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THE USE OF INTEGRATED CONSTRUCTED WETLANDS (ICWs) IN FARMYARD AND RURAL DOMESTIC WASTEWATER MANAGEMENT

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Summary: "Integrated Constructed Wetlands" (ICWs) are a specific design approach to water resource management. The concept, design, application and performance are described. The approach incorporates water quality management with "landscape fit" and biodiversity along with social and economic considerations that help facilitate the required larger land areas used in ICW design compared with those generally used in other surface flow constructed wetlands. As a surface flow constructed wetland system, the cleansing capacity of the ICW is largely dependent upon the ratio of water inflow to wetland area. Precipitation-derived influent fluxes to the wetland are the primary influence in determining the required wetland area and consequently their cleansing capacity. The composition of the influent is of lower significance, with ammonium concentration having a threshold impact on the survival of the emergent plant species. Results for phosphorus (P), nitrogen (N) and faecal coliforms are given for 13 individual ICWs.

INTRODUCTION

"Integrated Constructed Wetlands" (ICWs) are a specific design approach to the use of constructed wetlands in the treatment of waste water and to water resource management generally. As such they are ecologically engineered systems rather than being environmentally engineered solutions to improve water quality (Mitsch and Jørgensen, 1989). The ICW concept arose from the convergence of a number of factors. The principal of these was the need for improved environmental infrastructure in adjacent rural communities (Annestown and Dunhill, Co. Waterford, Ireland). These communities realised the potential for economic and social development through the restoration of their aquatic habitats. The initiative grew with Local Government, State and EU support. This support was both financial and professional. The communities and landowners matched this with their enthusiasm, resources and finance. Known as the "Anne Valley Project", it has become a leading example of sustainable rural development.

The basic restoration strategy for the Anne Valley Project has its roots in the "small watershed technique" and associated ecosystem studies developed by Bormann and Likens (1981) and Siccama *et al* (1970). This strategy focuses on input-output relationships and has particular advantages in understanding sources of pollution and the processes that provide the basis for water quality management. Historically, the Anne Valley's catchment has had many of its wetlands drained and watercourses canalised. The loss of this aquatic infrastructure and the increase in intensive agricultural production converged to severely reduce water quality in the catchment's streams. The Annestown and Dunhill communities were encouraged to undertake a twin-track approach to the restoration of the catchment's streams and its aquatic environments. These were:

- The reprofiling of the catchment's streams, especially its main channel
- The capture/treatment of point sources of water pollution, in particular farmyard waste water and runoff.

This combined approach has seen water quality of the streams in the 25 km^2 Anne Valley catchment significantly improve during the past seven years (EPA, 2002). The prevention of point source pollution from Dunhill village and from 12 of the 18 farmyards in the catchment through the application of the ICW concept has been the primary factor for this improvement. The following is a presentation of the ICW concept, its design, application and performance in the catchment.

THE ICW CONCEPT

Emergent vegetated wetlands are recognised as having significant capacity for the physical, chemical and biological cleansing of polluted water. Integrated Constructed Wetlands are a specific design approach in the use of surface flow emergent vegetated constructed wetlands. They are distinguished from other surface flow emergent vegetated constructed wetland approaches, as they are designed to provide a range of ecological services. They try to provide the widest possible range of ecological conditions as 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 holistic designs. These added values develop important synergies that facilitate a high degree of cleansing, sustainability and robustness. The required larger land areas used in the ICW design compared with those generally used in other constructed wetlands is offset by the site gaining new values through landscape fit and biodiversity.

BASIC REQUIREMENTS AND CONSIDERATIONS

The ICW concept strives to be holistic, as it combines capture and treatment of polluted and eutrophic water, sets the required wetland infrastructure aesthetically into the landscape, optimises its ecological function, and satisfies planning and regulatory requirements. The concept, by taking an ecosystem-based approach, focuses on all inputs and outputs to the wetland ecosystem. This ensures sustainability and robustness. These considerations help avoid exposure to malfunction through human error by being as self-managing as possible. The requirement of satisfying planning and regulatory authorities is achieved by demonstrating that the performance of an ICW is as least as good as other recognised /regulated water treatment systems through providing effective monitoring infrastructure.

