Science of the Total Environment 612 (2017) 1480–1487

Contents lists available at ScienceDirect

Science of the Total Environment

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

Changes in bacteria composition and efficiency of constructed wetlands under sustained overloads: A modeling experiment

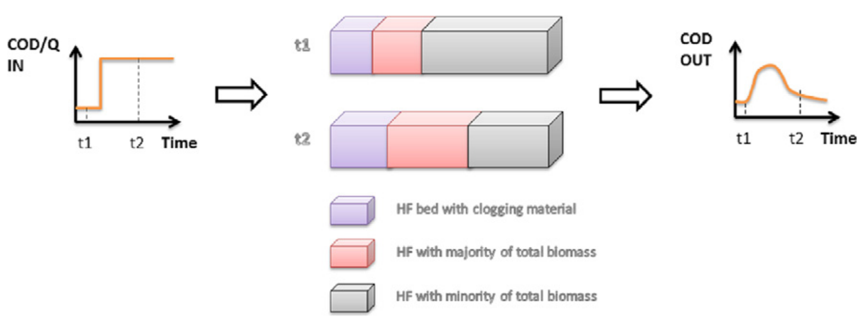
F. Boano[a,*], A. Rizzo[a,b], R. Samsó[c], J. García[d], R. Revelli[a,e], L. Ridolfi[a]

[a] Department of Environment, Land and Infrastructure Engineering (DIATI), Politecnico di Torino, Corso Duca degli Abruzzi, 24, Turin 10129, Italy
[b] Iridra S.r.l., Via Alfonso la Marmora, 51, Florence 50121, Italy
[c] IRSTEA, Freshwater Systems, Ecology and Pollution Research Unit, 5 rue de la Doua, CS70077, Villeurbanne cedex 69626, France
[d] GEMMA-Environmental Engineering and Microbiology Group, Department of Civil and Environmental Engineering, Universitat Politècnica de Catalunya-BarcelonaTech, c/ Jordi Girona 1-3, Building D1, Barcelona E-08034, Spain
[e] Department of Civil and Environmental Engineering, Duke University, Box 90287, Durham, NC 27708, USA

HIGHLIGHTS

- Little experimental evidence on the assumed buffering capacity of CWs has so far been provided.
- Five simulations representing different overloading scenarios on a HF CW were run.
- Removal efficiency temporarily drops before recovering pre-overload values.
- Microbial community composition is influenced by overload conditions.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 5 May 2017
Received in revised form 21 July 2017
Accepted 27 August 2017
Available online xxxx

Keywords:
Constructed wetland
Organic load
Hydraulic load
Buffering capacity
BIO_PORE

ABSTRACT

The average organic and hydraulic loads that Constructed Wetlands (CWs) receive are key parameters for their adequate long-term functioning. However, over their lifespan they will inevitably be subject to either episodic or sustained overloadings. Despite that the consequences of sustained overloading are well known (e.g., clogging), the threshold of overloads that these systems can tolerate is difficult to determine. Moreover, the mechanisms that might sustain the buffering capacity (i.e., the reduction of peaks in nutrient load) during overloads are not well understood. The aim of this work is to evaluate the effect of sudden but sustained organic and hydraulic overloads on the general functioning of CWs. To that end, the mathematical model BIO_PORE was used to simulate five different scenarios, based on the features and operation conditions of a pilot CW system: a control simulation representing the average loads; 2 simulations representing +10% and +30% sustained organic overloads; one simulation representing a sustained +30% hydraulic overload; and one simulation with sustained organic and hydraulic overloads of +15% each. Different model outputs (e.g., total bacterial biomass and its spatial distribution, effluent concentrations) were compared among different simulations to evaluate the effects of such operation changes. Results reveal that overloads determine a temporary decrease in removal efficiency before microbial biomass adapts to the new conditions and COD removal efficiency is recovered. Increasing organic overloads cause stronger temporary decreases in COD removal efficiency compared to increasing hydraulic loads. The pace at which clogging develops increases by 10% for each 10% increase on the organic load.

Abbreviations: HF CWs , Horizontal flow constructed wetlands; HLR , Hydraulic loading rate; HRT , Hydraulic retention time; OLR , Organic loading rate.

* Corresponding author.
E-mail address: fulvio.boano@polito.it (B. F.).

http://dx.doi.org/10.1016/j.scitotenv.2017.08.265
0048-9697/

1. Introduction

Experience shows that when adequately designed and operated, Horizontal Flow Constructed wetlands (HF CWs) are an efficient and reliable wastewater treatment technology for suspended solids and organic matter removal. The benefits of these systems are maximized when applied to small communities and in places where seasonal population changes may occur (Puigagut et al., 2007; Masi et al., 2007). CWs are renowned for their buffering capacity, i.e., the ability to tolerate relatively high variability of loading rates and influent wastewater quality (Weerakoon et al., 2013). However, a recently published study seems to put limits to this statement (Galvão and Matos, 2012). Even though complex multi-stage CW systems have been proved to be able to cope with load fluctuations (Ávila et al., 2016), the buffering capacity of single-stage CWs has been generally assumed while little consistent experimental evidence has been provided to show the extent of such capacity.

