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Constructed wetlands and their use to provide bioremediation of farm effluents in Northern Ireland

A review of current literature

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1 Introduction

This initial review has been undertaken within a wide remit, which has allowed the freedom to look at any aspect of the myriad range of research and commercial projects associated with Constructed Wetlands (CW), but particularly those in Agricultural systems.

For many years, the issue of pollution from farm effluent and run-off has caused serious concern to farmers. Greater control measures to prevent outflow, leakage and leaching from the liquid element of animal manures and silage has helped to reduce the likelihood of pollution incidents from farm sources.

However, preventative measures for containing these waste streams have not alleviated the pressure to address the long-term need to try to develop sustainable low-cost methods or systems for dealing with these wastes.

While farmers and horticulturalists have always valued animal manure for it's high nutrient content, most are aware of it's potential as a dangerous pollutant, which can be poisonous to water systems and aquatic life. Is it possible to counteract this view and in effect have a positive outcome for our farming industry? Well- managed systems can minimise and neutralise hazard potential and we must prove this to meet the challenge to be seen as a modern, efficient and environmentally friendly industry.

This literature search focuses on the use of CW in many countries with intensive farming regimes and whether such man-made vegetative filters may offer an effective, low cost and environmentally acceptable method of treatment for certain farm waste streams on Northern Ireland farms.

2 Legislative and regulatory aspects for animal manures

The storage and containment of farm animal manures and silage has now become an urgent issue for the Agricultural industry in Northern Ireland. New legislation from both the European Union (EU) and The United Kingdom (UK) parliaments is now in place, which will impose demanding restrictions on every aspect of storage, handling and disposal of animal manures and effluents emanating from these. Discharge from farms to surface waters, ditches, streams, rivers and lakes and particularly to groundwater will be very closely monitored and controlled.

Directives from the Department of Environment (DoE) (Northern Ireland) and the Department of Agriculture and Rural Development for Northern Ireland (DARDNI) are the application and enforcement vehicles for most of these decrees.

New requirements for the containment and safe storage of silage, slurry and agricultural fuel oils are contained in the control of Pollution (silage, slurry, and agricultural fuel oils) Regulations for Northern Ireland, which came into effect on 21 July 2003. (Statutory Rules of Northern Ireland 2003, No. 319).

These regulations (often referred to as SSAFO Regulations) state the new requirements for the containment and safe storage of these substances only.

Regulations on the use and treatment of substances are covered in the Code of Good Agricultural Practice for the Prevention of Pollution of Water (DARDNI, 2003.)

The legislation for preventing Agricultural pollution and ensuring the conservation of water is covered by the Water Order for Northern Ireland (1999), Water Framework Directive (2003) and Protection of Water against Agricultural Nitrate Pollution Regulations (Northern Ireland) (2003).

The Nitrates Directive (91/676/EC), will lead to the establishment of Nitrate Vulnerable Zones (NVZ) in Northern Ireland, and may severely curtail the use of fertiliser, both chemical and organic.

Many other legislative instruments also apply and enforcement will involve central and local government bodies. Information on EC Directives and Northern Ireland water and pollution legislation are available from The Environment and Heritage Service (EHS), Water Management section (http://www.ehsni.gov.uk).

3 Background-Farm waste and pollution

3.1 Pollution related waste on farms

The principal waste streams are:

- Animal manure and slurry
- Silage effluent
- Farmyard dirty water
- Dairy parlour washings (and occasionally whole milk)
- Poultry litter

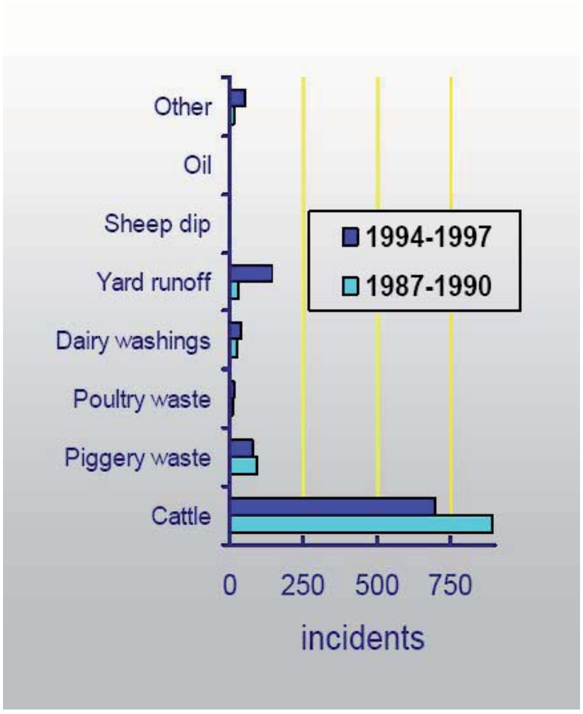
Spent mushroom compost may be also considered horticultural or farm waste.

Untreated effluent from any of the above outlined waste streams, particularly animal manure and slurry, silage effluent and farmyard dirty water (FDW) are detrimental to aquatic ecosystems. Accidental discharge or leakages and leaching of effluent from storage tanks and vessels are the most common reasons for pollution incidents in Northern Ireland. These are often affected by periods of heavy rainfall, which cause controls or restraints to fail due to hydraulic overloading.

3.2 Non-silage related waste on farm

Sources of farm related pollution (non-silage) recorded from 1987 to 1997 are shown in Figure 1. It is evident that the majority of pollution incidents recorded in this period have been caused by cattle manure, with yard run off also contributing to the problem, more so than poultry and piggery waste and dairy washings.

Figure 1 Sources of on-farm pollution (Non-silage related)



(Foy, 2004)

Farm waste contains high levels of organic and inorganic particulates, which, mixed with water, combine to produce effluents which have high loadings of suspended solids (SS), biological and chemical oxygen demands (BOD and COD respectively), nutrients as various compounds of Nitrogen (N), Phosphorous (P) and Potassium (K), faecal pathogens and micro-organisms. Residues of Agricultural chemicals (pesticides and fungicides), veterinary medicines and animal hormones may also be present in farm waste. Effluents from farm sources can have drastic effects on water quality and aquatic life.

Figures for estimating Northern Ireland farm animal manure and farmyard dirty water output (on a per animal basis) are available from the Code of Good Agricultural Practice for the Prevention of Pollution of Water (2003). Estimates for slurries, silage effluent, farm and dairy yard run-off and washings can vary enormously between farms, due to the variation in animal diets offered and flux of water and moisture content. However, this can be accounted for using the DARDNI calculation values.

3.3 Dealing with waste - Current practice

Normal Agricultural practice for disposal or dispersal of these manures and slurries and other effluents is by land spreading of solid manures and spraying or irrigating of slurries and liquids. This method is still considered safe and satisfactory as it recycles valuable nutrients to the soil. However, the imposition of the more strict controls on the level of contaminants, in particular nitrates and phosphates, dischargeable to water systems, will seriously affect this type of established farm waste-stream management. The Code of Good Agricultural Practice for the Prevention of Pollution of Water (2003) document provides an extensive guide to aid farmers in dealing with the pollution issues.

4 Sources of pollution in Northern Ireland

Data showing the various sources of pollution in Northern Ireland between the years 1996-2001 are shown in Table 1. The EHS aims to identify the source of any pollution, which falls within six categories as follows:

1. Agriculture
2. Industry
3. Water Service
4. Domestic
5. Transport
6. Other

"Other" sources include incidents where the source was not determined. It can be seen from Table 1 that the farming community is not the only contributor to the problem. Other contributing sources include industry, the Water Service, Transport sector and domestic amongst others.

