Design criteria for horizontal flow wetlands treating water with low nutrient content

Critères de dimensionnement pour des marais filtrants à flux horizontal sous-surfacique alimentés avec une eau faiblement chargée

Katharina Tondera[a,b], Florent Chazarenc[b], Kankan Shang[c], Yonghong Hu[c], Gilles Vincent[c], Jacques Brisson[d]

[a] IMT Atlantique, GEPEA, UBL, F-44307 Nantes, France
[b] Irstea, UR REVERSAAL, Reduce–Reuse–Recycle resources from wastewater, Centre de Lyon-Villeurbanne, Villeurbanne, France
[c] Shanghai Chenshan Botanical Garden, Shanghai Chenshan Plant Research Center, Shanghai, China
[d] Institut de recherche en biologie végétale, Département de sciences biologiques, Université de Montréal, Montréal, Canada

RÉSUMÉ

Au Jardin botanique de Chenshan (Shanghai), une station expérimentale composée de 14 marais filtrants à flux horizontal sous-surfacique a été analysée lors de la seconde année après sa mise en opération. L'objectif de cette étude était d'évaluer la capacité épuratoire entre des bassins plantés par 5 espèces différentes de macrophytes et des bassins non-plantés. Malgré une eau faiblement chargée, représentative des eaux pluviales de la région de Shanghai, nous avons pu observer un meilleur pourcentage d'enlèvement dans les bassins plantés comparativement à ceux non-plantés et ce, pour l'ensemble des paramètres mesurés ; par exemple pour TN, l'efficacité médiane d'élimination des filtres non plantés était de 53% et de 76% pour les filtres plantés. Toutefois, aucune corrélation de performance épuratoire n'a été observée entre l'oxygène dissous (DO) et les paramètres qui y sont associés. Pour tous les paramètres mesurés (DCO, DBO_5, NH_3-N, TN et TP), la taille des bassins pourrait même être optimisée en considérant une surface totale correspondant au tiers de la superficie de départ (58 m^2). Par contre, si d'autres objectifs de traitement étaient envisagés, tel que la réduction de pathogènes, la surface totale devrait possiblement être considérée et fait présentement l'objet de recherche.

ABSTRACT

14 horizontal flow treatment wetlands for the removal of pollutants from stormwater in Shanghai Chenshan Botanical Garden in China were investigated in the second year of a long-term trial. One aim was to compare the treatment efficiency of differently planted filter beds and unplanted ones. Despite the low nutrient concentrations, planted filters performed better than unplanted ones; e.g. for TN, the median removal efficiency for unplanted filters were 53% and 76% for planted filters. However, no correlations between dissolved oxygen and removal efficiency of oxygen depleting pollutants as well as between differently planted filters could be found. Regarding the targeted optimisation of the wetland design, for the investigated parameters COD, BOD_5, NH_3-N, TN and TP, the filter beds would perform almost as good if shortened by 1/3 of the length. However, it needs to be considered if further treatment goals such as reduction of pathogens should be achieved – here, the full filter passage might be necessary to achieve sufficient results. This should be subject to further research.

KEYWORDS

Constructed wetlands, horizontal subsurface flow, low nutrients, stormwater treatments, subtropical climate

1. INTRODUCTION

When designing constructed wetlands for treating stormwater from urban surfaces, its low nutrient concentration needs to be considered. Low nutrients load can limit macrophyte growth and favor the development of undesired species during the commissioning time (2-3 years). However, treatment wetlands have already been applied successfully to treat wastewater with low nutrient loads such as greywater (Li et al. 2009), stormwater (Tondera et al. 2018), and several low nutrient industrial wastewater (Wu et al. 2015).

In a pilot treatment wetland system in Shanghai Chenshan Botanical Garden (31°04'39''N, 121°11'12''E) in China, 14 different horizontal flow wetlands were implemented to treat water with low nutrient concentrations originating mostly from surface runoff of the botanical garden. The study presented here is a subsequent investigation of the first one-year start-up phase summarised in Vincent et al. (2018). While in the first year, the reaction of the plants to a system with low nutrient input was under observation, one aim of the following year was to optimize the design of the construction. This was achieved by measuring the nutrient decay over the length of the filter bed. The varying treatment efficiency of beds planted with different plant species as monoculture as well as an unplanted bed and one design with mixed vegetation was compared.

