Monitoring bioretention cell performance: A large-scale lysimeter study

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Highlights

- Pilot-scale lysimeters have been instrumented to monitor the hydrological effectiveness of SuDS
- Runoff simulator and dense sensor network provide real-time open-source data
- Evapotranspiration (ET) rates of different vegetation planting styles and outflow control device effects on SuDS performance have been established

Introduction

Sustainable Drainage Systems (SuDS) are a widely adopted approach for managing excess urban runoff by intercepting, retaining and attenuating the flow of water through the built environment, playing a key role in reducing urban flood risk (Berretta *et al.* 2018). Vegetated bioretention cells (alternatively referred to as 'rain gardens') are one of the most simple, practical and commonly implemented of SuDS options and can be easily retrofitted into urban spaces to deal with surface water from paved areas. Although current UK and international guidance provide design recommendations for SuDS devices (*e.g.* Australian Government, 2015; Woods-Ballard *et al.*, 2015), further quantitative indicators of hydrological performance based on monitored systems are required. The aim of this study is to provide an evidence base on the effectiveness of such systems to support the optimal implementation of vegetated bioretention cells for stormwater management. This paper presents the methodological approach using a series of large-scale lysimeter experiments based at the UKCRIC National Green Infrastructure Facility (NGIF), Newcastle University, UK. Lysimeter experiments were designed to provide long-term monitoring data of key hydrological variables to demonstrate the capacity and effectiveness of bioretention systems and improve future management and design.

Methodology

Four purpose built lysimeters (2.0 × 2.0 m, 1.2 m deep) were designed to provide pilot-scale simulation of bioretention cells under natural and simulated weather conditions (see Figure 1a). Each lysimeter was vegetated with different SuDS planting styles (bare earth, amenity grass and mono-cropped *Iris Sibirica* and *Deschampsia Goldtau*) to explore the influence of different vegetation types on lysimeter water balance and actual evapotranspiration (ET) rates. Each lysimeter was split into two 1.0 × 2.0 m hydrologically isolated cells to provide independent drainage conditions. One cell in each lysimeter cell pair featured an unrestricted outfall allowing free drainage whilst the other cell was fitted with an orifice restriction device to maximise soil water retention and attenuate drainage rates.

Substrates and growing media

The lysimeter cells are filled with an engineered soil profile based on international SuDS design specifications (see Figure 1b) and consist of: *(i)* a surface growing media to sustain vegetation and store/attenuate precipitation and inflows; *(ii)* a 2 – 6 mm fine gravel transition layer to prevent the migration of fines into; *(iii)* a coarse 4 – 40 mm gravel base layer to allow free-drainage. The profile is under-drained using 60 mm perforated land drain pipework within the coarse gravel layer to direct drainage towards the gauged outflow. Details and videos on lysimeter commissioning are available via the QR code shown in Figure 1b.

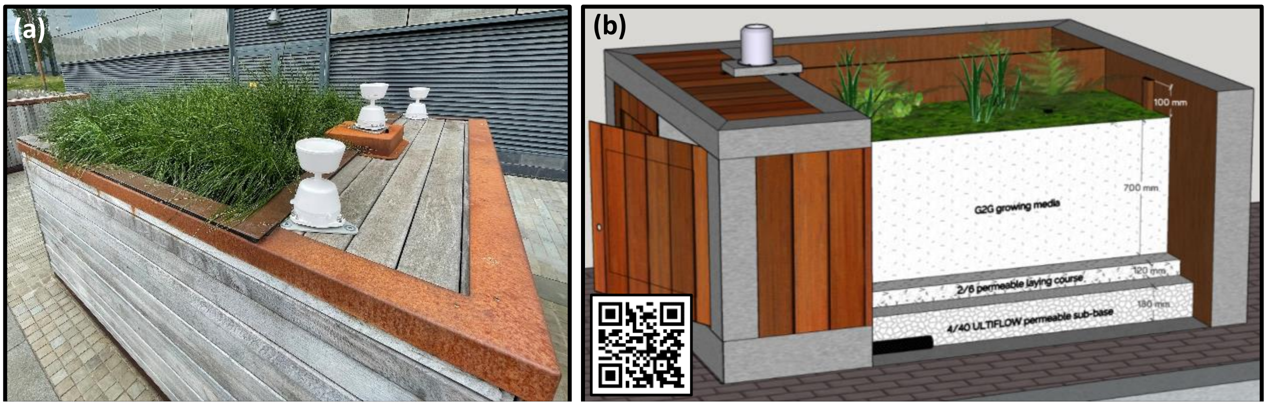

Figure 1: (a) Lysimeter bioretention cell, vegetated with mono-cropped shrub species *Deschampsia Goldtau*; **(b)** Soil profile and aggregate depths of lysimeter setups. The QR code links to the NGIF portal, where videos on lysimeter commissioning and setup can be viewed and data from the NGIF lysimeters can be viewed in real time: http://www.linktr.ee/NGIF_UK.

