A new design model for vertical flow wetlands

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Highlights:

- a new design model for vertical flow wetlands is presented
- the design model allows predicting COD and NH_4-N outflow concentrations for different filter materials and outflow water temperatures;
- input parameters are those design and operational parameters that have main influence on the treatment performance;
- input parameters include, e.g., granular size of the filter media, organic loading rates, loading intervals, and distribution openings

Keywords: HYDRUS Wetland Module; surrogate model; vertical flow wetland design

INTRODUCTION

Among the various types of Treatment Wetlands (TWs), Vertical Flow (VF) wetlands with intermittent loading are specifically used when nitrification is a requirement. Currently, the design of VF wetlands is based on using rule-of-thumb guidelines (e.g., DWA-A 262E, 2017). However, there is potential to further optimize wetland performance for specific goals, like reducing outlet concentrations or minimizing the surface area requirement per person.

Numerous studies have highlighted the significant impact of design and operational (D&O) parameters on treatment efficiency. For example, Pucher & Langergraber (2019) performed a simulation study on VF wetlands, examining different D&O parameters at temperatures between 5 to 20°C. Their results demonstrated improved COD and NH_4-N removal in VF wetlands using finer filter materials, longer loading intervals (e.g., hourly), or an increased number of openings in the distribution pipe (e.g., 4 holes per square meter). Stefanakis & Tsihrintzis (2012) found that substrate depth plays a crucial role in treatment efficacy, underlining the need for a thorough understanding of substrate depth's impact on VF wetland design.

This study aimed to use results from numerical simulation of VF wetland treatment preformance to develop a predictive model to aid in the design and optimization of VF wetlands that goes beyond existing guidelines.

METHODOLOGY

To carry out this research, the HYDRUS Wetland Module was utilized to simulate the treatment performance of a VF wetland (Langergraber and Šimůnek, 2012). HYDRUS is designed to model water, heat, and solute dynamics in variably saturated media, employing Richards' equation for water flow and the convection-dispersion equation for the transport of heat and solutes. Within a two-dimensional domain, the Wetland Module introduces a biokinetic model to account for transformation and degradation processes conducted by bacteria. The CW2D biokinetic model was selected for use in this study (Langergraber and Šimůnek, 2012).

The numerical experiments comprised combinations of organic loading rates (OLR), different grain sizes of the filter material of the main layer, loading rates and intervals between loadings, the number of openings per square meter in the distribution pipes, water temperatures, and substrate depths (Figure 1). Building on the work of Pucher & Langergraber (2019), this research broadened the scope by incorporating two additional substrate depths (30 and 80 cm). To streamline computing time and due to their marginal informative value, two operational configurations were omitted from this study: a loading interval of 3 hours and a distribution pipe configuration with 4 openings per m^2. A full factorial sampling has been chosen for this numerical experiment.

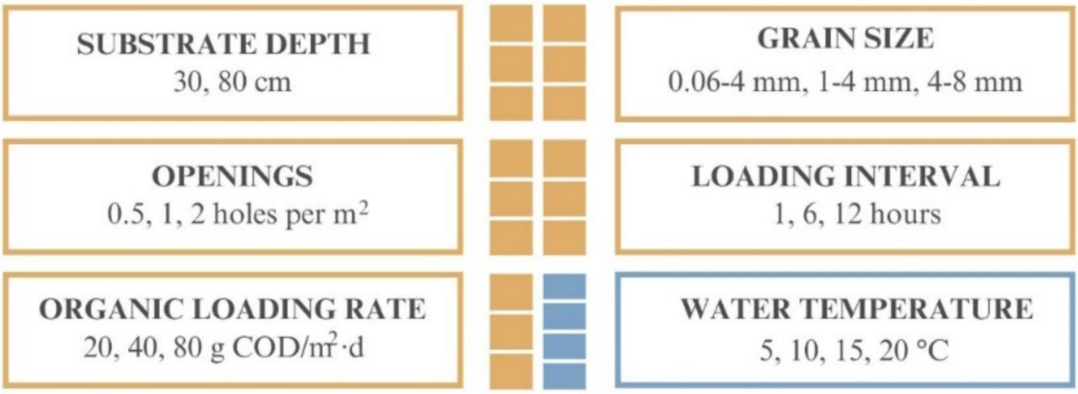

Figure 1. Operational and design parameters (in yellow), and water temperature (in blue) considered in the simulation study.