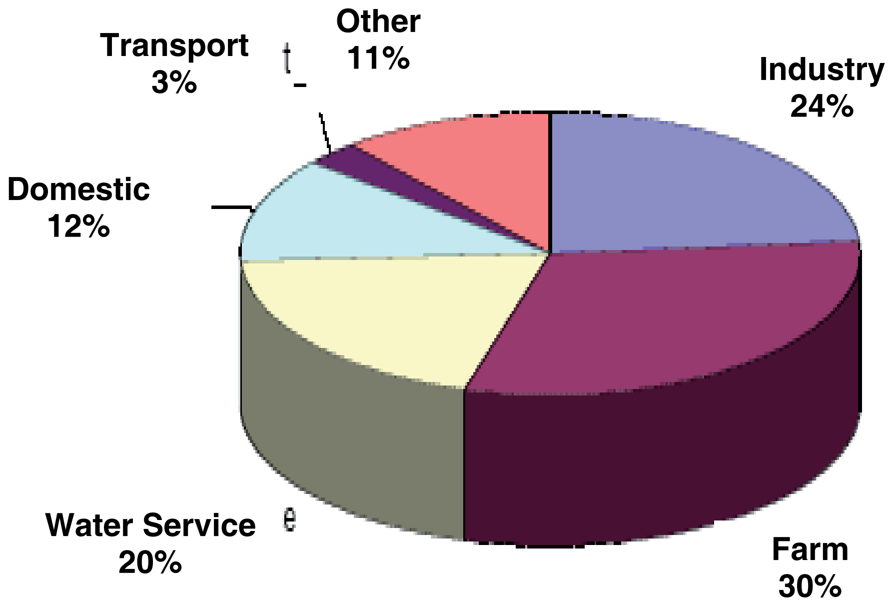
Table 1 Recorded pollution incidents from various sources (1996-2001)

Source	1996	1997	1998	1999	2000	2001
Industry	537	365	435	348	451	364
Farm	509	550	467	438	525	477
Water Service	377	353	278	347	322	305
Domestic	189	205	228	155	191	187
Transport	40	53	64	53	64	41
Other	435	300	172	166	152	172
Substantial incidents	2087	1826	1644	1507	1705	1546

(Environmental and Heritage Service, 2004)

However, some 30% of all recorded water pollution incidents are attributed to farms, making Agriculture the largest source of pollution in Northern Ireland (EHS, 2004). Pollution figures for the other sources are shown in Figure 2.

Figure 2 Source of Pollution Incidents (2001)



(Environmental and Heritage Service, 2004)

5 Defining Farm Pollution

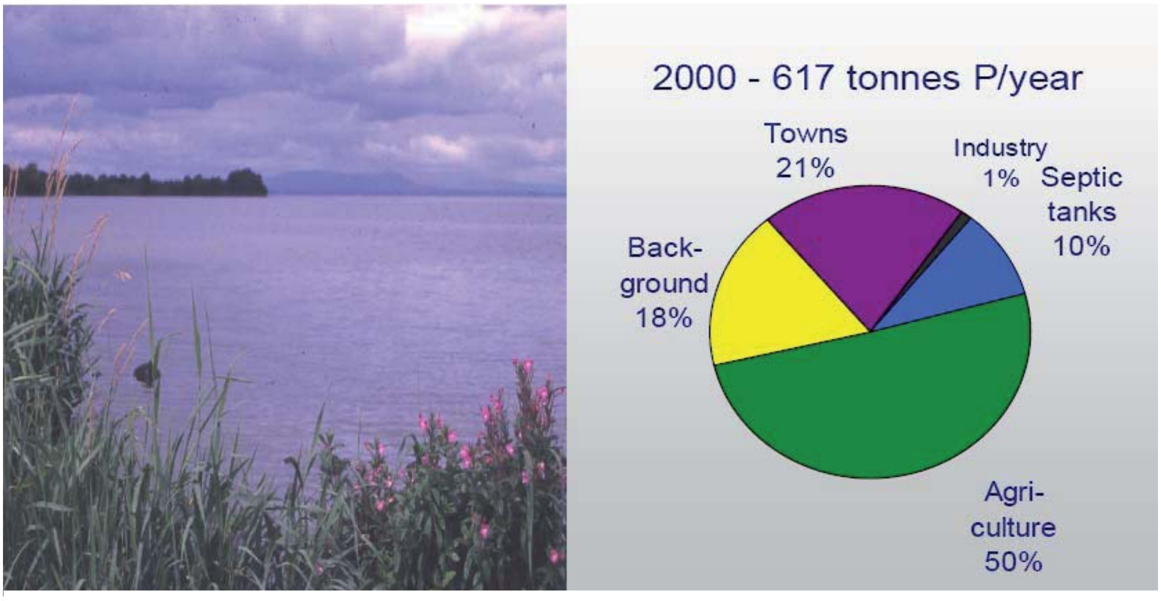
Farm pollution can be of two types as follows (1) Point source pollution (traceable to a single source i.e. a leaking tank) is often the most immediately visible type of incident, and (2) Diverse source pollution (i.e. soil leaching) is insidious and builds over time through intermittent or constant transfer of nutrients to water systems. This can be particularly heavy from bare cultivated land following periods of high precipitation.

Although most pollution events to river systems are fairly time limited, in that dilution (normally) diminishes the effects, recovery can take a long time and even minor pollution recurrences drastically alter the ecology and lead to long-term decline (Foy, 2004).

Nitrate and phosphate levels in open water have increased constantly over the years to the point where many rivers and lakes in Northern Ireland are now classed as eutrophic and can no longer sustain aquatic life (EHS, 2004).
Therefore, nutrient enrichment of water systems is probably the most significant area of concern in Agricultural and Environmental terms in Northern Ireland.

These increases can be directly related to the upsurge in fertiliser use in the latter half of the last century when the change to intensive farming transformed agricultural practice. It is well established that Agriculture is the single largest contributor of P to water in Northern Ireland, and the largest proportion of this is from diverse farm sources. The increase in levels of P in waters is comparable to the level of P loss from soil through run-off and leaching (Foy, 2004). Phosphorous pollution sources in Northern Ireland during the year 2000 are shown in Figure 3.

Figure 3 Lough Neagh Phosphorous sources (2000)

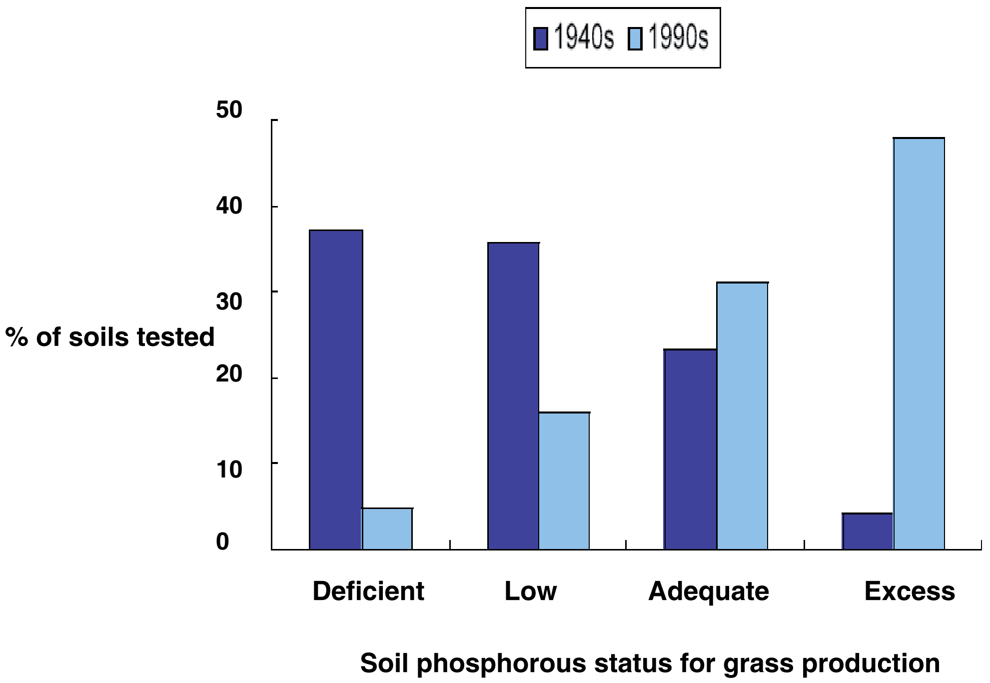


(Foy, 2004)

Not only does the issue of dealing with large amounts of animal manure have to be examined, but also large land areas where soils now have excess N and P leached to water systems also cause concern. The historical increase in Northern Ireland soil P levels since the 1940's is demonstrated in Figure 4.

This sort of change is not of course restricted to Northern Ireland and the UK. There is evidence of a ten-fold soil-P increase in the Republic of Ireland since 1950 (Tunney *et al.,* 2004). Environmental awareness and scientific investigation have exposed the causes and led to the establishment of strategies which aimed to reduce these levels of enrichment and pollution and reverse the damage to the aquatic environment.

