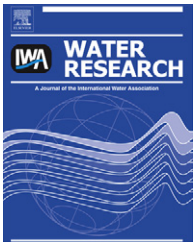
WATER RESEARCH 47 (2013) 1448–1458

Available online at www.sciencedirect.com

SciVerse ScienceDirect

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



Design configurations affecting flow pattern and solids accumulation in horizontal free water and subsurface flow constructed wetlands

A. Pedescoll[a,b,*], R. Sidrach-Cardona[a,b], J.C. Sánchez[a,b], J. Carretero[c], M. Garfí[c], E. Bécares[a,b]

[a] Environmental Institute, University of León, c/La Serna 56, 24007 León, Spain
[b] Ecology Section, Department of Biodiversity and Environmental Management, University of León, Campus de Vegazana s/n, 24071 León, Spain
[c] GEMMA – Group of Environmental Engineering and Microbiology, Department of Hydraulic, Maritime and Environmental Engineering, Universitat Politècnica de Catalunya-BarcelonaTech, c/Jordi Girona 1-3, Building D1, E-08034 Barcelona, Spain

ARTICLE INFO

Article history:
Received 20 July 2012
Received in revised form
5 December 2012
Accepted 7 December 2012
Available online 19 December 2012

Keywords:
Clogging
Flow path
Solids distribution
Permeability
Cattail
Common reed

ABSTRACT

The aim of this study was to evaluate the effect of different horizontal constructed wetland (CW) design parameters on solids distribution, loss of hydraulic conductivity over time and hydraulic behaviour, in order to assess clogging processes in wetlands. For this purpose, an experimental plant with eight CWs was built at mesocosm scale. Each CW presented a different design characteristic, and the most common CW configurations were all represented: free water surface flow (FWS) with different effluent pipe locations, FWS with floating macrophytes and subsurface flow (SSF), and the presence of plants and specific species (*Typha angustifolia* and *Phragmites australis*) was also considered. The loss of the hydraulic conductivity of gravel was greatly influenced by the presence of plants and organic load (representing a loss of 20% and c.a. 10% in planted wetlands and an overloaded system, respectively). Cattail seems to have a greater effect on the development of clogging since its below-ground biomass weighed twice as much as that of common reed. Hydraulic behaviour was greatly influenced by the presence of a gravel matrix and the outlet pipe position. In strict SSF CW, the water was forced to cross the gravel and tended to flow diagonally from the top inlet to the bottom outlet (where the inlet and outlet pipes were located). However, when FWS was considered, water preferentially flowed above the gravel, thus losing half the effective volume of the system. Only the presence of plants seemed to help the water flow partially within the gravel matrix.

1. Introduction

Constructed wetlands (CWs) are extensive, low energy systems for wastewater treatment which do not require specialised manpower for their management (Wallace and Knight, 2006). For this reason, and due to the large amount of land required for wastewater treatment, CWs are usually recommended for the sanitation of small communities (Cooper, 2005).

---

* Corresponding author. Environmental Institute, University of León, c/La Serna 56, 24007 León, Spain. Tel.: +34 987 29 10 00x5227; fax: +34 987 29 15 63.

E-mail addresses: apedea@unileon.es, pedescoll@hotmail.com (A. Pedescoll), rsidc@unileon.es (R. Sidrach-Cardona), nocardia.medioambiente@gmail.com (J.C. Sánchez), javier.carretero.ariza@upc.edu (J. Carretero), marianna.garfi@upc.edu (M. Garfí), ebecm@unileon.es (E. Bécares).

0043-1354/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.watres.2012.12.010

Despite the advantages that CWs offer, they also present a major operational problem, namely clogging of the gravel media. Clogging is the progressive loss of the initial hydraulic characteristics, mainly porosity and hydraulic conductivity of the granular media. This phenomenon is due to the accumulation of solids from the wastewater, biofilm and plant growth and chemical precipitates (Knowles et al., 2011), and can lead to a decrease in contaminant removal efficiency over time. Although clogging is an unavoidable process (since it is inherent to the treatment), it can be delayed by improving the design (Persson et al., 1999), operation and maintenance (Griffin et al., 2008) of the wetland. In fact, the degree of clogging depends on the accumulation of different nature solids, whereas the distribution of clogging basically depends on the hydraulic behaviour of the system. In order to determine whether intervention to reverse clogging is required, it is essential to assess not only the degree of clogging, but also its spatial distribution throughout the wetland.

