THE USE OF INTEGRATED CONSTRUCTED WETLANDS (ICW'S) IN THE MANAGEMENT OF FARMYARD RUNOFF AND WASTE WATER

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ABSTRACT

The concept of Integrated Constructed Wetlands is described, and specific results achieved with the process are detailed. Results indicate that the system has a unique and effective role to play in the future management of farmyard wastes. The system appears to cope with extensive variations in loads and can treat high levels of organic nutrients. It is an integrated design approach on a site specific basis. Further research is in progress and a design and construction protocol is being developed.

1 INTRODUCTION

The role of wetlands in Ireland has, since glacial times, been of major significance to the general functioning of the Irish ecosystem. Over thousands of years the country has been progressively 'wrung dry' by rural development through the drainage of; wet areas, fens, bogs, ponds and lakes, even Lough Neagh has not escaped with its water-level being dropped by about a meter in the 1950's. It is recognised that wetlands provide an essential service in the management of water quality; they also help regulate water flow and thence prevent or ameliorate flooding.

Wetlands both natural and constructed have an innate ability to cleanse water through physical, chemical and biological processes. The construction and/or reinstatement of wetlands that facilitate these processes have a potential application in the wider economic, social and environmental context of the sustainable development of the country.

ICWs (Integrated Constructed Wetlands) are a specific design approach (developed by Dúchas) to the widely used concept of constructed wetlands. ICWs are distinguished from other constructed wetland approaches because they are designed to facilitate the widest possible range of ecological conditions normally found in natural wetlands, including those of soil, water, plant and animal ecology. In addition, the ICW concept strives to achieve 'Landscape fit' and 'Habitat Restoration/Creation' into its designs. These added values necessitate the required larger land areas used in the ICW design compared with those generally used in other constructed wetland designs. This relatively larger land area facilitates a greater range of the physical, chemical and biological processes that occur in the wetland environment including those required for the removal of the more difficult contaminants, especially phosphorous.

ICWs also provide greater robustness and remove the need for intensive management. This paper will provide information on the overall concept and the design process. While this paper primarily addresses the cleansing of farmyard runoff and waste water the ICW concept can be applied to a wide range of circumstances where it may be challenged by either high or low concentrations of contaminants and hydraulic loading that may vary over time. The sizing of ICWs reflects these varying challenges and circumstances that may be on scales of tens of square meters to many hectares. ICWs may be built as an entirely new entity or they may form part of an existing wetland, aquatic landscape feature or water treatment facility.

2 AGRICULTURAL POLLUTION – A NATIONAL PROBLEM

Agriculture in Ireland is recognised as one of the primary contributors to the eutrophication of Irish surface waters and pollution of ground water (1). Agricultural inputs to surface waters can include both point and non-point source pollution. Point source pollution from agriculture is typically dirty water runoff from farmyards. Farmyard dirty water (FYDW) can include yard washings, parlour washings, seepage of silage and farmyard manure effluents. The volume of such polluted water is greatly increased in most incidences from rainfall falling on open concrete yard areas.

Conventional management of this polluted water is land application using either tractor and vacuum tank or pump operated sprinkler systems. Although land application returns nutrients generated on the farm back to agricultural land, there are significant costs that can far outweigh the value of such nutrients to the soil. Furthermore the practice of land spreading of FYDW is heavily weather dependant and open to substantial abuse. Indeed conventional land application of FYDW, and other liquids such as slurrys and sludges, has significant agricultural, economic and environmental disadvantages.

In recognition of these disadvantages, and the increasing threat posed to the wider environment, Dúchas, the Heritage Service embarked on a program of research and development in the use of ICWs.