Figure 4 Phosphorus fertility of Northern Ireland soils (1940's vs. 1990's)



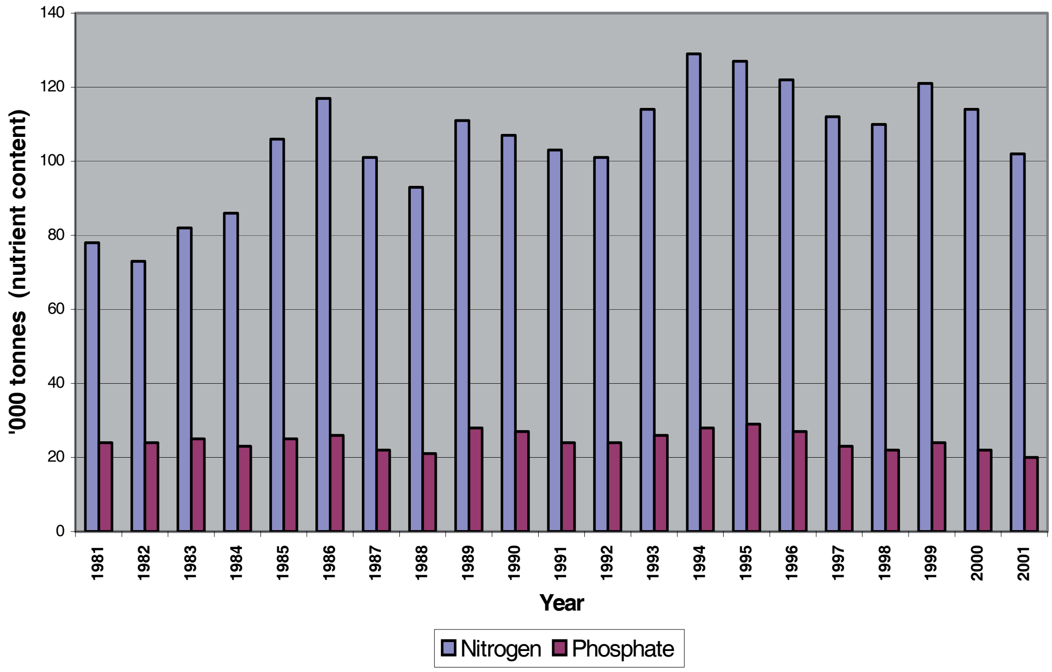
(Environmental and Heritage Service, 2004)

The link between Agricultural land use and nutrient enrichment of water systems is well established. A Department of Environment Food and Rural Affairs (DEFRA) commissioned report (amendment to PE0203), (2003), cite studies e.g. (McGuckin, *et al*., 1999; Meeuwig *et al*., 2000) which show that Agricultural land exports significantly more P than non-Agricultural land. Findings by Meeuwig and Peters (1996) demonstrate a clear correlation between land use and lake chlorophyll levels (an indicator of Eutrophication). The report also states that to meet the Water Framework Directive (WFD) targets for England and Wales, large reductions in aqueous P concentrations were necessary. The implications for Northern Ireland, where P saturation of soils and high levels of P in water systems are ubiquitous, must be that radical action will be needed and probably demanded, to adhere to the WFD.

6 Measures for reducing pollution

Many measures have been instigated to reduce diverse pollution from Agriculture in Northern Ireland and these are specified and promoted by DARDNI in the Code of Good Agricultural Practice for the Prevention of Pollution of Water and other publications. General awareness by farmers and a willingness to instigate fertiliser application reduction measures and good management practices is already working and some reduction in fertiliser use has been recorded (Figure 5).

Figure 5 Purchased fertiliser (Nitrogen and Phosphorous) quantities in Northern Ireland (1981-2001)



(Department of Agriculture and Rural Development for Northern Ireland, 2003)

However, dealing with the wastewaters and effluent produced on farms to prevent point source pollution is still to be addressed. Farmyard Dirty Water has traditionally been collected and held with slurry in either open slatted pits, lagoons or in storage tanks. On most farms this would have been sprayed onto pastures using high-pressure slurry tankers as and when storage reached capacity. Some farms have field irrigation systems, which allow pumping of wastewaters regardless of ground or weather conditions. Now however, the restrictions on when and how much slurry can be applied according to nutrient values and within narrow seasonal time frames, will severely restrict disposal options and require larger storage facilities on farms. It is now also necessary to collect and store FDW separately from solid manure and slurry to reduce disposal and pollution problems.

6.1 Storage systems

Conventional collection, storage and treatment systems for farm wastes are likely to become increasingly complex with high levels of technical and engineering specification to meet the new standards. This will result in higher capitalisation costs for farmers and under the DARD Farm Waste Management Scheme, costs to the public purse in 40% grant aid (up to £34,000) are quoted as over £30m for 2004 (Ulster Farmers Union conference report, Farming Life, 2004). For NVZ compliance, the cost of provision to farms with five months storage facilities is estimated at £200m (Foy, 2004). Hence, the search for alternative treatment systems to overcome pollution problems is appropriate.

Constructed Wetlands, which are claimed to be a low tech, semi-natural reliable method of dealing with some of these farm wastes. They will be the subject of the remainder of this report.

7 Constructed Wetlands

7.1 What are Constructed Wetlands?

Constructed Wetlands are man-made wetlands designed to mimic the bio-filtration action of natural wetland systems. Shallow, permanently flooded or wet marshy ground populated with macroyphytic vascular plants (i.e. reeds) are known to trap and hold large amounts of solids, particulates and dissolved constituents of waters that pass through them. Table 2 shows the inherent filtering ability of natural wetlands.

Table 2 Percentage removal of several pollutants from secondary effluent in Natural Wetlands

Pollutant	% Removal
BOD	70-96
Suspended solids (SS)	60-90
Nitrogen	40-90
Phosphorous	Seasonal

(United States Environmental Protection Agency, 1988)

In CW effluents/polluted waters are channelled into a series of man-made ponds with an impermeable synthetic liner or clay base, filled with either the original soil from the site or with selected substrates (normally sands and gravels). These are planted with vascular hydrophytes, aquatic plants, which quickly develop extensive submerged root systems. A picture of a vegetated pond in Kilmeaden Co Waterford can be seen in Figure 6.

Figure 6 Vegetated pond at Kilmeaden, Co Waterford, Republic of Ireland

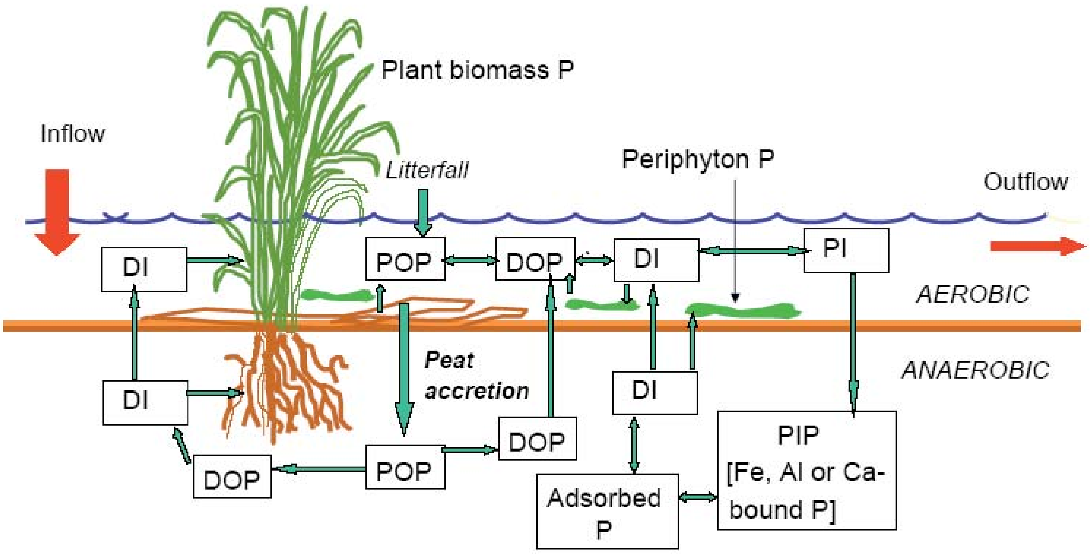
(Irvine, 2004)

Constructed Wetland research has been ongoing for several decades, firstly in Europe with urban waste streams, principally sewage and domestic and latterly globally, with industrial effluents (Hammer, 1989). Interest and research investigations spread to other countries and since the mid 80's, CW have been examined in greater detail.