DESIGN

While wetland configuration/landscape fit and emergent plant species/biodiversity are important components of the ICW design (Harrington and Ryder 2002) emphasis in this presentation is on hydraulic management.

The ICW design requires that all potential water drainage to the wetland be considered. The wetland is in effect, a bunded system. It requires that all flows are effectively collected and directed to the wetland. This may include roof water from buildings, intercepted precipitation from the farmyard (including land sloping to the yard unless deflected), dirty water from dairy washings, yard-cleaning water, silage effluent and water from open slurry pits and dungsteads. The design also requires the effective containment of all contaminated water and that the wetland should not be a source risk of either point or diffuse pollution through inadequate design and construction. Design protocols and guidelines which are in preparation will include appropriate site assessment that takes into account:

- Consideration of whether some sites may be appropriate or not
- Soil type/geology/topography/coefficients of site uniformity
- Site values for nature conservation and archaeology/built-heritage
- Characteristics of influent (particularly ammonium concentrations)
- An appropriate monitoring strategy, including consideration of adjacent wells, watercourses and ground water

DETERMINATION OF WETLAND AREA AND INFLUENCE OF PRECIPITATION

The cleansing efficiencies of surface flow wetland systems are based on appropriate hydraulic residence times (HRTs). This depends on having sufficient functional wetland area. The segmentation of the wetland into a number of cells and the avoidance of preferential flows through these cells by managing water depth ensure optimal functioning.

Determination of wetland functional surface area for improving water quality has been calculated on the basis of first order rate decay (Kadlec and Knight, 1996) and plug flow equations (O'Sullivan, 1998). These are appropriate for relatively constant flow systems. However, the ICWs must treat water inflows of variable quality and quantity that are greatly influenced by precipitation events. This is particularly so when considering water from farmyards and combined stormwater sewage systems. The ICW concept takes into account both extreme precipitation events and the variable composition of influents in calculating wetland area.

Precipitation events are the dominant factor in determining the volume of farmyard dirty water and combined stormwater sewage effluent. These precipitation-generated volumes may be many orders of magnitude greater than that derived solely from farmyard wastewater or sewage inflows. This requires calculating the wetland area on the basis of fluxes generated by precipitation to and on the wetland system. This is demonstrated by the following indicative example of relative hydraulic loading at a farm scale whose farmyard area is 0.5 ha and annual rainfall is 1,000mm.

- Volume of farmyard dairy washings at 50 l/day
  5000 l/100 cows = 5,000 l (a comparative unit of 1.0)

- Average volume of daily intercepted precipitation at 1,000 mm/yr
  0.5 ha farmyard = 13,700 l (or 2.75 times the above volume of wash water)

- Flux volume
  Precipitation event of 50mm/24 hrs = 250,000 l (or 50 times the volume of wash water or > 13 times the combined volume of wash water and average daily volume of intercepted precipitation)

PHOSPHORUS MANAGEMENT

By focusing on the sustained management of phosphorus, which is the most limiting factor in determining effective wetland area (Kadlec and Knight, 1996), the impact of precipitation derived fluxes can be best understood and managed. The ICW design has generally considered a ratio of 1.4 times the area of interception as an appropriate determinant of wetland area for farmyard management. As this recommended ratio was not always implemented in the construction of each of the 13 ICWs presented in this paper, the effectiveness of the ratio can be examined. This is illustrated by the phosphorus discharge performance of seven of the 13 constructed wetlands whose hydraulic integrity could be best accounted for. The average performance of each of these seven ICWs, measured over two years, with regard to their degree of compliance to 1.4 times the area of precipitation interception requested by the design, is presented (Fig. 1).

