Abstract

Nature-based solutions, such as bioretention systems, are in growing use for resilient urban runoff management. A bioretention system includes a vegetated depression to collect and infiltrate runoff, a substrate to provide water filtration and retention/evapotranspiration, and optionally a transition, drainage or storage layer. Bioretention can control runoff volume, delay flow peaks and enhance evapotranspiration (ET), thereby contributing to a more natural local water balance. However, its hydrological performance is likely to vary, depending on system design and local context. The objectives of this research are: i) to elucidate the impacts of various bioretention design characteristics on their hydrological functioning, with a special focus on cases with low exfiltration potential and under an oceanic climate, typically corresponding to the conditions found around Paris; and ii) to assess the reliability and robustness of HYDRUS-1D model in representing different designs and input parameters.

Through a thorough literature review, this research began with a comprehensive overview of bioretention designs, experimental setups and modelling approaches considered in previous studies. The analysis also highlighted the following knowledge gaps: 1) underrepresentation of some local contexts and designs; 2) limited studies on long-term water balance monitoring; and 3) insufficient investigation on subsoil and shallow groundwater interactions.

The PhD relied on continuous monitoring of three bioretention prototypes in Paris region and on field investigations to explore the efficiency of runoff volume reduction under unfavourable subsoil conditions (e.g., limited or forbidden exfiltration), the relative importance of different hydrologic processes and ways to enhance them. The field conditions include: 1) An unlined system with a relatively high hydraulic loading ratio (HLR) of 13over clay soil, examining how IWS may enhance exfiltration; 2) Two lined systems, assessing whether a combination of low HLR (i.e.4), fine-textured substrate and IWS can enhance ET and act as a primary mechanism for volume reduction.

Overall, the three systems achieved significant runoff volume reduction over the monitoring period (43% for JdB1, 48% for JdB2, 63% for SC), despite the lack of exfiltration or low permeability of the subsoil. For the unlined system, the volume reduction performance was largely controlled by the thickness of the IWS (extending IWS from 2 cm to 22 cm increased volume reduction from 27% to 55%). For the lined systems, it is controlled by ET, which was more than doubled in presence of an IWS. In the unlined system, a capillary barrier between the transition and drainage layers promoted soil water retention, yet ET remained lower than potential evapotranspiration (PET). Silt loam substrate in the lined systems supported vegetation but led to clogging and cracking issues which were mitigated by the IWS. A risk of water intrusion from perched lens was also identified when the bottom of the bioretention is connected to a low permeability subsoil.

The final part of this research involved an evaluation of HYDRUS-1D for bioretention modelling. A sensitivity analysis assessed how varying levels of input knowledge impact the model robustness. The results on water balance, especially drainage volume, proved to be robust and accurate and were not significantly affected by uncertainties in input parameters. However, the soil moisture profile results were highly dependent on the bottom boundary condition and, to a lesser extent, on soil hydrodynamic properties. Neither of the two tested boundary conditions allowed for a good description of soil moisture, indicating that the model could not adequately capture the hydraulic behaviour of the system. Besides, for a HLR of 13, vegetation properties had a very limited impact on the water balance.

Key words: infiltration, evapotranspiration, monitoring, modelling, urban runoff, bioretention