Previous research has examined potential and feasibility of CW to provide a low cost, "soft engineering" alternative to traditional methods of farm waste storage and treatment. The basic idea is that man-made vegetative filters (ponds filled with plants) can ameliorate dilute farm effluents from manures, silage and dairy parlour washings and general farmyard wastewaters.

Within the submerged soil/root profile distinct zones of aerobic and anaerobic activity develop, where roots, soil, algae and microbiotic aquatic fauna trap, hold, absorb and transform pollutants from effluent waters. These changes are affected by many mechanisms, from simple accretion to soil particles and root systems, sedimentation, chemical precipitation, adsorption and the complex chemical pathways of algal and phyto-utilisation of nutrients for transformation to biomass and eventual carbon sequestration. Some of the pathways for P in wetlands are demonstrated in Figure 7.

Figure 7 Pathways for Phosphorous in Constructed Wetlands

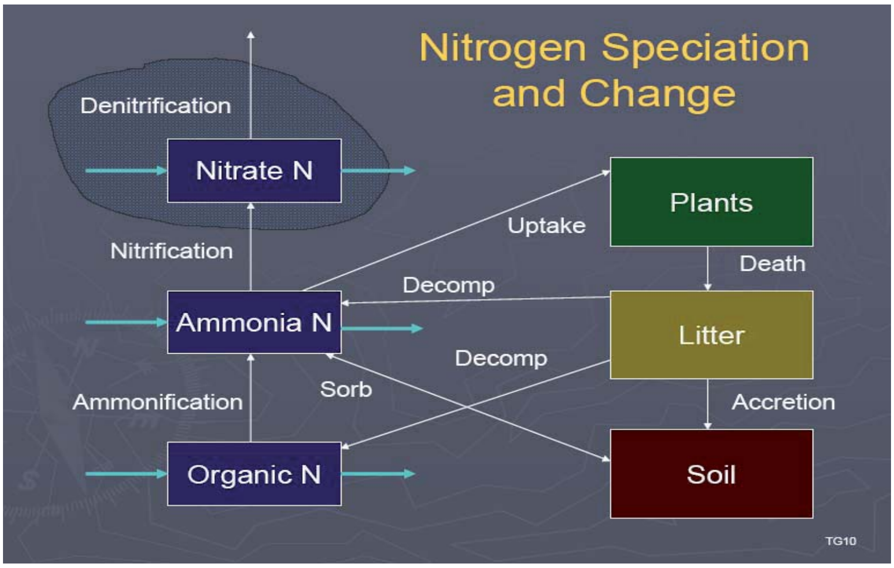


POP=Particulate organic phosphate; DOP=Dissolved organic phosphate; PIP=Particulate Inorganic phosphate; DI=Dissolved Inorganic; Periphyton P=Algal adsorbed phosphate

(Reddy, 2004)

Pathways for N in CW, which are equally complex and convoluted, are given in Figure 8.

Figure 8 Pathways for Nitrogen in Constructed Wetlands



(Kadlec, 2004)

7.2 Plant types for Constructed Wetlands

Different authors, designers and installers of CW have their own preferences for suitable types of plants. However the common reed, *Phragmites australis*, is the first choice in the UK and ROI. Kadlec (2004) advises that the large vascular macrophytes such as this offer the best opportunity for efficient, reliable and durable CW. Many aquatic plant species common to Northern Ireland such as sedges, rushes and marsh grasses could also possibly be used for CW planting. Lists of suitable plant types for the UK and Northern Ireland are available in guides and manuals cited in references, Section 6.1.

Reports that some sites in ROI have found difficulty in establishing *Phragmites* is contrary to findings in the UK in general, where high rates of survival and establishment are normal, especially where plants are propagated from seed. Vegetative propagation is not regarded as advisable due to low survivability.

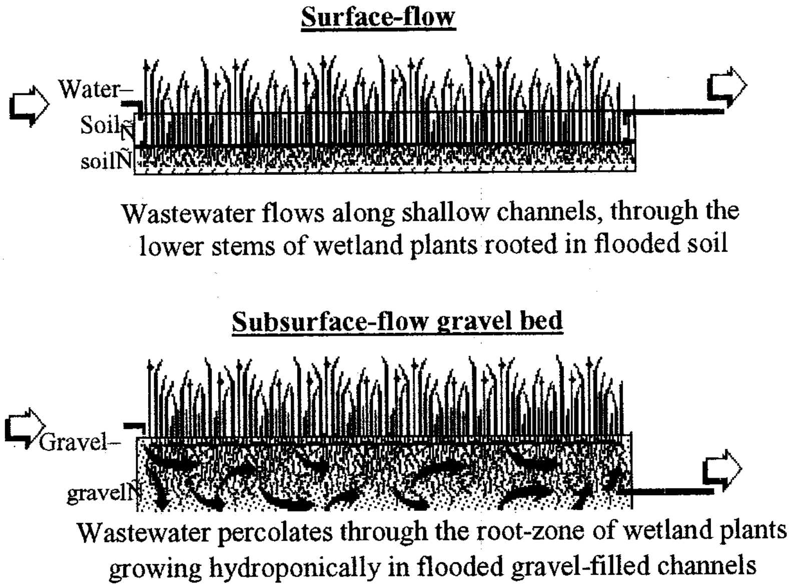
Some foreign aquatic plant species have been used in CW in ROI, which reportedly are very good at establishment and quite tolerant of Irish conditions, (Personal communication, Dr Rory Harrington, National Parks and Wildlife Service, Department of Environment and Local Government, Dublin). However, it would not be advisable to consider this sort of action in Northern Ireland except within a full research environment, with stringent controls and permissions.

The plants species for the Greenmount College CW are:
Phragmites australis (common reed), *Sparganium erectum* ((burr-reed), *Iris pseudacorus* (yellow flag iris), *Typha latifolia* (cattails) and *Carex riparia* (sedge).

7.3 Constructed Wetlands – Types and design

There are numerous types and designs of CW but these can be categorised as mainly Surface Flow (SF) or Sub-Surface Flow (SSF) as shown in Figure 9.

Figure 9 Two main types of Constructed Wetland



(Tanner and Kloosterman, 1997)

Ingress of water is normally defined as Vertical Flow (VF), where water falls or cascades onto the wetland or Horizontal Flow (HF), where it flows level with or slightly above the surface. There is any number of variations and themes of CW that one might use to describe their particular design or working method. However, these are the most common forms. An example of a surface flow CW with VF inlet is shown in Figure 10.

Figure 10 Vertical Flow inlet at Kilmeaden surface flow Constructed Wetland

(Irvine, 2004)

7.4 Constructed Wetland size (operational area)

There is little agreement yet on how the appropriate size and operational area for a CW is arrived at. Recommendations are variable and often appear to follow no formula or pattern. Some authors quote on the basis of scientific trial results, some on basic hydraulic flow or volume estimates and some seem to use anecdotal evidence to arrive at their estimate for types of effluent and degree of 'improvement' required.

A very comprehensive guide to sizing wetlands on the basis of area per cow for three treatment levels on surface flow and gravel bed CW is given in Tanner and Kloosterman (1997). The total area per cow over 3 treatment ponds combines to 7.1 m^2, which for a 100 cow herd would be 710 m^2. However, this is qualified by stating that CW should be designed to suit effluent flows and required outflow water quality. There are also many other factors to be considered for size determinations and include:

1. Topography
2. Local precipitation rates
3. Variations in water/effluent contamination
4. Mean temperatures
5. Evapo-transpiration rates
6. Resonance time (time water is in CW).

In the ROI, it is considered that 1 to 2 times the area of a farm yard is sufficient for a CW, or that 1% to 2% of total farm watershed area may be sufficient (Personal

communication, Dr Rory Harrington, National Parks and Wildlife Service, Department of Environment and Local Government, Dublin).
Conversely, Norwegian researchers have developed four surface flow CW, being 0.06% to 0.4% of watershed area (Braskerud, 2002a). This is deemed to be sufficient for a relatively high hydraulic load rate (0.7 to 1.8 m/day) and has been intensively monitored for some 7 years without adverse reports.

7.5 Constructed Wetland design

Again, this is an area where there are no set rules. No two farms are the same and all the factors mentioned previously for sizing CW come into play here. Position, shape, style and type of CW can be decided upon to fit the needs of the farm within the limits of available area, topography and soil suitability. Designs range from simple straightforward square or rectangular ponds to long narrow channels or to elaborately curved and landscaped water features surrounded by trees and shrubbery. Some designers advocate single CW units with dense vegetation and direct discharge to land or water while others advise multiple separate stage units, ranging from primary, fully planted to final, clear water ponds.

