Influence of the drainage network on flow patterns within a treatment wetland: the case study of the Life ADSORB project

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Abstract
Two 600 m² experimental treatment wetlands (TWs) designed within the Life ADSORB project in Paris (France) for the treatment of road runoff are considered. The first objective of this study was to develop an analogous hydraulic model to calculate flow rates and pressure head in drainage networks to determine if the length of TW drainage systems affected water flows. Secondly, this model was implemented to adjust the flow at each node (slot) of the lower boundary condition and at each time step according to the pressure at the considered node, in a 2D model developed with COMSOL Multiphysics® representing the TWs. The results of the analogous model indicated that at constant load in the TWs the flow was not equally distributed between the slots. The modeling results allowed to observe the influence of the drainage network on the flow patterns within the TW.

Keywords
Analogous hydraulic model; drainage network; mechanistic modelling; pressure head; water flow

INTRODUCTION

Urban runoff, and especially runoff from heavily trafficked road, is a major contributor to non-point source pollution due to its important loading with metals, suspended solids, hydrocarbons and other toxic compounds (phthalates, alkylphenols, perfluorinated compounds, etc.). The Life ADSORB project aims to evaluate the performances of two treatment wetlands (TWs) for the treatment of road runoff, mixed with occasional combined sewer overflow, focusing on both the particulate and dissolved phases. The full scale TWs implemented in the project follows the French design and is divided into 2 cells in parallels, one with a conventional design and a second one with an additional specific adsorption substrate layer. These treatment wetlands have a saturated layer at the bottom with a drainage network connected to a throttle outflow ensuring a minimum hydraulic residence time and infiltration rate during rain events. Most of the time when modelling this type of TW, conventional models assume that flows in drains are not limiting (Pálfy et al., 2016). Thus, the head losses induced by the drainage networks are considered negligible. However, depending on their design, drains and drainage networks may influence the distribution of flow within the TWs and those entering the drainage pipes, e.g.: significant linear head-losses may develop in an undersized drainage network, resulting in more water entering the slots downstream than upstream. Thus, the assumption of the usual models is not adapted.

The overall objective of mechanistic modelling in the Life ADSORB project is to better understand and identify the mechanisms taking place in the TWs. It will then be possible to identify the parameters influencing the water flow, the transport and the fate of micropollutants. In this study, using numerical modelling, we aim to evaluate the impact of the drainage network design on flow patterns within the treatment wetland.

THE LIFE ADSORB TREATMENT WETLANDS

The studied system consists in two 600 m² treatment wetlands (TWs) situated in the Bois de Boulogne park (Paris, France). Each one was designed for the treatment of runoff water and more particularly for the treatment of selected metallic and organic micropollutants. These two pilots are similar in terms of configuration (100 m long, 1 m deep) and operated with equal feeding period (alternation every month). The only difference between the two being the composition of the filtering layer, which for one (TW1) consists only of sand (40 cm) while for the other (TW2) a specific layer of adsorbent material specific for micropollutants removal (Rainclean®, 20 cm) is located between two layers of sand (10 cm each). A 10 cm transition layer and a 50 cm drainage layer are present in both TWs. There is only one feeding point per TW, at one extremity of each and the treated water outlet is located at the opposite. A throttle outflow located 30 cm above the bottom of each TW maintains a saturated layer and controls the outlet flow rate to not exceed 20 L/s when the TW is fully saturated.

The drainage system

Figure 1 shows the drainage networks of the two Life ADSORB treatment wetlands.

