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Instrumentation and modelling of stormwater trees to determine their hydrological performance in a future climate

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Abstract

Stormwater trees are nature-based solutions for stormwater management. Often, the infiltration capacity of existing roadside trees is improved to increase collection of runoff from neighbouring streets and sidewalks. Stormwater trees are considered as a pertinent stormwater control measure in highly urbanised areas, but the contribution of the tree (evapotranspiration) to the water balance remains unclear due to measurement challenges. This extended abstract presents preliminary data from a starting PhD project, aimed at continuously monitoring five stormwater trees and two control trees for water level in an infiltration trench, soil water content and matric potential in the tree pit, and sap flow to characterize the water balance. The seven trees have been progressively equipped since December 2024, with the latest equipped in June 2025. By the conference, several months of data from all trees will be available. This data will be used to calibrate a stormwater tree model in HYDRUS, with a preliminary version to be presented at the conference. A later objective is to assess the hydrological performance of stormwater in future climates using downscaled climatic projections.

Highlights

- Several months of continuous monitoring of water balance of stormwater trees
- Modelling of the water balance of a tree on isolated rainfall events in HYDRUS 1D.

Introduction

Decentralized stormwater control measures (SCMs) are used to reduce runoff induced by rainfall on impervious surfaces. They contribute to flood risk mitigation, natural hydrology restoration, and water pollution reduction (Walsh *et al.*, 2016).

Among SCMs, stormwater trees lack so far a clear definition in literature, and there is no common terminology among articles. Indeed, trees can be used to manage stormwater in a variety of designs, which leads to different terminologies (Richter *et al.*, 2024). Different from roadside trees, in this abstract we define stormwater trees as existing street trees, retrofitted to receive runoff from the surrounding impervious areas (road, pavement), a local definition used by practitioners in the metropolis of Lyon, France, where this study is located.

Design suggestions point towards growing them in large pits, with a system to catchment area ratio around 5% (Grey *et al.*, 2018b; Thom *et al.*, 2020). They need a facilitated access for stormwater to enter the system (inlet, trench, etc.), along with regular maintenance to avoid clogging (Szota *et al.*,

2019). In low permittivity soils, stormwater trees must be equipped with an underdrain (Hanley *et al.*, 2024) or with structural soil (Ow and Chan, 2021) to avoid waterlogging, which reduces tree growth and transpiration and may lead to plant death (Grey *et al.*, 2018a).

Although using trees for stormwater management is not new, there is little quantitative/experimental data for these systems. Thom *et al.* (2020) attempted to measure the impact of the tree on the water balance of stormwater trees, by measuring tree transpiration through sap flow sensors installed on the stem. Transpiration represented on average 71% of the water entering the system, though only a small fraction (24%) of annual runoff did enter the tree pit due to inlet clogging issues.

Hence, the first objective of this study is to improve our knowledge of the water balance of stormwater trees through exhaustive monitoring and mechanistic numerical modelling with HYDRUS. The second objective is to determine the hydrological performance of stormwater trees in future climatic conditions. This abstract presents the monitoring setup, the first experimental results, and the planned modelling approach.

Methodology

The experiment is carried out in an urban street located in the densely populated city centre of Lyon (France), which contains five stormwater trees and two roadside trees (controls) (Figure 1). The stormwater trees were retrofitted in 2022 by equipping roadside trees of approx. 30 years old (Crimean linden, *Tilia euchlora*) with an infiltration trench with dimensions $0.6\text{m} \times 0.6\text{m} \times [3.08\text{--}5.16]\text{m}$ to facilitate capturing runoff from the street (Métropole de Lyon, 2022). Their pits were also enlarged to $10\text{--}16\text{m}^2$, by removing concrete, and the top 0.5 m urban soil layer was replaced by vegetal topsoil. The impervious watershed connected to the five stormwater trees has a surface of 665m^2 , resulting in an average 10.6% system to catchment area ratio.



Figure 1. Study site. Left: Stormwater Trees. Right: Stormwater tree's infiltration trench during a rainfall event. Bottom: schematic top view of the site.

The monitoring setup is presented in Figure 2. Each stormwater tree has been equipped with six soil water content probes (capacitance based, TEROS 10 & TEROS 11 from METER), at two positions and three depths (Figure 2, left panel), to measure the 2D repartition of soil moisture in these asymmetrical SCMs, as well as a sap flow sensor (dual method, SFM-5 from UGT) on the trunk to estimate tree transpiration. Two stormwater trees have been equipped with a piezometer in the infiltration trench to measure its water level, and six matric potential sensors in the same place as the water content probes. Each of the two control trees has been equipped with three soil water content probes at one position and three depths, and a sap flow sensor. A weather station has been installed on the roof of a nearby building to measure local rainfall and meteorological conditions.

The mechanistic HYDRUS model was employed to simulate the hydrologic behaviour of stormwater trees, aiming to identify governing processes, estimate associated parameters, and quantify the unmeasured components of the water balance. A preliminary model using HYDRUS-1D was calibrated via inverse modelling with data from control tree 1. Soil hydraulic properties based on the (Van Genuchten, 1980) retention curve—specifically θ_r , θ_s , α , n , and K_s —were optimized using a least squares objective function. The 70 cm soil profile was modelled as two distinct layers, 30 cm and 40 cm deep, based on field observations, resulting in the calibration of 10 parameters (5 per layer).

Once the models validated with data from the experimental setup, downscaled climatic projections of rainfall, temperature, and evapotranspiration (Pons *et al.*, 2022) will be used to assess the performance of stormwater trees under future climate scenarios.