However, CW designs for Northern Ireland will have to meet the criteria and standards for discharge permission set by the Department of the Environment (DoE), EHS, DARDNI and other bodies responsible for monitoring and authorising land use and water treatment. It is likely that design plans would also possibly require extensive surveys of the geology, topography, soils and hydrology, presented along with a full Environmental Impact Assessment Report.

7.6 Estimating effluent flows/hydraulic loading of Constructed Wetlands

Easy and reliable methods for estimating effluent volumes from farms are included in the Code of Good Agricultural Practice for the Prevention of Pollution of Water (2003). For example, dairy parlour washed down with a power hose uses ~35 litres/cow/day. A 50 cow herd would produce ~1750 litres/day, which over a 180 day period would produce 315000 litres (a volume of ~315 cubic metres of FDW). To add to this yard, stock house and walkway run-off water and address all the factors necessary for CW development would require fairly complicated calculations and it is likely that professional engineers would need to be consulted to provide these.

Maxpro Ireland, claim to be the foremost installers/constructors of CW in ROI having installed over 100 in total to date (Costello, 2004). Most of these are for urban waste flows but Maxpro have also undertaken the construction of a substantial number of CW for farm schemes. Maxpro Ireland use a formula based on hydraulic loading, effluent contamination levels and hydraulic resonance time to meet ROI discharge pollutant content limits.

The following equation was used to establish a system model for a CW installed at Glenstall Abbey, Co Limerick, ROI, 1998, (Costello, 2004).

$R_t \times U_c = [\ln(C_o\text{-}C_b)\text{-}L_N(C_o\text{-}C_b)]/K_{20} x S^N x F_t$

Where:

	R_t	=	Residence time (days)
	C_b	=	Background BOD
	C_o	=	Inlet BOD
	C_e	=	Effluent BOD
	K_{20}	=	Reaction rate constant
	U_c	=	Plug flow uniformity
	S^N	=	Specific contact surface area/m^3 factor

All CW must of course have capacity to accept extra volumes of water during flood periods and these must also be included in calculations to allow for flood events.

7.7 Manuals and information on Constructed Wetland Design

There are numerous books, manuals, pamphlets and peer reviewed articles available, which offer advice and guidance on all the various aspects covered above and some are listed in the references and appendices.

Although the most relevant of these for Northern Ireland are those specifically applicable to the UK and Ireland, the contribution to CW science and engineering from other countries is also relevant. Further details of CW systems based on calculated hydraulic requirement (i.e. how much water or effluent will pass through the wetland), with full consideration given to the contaminant loading and the resonance time necessary to allow filtering and removal of these before discharge of the outflow are available (Kadlec and Knight, 1996).

A design manual produced for CW in America (Environmental Protection Agency (EPA), 1988), place emphasis on establishing a water balance with all the aforementioned parameters included. This is expressed in the formula:

$Q_i – Q_o + P – ET = [dv/dt]$

Where:

	Q_i	=	Influent wastewater flow, volume/time
	Q_o	=	Effluent wastewater flow, volume/time
	P	=	Precipitation, volume/time
	ET	=	Evapotranspiration, volume/time
	V	=	Volume water
	T	=	Time

Studies from an extensive P-reduction wetland at Rockledge, Florida, USA, (DeBusk *et al.,* 2004) found that on an area basis, there is a large difference in requirements for pollutant removal between BOD, N and P especially. To remove 1 kg BOD/year, 5 m^2 of wetland was required, with a respective value of 78 m^2 for N. However, for P-removal of 1 kg/year (to achieve a 1.0 mg/L outflow), approximately 160 m^2 of wetland was required, with a respective requirement of 720 m^2 wetland for 0.1 mg/l outflow.

It therefore seems reasonable and logical to expect that any CW design should be based primarily on the known pollution levels of the wastewater, the hydraulic load and the hydraulic resonance period required to achieve the desired contaminant removals.

7.8 Discharge from Constructed Wetlands

Few of the authors of the reviewed information refer to either required or desired pollutant levels for final discharge outflow, rather, they just state their findings. Where they are given, target discharge levels range considerably between and within countries. This reflects different needs and attitudes to water pollution and many are therefore of little relevance to Northern Ireland.

Discharge licence limits set for the Glenstall Abbey CW are shown in Table 3.

Currently, these limits do not seem to be applied as targets to most CW schemes throughout ROI and experience there has shown that some farmers allowed neat silage effluent and raw slurry to enter their CW with pollution resulting. Most have been installed without planning permission and operate unregulated and without monitoring (Robson, 2004).

Table 3 Discharge licence limits for Glenstall Abbey Constructed Wetland

	mg/l
BOD	10
TSS	20
N (as Ammonium)	5
P (Phosphorous)	2
N (Nitrates)	1.5

(Costello, 2004)

On this issue alone, the Environment Protection Agency in ROI has acted to start to impose strict monitoring on the dozens of unlicensed CW brought to their notice. Planning consent will now be strictly imposed on all new and proposed CW and monitoring programmes enforced on existing schemes in ROI.

At present, no limits have been set for Northern Ireland, including the CW about to be installed at Greenmount College, Co Antrim. Conversations with DARDNI staff involved in this project, suggest target limits will probably be half or less, of those for Glenstall Abbey. Ideally, CW discharges would have ≤1 mg/l P (as phosphorous), ≤1 mg/l N (as ammonium) and BOD ≤5 mg/l. Discussions with EHS regulatory staff and DARDNI CW project staff are ongoing to resolve this matter.

7.9 Evidence of Performance

There is no doubt that CW can achieve good levels of pollutant removal from wastewaters. Hammer (1989) contains numerous early papers on all aspects of CW performance from around the world as does Kadlec and Knight (1996), and more recently the symposium, Nutrient Management in Agricultural Watersheds - A Wetland Solution, Teagasc Research Centre, Johnstown Castle, Co Wexford, ROI (24-26 May, 2004), provided more up-to-date information on these issues.

Performance of CW depends on many factors, for example, the variability between design and type of CW, the influent and hydrologic conditions, the aquatic plant type and local climate.

7.9.1 Farmyard Dirty Water Contaminants

In general, it is accepted that CW deal well (in most scenarios) with contaminants relevant to dilute farm wastes, particularly:

(1) Suspended solids
(2) Biochemical oxygen demand
(3) Nitrogenous compounds
(4) Phosphatic compounds
(5) Faecal pathogens and micro-organisms
(6) Pesticides

Contaminant removal from effluents is often expressed in percentage terms, but a high percentage removal does not always equate with producing outflows with acceptable contaminant levels. For example, a 95% reduction of BOD at 100 mg/l, leaves 5 mg/l in outflow water, whereas 95% of 1000 mg/l results in an outflow BOD of 50 mg/l. Furthermore, concentrations of the constituents of wastewaters are expressed in various formats, mg/l, g/m^2, kg/ha, ppm. For continuity and ease of comparison, this report will give concentration values as reported, with mg/l as the norm for effluent contaminants.

7.9.2 Suspended solids

Suspended solids form the bulk of material suspended in the water column. In FDW, this consists mostly faecal organic matter, undigested herbage, waste meal, feed, bedding and soil particles. This can be passed directly to surface flow (SF) wetlands, but sub-surface flow (SSF) wetlands are not suitable for unfiltered effluent due to the high likelihood of clogging (Kadlec, 2004). Most wetland practitioners advocate pre-treatment (filtering) to remove SS, even before application to SF units as continuous flooding with high SS fractions can cause build-up of sediments in the influent area, block pipes and affect flow patterns. Pre-treatment removal, by mechanical separation, filtering and sedimentation is recommended by many authors (Uusi-Kämppä *et al.*, 2000, Hunt *et al.*, 2004). Constructed Wetland treatment can effectively retain >90% SS, through a sedimentation and accretion processes (Dunne and Culleton, 2004). Constant influx of organic matter and plant biomass leads to a build-up in the CW surface level. Tanner *et al*. (1998) estimated mean organic matter accumulation to range between 6-15 kg/m^2 over 5 years in a CW with a hydraulic loading rate (HLR) of 21-72 mm/day.

7.9.3 Biochemical oxygen demand

Farmyard dirty water and dilute dairy and parlour washings have BOD of about 1500 and 1000-2000 mg/l. Biochemical oxygen demand is a measure of the oxygen consumed by micro-organisms as they breakdown organic matter and high BOD values result in depletion of dissolved oxygen in water to the detriment of other aquatic organisms. Constructed Wetlands are extremely efficient at reducing BOD to low levels, even when the hydraulic residence time (HRT) is relatively short. This effect is true for CW of different design and the reported percentage reduction is usually around the 90-95% mark.

