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Long-term performance of a representative integrated constructed wetland treating farmyard runoff

Atif Mustafa[a], *Miklas Scholz*[a,*], *Rory Harrington*[b], *Paul Carroll*[c]

[a] *Institute for Infrastructure and Environment, School of Engineering and Electronics, The University of Edinburgh, Mayfield Road, The King's Buildings, Edinburgh EH9 3JL, UK*
[b] *National Parks and Wildlife, Department of Environment, Heritage and Local Government, The Quay, Waterford, Ireland*
[c] *Waterford County Council, Kilmeaden, Waterford, Ireland*

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ABSTRACT

The integrated constructed wetland (ICW) system studied in this research paper was constructed as part of a series of 15 wetland systems to improve the water quality of an entire catchment area (Annestown Stream watershed, Ireland) dominated by farming activities. The studied ICW comprised four cells and was used for the treatment of farmyard dirty water from a dairy farm near Dunhill (Ireland). The performance of this system was evaluated through physical, chemical and microbiological parameters collected for 7 years. The removal efficiencies were relatively good if compared to the international literature: biochemical oxygen demand (97.6%), chemical oxygen demand (94.9%), suspended solids (93.7%), ammonia-nitrogen (99%), nitrate-nitrogen (74%) and molybdate reactive phosphorus (91.8%). A molecular microbiological analysis of sediment samples collected from the site indicated that the number of denitrifying bacteria detected in the ICW system was higher than the number of ammonia-oxidizing bacteria. The monitored nutrient concentrations in groundwater and surface waters indicated that this ICW system did not pollute the receiving waters. The results showed that ICW are likely to be efficient in removing nutrients from farmyard runoff rich in nitrogen and phosphorus.

1. Introduction

Farmyard runoff, which is rich in nutrients, is a source of diffuse pollution, and potentially a serious risk to receiving watercourses by contributing to eutrophication (Cleneghan, 2003). Constructed wetlands have been used worldwide to treat different categories of wastewater, including domestic, industrial, acid mine drainage, agricultural runoff and landfill leachate (Kadlec and Knight, 1996; Scholz, 2006).

The integrated constructed wetland (ICW) concept (Harrington et al., 2007; Scholz et al., 2007) is based on an approach that endeavors to achieve water treatment, landscape fit and biodiversity enhancement targets by an innovative wetland design methodology. One sub-group of ICW is farm constructed wetlands (FCW) as defined by Carty et al. (2008).

The conventional practice in Ireland is land spreading of farmyard dirty water (Tunney et al., 1997). The storage and spreading are governed by rules to prevent water pollution. However, this practice requires considerable labor and machinery resources, as well as storage infrastructure. Improper storage and spreading has been linked to water

* *Corresponding author*. Tel.: +44 131 650 6780; fax: +44 131 650 6554.
E-mail address: m.scholz@ed.ac.uk (M. Scholz).
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pollution, particularly to increased levels of nitrogen and phosphorus in surface and ground waters (Healy et al., 2007). In contrast, the ICW concept is founded on the holistic use of land to protect and improve water quality. These systems are areas of land–water interface that form an integral part of the environmental and ecological structure of the landscape. They act as buffer lands that control the transfer and storage of farmyard dirty water rich in nutrients (Scholz et al., 2007).

The main characteristics of an ICW, such as shallow water depth, emergent vegetation and the use of *in situ* soils, mimic those found in natural wetland ecosystems (Harrington et al., 2005). Scholz et al. (2007) reported on the detailed concept of these synergistic, robust and sustainable systems by referring to case studies in Ireland.

The contaminated effluent is treated in an ICW through various physical, chemical and biological processes involving plants, microorganisms, water, soil and sunlight (Kadlec and Knight, 1996; Scholz, 2006). The extent of treatment in constructed wetlands depends upon the wetland design, microbial community and types of aquatic plants involved. Water quality improvements are predominantly caused by bacteria (Ibekwe et al., 2003); for instance, most of the biological degradation takes place within bacterial films present on sediments, soils, live submerged plants and the associated litter. Microbes catalyze chemical changes in wetland soils and indirectly control the nutrient availability to plants and in turn the water quality (Mitsch and Gosselink, 2007). The litter and associated sediment originating from decaying macrophytes provides considerable surface area for the attachment of biofilms, and is therefore important for microbial processes such as the transformation of nutrients in wetlands (Scholz, 2006).