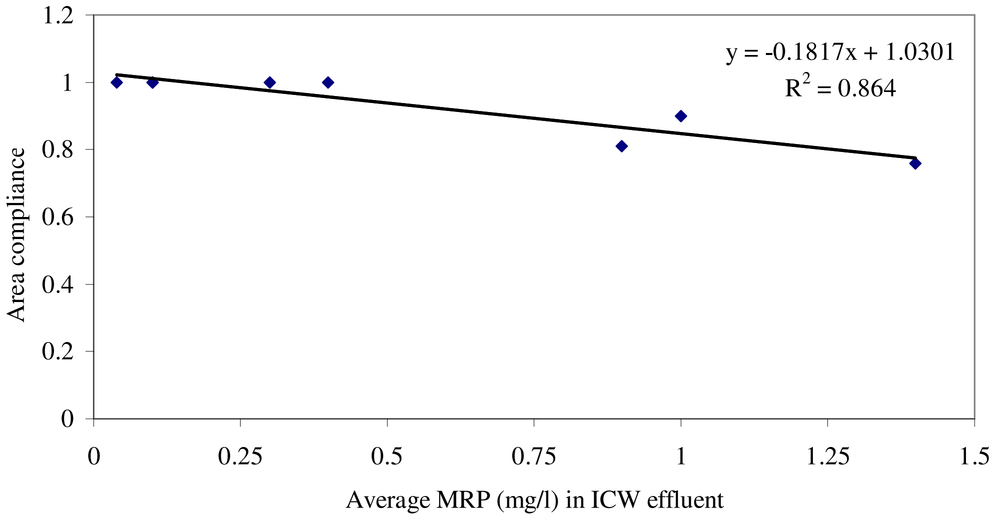

Figure 1. Phosphorus (MRP) in effluent from seven constructed wetland relative to functioning wetland area, as a percent of compliance to design requirement.

As no correlation was found between inlet and outlet concentrations for water quality parameters the area based relationship as shown in figure 1 would appear to be the primary factor determining ICW water quality effluent. It appears that compositional impact is only manifest at the point of entry to the wetland. Two additional ICWs outside the Anne valley with high ammonium concentrations, one built to treat dilute pig slurry (340 mg/l) and the other treating meat processing wastewater (700 mg/l), showed vegetation stress and die-off. A threshold ammonium concentration of 280 mg/l for vegetation survival and hence a limiting factor in the design is presented (Table 1). Influents with a higher concentration require dilution and until further data are available, survival to sustained exposure at concentrations of 280 mg/l must be regarded as tentative.

Table 1. Threshold limit of ammonium concentration for emergent wetland plants in the transition between wetland cells three and four treating pig slurry.

WETLAND CELL	AMMONIUM 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

GENERAL PERFORMANCE

The performance of all ICWs complied with regulatory requirements as they presently stand. Phosphorus (MRP) concentration of discharge water showed a consistent correlation to the relative size of the wetland. Discharge ammonium and nitrate concentrations also correlated to wetland area but were easier to attain. Faecal coliforms were the most easily managed parameter.

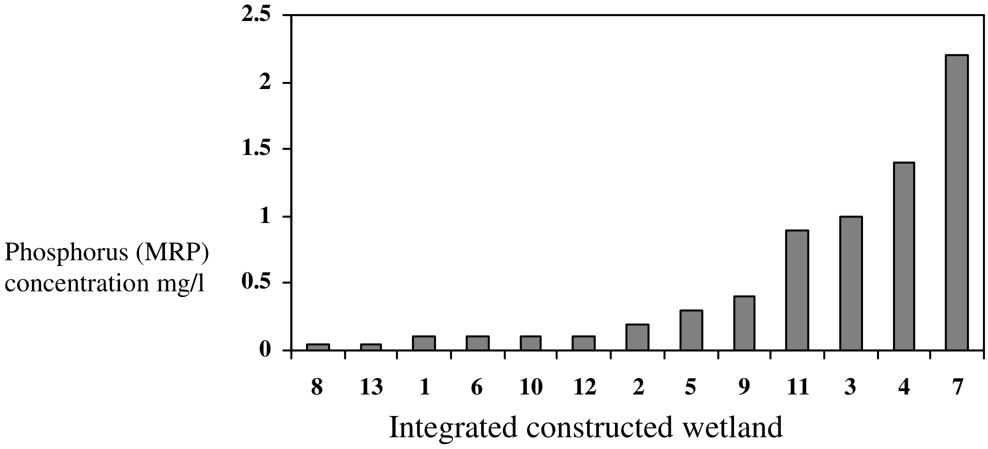

Figure 2. Thirteen integrated constructed wetlands ranked in order of average performance in MRP effluent concentration over a two year period (August, 2001 to August, 2003).