Dunne and Culleton (2004) reported reduction rates of BOD of >95% from a dairy farm CW in Co Wexford, ROI. Similarly, Sun *et al.* (1998a) recorded BOD removal in a three-stage reed bed system of 99%. Many other authors confirm a similar BOD reduction capability by CW (Table 4), but they also stress that HRT is crucial for success.

Table 4 Percentage reductions of biochemical oxygen demand and total suspended solids as recorded by various authors

Author	CW Type	BOD % Reduction	TSS % Reduction
Koskiaho *et al.* (2003)	SF	-	5-72
Tanner and Sukias (2003)	SF/SSF	33-67	40-75
Dunne and Culleton (2004)	SF	95-99	99
Sun *et al*. (1998a)	SF	98	83
Luderitz *et al*. (2001)	SF	83–95	-

The BOD concentrations from some of the trials in Table 4 are given in Table 5.

Table 5 Biochemical Oxygen Demand concentrations in mg/l as recorded by various authors

Author	Value range	Inflow mg/l	Outflow mg/l	% Reduction
Dunne and Culleton (2004)	Max	3400	14	>99
	Min	1784	85	95
	Mean	2494	34	98
Sun *et al.* (1999)	Mean	1100	26	98
Luderitz *et al.* (2001)	Mean	123	8	93
	Mean	162	8	95
	Mean	490	24	95

From Table 5, it can be seen the best reduction occurs in the highest inflow concentration, from 3400 mg/l (inflow) to 14 mg/l (outflow). This conforms to the predictive model of Sun *et al*. (1998b), in that BOD removal rates increase with organic loading in Agricultural wastewaters up to 1500 mg/l BOD. The figures from Luderitz *et al.* (2001) were from three different municipal (low strength) wastewater treatment wetlands. These figures demonstrate that very high percentage reductions are achievable but that outflow contaminant concentrations can still be relatively high.

7.9.4 Nitrogen – Nitrogenous compounds

Once again, many studies show that CW are effective at removing and retaining N in various forms. Percentage removals of N using CW vary however and a proportion of the total N is volatised to the atmosphere in gaseous form as nitrous oxide (and ammoniacal N when dry conditions occur) (Hunt and Poach, 2001). Nitrogen in Agriculture effluents takes many different forms (Figure 1) and transformation pathways and removal from solution are well documented. However, new discoveries such as the Anammox bacteria ammonium removal pathway are now recognised as very important for nitrate removal (Hunt *et al*., 2004). Nitrate reduction in CW is proven in numerous studies (e.g. Luderitz *et al.,* 2001) although there can be large differences between trials (Table 6). Sun *et al.* (1999) and Dunne and Culleton (2004), provide clear evidence of this. Tanner *et al.* (2003) report N removal from rain-fed and irrigated dairy pasture run-off to CW as follows: NO_3-N (78%), NH_4-N (41%), Organic-N (99.8%), with total N (TN) (~96%) (3 months mass balance for TN). Braskerud (2002a), reporting on a small scale Norwegian CW, found that with relatively dilute effluents of 3.2 – 5.1 mg/l TN, the retention varied from only 8-15%. Koskiaho *et al*. (2003) found maximum TN retention of ~40%.

Table 6 Percentage Nitrogen removal as recorded by various authors

Author	CW type	NH_4-N % reduction	NO_3-N % reduction	TN % reduction
Sun *et al.* (1999)	SF	93	-	-
Sun *et al.* (1998a)	SF	62	-	-
Braskerud (2002a)	SF (cold climate)	3	9	3-15
Tanner *et al.* (2003)	SF	41	34-94	56-33
Poach *et al.* (2003)	SF	91-52	-	64-78
Dunne and Culleton (2004)	SF	89-98	-	-
Koskiaho *et al.* (2003)	SF (cold climate)	50-57	8-38	7-40

Outflow concentration values vary in line with percentage reductions shown in Table 6. Dunne and Culleton (2004) recorded inflow concentrations ranging from 17 to 70 mg/l and outflows of 0.6 to 1.4 mg/l respectively. Sun *et al.* (1999) recorded average NH_4-N inflows of 330 mg/l and outflows of 23 mg/l. Hunt and Poach (2001) concluded that although CW are very effective at mass removal of N, the high loading rates necessary result in outflows unsuitable for discharge to water courses.

7.9.5 Phosphorous – Phosphatic compounds

Phosphorous is probably the most contentious area of CW investigations and as P is of particular concern in Northern Ireland, this aspect of CW performance is most pertinent. Generally, from the results of the large number of investigations read for this report, the conclusion is that total P removals are usually of the order 35-65%. However, there are many different forms of P carried in FWD/effluent and dissolved reactive P (DRP) is especially prone to cause fluctuations in levels, particularly during high rainfall periods (Dunne and Culleton, 2004). Other studies indicate P removals of >85% (Robinson *et al.*, 2004, Harrington *et al.,* 2004), while Uusi-Kämppä *et al.* (2000) report percentage removals of just 41% from effluents with inflow concentrations of 0.1 to 1.1 mg/l. Similarly Tanner and Sukias (2003) report TP reduction in a six-day CW to average only 20%. This is at odds with the findings of Dunne and Culleton (2004) and Harrington *et al.* (2004).

Dunne *et al.* (2004), indicate that P levels in outflow waters can actually increase after periods of high rainfall, rather than be reduced by dilution (due to the high proportion of dissolved reactive P retained in CW during the steady state). Graetz *et al.* (2004) found that the highest concentrations of all forms of P are located in the top detrital and underlying mineral layer of wetland soil. Organic P and labile P (especially water soluble P) were the dominant forms.

There are also conflicting views on the long term P retention capacity of CW. Reddy (2004) suggests that wetland ageing and accumulation of organic matter might alter the characteristics of wetland systems and reduce P assimilation. He suggests that consolidation or removal of accumulated material could restore capability. However, Braskerud (2004) contends that accumulation of sediments and organic material and accretion of clay particles especially, can actually increase P retention. Kadlec (2004) advises that biomass accumulation from sedimentation of suspended solids and decomposing plant material is an essential feature for functioning wetlands.

DeBusk *et al.* (2004) demonstrated how CW design and management schemes for "higher strength" Agricultural effluents (dairy and food processing) have achieved improved P retention and sustainability. Furthermore, DeBusk *et al*. (2004) favoured CW advancement, by suggesting that they are as good, and often better than, conventional chemical treatment technologies. Details of CW outflow for ROI, that claim to meet the present discharge licence limit of 2 mg/l P, are provided by Harrington *et al.* (2004), Dunne and Culleton (2004) and Costelloe (2004). Table 7 shows percentage removals of P (as various compounds) as recorded from CW by different authors.

Table 7 Percentage reduction of Phosphorous as recorded by various authors

Author	**CW Type**	**DRP % Reduction**	**TP % Reduction**
Koskiaho *et al*. (2003)	SF (cold climate)	33	6-67
Uusi-Kämpä *et al*. (2000)	SF (cold climate)	-	41
Sun *et al*. (1999)	SF	55 (PO_4-P)	-
Luderitz and Gerlach (2003)	SF (HF & VF)	-	95-97
Shilton *et al*. (2003a)	SF	45 (PO_4-P)	-
Braskerud (2002b)	SF (cold climate)	-	21-44
Dunne and Culleton (2004)	SF	93-98 (Po_4-P)	-

Constructed Wetland outflow water concentrations of P are (as for N) as variable as the percentage reductions shown in Table 7. Sun *et al*. (1999) report inflow values for DRP as 70 mg/l and outflow 32 mg/l Dunne and Culleton (2004) recorded inflow and outflow concentration ranging from 13 to 20 mg/l and 0.3 to 1 mg/l respectively.

The HF and VF wetland results of Luderitz and Gerlach (2003) were for municipal effluents and the low N inflow concentrations of 12 and 15.5 mg/l were reduced to 0.5 and 0.7 mg/l. Koskiaho *et al*. (2003) found that of three CW used in the trial, the wetland with the shortest retention times became a net source for dissolved reactive P.