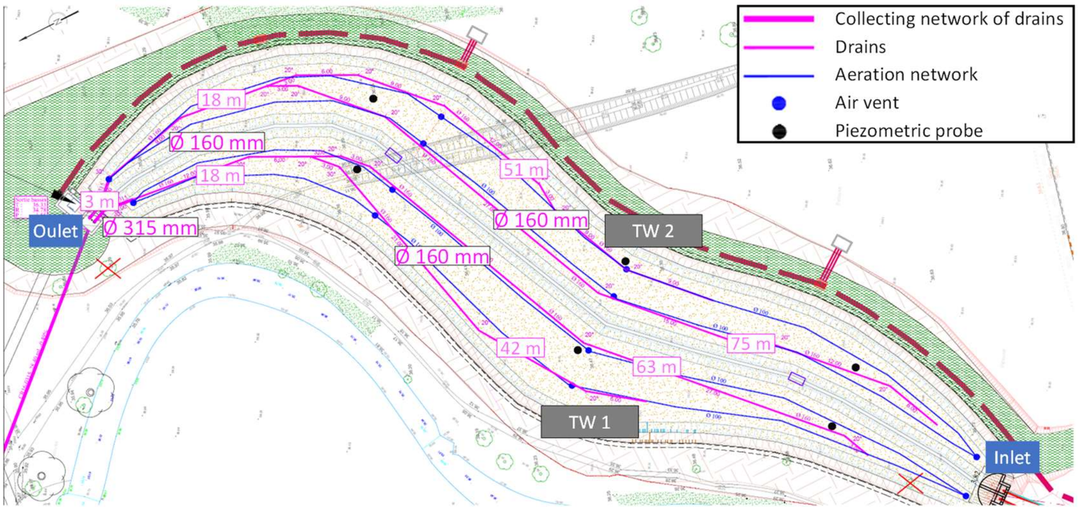

Figure 1. Drainage system of the Life ADSORB treatment wetlands.

The drainage network of each TW is made of 160 mm diameter pipes and is distributed as follows (Figure 1): two parallel branches with a cumulative length of 105 and 126 meters for TW1 and TW2, respectively, merging downstream to a main branch of 18 meters in length. The last 3 meters of the drainage network are made of a 315 mm in diameter pipe on which the outlet valve is mounted. The slots allowing the collection of the water along the drainage pipes are oriented upwards and are present along the whole length of the 160 mm diameter drains. They are 10 mm wide and spaced every 120 mm (8 slots/m, in total, 946 and 1107 for TW1 and TW2, respectively).

THE ANALOGOUS HYDRAULIC MODEL

An analogous hydraulic model was developed to evaluate the influence of the drainage network design on the spatial distribution of the flow entering the slots in the saturated layer.

Procedure

The following approach was followed:

1. Preliminary calculation of the linear head losses. The linear head losses were first estimated for a range of water flows. Since these linear head losses were not negligible, the distribution of flow passing through the slots along the drainage pipes cannot be considered regular.

2. Calculation of the coefficient of singular head loss associated with a slot of the drains. A 3D model of a slot of the drainage network was created using COMSOL Multiphysics®, and used to calculate the associated singular head loss coefficient by solving the Navier-Stockes equation for the drain domain and the Brinkmann equation for the porous medium.

3. Calculation of flow and pressure head in the drainage system. The calculation of the total head losses and the flow rate along the drainage network, for a given longitudinal distribution of the pressure head in the TW (P_{init}), was carried out according to the approach presented in Figure 2.

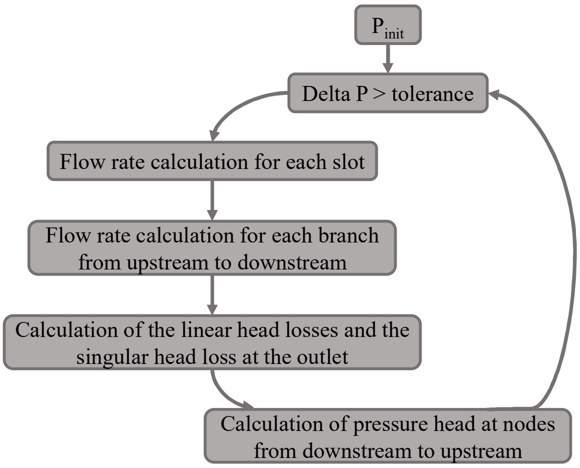

Figure 2. Approach used to calculate the pressure head at each slot and the flow through the slots and the drainage pipes. P_{init}: pressure head in the TWs. Tolerance set at 1.10^{-3}.