The development of a design equation from the modeling results involved fitting a second-order quadratic model that encompasses linear, quadratic, and cross-product terms. The model coefficients were determined using the response surface method, applied via the R package 'rsm' (Lenth, 2009). At this stage, the parameter values for the equation were determined individually for each granular size (0.06-4mm, 1-4mm and 4-8mm). The independent variables comprised in the design equation are those parameters shown in Figure 1.

$$C_{outflow} = f(Temp, Openings, Depth, Interval, OLR, Openings) \tag{1}$$

where: $C_{outflow} =$ COD or NH_4-N outflow concentration, mg/L

$Temp =$ Outflow water temperature, °C

$OLR =$ Organic loading rate, g COD/m².d
$Openings =$ Openings in distribution pipes per m², openings per m²
$Depth =$ Depth of the main layer, cm
$Interval =$ Loading interval, h

RESULTS AND CONCLUSIONS

A total of 1224 numerical experiments were conducted using a calibrated model of a VF wetland. These simulations provided a comprehensive understanding of the effects that variations in D&O parameters have on the treatment performance (Pucher & Langergraber, 2019). By incorporating simulation runs that varied the filter depth, a more precise dataset was created, facilitating the development of a surrogate model for design purposes.

The fitting of the design equation for each granular size under investigation yielded a total of 21 coefficients. The surrogate model's predictions for the COD effluent concentration of a VF wetland are presented in Figure 2.

In the next steps the developed surrogate model will be tested on available experimental data and further investigated for a global application including the variation of the grainsize in one parameter set.

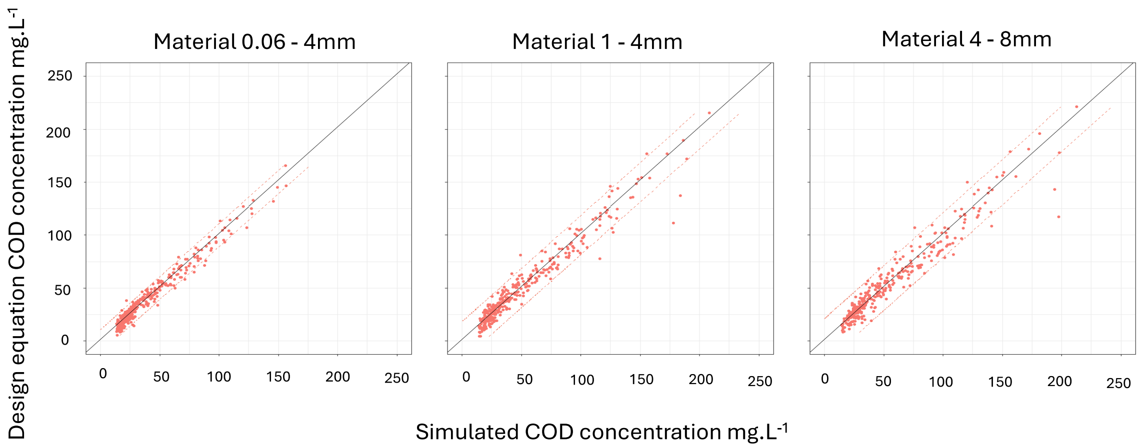

Figure 2. Design model predictions vs. simulated COD outflow concentration for each investigated filter material. The dashed lines represent to upper and lower prediction interval.

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