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Improved design and optimization of subsurface flow constructed wetlands and sand filters

A. Brovelli, O. Carranza-Díaz, L. Rossi, and D.A. Barry

Institut d'ingénierie de l'environnement, Ecole Politechnique Fédérale de Lausanne, Lausanne, Switzerland (alessandro.brovelli@epfl.ch)

Subsurface flow constructed wetlands and sand filters are engineered systems capable of eliminating a wide range of pollutants from wastewater. These devices are easy to operate, flexible and have low maintenance costs. For these reasons, they are particularly suitable for small settlements and isolated farms and their use has substantially increased in the last 15 years. Furthermore, they are also becoming used as a tertiary – polishing – step in traditional treatment plants. Recent work observed that research is however still necessary to understand better the biogeochemical processes occurring in the porous substrate, their mutual interactions and feedbacks, and ultimately to identify the optimal conditions to degrade or remove from the wastewater both traditional and anthropogenic recalcitrant pollutants, such as hydrocarbons, pharmaceuticals, personal care products.

Optimal pollutant elimination is achieved if the contact time between microbial biomass and the contaminated water is sufficiently long. The contact time depends on the hydraulic residence time distribution (HRTD) and is controlled by the hydrodynamic properties of the system. Previous reports noted that poor hydrodynamic behaviour is frequent, with water flowing mainly through preferential paths resulting in a broad HRTD. In such systems the flow rate must be decreased to allow a sufficient proportion of the wastewater to experience the minimum residence time. The pollutant removal efficiency can therefore be significantly reduced, potentially leading to the failure of the system. The aim of this work was to analyse the effect of the heterogeneous distribution of the hydraulic properties of the porous substrate on the HRTD and treatment efficiency, and to develop an improved design methodology to reduce the risk of system failure and to optimize existing systems showing poor hydrodynamics.

Numerical modelling was used to evaluate the effect of substrate heterogeneity on the breakthrough curves of both a conservative tracer and a reactive organic compound. Random, spatially correlated hydraulic conductivity fields following a log-normal distribution were generated to represent the heterogeneous distribution of the hydraulic properties. The effect of the variance of the hydraulic conductivity distribution, as well as the aspect ratio of the correlation lengths were analyzed and compared to experimental findings.

The proposed design methodology is based on the target hydraulic residence time, that is, the residence time required to achieve the degradation of the contaminants. The effect of the heterogeneity is accounted for using a Monte Carlo approach. From the analysis of the simulation results the probability of failure of the system can be estimated and used to design a new system or optimize existing systems. The methodology was illustrated using a realistic test case with water contaminated with benzene.