands could successfully treat dirty water from the Greenmount Campus Dairy Unit.

The Wetland consists of five ponds with a combined area of 1.2 hectares. This represents a considerable area of agricultural land, especially given N. Ireland's historically high land prices. In designing the Greenmount Wetland, the scale of the system was deliberately kept large with the view to use the research findings to assess the scale of a system necessary for typical commercial dairy farm.

In the initial phase of the research monitoring, existing drainage systems on the dairy unit which did not separate clean and dirty water have been retained. The second phase of the research monitoring will involve separation of the clean roof and yard water from the effluent directed to the Constructed Wetland. This will reduce the rainfall catchment area in the dairy unit by half to approximately 3000 m^2. This will reduce the volumes of effluent reaching the wetland again by about 50%, increasing the residence time of effluent in the wetland.

Based on results from the Greenmount Constructed Wetland to date, it is anticipated that a much smaller wetland footprint would therefore be adequate to treat dirty water from a 180 cow dairy unit. Consequently, the following calculations and cost benefit analysis have been worked through assuming a Constructed Wetland size of 6000 m^2 in 5 equal sized ponds.

Figure 16. Greenmount Campus CFW, 2004

Cost Benefit Analysis of a Constructed Farm Wetland

This cost benefit analysis is based on experiences to date of constructing and operating a Constructed Wetland System at the Greenmount Campus, CAFRE, Dairy Unit. The calculations assume best management practice in minimising dirty water production through separating clean and dirty water at source. The 180-cow Dairy Unit has a dirty yard area of approximately 3000m^2 and produces 5.0 m^3 dairy parlour washings each day.

Assumptions:

- 3000m^2 dirty yard area
- Average rainfall 4 mm per day
- Dairy washings 5m^3/day
- Dirty water storage cost £40/m^3 (block built tank, dirty water only, estimated cost)
- Land spreading cost £20 per hour (9 m^3 slurry tanker, DARD, Farm Business Data 2008)
- Ratio of wetland to dirty yard area 2:1
- Wetland construction cost £22,000 (I Stevens, Chartered Quantity Surveyor)
- Wetland planting cost £7,500 (based on Greenmount Campus Wetland)

At an average rainfall level of 4 mm per day, 1,910 m^3 of diffuse dirty water would be produced over a 16* week period. Providing storage capacity for this volume would cost approximately £76,500 for an above ground slurry store at £40/m^3. Land spreading of the annual volumes of dirty water would cost £1,415 per annum based on contractor costs of £20 per hour using a 9 m^3 slurry tanker. Land taken out of production for the constructed wetland is valued at an annual rental of £250 for 1.0 ha. Little information is currently available about the need for maintenance of constructed wetland systems. However, provision has been made within the maintenance costs for the first pond to be dredged and replanted every 5 years at a cost of £7,500. See Table 8.

Table 8: Cost benefit analysis

Constructed Farm Wetland	**£**	**Storage and Land Spreading**	**£**
Annual depreciation £29,500	2,950	Annual depreciation £76,500	7,650
Maintenance costs of 5 year dredging and replanting of Pond 1. Rental of 1.0 ha of land	1,500 250	Annual costs field spreading dirty water	1,415
Total Cost	**4,700**	**Total Cost**	**9,065**
		Extra Costs	**4,365**

*Based on Culleton et al, Nutrient Management in Agricultural Watersheds, A Wetland Solution (2005)

In summary, a constructed wetland system would represent an annual saving of £4,365 compared to a conventional storage and land spreading system, based on the above assumptions. However, of critical importance is the length of storage period required for holding dirty water. On a dry farm, where dirty water could be spread every 7-8 weeks the storage and land spread and constructed wetland options would incur equivalent cost in this analysis.

Appendix 2: Case Study - Integrated Constructed Wetlands (ICWs), Anne Valley, Waterford, Ireland.