2. MATERIAL AND METHODS

2.1. Experimental setup

Each of the 14 separate parallel units with the same sizing (13 m long by 4.5 m wide; total filter bed surface of each 58.5 m^2) is filled with 60 cm of granitic river gravel (10/20 mm). While two replicate filter beds remained unplanted, clumps of five common macrophytes were planted in two replicates in March 2016: *Phragmites australis (Cav.), Trin. ex Steud., Typha orientalis C. Presl., Cyperus alternifolius L., Thalia dealbata Fraser ex Roscoe*, and *Arundo donax L.* (hereafter referred to as *Phragmites, Typha, Cyperus, Thalia and Arundo*). Two additional beds were replanted as replicates with a mix of *Phragmites, Typha* and *Thalia* in March 2017.

All units were fed with 4 m^3 of water each from an artificial lake of Chenshan Botanical Garden. In order to increase the nutrient concentration slightly, we added to the feeding unit of seven different tanks 175 ml of NPK solution corresponding to 125 mg of fertilizer (15:15:15) as low nutrient concentrations (NPK1), and 350 ml to the replicates. This way, the resulting concentrations reached representative concentrations of regularly occurring urban stormwater quality in the region of Shanghai. As described in Vincent et al. (2018), the pilot-scale system was fed for approximately 12-15h per day and five days a week by gravity (hydraulic rate of 4 m^3/d or 5.6 cm/d). Flow rate thus varied, but the theoretical hydraulic retention time (HRT) averaged 5 days. During the experiment, water level was maintained under 2 cm below the surface of the units. Data on rainfall and temperature were collected from a meteorological station located at Chenshan Botanical Garden, close to the pilot-scale system.

2.2. Sampling strategy

Grab samples were taken at inlet and outlet as well as on two points in each filter bed at 1/3 and 2/3 over the filter length via piezometers installed over the whole filter depth on eight days between May 10 and November 15, 2017 (monthly sampling). The experimental setup of a single filter bed is shown in Figure 1. The following parameters were measured according to Standard (APHA, 2005): COD, BOD_5, NH_3-N, TN and TP, as well as DO.

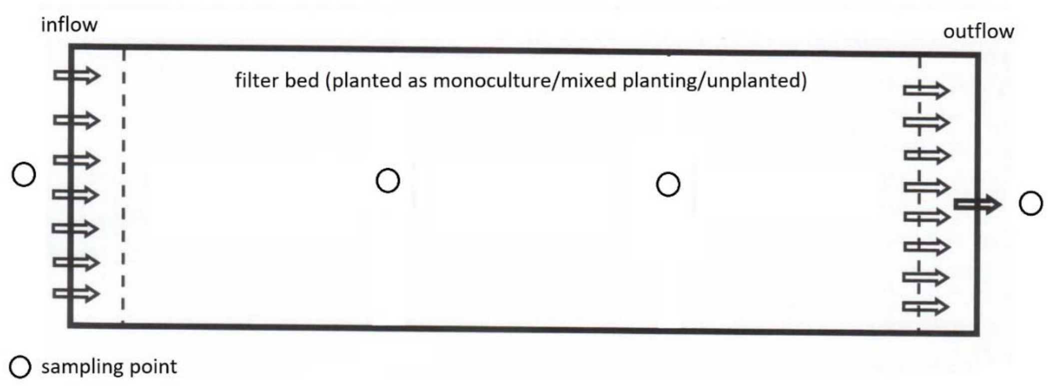

Figure 1: Experimental design of a single filter bed

2.3. Statistical analysis

All results from samples collected at inflow, 1/3 and 2/3 of the filter bed and the outflow were evaluated by summarising the values and the respective treatment efficiencies calculated from single events in boxplots following a Tukey distribution. Pearson correlations between the filter beds with low and high nutrient dosing with the same plant species were sought for the same treatment parameters as well as between the different treatment parameters at single beds.