The calculation loop presented in Figure 2 was performed for each TW, their drainage networks and their associated number of slots for each branch. We created abacus for the case of a constant water height (P_{init}) along the TWs with values ranging from 0.4 m to 1 m.

THE FILTER MODEL

A 2D numerical model of the TWs including a specific boundary condition for the outlet was created with COMSOL Multiphysics®. It consisted of a longitudinal cross-section of the two TWs.

A surface overflow was simulated at the inlet by creating a runoff layer with a porosity of 1 and a hydraulic conductivity dependent on the water height in the layer. For the outlet, the link was made between the drain model developed above and the COMSOL Multiphysics® model using MATLAB® Livelink™ to adjust the flow rate at each node of the lower boundary that corresponds to a slot by applying a sink term. Its value was updated at each time step according to the pressure head at the considered node in order to compute the flow rates along the whole drainage network (for each slot).

RESULTS

The analogous hydraulic model

The obtained modelling results of the flows through each slot of the TW1 drainage networks are presented in Figure 3. Regardless of the simulated pressure head in the TW, the greater the distance between the slots and the outlet, the greater the pressure head losses (results not shown) and the decrease in flow through the slots. From 63.2 m of drain for TW1 for a simulated pressure head of

0.4 m, this flow was even null. Thus, for TW1 the proportion of useless drain (for which no water passes through the slots) was 14 % for a simulated pressure head of 0.4 m. Conversely, the flow through the slots increased as the distance to the outlet decreased. In addition, the head losses were greatest in the main branch of both drainage networks (results not shown); therefore, the decrease in flow passing between two slots in this branch was greater than that simulated between two slots in the two parallel branches (Figure 3). For a simulated pressure head of 0.4 m in TW1, the calculated pressures at the first and last slots of the drainage network were 0.40 m and 0.38 m, respectively, while they were 1.00 m and 0.89 m for a simulated pressure head of 1 m.

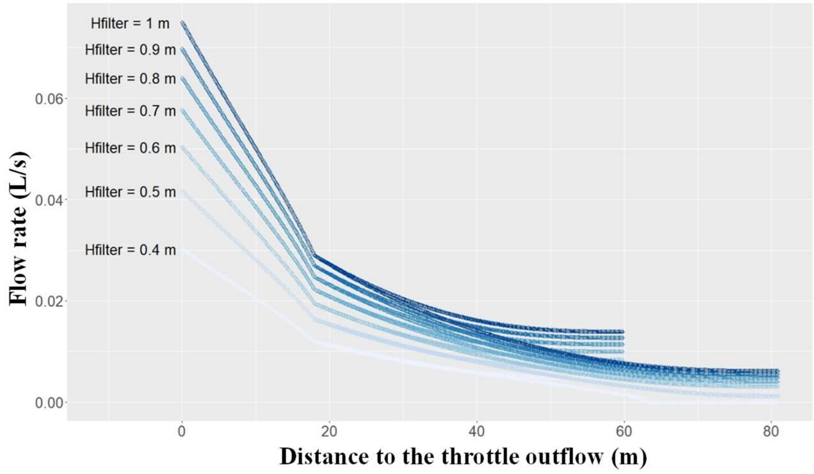

Figure 3. Abacus of the distribution of simulated flows at each slot in the drainage network as a function of its distance from the outlet for different water depths in TW1.

The filter model

Full 2D TW modeling (COMSOL Multiphysics®) with this hydraulic model as the low boundary condition is in progress and will be presented at the conference.

CONCLUSION

The analog numerical model created during this study allowed the evaluation of the linear and singular head losses as well as the flows passing through the slots of the drainage networks for several water heights in the TW of the Life ADSORB site. The drainage network design strongly affects the flow patterns within the porous media and therefore the treatment efficiency. Techniques to optimize the drainage network design could be derived from the methodology presented in this article (abacus, surrogate models) to wide spread their usage. The numerical model developed during this project will be generalized and used as a tool for the design and verification of drainage networks in saturated TWs.

REFERENCE

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