Area description. In 1999 and 2000, twelve ICWs were designed within the Annestown-Dunhill catchment, planning permission from the local government (Waterford County Council) was applied for and received, and construction was carried out to intercept and treat farmyard dirty water from twelve farmyards. ICWs were constructed on various farm enterprises within the watershed. In general, ICW sizes ranged between approximately 3,000 m^2 and 22,000 m^2. Components of farmyard dirty water discharged to the wetlands were variable; the runoff typically consisted of yard and dairy washings, rainfall on open yard and farmyard roof areas along with silage and manure effluents. The mean ICW size was approximately 1.4 times the size of the open farmyard areas [11].

Water quality. Phosphorus concentration reductions were generally greater than 90%. Table 9 shows the inflow mean water quality values.

Table 9: Mean inflow water concentration.

Parameter	Range
COD	1788 ± 2248 mg l^{-1}
BOD	791 ± 1587 mg l^{-1}
Suspended solids	358 ± 318 mg l^{-1}
Ammonia-nitrate	68.7 ± 48.9 mg l^{-1}
MRP	19.83 ± 20.98 mg l^{-1}
E. Coli	833396 ± 2022116 CFU per 100 ml

This indicates a very large variability in terms of water quality for all the tested substances in the farmyard dirty water discharged to the ICW.

Performance data

The characteristics of ICW treated waters discharged to surface waters (mean values) are listed in Table 10 on the following page [2].

Table 10: Mean values of ICW treated waters.

Parameter	Concentration
COD	50 mg l^{-1}
BOD	20 mg l^{-1}
TSS	20 mg l^{-1}
Ammonium (NH_4^+)	0.5 mg l^{-1}
Nitrate	<1 mg l^{-1}
Total phosphorus	1.0 mg l^{-1}
Phosphate (PO_4^{3-})	0.5 mg l^{-1}
Faecal coliforms per 100 ml	<500

Costs

ICWs in the Anne Valley between 2000 – 2005 were constructed and planted at a cost of € 17,000 - € 21,000 per hectare. Construction costs depended on site conditions and specific requirements for each site. All ICWs were constructed using in-situ soil material.

A study undertaken to assess cost effective management of soiled water from agricultural systems in Ireland [(17)] compared and contrasted the monetary costs of various systems for managing agricultural soiled water with alternative low cost systems. The study showed that alternative low cost ICW systems were the cheapest method in wet soil areas and the second cheapest on dry soil areas. One week storage and auto irrigation system indicated to be the cheapest on dry soil areas.

Figure 17. Anne Valley, Co. Waterford.

ICW development

ICWs are being applied throughout Ireland for the treatment of contaminated waters for agricultural, industrial and civic use. A guidance document is currently being finalized on 'Integrated Constructed Wetlands' by Water and Natural Heritage Division, Department of Environment, Heritage and Local Government.

Appendix 3: Checklist

1	Assess the need for a CFW	√
2	Ensure drainage types can be legally conveyed to a CFW	
3	Assess the suitability of a site for a CFW	
4	Obtain necessary authorisation e.g. planning permission	
5	Employ suitably qualified contractors to undertake design, construction and planting	
6	Provide sufficient area for CFW system (surface water area of CFW 2 x the intercepting farmyard area) and embankments (minimum 2-3 m wide embankments and access).	
7	Ensure the base of the CFW lies 1 m above the water table	
8	Provide necessary 'liner' with a minimum of 1.0 m of subsoil with a permeability of 1×10^{-8} m s^{-1}. Undertake any necessary compaction and ensure top layer of liner is puddled and tracked, using sub-soil, topsoil and water.	
9	Form 4 ponds, curvilinear in shape and with a length:width ratio ideally 1:1 or 1:2. Inside embankment slopes should ideally be 1:4, but no greater than 1:2 and a minimum of 1.0 m in height.	

10	Install pipe work between ponds and any associated drainage or pumps. Scour protection to be provided beneath each inlet pipe.	
11	Redistribute the topsoil to a minimum cover of at least 100 mm for plant establishment.	
12	Plant each pond with suitable locally native wetland species each pond to be planted with a minimum of 2 plants/m^2, with pond 1 having 3 plants/m^2 where possible.	
13	Gradually release drainage from farmyard to CFW, ensuring water depth is between 100-200 mm for the first few months after planting. Water depth can be increased to a maximum of 300 mm once plants have established.	
14	Commence operation and maintenance of CFW.	