Several experimental studies exist on the effects of organic and hydraulic loadings, but those studies analyze the response of the system to isolated steady state conditions (e.g., Ojeda et al., 2008), rather than their response when those conditions suddenly change (Galvão and Matos, 2012). Moreover, interdependence of HLR and OLR makes it difficult to study the effects of these two operating parameters separately (Galvão and Matos, 2012). Examples of those facts are the works of Caselles-Osorio and García (2006) and Weerakoon et al. (2013). Results from both studies seem to point to the fact that lower HLRs improve pollutants removal efficiencies. However, in Weerakoon et al. (2013) the HLR was linked to the OLR and thus the effects of each could not be analyzed separately. Although in Caselles-Osorio and García (2006) the HLR was changed while maintaining a constant OLR, several other operation parameters were modified for each phase of the study. Moreover, neither of these studies addresses the adaptation of the systems between changing operation conditions, nor they considered how their results were influenced by the long-term evolution of total microbial biomass and of its composition.

Acknowledging the difficulty of extracting reliable results on the effects of organic and hydraulic overloadings from the available experimental studies, Galvão and Matos (2012) studied the effects of punctual and sudden organic overloadings on 9 lab scale HF CWs. The total mass loading was increased for 2 weeks while the HLR was unchanged. Although the mass removal rate increased (indicating an adaptation of the microbial communities), they observed a general increase in the effluent COD concentrations and a decrease in the removal efficiencies. When the OLR was set back to the initial conditions, microbial activity and removal efficiencies also went back to match the initial ones. Galvão and Matos (2012) concluded that, for the organic loads applied in their study, the buffering capacity of CWs in the short term was not sufficient to absorb the rapidly increasing mass loadings. They also stated that the buffering capacity of CWs is not yet well understood and that further work is required to understand their capacity to adapt to sudden changes of their operating conditions.

The data from the Galvão and Matos (2012) experiments were employed by Rizzo et al. (2014) to calibrate a HYDRUS-CWM1 model. The calibrated model was later used (Rizzo and Langergraber, 2016) to investigate the response of the pilot systems to sudden changes of influent organic load simulated following the European Standard (12556-3, 2005) . The simulated results suggested a good buffering capacity of the CW to daily sudden loads. On the other hand, an increase in COD effluent concentration was also predicted during the two weeks of high load due to slow response of anaerobic bacteria. Moreover, the increase in influent organic load led to a longitudinal shift of fermenting bacteria towards the outlet, suggesting that an undersized HF CW could efficiently treat nominal loads but would fail in case of an influent sudden load. These results confirm that duration timescale of overload application significantly affects treatment efficiency.

In order to elucidate the long-term response of CWs to increase in inflow loads, the objective of this work was to evaluate the effect of sudden but sustained organic and/or hydraulic overloads on pollutants removal efficiencies, bacterial functional groups, and accumulated solids. We also investigated which of the two, either the organic or the hydraulic overloads, has the largest impact on the overall functioning of CWs. To that end, in this work we use a mathematical model called BIO_PORE (Samsó and García, 2013a) which was specifically developed to simulate subsurface-flow Constructed Wetlands general functioning. This model has already been calibrated and used in several works, which have provided new insights on the internal dynamics of CWs and the dynamics of solids accumulation and bacterial growth (e.g., Samsó and García, 2013b, 2014). In this work, five long-term numerical simulations were performed that correspond to four different overloading scenarios and one scenario with no change in inflow load. The simulations involved sudden organic overloads, hydraulic overloads, and both organic and hydraulic overloads at the same time. Each simulation was continued after the sudden inflow load variation until a new equilibrium state was reached. This work puts to tests well accepted beliefs on CWs capacities and provides further insights on their internal functioning and long-term response to operation changes. Moreover, despite that in this work we have considered a wetland treating domestic wastewater, the results can be extrapolated to other types of wastewaters and wetland configurations. In particular, the findings of the present study are useful to understand the potential limits of CWs whose performance depends mostly on their short-term buffering capacity.

2. Methods

2.1. The BIO_PORE model

BIO_PORE is a 2D mechanistic model built in COMSOL Multiphysics™ software that includes a wide range of physical and biological processes to reproduce the general functioning of CWs (Samsó and García, 2013a). To that end, it includes fluid flow and transport equations together with the biokinetic model Constructed Wetland Model number 1 (CWM1) (Langergraber et al., 2009). CWM1 is based on ASM and ADM formulations (Batstone et al., 2002; Henze et al., 2000), and is seen as the most advanced biokinetic model developed for CWs. The wastewater constituents and the bacteria groups considered in CWM1 are listed in Table 1. BIO_PORE was validated by Samsó and García (2013a) on time-variable influent data. These variations in inflow COD concentrations and hydraulic loading rates bracketed those considered in this study. Calibrated values of model biokinetic parameters can be found in Samsó and García (2013a).

2.2. Simulation strategy

2.2.1. System characteristics

This work analyzes the same domain configuration used by Samsó and García (2013b), who considered a pilot wetland located at les Franqueses del Vallès, Barcelona, Spain (García et al., 2004). The pilot HF CW has a horizontal area of 54.6 m^2 (10.3×5.3 m), and it is planted with *Phragmites australis*. It contains a layer of fine gravel (D_{60} = 3.5 mm, initial porosity n = 0.4, hydraulic conductivity K = 50 m d^{-1}) whose depth varies between 0.6 m at the inlet and 0.7 m at the outlet.

Samsó and García (2013b) performed a numerical simulation of the behavior of this HF CW for a period of three years under a constant HLR of 36.6 mm d^{-1} of pre-treated urban wastewater. Values of inflow concentrations are described below. Results of the simulations at the end of this period showed that effluent concentrations