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Influence of substrate heterogeneity on the hydraulic residence time and removal efficiency of horizontal subsurface flow constructed wetlands

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Horizontal, subsurface flow constructed wetlands are wastewater treatment devices. The influent polluted water flows through a porous substrate where the contaminants are removed, for example by microbial oxidation, surface adsorption and mineral precipitation. These systems are widely used with varying degrees of success to treat municipal and agricultural contaminated waters and remove the organic carbon and nutrient load. Constructed wetlands are an appealing and promising technology, because they (i) are potentially very efficient in removing the pollutants, (ii) require only a small external energy input and (iii) require low maintenance. However, practical experience has shown that the observed purification rate is highly variable and is often much smaller than expected. One of the numerous reasons proposed to explain the variable efficiency of constructed wetlands is the existence of highly conductive zones within the porous substrate, which produce a dramatic reduction of the hydraulic residence time and therefore directly decreases the overall water purification rate.

This work aims to understand quantitatively the relationship between the spatial variability in the hydraulic properties of the substrate and the effective residence time in constructed wetlands. We conducted two suites of stochastic numerical simulations, modelling the transport of a conservative tracer in a three-dimensional simulated constructed wetland in one case, and the microbial oxidation of a carbon source in the other. Within each group of simulations, different hydraulic conductivity fields were tested. These were based on a log-normal, spatially correlated random field (with exponential spatial correlation). The amount of heterogeneity was varied by changing the variance correlation length in the three directions. For each set of parameters, different realizations are considered to deduce both the expected residence time for a certain amount of heterogeneity, and its range of variation. We found a clear relationship between the extent of heterogeneity and both the residence time decrease and its variability. These results provide a design aid for the optimal design of new constructed wetlands or for retrofitting old systems.