3. RESULTS

The operation of the pilot scale horizontal flow wetlands was successful and without operational disturbance in year 2 of the trial. The overall removal was positive for the investigated parameters; e.g. inflow values for TN were between 5.6 and 20.7 mg/l and outflow values between 0.2 and 14.5 mg/l (median removal efficiency for unplanted filters 53% and 76% for planted filters). Figure 2 shows the results unplanted filters for both nutrient concentrations and an example for a planted filter as well in both nutrient concentrations (Arundo). The graphs show the concentrations of NH3 at the four sampling points and the removal efficiency calculated from the single events. As already shown in Vincent et al. (2018), the planted filter performed better for the pollutant removal than the unplanted ones. However, the figures show a typical pattern: the concentrations from inflow to the sampling point at 1/3 of the filter length decrease significantly, and a further decrease to the sampling point at 2/3 for Arundo NPK1, but no further decrease to the outflow. This pattern repeats itself for several plant species and analysed parameters.

Regarding the investigated Pearson correlations, no significant ones were found for the sought comparisons. This is also the case for the differences between the monoculture and mixed planted beds.

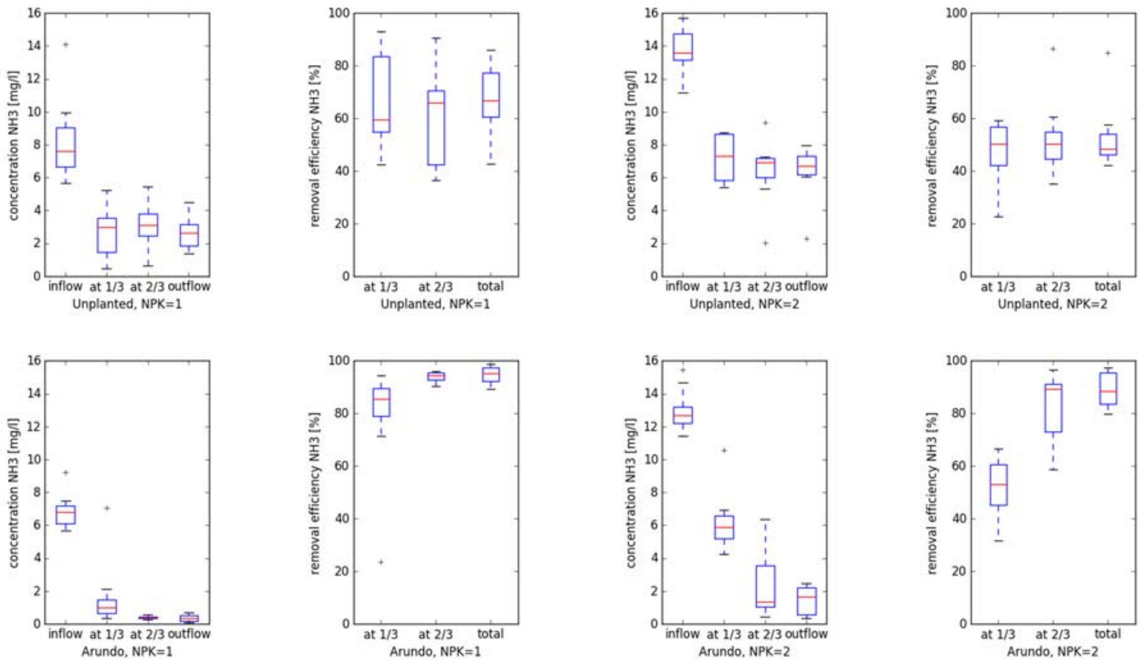

Figure 2: Results for concentrations and removal efficiency along the filter beds: Unplanted – low nutrient concentration (NPK1) and Unplanted – high nutrient concentration (NPK2) (upper row); planted with Arundo – low nutrient concentration (NPK1) and Arundo – high nutrient concentration (NPK2) (lower row) DiScussion

The removal of pollutants from stormwater with low nutrient concentrations can be performed with horizontal flow wetlands over a longer period of time without further disturbances such as clogging. Regarding the lack of correlations between the filter beds, further investigated parameters such as electrical conductivity, the total biomass and the gradient of plant growth should be taken into considerations and different statistical methods such as ANOVA. The limited removal from the sampling point at 2/3 of the filter length and the outflow shows that the total filter length could be reduced by 1/3 in order to make it more cost efficient. However, it needs to be considered if further treatment goals such as reduction of pathogens should be achieved – here, the full filter passage might be necessary to achieve sufficient results. This should be subject to further research.

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