Some of the main processes for nitrogen transformation in constructed wetlands are nitrification, denitrification and anammox (Shipin et al., 2005; Vymazal, 2007), which are all microbial-mediated processes (Wallace and Knight, 2006). It is expected that nitrogen removal fluctuates and increases over time as vegetation becomes established, and sufficient carbon is available for denitrification (Kadlec and Knight, 1996).

Wetlands have a relatively high capacity for storing nutrients (Braskerud, 2002). The phosphorus assimilation in constructed wetlands depends on factors such as the influent phosphorus concentration, the rate of internal biomass cycling, and the wetland age (Kadlec, 1999; Wallace and Knight, 2006). However, the long-term storage of phosphorus in these systems is linked to the cycling of phosphorus through the growth, death and decay of plant biomass. Previous studies on wetland ecosystem structure and function have shown that soil is the most important long-term ecosystem phosphorus storage compartment (Richardson and Marshall, 1986). The processes such as soil adsorption and peat accumulation control the long-term sequestration (i.e. capture) of phosphorus (Richardson and Marshall, 1986; Reddy et al., 1999).

Most previous studies have been short-term, and on either pilot plant- or laboratory-scale experimental systems. Very few studies have been conducted on full-scale constructed wetlands with long-term evaluations (Brix et al., 2007; Newman et al., 2000). There is a lack of information on the performance of mature constructed wetland and ICW systems including FCW structures. The purpose of this study was therefore:

- to evaluate the treatment efficiency of a full-scale mature ICW system that is in operation for 7 years;
- to assess the annual and seasonal variations in nutrient removal;
- to identify the presence of microorganisms responsible for nitrogen transformations within these systems;
- to investigate the impacts of potential contamination of nearby surface waters and groundwater.

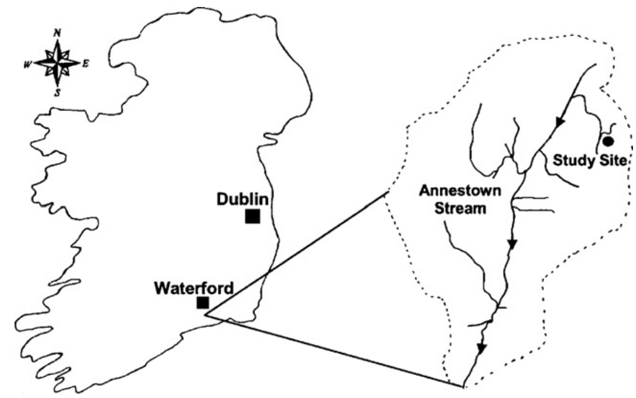

Fig. 1 – Location of the integrated constructed wetland site within the Annestown catchment near Waterford, Ireland.

2. Materials and methods

2.1. *Site description*

The researched ICW treatment system is a FCW, situated in County Waterford (south-east of Ireland), at a longitude of 07°02′40″W and a latitude of 52°11′28″N (Fig. 1). The case study area is located in a temperate zone with a mean annual temperature and precipitation of 11.4 °C and 1094 mm, respectively (Met Éireann, 2007). Mean seasonal temperatures for the region in 2007 were as follows: winter, 7.8 °C; spring, 10.3 °C; summer, 14.9 °C; fall, 12.2 °C.

The ICW system was constructed in 2000, and commissioned in February 2001 to contribute to the improvement of the water quality of the Annestown Stream. The ICW system has a total area of 0.76 ha. The primary vegetation types used in the ICW are emergent plant species (helophytes). The first three cells were densely vegetated while the last cell had only sparse vegetation (Table 1).

The cells were not lined with an artificial liner. However, the subsoil was reworked and used as a natural liner. The cells were only partly planted with vegetation naturally available on the site. Further plant growth occurred by natural recruitment. Each cell had one inflow and one outflow structure. The flow between each cell was by gravity through a PVC pipe.

The effluent entering the ICW system comes from a dairy farm of 0.5 ha with 77 cows. The wastewater contained farmyard and roof runoff occasionally contaminated by manure, and was conveyed to the ICW system by gravity through a pipe. The key features of this constructed wetland were hor-