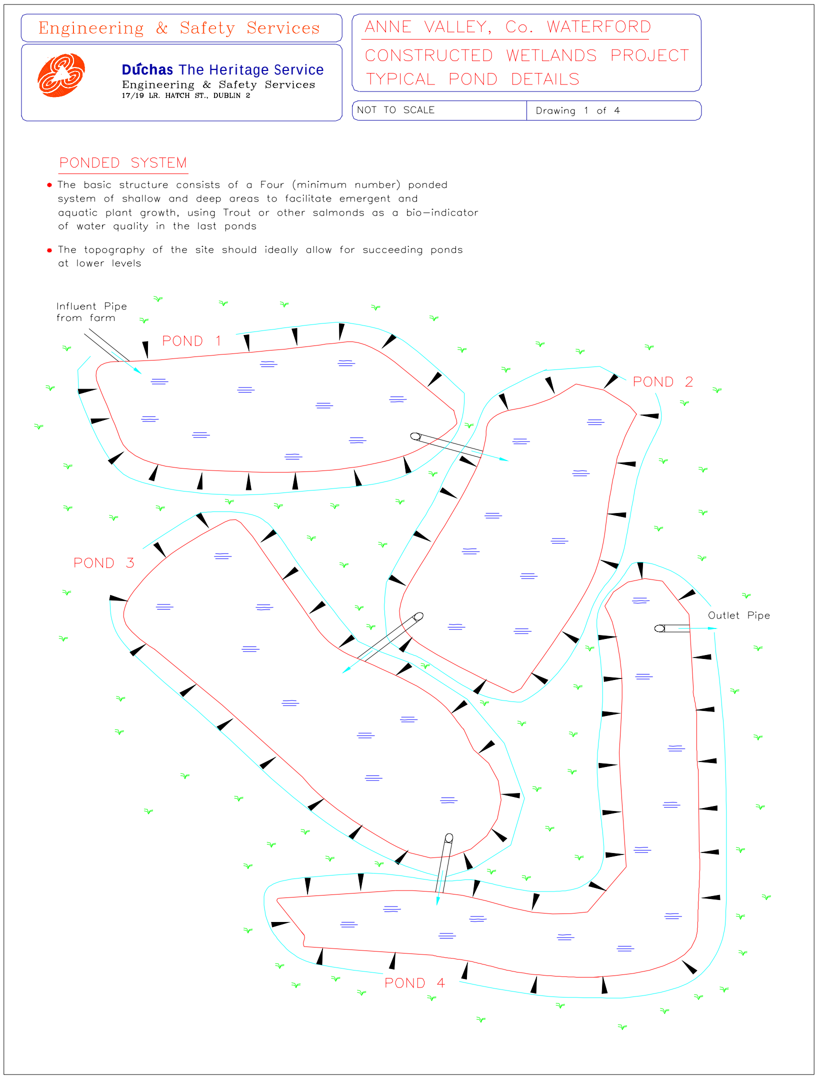
3 THE ICW CONCEPT

The ICW concept and design approach was initially developed by Dr Harrington, one of the authors of this paper,and subsequently expanded and developed by a multi disciplinary team consisting of the authors, other Dúchas personnel and Dr Jer Keohane a consultant hydrogeologist. It is a Dúchas initiative.

The description, data and performance of the ICW study presented in this paper are primarily based upon the 13 ICWs constructed within the Anne Valley on the south coast of Co. Waterford over the past 6 years. This valley is the focus of a broader Dúchas-led ecological restoration project. The valley and its 7km long mainstream has a catchment area of c. 25km2. The project initially comprised re-profiling of the canalised stream and creation of a mosaic of medium to small water-bodies. The need for water quality management especially from point sources e.g. farmyards became apparent in the early stages of the project. Various methods of intercepting polluted water from point sources were examined, and stimulated the quest for alternative methodologies that were more cost effective, sustainable and that might even give rise to the development of new resources and values.

The ICW concept is based on the long recognised ability of wetlands to cleanse dirty water. ICWs are free water surface flow systems, and consist of a series of shallow lagoons or ponds across which influents flow. The bottoms and sides of these are made impervious, ideally through use of in-situ soils, to prevent the seepage of contaminants to groundwater. The initial receiving pond serves as a mixing, diluting, and balancing area for the various influents. Subsequent ponds, usually 3 to 4, and often more, are sequentially arranged to maximise the distance over which the influent must travel, and are ideally designed to allow for maximum retention time. A typical layout of an ICW, which is shaped into the landscape, is shown in The Figure below.