7.9.6 Pesticides

Pesticide (herbicide, insecticide and fungicide) residues, especially those that are N-based, appear to be very effectively broken down and rendered inactive in CW, even after short hydro-periods (retention times). For example, Braskerud and Haarstad (2003) reported that the reduction in detection of 13 common Agricultural pesticides (including MCPA, Mecoprop, Dicamba and Propachlor) decreased by >65% in a small CW, less than 0.04% of catchment area with an average hydraulic loading >0.8 m/day. The reductions were sufficient to allow remaining levels to be regarded as non-toxic though retention decreased by up to 19% the following year.

Furthermore, Stearman *et al*. (2003), in a 2-year study of 14 planted and clear water CW, reported removals of the pesticides Metalachlor and Simazine, as 82% and 77% respectively in the planted CW. Respective removal rates in clear ponds were less effective, at 63% and 64%. It was also concluded that SSF wetlands were the best performing design for pesticide removal. The process by which CW are so effective in dealing with these chemicals is not wholly understood, but Friesen-Pankratz *et al.* (2003) examined the relationship between a CW algal species (*S. capricornutum*) and levels of two Agri-pesticides, namely Lindane and Atrazine. They observed that algal counts increased as pesticide detection decreased, possibly through sorption and molecular degradation of the chemicals by the algae.

7.9.7 Hormones

There is little information for Agricultural CW on the fate of hormones, whether naturally produced or administered, which are excreted in the urine and faeces of cattle, pigs and poultry. This is an area of increasing interest and some concern to researchers. The negative health effects of involuntarily ingested exogenous hormones, hormone precursors and related compounds are already well known. Even at very low levels, these can disrupt the endocrine systems, which regulate all cellular functions in higher organisms. Velle (2003) states that faecal excretion of endogenous and exogenous hormones is the main route of elimination in ruminants, while urinary excretion is the main course from swine.

Many of these hormones (particularly estrogens) remain potent in faecal matter and urine and these and other endocrine disrupting compounds are cited as causes of health problems in humans and animals. An example is the well-documented phenomenon of changes in sexual characteristics of fish, where male fish develop female functions (high levels of egg precursor protein, vitellogenin) as reported by Folmar *et al*. (1996) and Harries *et al*. (1996).

Conventional treatment systems only partially remove estrogenic compounds from wastewater (Huang and Sedlak, 2000) and the implications for the effectiveness of Agricultural CW is unclear, though research at the University of Tennessee (http://www.ohld.ag.utk.edu) is currently active on this topic. It might be reasonable to expect that hormones could become an issue (for all effluent treatment systems) in the future.

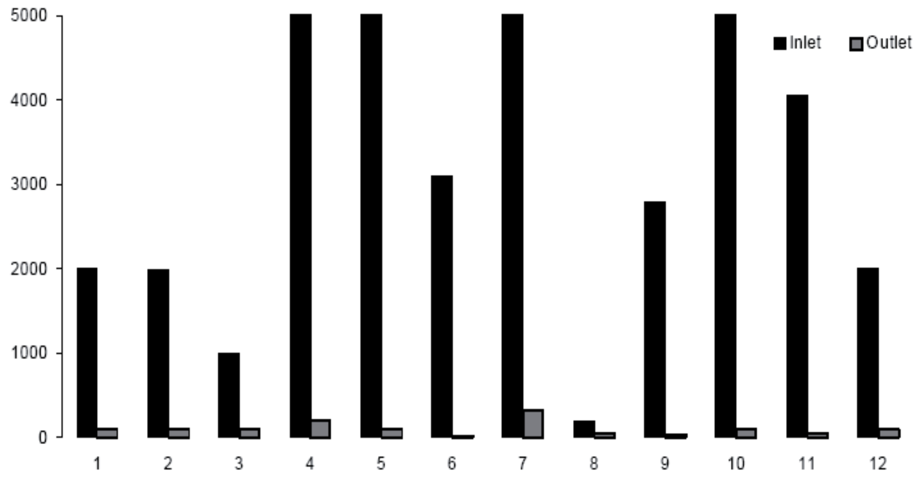
7.9.8 Pathogens

Removal or eradication of animal pathogens in CW appears to be consistently high and studies measuring faecal coliform counts from agricultural effluents in CW, indicate this. Because faecal coliforms, i.e. *Streptococci*, are naturally present in most water bodies (Fox *et al.,* 1984), it is therefore accepted that total elimination is not feasible. Karpiscak *et al*. (2002) report that results for an integrated dairy wastewater and municipal CW, show *Enterococci* removal of 74% and coliphage at 95%, though neither organism was significantly reduced after a four-day retention period. Facultative anaerobic lagoons with a 60-day retention period produced the best results. The range of organisms investigated in the study included: *Enterovirus*, *Listeria monocytogenes, Clostridium perfringens, Giardia lamblia, Giardia duodenalis* and *Cryptosporidium parvum.* Shilton *et al.* (2003b) found that bacterial indicators are often reduced to one log unit, though levels below 500 cfu/100 ml are difficult to achieve. Tanner and Sukias (2003) reported findings of faecal coliform removal from CW of 30% to 85% and suggest reductions below 300-500 cfu/100 ml are unrealistic.

Parasite eggs, particularly Helminthes (i.e. *Ascaris, Trichuris and Hymenolepsis spp.*) were reduced by 94% in aerobic and 100% facultative ponds respectively (Shilton *et al.,* 2003c). Virus reductions were also shown to be effectively attained and Vidales *et al*. (2003), in a study of a 6-year old SSF wetland achieved results suggesting that after a 5.5 day retention period, 99% reductions in viruses were realised.

It was concluded from these studies that longer resonance periods in CW ponds achieves the best reductions in pathogens. Faecal coliform counts from 12 CW in ROI are shown in Figure 11.

Figure 11 Mean faecal coliform count (cfu/100 ml) in twelve Constructed Wetlands in the Republic of Ireland



(Harrington *et al.,* 2004)

7.10 Durability and Longevity

It takes 2 years, from excavation to vegetative establishment, for a CW to become fully functional. How long CW may remain operationally effective is uncertain and numerous views are held on this aspect of CW performance. A general consensus, borne out by scientific studies, is that CW remain effective (and indeed increase in effectiveness) for up to 10 years. Dr Rory Harrington, National Parks and Wildlife Service, Department of Environment and Local Government, Dublin, (Personal Communication) believes that CW can be expected to function for at least 25 years and possibly longer. Others contend that 25 years is too optimistic. For example, DeBusk *et al*. (2004) suggest that P removal from CW in the long-term steady state is likely to markedly decline, compared to the early years in the life of a CW. Langergraber *et al*. (2003) cite substrate clogging by accumulated organic matter as being a major operational problem in vertical flow CW. Tanner and Sukias (2003) also conclude this to be an area of concern in CW effectiveness.

Reddy (2004) suggests that regular removal of plant and substrate from CW is desirable, to both maintain performance, prevent excessive nutrient build up and to return the valuable nutrient deposits to the soil. However, Kadlec and Knight (1996) contends that successful harvesting of macrophyte root systems is difficult, the actual P reclamation is low and that such operations are contrary to the low-cost, long-term aim of intentionally passive systems.

No information was found relating to procedures or methods for dealing with CW that cease to function or have become inefficient or degraded. It is possible that soils and sediments that have been constantly infused with high levels of nutrients and other contaminants might present disposal problems for the future.

7.11 Temperature effects
The effect of low temperature on CW and the reduction in the rate of the biological processes that drive pollution removal are well known. Below 10°C, the functions of many aquatic organisms slow down considerably and can stop as 0^{o}C approaches. If ice forms, lack of surface re-aeration of water causes oxygen depletion, which further inhibits mitigation processes (Kadlec and Knight 1996). Values for N and P removal rates (Tables 4 and 5) in cold climates are very low during winter periods.

This is an important factor for CW consideration in Northern Ireland where winter housing of stock means that FDW production increases at a time when any wetland might be less effective.

7.12 Odours
Very few researchers record or remark upon odour problems with CW and of the sites visited during a wetlands symposium at Johnstown Castle, Co. Wexford, ROI, (24-26 May, 2004), the two farm and the two rural catchment CW were not noticeably odorous despite warm humid conditions. The large multi-ponded Kilmeaden cheese factory CW (Figure 12) was very pungent, with a strong sour milk odour permeating the top levels of the gravity-flow pond system. Influent BOD concentration was 1500-2000 mg/l, P ~0.4 mg/l, with P outflow >0.007 mg/l and the pungent odour was attributed to the hot weather (Personal Communication, Dr Rory Harrington, National Parks and Wildlife Service, Department of Environment and Local Government, Dublin).