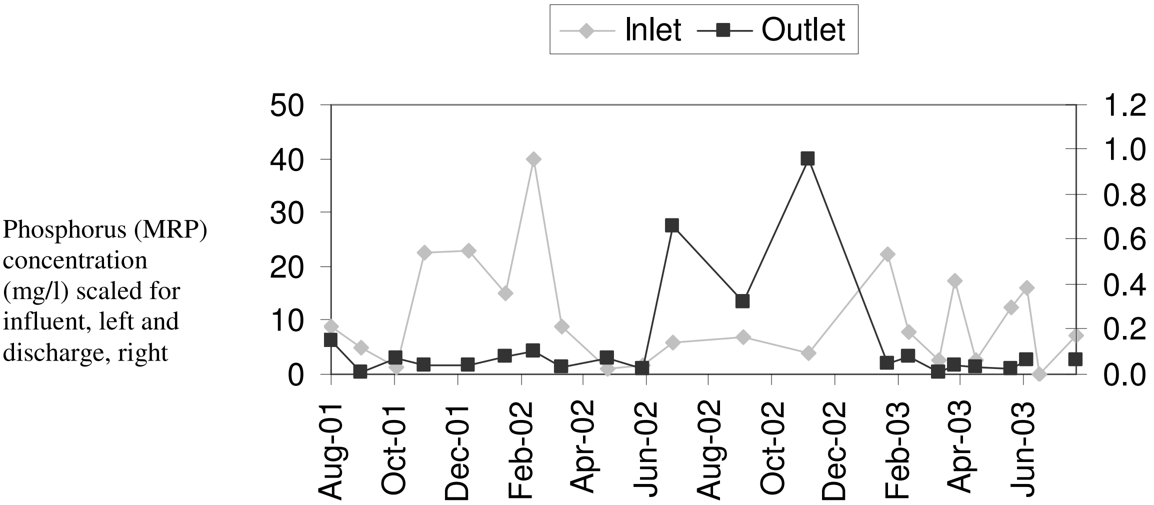

Figure 3. Inlet and outlet concentrations for ICW number six above, over two year period (August, 2001 to August, 2003).

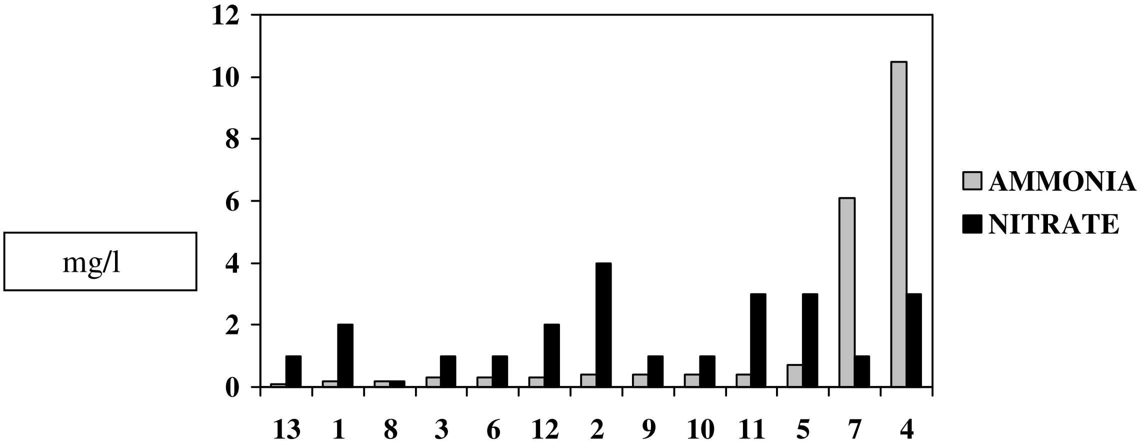

Figure 4. Average outlet ammonia/nitrate concentrations for 12 farm based ICWs over a two year period (August, 2001 to August, 2003).