The unique emphasis in the ICW approach is on establishing an integrated system based upon Ecosystem function. While the cleansing of polluted water is the primary function, it is not the only function. The inclusion of various other elements in the design ensures the sustainability of the process, and it becomes an added resource to the surrounding landscape. Maximum vegetation cover with semi aquatic plant species is established through the use of plants from suitable nurseries. The ponds are generally shallow, 10-30 cm deep, although they should ideally have sections which are deeper and where vegetation is more sparse. The pond surface area is calculated on the basis of total peak influent, related to precipitation events and the design population equivalent required for the system.



4 THE DESIGN APPROACH

While simultaneously developing sample sites for construction of ICWs, mainly in the area of the Anne Valley as previously referred to, the design team carried out an extensive literature review with the support of the EPA (2). This review highlighted many of the difficulties associated with different forms of constructed wetlands in dealing with particular pollutants such as phosphates and nitrates, but emphasised the importance of sizing of the wetland and site specific design in dealing with these issues.

4.1 Phosphorous

Phosphorous is generally the most limiting factor in fresh-water ecosystems and consequently, in excess, leads to eutrophication of surface waters. It is the principal water quality factor by which ICW performance is measured. Its capture and retention is dependant on the plant density, and soil properties, but principally on the available wetland area and the consequent residence time within the wetland (3)(4). Area determination is based upon volume flow that in the context of this paper is dominated by precipitation. See Appendix 1 for sample hydraulic model calculations.

Fluxes in volume flow due to precipitation are the primary factor modifying these hydraulic models. The surface flow is increased both by increased pollutant influent and incrementally on its journey through the wetland during precipitation events. Meniscus height at each stage/pond outlet and resistance to flow by the emergent vegetation both contribute to increased residence time and its area dependent calculation. Zonation within the vertical wetland water column preferentially ensures the cleaner water falling on the surface remains flowing on the surface. It also preferentially allows the disturbed water arising from mixing at each pond inlet to resume flow along the surface, its course of least resistance.

4.2 Infiltration to Groundwater

A further issue of major importance in the design and construction of ICWs is the possible infiltration of pollutants to ground water. The shallow water depths and associated low hydraulic pressure that are part of the free-water-surface-flow ICW design not only simplify design and construction but greatly reduce the potential for infiltration. By making extensive use of emergent vegetation and by having the necessary soil type and depth, the very important de-nitrifying role that wetlands provide generally in the wider landscape, can also be provided in the treatment context. The presence of organic matter in the soil and the accumulating Necromass further decreases water infiltration. This process has been researched and reported by Purcell et al (5)(6) and is further illustrated in Section 5 below by results from ongoing research of the ICW research team.

4.3 Plant Functions

The macrophytic vegetation used in the ICW design essentially performs a variety of functions; its primary function is the support of biofilms (slime layers) which carry out the principal cleansing functions of the wetland; it also facilitates the sorption of nutrients, and acts as a filter medium, and through the use of appropriate emergent vegetation can control odours and pathogens (7)(8). While the vegetation has the capacity to filter suspended solids it also increases the hydraulic gradient, thus increasing residence time. The appropriate choice of plant species and the density at which they are planted are important in the overall functioning of the wetland. Generally emergent species such as sedges, rushes, grasses, etc. that are rooted in the wetlands' soil and which grow through the water column are most effective, though floating and submerged plants also perform useful functions. The use of the common reed (Phragmites australis) has been a minor component of the vegetation in ICWs unlike many other treatment wetland systems.

4.4 Multi-Stage and Free Water Surface

The number of ponds, and the sequential processing and cleaning of the contained dirty water, ensures that there is segregation between the differing degrees of contamination. This consequently facilitates the concentrated management of ammonium, which is of particular relevance to the welfare and growth of plants. It also enhances the potential for habitat diversity due to differing plant densities and the relative areas of open water.