Figure 12 Settlement pond at Kilmeaden Constructed Wetland

(Irvine, 2004*)*

Personal communications from other symposium attendees did not identify odours from CW as problematic. Considering that CW should be dealing with dilute farm wastes and would be located in close proximity to animal houses and manure stocks, noticeable odours would be unusual.

7.13 Cost

It has proved extremely difficult to get firm figures for CW construction design, establishment and monitoring costs. No two farms will accrue the same cost for CW development, with location, climate, topography, water catchment area and the host of other factors, varying from farm to farm. Full costs for only two schemes have been provided for this report and requests for information from professional installers have at best been vague and at worst met with none. Costs provided by Costello (2004) for the 2 hectare Glenstall Abbey farm CW, Co. Limerick, ROI, installed by MAXPRO ROI, were given as £59,000. The costs comprised £17,000 for surveys, plans and permit applications, £26,000 for materials such as pipes, tanks and pumps, £11,000 for labour and plant hire and £4,000 for miscellaneous costs.

Williams (2004) quotes Mr David Cooper, ARM (sewage and effluent consultants, UK), who gives as a rough guide, a current cost of £20,000-£30,000 for designing and installing a treatment reed bed for parlour washings from a 150 cow dairy herd (Farmers Weekly, April 16-22, 2004). This quotation does not state if surveys and reports are included in the cost.

Constructed Wetland at Greenmount College, Co. Antrim, Northern Ireland

Costs for the Greenmount College CW currently under construction, will be collated and made available to DARDNI after conclusion of works (Personal Communication, Mr Martin Mulholland, Project Manager, Greenmount College, Co Antrim).

8 Discussion

It is clear from the literature reviewed, the data investigated and the CW visited, that CW can remove and retain nutrients and pollutants from dilute farm waste streams. However, the true effectiveness of CW is still open to question and most of the evidence for nutrient removal is inconclusive, in that discharge levels are inconsistent and often higher than those likely to be sought for Northern Ireland.

Determining the size of potential CW is an area where uncertainty abounds. The number of different methods for calculating size requirements makes it difficult to decide on the best method to choose. If the findings of DeBusk *et al.* (2004) hold for all CW, then the area needed to treat effluent to obtain P discharges of less than 1 mg/l could greatly enlarge CW sizes. To simply guess a size or ratio for a CW based on anecdotal evidence or to assume that they appear to work for some systems is not acceptable where inflow and outflow pollutant levels must be reliably predicted. Few Northern Ireland farmers would contemplate giving up valuable land on this basis.

Where CW might be established, set protocols for sampling, analysis and recording of performance will be necessary. This will undoubtedly add to the cost of any scheme and would have to be paid for by the discharger. Such sampling and monitoring would be required throughout the lifetime of the CW. Combining all these factors with the difficulty of predicting installation costs might well deter many prospective farm schemes.

The lack of guaranteed performance may discourage farmers from considering CW as they may prefer to use proven tank storage facilities and eventual land spreading or irrigation of FDW. It is likely that only medium or large dairy farms and some pig producers with land available might be interested. The idea that CW can be viewed as a panacea for farm pollution ills is receding as experience and information, especially from ROI becomes available.

The DEFRA commissioned final report (GRP-P-175) on diffuse water pollution from Agriculture (DWPA) and CAP reform impacts, does not mention CW technology. New, high specification engineered storage and treatment methods are the only options discussed for farm waste streams. Also, better fertiliser management, pollution awareness and avoidance in farming practice will play a part in reducing Agricultural prominence as a polluter. The Environment Agency for England and Wales report a 25% decline in farm-caused serious pollution incidents (Anderson, 2004). National Farmers Union Deputy President, Mr Peter Kendall, attributed this to better farm management by farmers.

Constructed wetlands may yet have a place on farms in Northern Ireland, but there are many gaps in the current knowledge, which will restrict widespread adoption of these for farm wastewater remediation and pollution prevention. Further firm evidence of the performance of CW is required in Northern Ireland and the scheme beginning at Greenmount College will afford and excellent opportunity to gather data, monitor performance and provide valuable information based on experience.

Discharge to water systems may not be the only option as DARDNI bio-remediation research using municipal sewage effluent and landfill leachate as a nutrient source for short rotation coppice (SRC) forestry, has returned positive results in Northern Ireland. In Sweden some leachate and industrial effluents are irrigated to forestry land without reports of adverse effects. A variation of the Greenmount scheme on a farm discharging to Short Rotation Coppice (SRC) or afforested land rather than a watercourse, would allow comparison and scientific validation and conclusions to be drawn from the findings.

9 Conclusions

1. The evidence for CW contaminant removal from agricultural wastewaters is not conclusive. The BOD, N, P and pathogen removal are good, though not always to levels likely to be specified by the Northern Ireland environmental and water authorities.

2. Constructed Wetlands are designed to treat dilute farm waste effluents. There is no evidence that they are capable of dealing with raw slurry or silage effluents nor high milk levels.

3. CW consistency of performance is not clearly demonstrated and there are large differences between results for different types of CW systems.

4. Reliability is questionable and CW appears to be vulnerable to heavy rainfall, which can cause outflow nutrient levels, especially P, to rise. When infrequent, this may be no worse than leaching and run-off from irrigated or land spread areas, but frequent episodes are potentially harmful to water systems.

5. Longevity of CW is uncertain. Some experimental Agricultural units have been functioning for ~10 years and some domestic and Industrial CW have been operating for 25+ years, though monitoring records are incomplete.

6. Size and sizing remain contentious issues with regard to CW. If they are undersized they will fail to meet contaminant removal targets, but oversize and valuable land and money are lost unnecessarily.

7. Aesthetically, CW can be landscaped and provide a wildlife refuge on working farms and to some, CW may seem preferable to corroded concrete and steel and faded plastic. To others, they may be seen as unsightly open dumps likely to require costly safety measures.

8. Costs for CW have proved impossible to confirm, bar those given for Glenstall Abbey, ROI. The CW underway at Greenmount College should provide a good indication for Northern Ireland costings.

9. Dealing with CW at the end of the working life could become problematical. After years of being loaded with nutrients and pollutants they may well be regarded as contaminated.

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12 Appendices

Appendix 1-Further Reading, Guides and Manuals

A Handbook of Constructed Wetlands. A guide to creating wetlands for: Agricultural Wastewater, Domestic Wastewater, Coal Mine Drainage, Storm water in the Mid-Atlantic Region. Volume 1. U.S Government Printing Office. ISBN 0-16-052999-9. 52 pp.

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Appendix 2-Other Reading (Website addresses)

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Constructed Wetlands in Ireland. Contact: Dr Marinus L Otte. WERG, University College, Dublin. http://www.ucd.ie/wetland/construcwet/irishwetlands.htm

Laboratory and *in situ* reductions of soluble phosphorus in liquid swine waste slurries. http://www.ohld.ag.utk.edu

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Appendix 3-Terms and Abbreviations

ANNAMOX	A nitrogen utilising Bacterium
BOD	Biochemical oxygen demand (refers here to BOD5)- the consumption of oxygen by biological/chemical reactions
BOD5	5 day biochemical oxygen demand
DAIRY WASHINGS	Washings from milking parlours
DARD	Department of Agriculture and Rural Development, N.I.
DARD[1]	Code of good Agricultural practice for the prevention of pollution of water. DARDNI, 2003.
DEFRA	Department of Environment, Farming and Rural Affairs, UK.
EC	European Commission
EHS	Environment and Heritage Service
EUTROPHIC	Waters high in nutrients often resulting in plant and algal growth which can eventually reduce aquatic life
FDW	Farmyard dirty water – water resulting from washing of stock houses, milking parlours and yards
HF	Horizontal Flow
HRT	Hydraulic Resonance Time (time effluent is in CW)
HYDROPHYTES	Plants able to withstand constant or frequent submergence of roots and stems
MACROPHYTE	Plants (& higher algae) large enough to be seen by eye.
mg/l	milligram per litre
N	nitrogen-nitrogenous compounds
NIWA	National Institute of Water and Atmospheric Research Ltd, New Zealand
P	Phosphorous-Phosphatic compounds
ROI	Republic of Ireland
SF	Surface Flow
SS	Suspended solids
SSF	Sub-Surface Flow
TN	Total nitrogen
TP	Total phosphate- soluble and insoluble
TSS	Total suspended solids
VF	Vertical Flow
WFD	Water Framework Directive

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