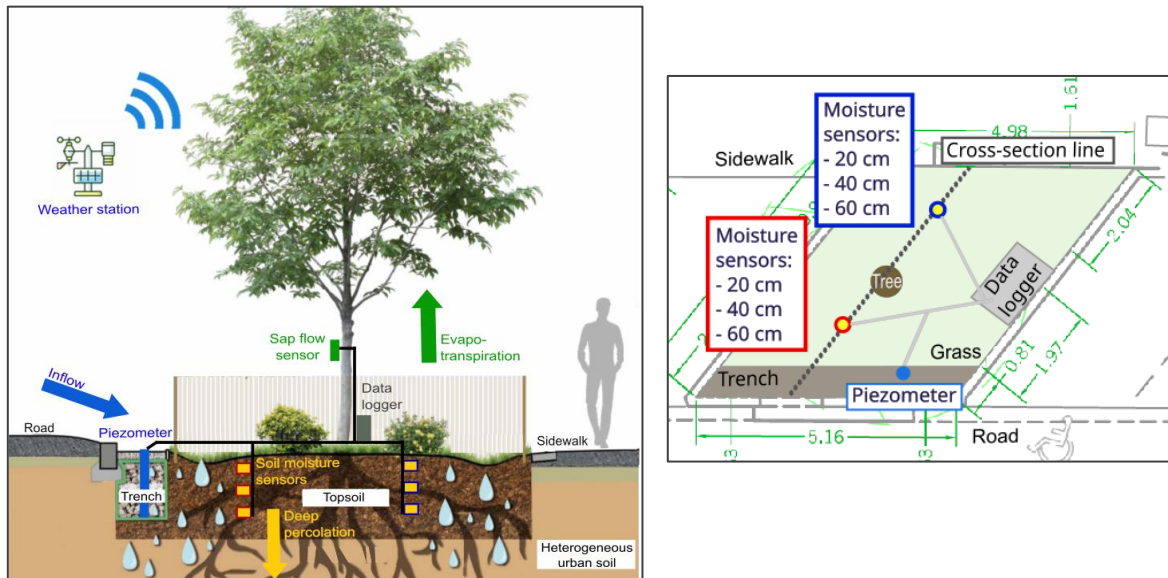


Figure 2. Experimental setup. Left: cross-section, adapted from Métropole de Lyon – technical guide. Right: top view.

Preliminary results

Figure 3 below presents measured data on stormwater tree 3 and a preliminary HYDRUS simulation on control tree 1.

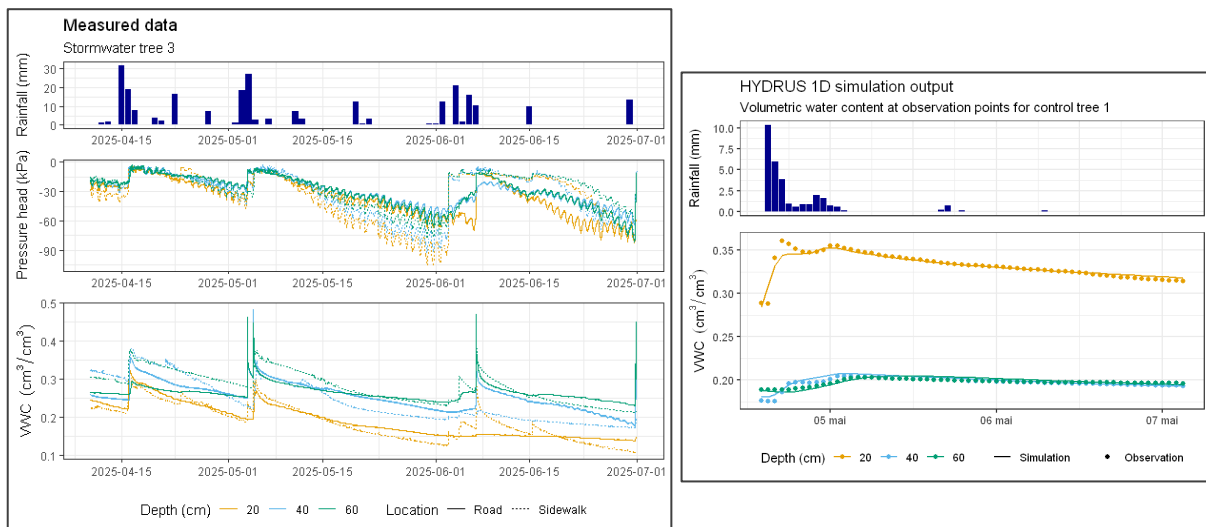


Figure 3. Left: Measured data from stormwater tree 3. Right: Preliminary model on HYDRUS 1D for the control tree 1 on one rainfall event.

Temporal evolution of soil volumetric water content (VWC) and pressure head are overall coherent with rainfall measurements on the site. Soil VWC ranges from 0.1 to 0.5, and soil pressure head ranges from 0 to -100 kPa, which are commonly observed ranges. Soil VWC and pressure head show different behaviours depending on their location and depth. The infiltration trench being located on the *Road* side and being 60 cm deep, we observe that the closest sensor (*Road – 60 cm*) has the largest reactions during rainfall events. Sensors at the surface are the most sensitive to evaporation and thus show a faster desiccation rate. These results indicate that a 2D HYDRUS model will be necessary to represent the hydrological processes occurring in stormwater trees.

The HYDRUS 1D model has been calibrated with inverse modelling on the control tree 1. We are able to reproduce a trend in soil VWC for a single rainfall event, by considering two distinct soil profiles.

Conclusions and perspectives

The experimental setup has been mostly installed to assess the water balance of stormwater trees, and it shows encouraging results regarding the feasibility of the study. We will present a comparative analysis during the conference, based on several months of data. Later, we will develop models on HYDRUS 1D and 2D to evaluate the hydrological performance of control and stormwater trees under future climate conditions. We hope this analysis will help to optimize future designs of stormwater trees.

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