4.5 Landscape Fit

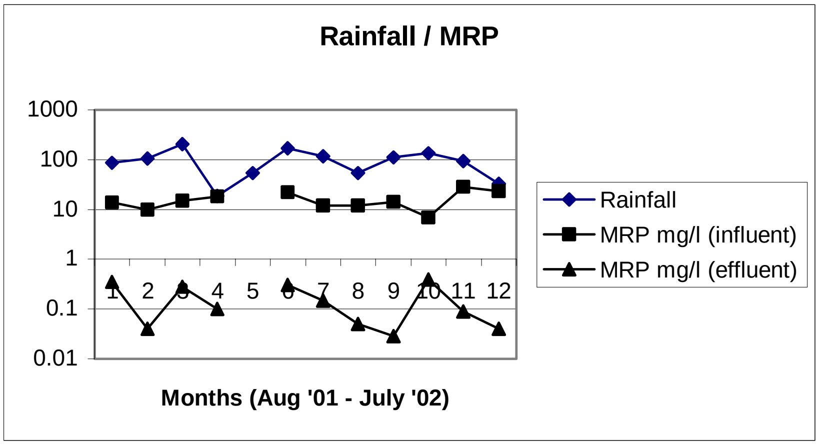
Consideration of how the necessary wetland area is accommodated on site and generally in the location are a strategic issue in the ICW design approach. Site assessment provides the necessary information with regard to; the actual size of the area required, the overall topography, adjacent structures and the general landscape into which the wetland structure will be placed (9). Curvilinear shaping, appropriately proportioned spacing between wetland segments, consideration of the way adjacent topography connects to the wetland, and vegetation structure, are fundamental to achieving the appropriate fit.

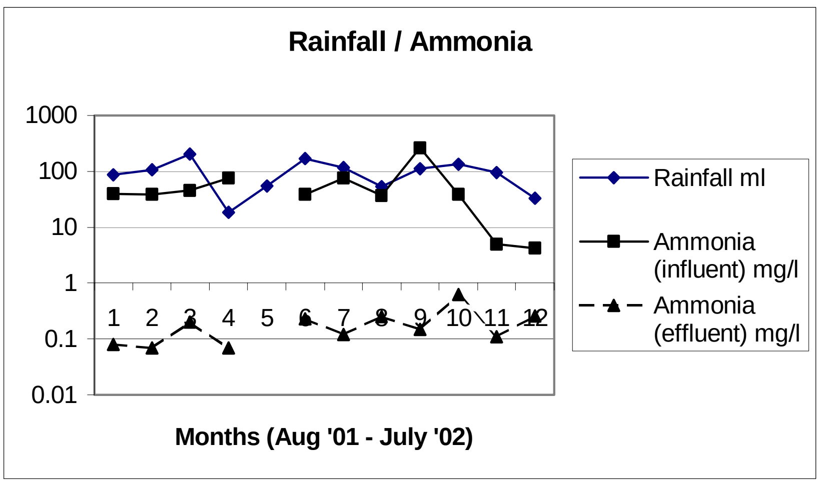
4.6 Habitat Restoration and Biodiversity

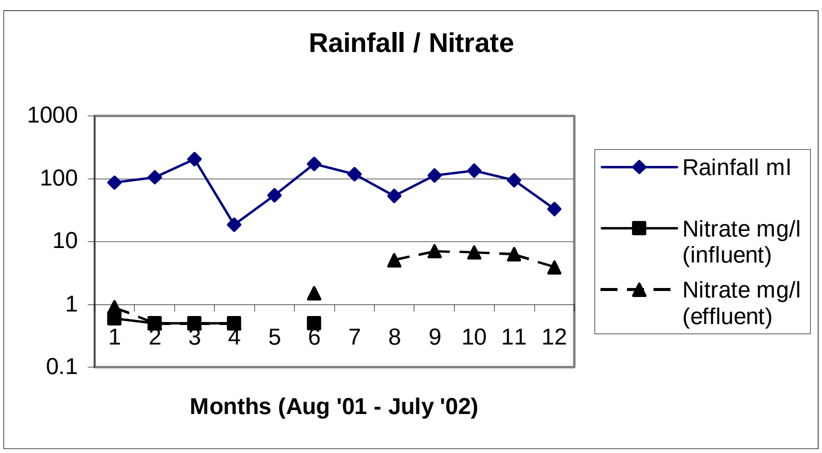
The progressive loss of wetland area from the Irish countryside over the last millennia provides opportunities for reinstatement, habitat restoration and generally re-establishing the support function of wetlands in the landscape. Although treatment wetlands are generally likely to be eutrophic, their segmented structure through which water passes provides a series of habitat environments with diminishing levels of nutrition. The selection and pattern by which plants are established not only affects the ICW's communities of microorganisms, plants and animals but may also impact on neighbouring wetland communities. Due consideration in planning and designing are necessary in order to ensure the most appropriate plant communities and indeed in some cases animal communities are chosen.

