Journal of Environmental Management 210 (2018) 263–272

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Review

An assessment of the performance of municipal constructed wetlands in Ireland

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ARTICLE INFO

Article history:
Received 10 May 2017
Received in revised form
28 December 2017
Accepted 30 December 2017

Keywords:
Constructed wetlands
Wastewater treatment
Water quality
Phosphorus
Nitrogen
Storm management
Specific area

ABSTRACT

While performance assessments of constructed wetlands sites around the world have appraised their capacity for effective removal of organics, a large variance remains in these sites' reported ability to retain nutrients, which appears to depend on differences in design, operation and climate factors. Nutrient retention is a very important objective for constructed wetlands, to avoid eutrophication of aquatic environments receiving their effluents. This study assessed the performance of constructed wetlands in terms of nutrient retention and associated parameters under the humid conditions of Ireland's temperate maritime climate. A review of the performance of 52 constructed wetland sites from 17 local authorities aimed to identify the best performing types of constructed wetlands and the treatment factors determining successful compliance with environmental standards. Data analysis compared effluent results from constructed wetlands with secondary free surface flow or tertiary horizontal subsurface flow, hybrid systems and integrated constructed wetlands with those from small-scale mechanical wastewater treatment plants of the same size class. Nutrient concentrations in effluents of constructed wetlands were negatively correlated ($p < .01$) with specific area, i.e. the ratio of surface area and population equivalents. The latest generation of integrated constructed wetlands, which had applied design guidelines issued by the Department of the Environment, performed best. Storm management design features improved treatment performance of constructed wetlands significantly ($p < .05$) for total suspended solids concentrations and exceedance frequency of limit values for total nitrogen. Mechanical wastewater treatment plants, secondary free surface water and tertiary horizontal subsurface flow wetlands showed a very large variance in effluent concentrations for organic and nutrient parameters. *E. coli* numbers in effluents were lowest for integrated constructed wetlands with an arithmetic mean of 89 MPN/100 ml. Despite Ireland's humid climate, some constructed wetland sites achieved long or frequent periods of zero effluent discharge and thus did not transfer any waterborne pollution to their receptors during these periods.

Contents

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https://doi.org/10.1016/j.jenvman.2017.12.079
0301-4797/

Acronyms

CW	Constructed Wetlands
DOE	Department of the Environment
ELV	Emission Limit Value
EPA	Environmental Protection Agency in the Republic of Ireland
FSFW	Free Surface Flow Wetland
HSSF	Horizontal Subsurface Flow
ICW	Integrated Constructed Wetlands
PE	Population Equivalent
SSF	Subsurface Flow
VSSF	Vertical Subsurface Flow

1. Introduction

Provision of economically and environmentally sustainable wastewater treatment for small communities remains a great challenge all over Europe, but particularly so in countries with large numbers of small and scattered settlements like Ireland. In recent reviews of Irish wastewater licensing 515 authorisations were issued for settlements with less than 500 population equivalents (PE) and a further 359 for settlements with 500–2000 PE (EPA, 2012, 2014). A very high failure rate with 37% of tested licensed agglomerations in a 2014 survey highlighted the challenge in striving for compliance of mechanical small scale wastewater treatment plants with treatment standards for the >2000 PE licensed category (EPA, 2014). Constructed wetlands (CW) may offer an economically feasible solution for this problem.

All municipal CWs in Ireland are operating under the Wastewater Discharge (Authorisation) Regulations (Department of the Environment, Heritage and Local Government, 2007). According to Article 2 in the Wastewater Discharge Regulations, CW operation must satisfy the objectives of the EU Water Framework Directive and associated legislation (Department of the Environment, Housing and Local Government, 2009).

The implementation of the Wastewater Discharge Regulations supports the Water Framework Directive's goal to achieve good ecological status in all water bodies. The Environmental Protection Agency (EPA) sets emission limit values for wastewater treatment plants in consideration of this long-term requirement to achieve good status in the receiving water body or according to its designation. Emission limit values on organic pollutants, nutrients and in some cases bacteria concentrations in wastewater effluent are licensed under the Wastewater Discharge Regulations 2007.

In regard to operational and maintenance costs CWs compare favourably to mechanical wastewater treatment plants (United States Environmental Protection Agency, 1999; Haberl, 1999; Gopal, 1999; Bialowiec et al., 2014; Wu et al., 2014). Based on a whole life cycle assessment Doody et al. (2009) estimated savings of 50% for capital costs and approximately 90% for operation and maintenance of CW systems in comparison to mechanical activated sludge, attached media and membrane plants. This estimate rested on the assumption that the necessary land was available at a reasonable purchase price or that it was possible to negotiate reasonable leasing arrangements.

For continuous optimisation of CW technology through adaption to specific regional conditions, it is necessary to gather data pertaining to the operation, maintenance and performance, in order to inform design and future investment decisions. Two examples of successful projects of this kind already exist in the United States and the United Kingdom. The United States Environmental Protection Agency has compiled the North American Wetlands for Water Quality Treatment Database (NADB), which e.g. contains data on flow, dimensions, plant species, and analysis results for samples from influent and effluent water from several hundred locations in the United States and Canada. This information has been utilised to assess constructed wetlands as a treatment alternative to inadequate mechanical wastewater treatment for small communities (United States Environmental Protection Agency, 1999). The United Kingdom's Constructed Wetlands Association formed in response to malpractice of unscrupulous contractors; it maintains a frequently updated CW database containing information on more than 900 beds in the United Kingdom (Cooper, 2007).

As in many other countries, publicly available CW reference data are still scarce in Ireland. This lack of detailed information on design standards and often spurious performance claims by manufacturers reflect badly on regulation and public opinion. Under such circumstances, apprehension to considering CWs as a realistic