Since clogging occurs through the accumulation of solids in the interstitial spaces of the gravel, it is obvious that the organic load, and especially the solids loading rate, are of paramount importance in the design. In the early stages after commissioning the plant, clogging occurs mainly at the inlet, spreading progressively towards the outlet. It is at the entrance to the wetland where solids are filtered, thus most of the suspended solids are retained in this zone. Therefore, an overload promotes the increase of sludge in this area, followed by rapid loss of the water infiltration rate and the appearance of ponding (Rousseau et al., 2005). Many authors have shown that the solids loading rate is directly related to sludge accumulation (Tanner et al., 1998; Caselles-Osorio et al., 2007; Pedescoll et al., 2011a). Primary treatments based on physical processes play an important role in decreasing the solids load applied to the system. However, if poorly designed or maintained, they can contribute to an undesirable solids overload at the wetland inlet (Knowles et al., 2010).

Many other factors also contribute to undesirable clogging distribution. Water tends to flow along the path of least hydraulic resistance (Pedescoll et al., 2011b), which is influenced by different design parameters and operational aspects, including the length to width ratio (García et al., 2005; Jenkins and Greenway, 2005; Persson, 2000) and the inlet and outlet position. Suliman et al. (2006, 2007) observed differences in flow pattern of an experimental flow cell depending on the strategy employed to fill the filter medium in the basin and the inlet-outlet position.

The development of below-ground vegetation may have implications for wetland hydraulics (Knowles et al., 2011), because the growth of below-ground plants involves a loss of effective volume, which is occupied instead by the roots and rhizomes. The hydraulic conductivity of the medium in similar systems is greater in unplanted wetlands (Sanford et al., 1995). Edwards (1992) estimated the volume occupied by roots as being 5% of total substrate volume of a subsurface flow wetland (45 cm deep) planted with bulrushes (*Scirpus validus*), where roots penetrated between 12 and 15 cm below the surface. Moreover, Pedescoll et al. (2011a) observed a drastic decrease in hydraulic conductivity in shallow subsurface flow CWs in which the below-ground biomass penetrated the entire wetland depth (25 cm of water column). In addition, the growth of roots and rhizomes creates a zone of increased resistance to water flow, promoting the establishment of preferential flow paths. Jenkins and Greenway (2005) found decreased hydraulic efficiencies with increasing vegetation cover and density.

The aim of this study was to evaluate the hydraulic performance of eight different configurations of wetlands in terms of clogging development, and to compare design parameters such as organic loading rate, presence or absence of vegetation, plant species and flow type. For this purpose, an experimental plant was built at mesocosm scale and operated for more than 3 years. Each of the 8 wetlands studied incorporated a different design parameter, and pairwise wetland comparisons were conducted to determine their effect. The most commonly used technologies for horizontal flow were evaluated (floating macrophytes, free water surface flow and subsurface flow). Common reed (*Phragmites australis*) and cattail (*Typha angustifolia*) were chosen in order to evaluate the effect of plant specie due to their wide use in constructed wetlands. Several clogging indicators were used to characterise the hydraulic behaviour of the wetlands studied, including hydraulic conductivity, solids accumulation, effective volume and hydraulic efficiency. To the best of our knowledge, this is the first time that clogging has been evaluated considering such a wide variety of technologies in CWs under the same climatic and wastewater conditions.

2. Methods

2.1. Experimental plant

Eight mesocosm-scale CWs were placed inside the facilities of the León wastewater treatment plant (WWTP), in the northwest of Spain (Latitude: 42°33′51″; Longitude: −5°34′43″). Each CW consisted of a fibreglass container (80 cm wide, 130 cm long and 55 cm high). A diagram of the experimental device is shown in Fig. 1. The CWs differed from each other in their design configuration. CW1 and CW5 were constructed as soilless wetlands with floating macrophytes. In these two wetlands, water depth was 30 cm and plant species were supported by garden net cylinders. CW2, CW3 and CW4 were designed as free water surface (FWS) systems, with 25 cm of siliceous gravel ($d_{10} = 4$ mm) and 50 cm of water depth. CW2 was a strict FWS with inlet and outlet pipes located at the wetland surface. In contrast, CW3 and CW4 were FWS systems with the outlet placed at the bottom of the container, thus forcing the water to take a partially subsurface pathway. CW6, CW6′ and CW7 were designed as subsurface flow (SSF) wetlands, with 50 cm of gravel layer and 45 cm of water depth. CW6′ received twice the organic load as CW6. The macrophyte species chosen were *Typha angustifolia* for CW1, CW2 and CW3, and *Phragmites australis* for CW5, CW6 and CW6′. Finally, CW4 and CW7 were unplanted systems. Consequently, pairwise comparison of wetlands, differing in only one design parameter, allowed us to evaluate the effect of different design parameters, as shown in Fig. 1.

The experimental plant began operating in May 2007 and continued until December 2010. Each wetland was fed with homogenised wastewater from the primary settler at the León