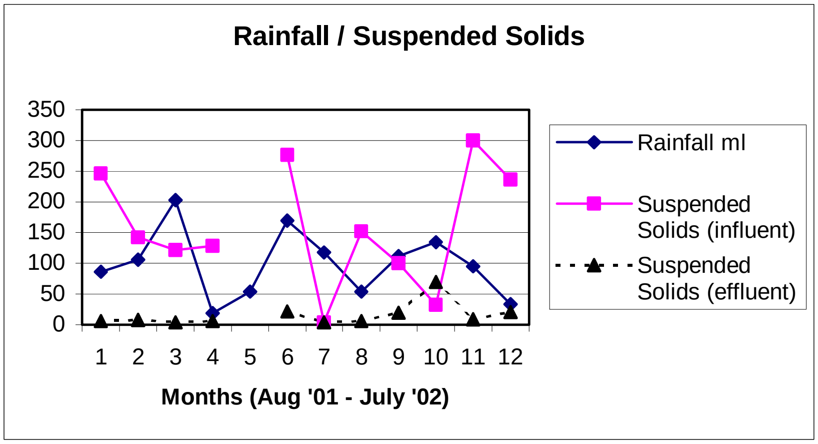
5 PERFORMANCE DATA

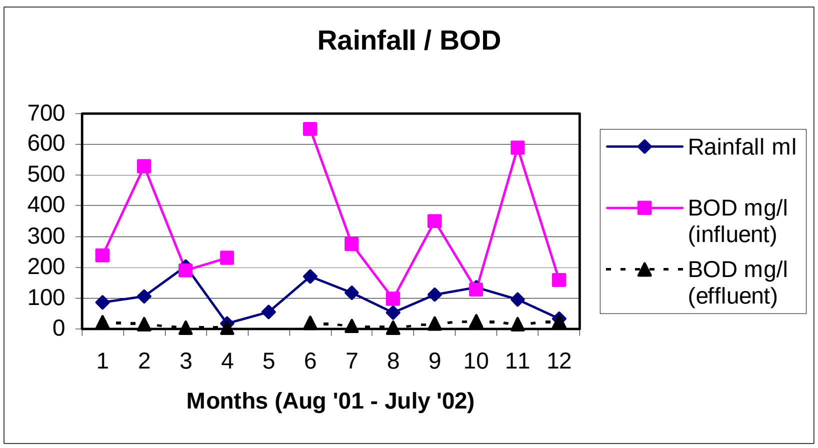
Over the past number of years, particularly in the Anne Valley Project in Co Waterford, continuous data has been assembled on a number of sample ICWs. The data illustrated below in the initial five charts, has been taken from one of these sample ICWs, and is representative of the overall results being achieved.











The data below illustrates the progressive effect of the treatment processes in the ICW multi stage system. It also particularly shows the capability of the system to assimilate and process very high ammonia levels.

POND NUMBER	AMMONIA mg/l NH4	NITRATE mg/l N	MRP mg/l P	C.O.D. mg/L
1	340	0.3	25.8	1310
2	340	<0.20	20.6	680
3	280	<0.20	18.1	345
4	4.4	1.2	3.65	85
5	0.17	0.65	1.57	65
6	0.53	<0.10	0.25	< 50
7	0.03	0.8	0.21	< 50

Data from multi stage ICW treating Piggery Effluent

The data below is taken from an ICW built at Teagasc, Johnstown Castle. It is representative of a wider data sample. It refers to the groundwater quality in a terrestrial site adjacent to the ICW, and that directly in the zone of influence of the ICW. As can be seen there is no deterioration in groundwater quality under the ICW as compared to the 'normal' levels on the terrestrial site. This indicates that the bed of the ICW is effective in blocking the path of nutrients to the underlying groundwater and in particular has a major denitrifying effect. These results bear out the work of Purcell et al (5)(6). Further research in this area is being developed (See Section 6 below).