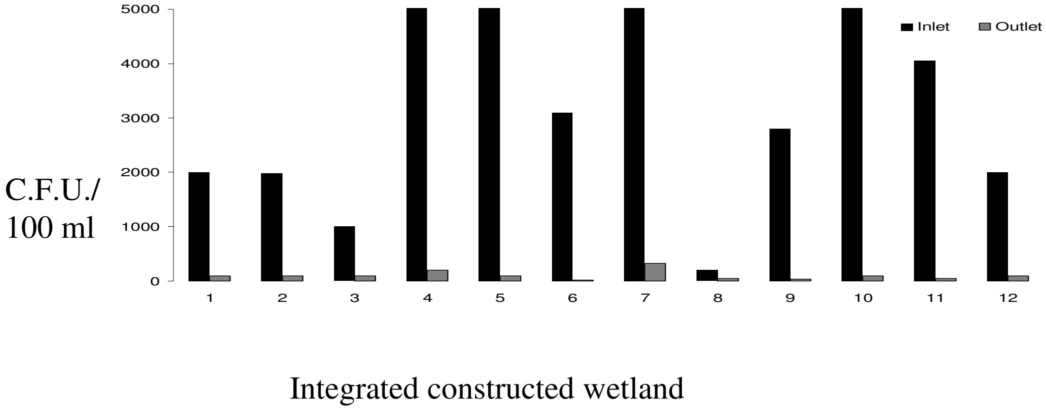

Figure 5. Average inlet and outlet Faecal Coliforms (C.F.U./100 ml) values for 12 ICWs over a two year period (August, 2001 to August, 2003).

The collective impact of intercepting about 75% of farm and sewage point sources of pollution with ICWs (mainly built in 1999/2000 period) appears to have had a rapid improvement in the receiving surface waters of the Anne Valley. The median phosphate (MRP) concentration for the main receiving stream in the Anne Valley stream was 0.02 mg/l for 2003. Bio-indicated Q values in the stream based on ecological assessment was Q 2 in 1999 with Q 3-4 in 2001 (EPA 2002).

CONCLUSIONS

The effectiveness of ICWs is largely dependent upon having an appropriate water surface area to cleanse influents. Whilst the concentration of contaminants in the influent has less influence on the area required, concentration, especially of ammonium, is important for the survival of emergent plants that provide the hydraulic resistance and reactive surfaces. The variation in ICW performance with regard to phosphorus, recognised as the most area-dependent constituent (Kadlec and Knight 1996), was shown to be strongly related to the effective area of the wetland. In the pursuit of achieving low phosphorus concentrations (< 0.2mg/l), a ratio of 2.0 (precipitation interception area to wetland area) appears to be more appropriate and is being researched.

The Integrated Constructed Wetland design is a unique approach to the use of constructed wetlands to water quality management. It utilises the ecosystem studies approach (Bormann and Likens 1981) to understand its physical, chemical and biological supporting processes. It draws on the science of wetland ecology and on landscape aesthetics to build new values for the sites involved. They have the capacity to effectively treat a wide range of types of contaminated water in a sustainable way and to enhance site values as well as turning "problem" farm and rural derived wastewater into significant economic, social and environmental resources.

REFERENCES

Bormann F H and G E Likens (1981). Pattern and Process in a Forested Ecosystem. Springer-Verlag New York 253p.

EPA (2002) Interim Report: The biological survey of river quality 2001. Environmental Protection Agency Johnston Castle Ireland.

Harrington R and C Ryder (2002) The use of Integrated Constructed Wetlands (ICWs) in the Management of Farmyard Runoff and Waste Water. National Hydrology Seminar 2002: Water Resource and Management Sustainable Supply and Demand. Irish Nat. Committees of IHP and ICID. The Institution of Engineers of Ireland 55-63.

Kadlec R and R Knight (1996). Treatment Wetlands. Lewis Publishers. Boca Raton.

Mitsch W J and S E Jørgensen (1989). *In* Ecological Engineering: An introduction to ecotechnology. Mitsch W J and S E Jørgensen(Eds). J Wiley and Sons Inc, New York..

O'Sullivan C T (1998) Constructed Wetland Treatment Facilities for Small and Medium Size Communities. Unpublished M.Sc. Dissertation. Dep. Civil Engineering, Trinity College Dublin.

Siccama T G, F H Bormann and G E Likens (1970). The Hubbard Brook Ecosystem Study: Productivity, nutrients and phytosociology of the herbaceous layer. Ecol. Monogr. 40:389-420.