Glossary

Adsorption: The adherence of gas, vapour or dissolved matter to the surface of a solid.

Anaerobic: Occurring in the absence of oxygen or not requiring oxygen to live.

Biobed: In-ground treatment unit designed to contain spills of pesticides and to destroy them through microbiological activity.

Biochemical Oxygen Demand (BOD): Amount of oxygen in water consumed by a waste through bacterial degradation.

Biodiversity: The number, variety, and genetic variation of the different organisms (e.g. plants, animals, fungi and bacteria) found within a specified geographic region.

Catchment: The area contributing surface water flow to a point on a drainage or river system.

Chemical Oxygen Demand (COD): amount of a strong chemical oxidant that is reduced by a waste, the results of which is expressed in terms of the equivalent amount of oxygen.

Denitrification: Process by which nitrate (NO_3^-) is reduced to nitrite (NO_2^-), and nitrite to nitrogen gas (N_2).

Design criteria: A set of standards agreed by the regulators, developers and planners that a given system should satisfy.

Diffuse pollution (as opposed to point-source pollution): Pollution arising from land use activities (urban or rural) that are dispersed across a catchment and which do not arise as a process effluent, municipal sewage effluent or an effluent discharge from farm buildings.

Eutrophication: Water pollution caused by excessive amounts of nutrients (especially N and P) that result in excessive plant and algal growth, increased turbidity and oxygen depletion.

Evapotranspiration: A measure of the amount of water lost by transpiration and evaporation from a given area.

Nitrification: The biological transformation (oxidation) of ammonia into nitrite and nitrate.

Pond: Permanently wet basin designed to retain storm water and permit settlement of solids and removal of pollutant to a certain extent.

Runoff: Water that flows over the land surface over impermeable (e.g. concrete yards) or permeable (e.g. fields, tracks) surfaces.

Steading: The land and buildings (The barns, stables, cattle-yards, etc.) of a farm (syn. Farmstead)

Swale: A shallow vegetated channel designed to conduct and retain water and to offer a small degree of treatment.

Wetland: A relatively shallow pond that has a high proportion of emergent vegetation in relation to open water.

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Supplementary Information

Northern Ireland Environment Agency website www.ni-environment.gov.uk

Scottish Environment protection Service website www.sepa.org.uk

Department of Agricultural and Rural Development (DARD) website www.dardni.gov.uk

Department for Environment Food and Rural Affairs (DEFRA) website www.defra.gov.uk

SNIFFER website

http://www.sniffer.org.uk/Webcontrol/Secure/ClientSpecific/ResourceManagement/UploadedFiles/WFD28.pdf)

Water Framework Directive (2000/60/EC)

Nitrates Directive (91/676/EEC)

Bathing Water Directive (76/160/EEC)

Groundwater Directive (2006/118/EC)

United Nations Environmental Programme (UNEP) www.unep.org

Convention on Biological Diversity (CBD) www.cbd.int

Ramsar Convention on Wetlands (Ramsar, 1971) www.ramsar.org

Control of Pollution (Silage, Slurry and Agricultural Fuel Oil) (Scotland) Regulations 2003

Water Environment (Controlled Activities) (Scotland) Regulations 2005

The Environment Protection (Duty of Care) Regulations 1991

The Environmental Impact Assessment (Agriculture) (Scotland) Regulations 2006

Uncultivated/Semi-natural Areas Regulations 2001

Prevention of Environmental Pollution From Agricultural Activity" (PEPFAA) (Scotland)

4 Point Plan (Scotland)

Code of Good Agricultural Practice for the Prevention of Water Pollution (Northern Ireland)

CAP Reform Cross Compliance www.cross-compliance-fp6.eu

Met Office UK (NI and Scotland) www.metoffice.gov.uk

BS 5930 - Code of practice for site investigations, British Standards Institute, 1999

Royal Commission on the Ancient and Historical Monuments of Scotland, Historic Scotland

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