Location	PO4	NH4	NO3	TON
Terrestrial Site Near Wetland	0.023	0.2	0.58	0.51
Directly Under Wetland	0.02	0.22	0.15	0.15
% Differential	0	0	74	70

All concentrations of parameters are shown in mg/l

6 FURTHER DEVELOPMENT OF THE ICW CONCEPT

The basic ICW concept and design approach have been described above in Sections 4 and 5. It is a unique approach in that it does not merely consider the pollutants to be treated, but places this treatment in the much wider context of habitat restoration and biodiversity. The benefits of the approach, in pure water quality improvement terms, have been demonstrated, and that alone merits further consideration. The ICW design approach has the following critical criteria:

- Site assessment and site specific design
- Containment and cleansing of contaminated water on site
- A fully integrated infrastructure for containment and cleansing
- The appropriate building materials used in the construction are, ideally, found locally or on site.
- Robust system able to withstand extreme load variations
- Sustainable design and construction to ensure long life (50-100 years)
- Minimal management and capacity for self-regulation
- The site is not irrevocably lost and is ideally enhanced
- Appropriate plant species and distribution are used
- Opportunities are provided for habitat development and biological diversification.

The ICW design/research team, in recognition of the potential of this design approach, and its possible adoption on a national basis, organised a colloquium of professionals involved in the area earlier this year. The outcome of this colloquium was the agreement to develop a <u>Protocol for the Design and Construction of ICWs for Farm Wastes.</u> The issue of farm waste treatment and farm related pollution was seen by the colloquium as the most critical area needing to be addressed. It is proposed that the protocol will have 5 main chapters dealing with the following issues:

- Site assessment
- Design
- Planning
- Construction
- Aftercare / monitoring

A working group for each chapter has been constituted and progress is being made. Further detailed monitoring and assessment of individual sites is continuing, in particular to assess the impact from stage to stage of variations in rainfall and flow. These impacts will be particularly assessed in order to improve the modelling of the physical and biochemical processes from stage to stage within the ICW system. This should ultimately lead to overall improved design processes. Monitoring of groundwater quality at a variety of sites is also continuing.

7 CONCLUSION

The ICW design concept for constructed wetlands is a unique integrated approach to the treatment of waste waters.
It draws on traditional known capabilities of wetlands, and utilises research data in this area, to develop the basic wetland concept further.
It delivers substantial improvements in effluent quality over a wide range of input parameters.
It has the capability to enhance various sites and to turn the ‘problem’ of farm pollution into a major economic, social and environmental resource.

Appendix 1
ESTIMATE OF NORMAL RETENTION TIME: WILLY MOORE’S FARM (ANNE VALLEY, CO. WATERFORD)

(a) Dirty Water Arising

Minimum:
Yard and roof areas are approximately 5,000m^2 x AAR* (1,000mm) = 5,000m^3/365
= 13.7m^3/day average PLUS Parlour washings 70 cows x 18 1/day = 1.2m^3/day
Total 14.9m^3/day average

Maximum:
Yard and roof areas plus other areas, say 7,000m^2 x AAR* (1,000mm)= 5,000m^3/365
= 19.1m^3/day average PLUS Parlour washings 70 cows x 18 1/day = 1.2m^3/day
Total 20.3m^3/day average

(b) Lagoon Capacity

Maximum	
(1) and (2) 2,000 x 0.2x2	800m^3
(3) 3,000 x 0.8	2,400m^3
Total	3,200m^3 (excluding Pond 4)
Minimum	
(1) and (2) 2,000 x 0.15 x 2	600 m^3
(3) 3,000 x 0.6	1,800m^3
Total	2,400m^3 (excluding Pond 4)

(c) **Estimated Nominal Retention Time**

Minimum : 2,400m^3/20.3m^3/day = 118 days

Maximum : 3,200m^3/14.9m^3/day = 214 days

(d**) Storm Flow Situation**

Assume 100mm rainfall storm (over 2 day period)
= 5,000 x 0.1 = 500m^3 in 2 days = 250m^3 per day
Parlour Washings = 1.2m^3 per day
Total = 251.2m^3 per day
Lagoon Capacity = 3,200m^3
Retention Time = 3,200/251.2 = 12.7 days

*AAR = Average Annual Rainfall

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