Instrumentation

Each lysimeter is equipped with a tipping bucket rain gauge to quantify plot precipitation (inflows). Outflow from the drainage layer of each lysimeter cell is measured using a 100 ml tipping bucket gauge. A dense network of soil sensors exist throughout the substrate profile at various depths (see Figure 2) to record soil-specific parameters including volumetric water content, soil temperature, electrical conductivity, soil-water potential and hydrostatic water level at high temporal (< 5 minute) resolution. These enable soil-atmosphere interactions to be observed over time to determine long-term seasonal trends or changes associated with shorter event-based storm conditions, as well as any losses in performance associated with ageing. Field data is analysed in the context of an on-site weather station measuring key meteorological parameters (*e.g.* wind speed, air temperature, solar radiation, relative humidity) to enable Penman-Monteith estimated ET to be calculated for different vegetation scenarios. By combining rainfall, drainage and estimated ET, lysimeter water balances are established to determine the hydrological effectiveness of the bioretention systems. Details of the lysimeter sensor networks are provided in Figure 2.

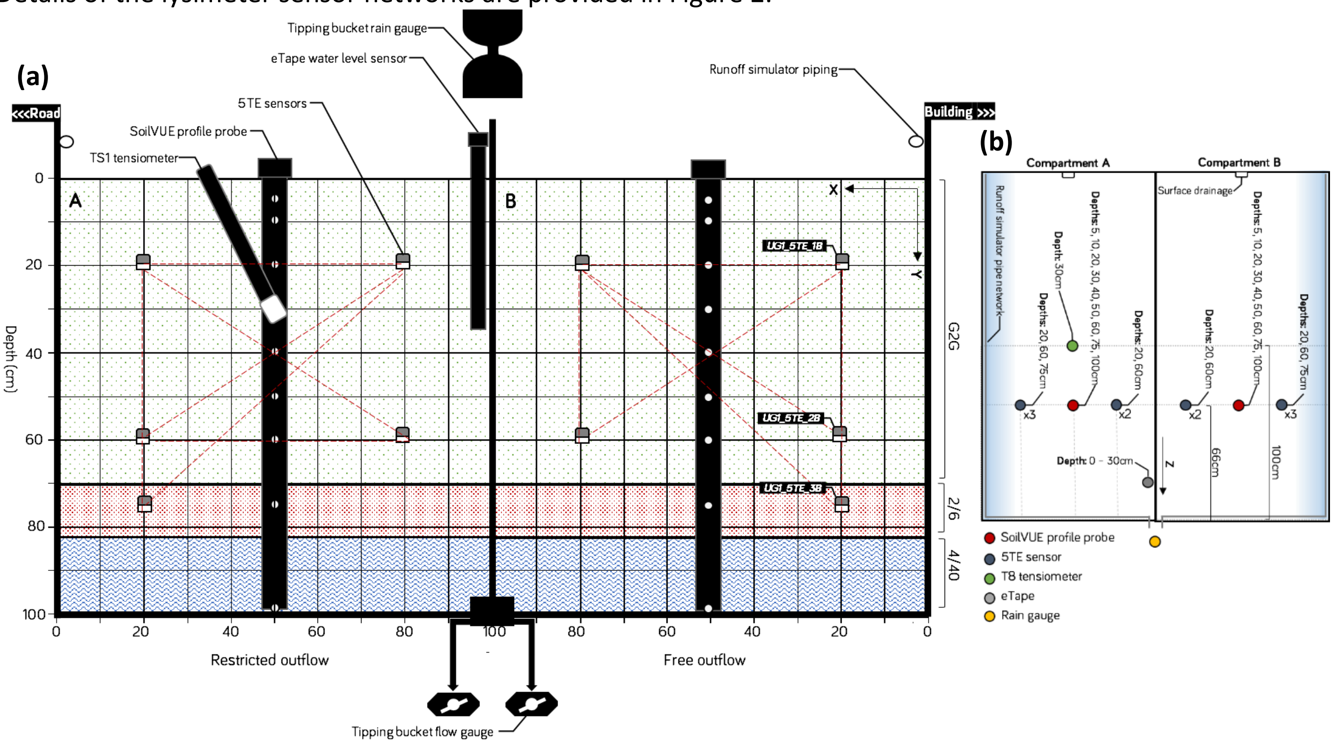

Figure 2: (a) cross section of instrumentation within the lysimeters, showing Cell A (restricted with an outflow control device to attenuate and slow outflow discharge) and Cell B (free drainage); **(b)** plan view of instrumentation spatial layout within lysimeter.

Runoff simulator

As well as operating under natural weather conditions, a runoff simulator setup was established to simulate high intensity storm events and to subject the lysimeters to artificial runoff conditions. The runoff simulator was interfaced with real-time rain gauge measurements to augment weather conditions and to account for runoff rates from pre-prescribed catchment areas and was used to simulate typical design storm events beyond the observation period.

Results and discussion

The monitored bioretention systems at NGIF allow an extensive environmental dataset for evaluating SuDS performance in the context of natural and simulated weather events under diverse boundary conditions (*i.e.* differences in planting styles, restricted outflow scenarios). Results will be presented for a year long period (August 2020 – August 2021), highlighting the hydrological performance of the lysimeters under a range of natural storm events and under artificially produced runoff simulator conditions. A snapshot of data from the lysimeter setups is presented in Figure 3.

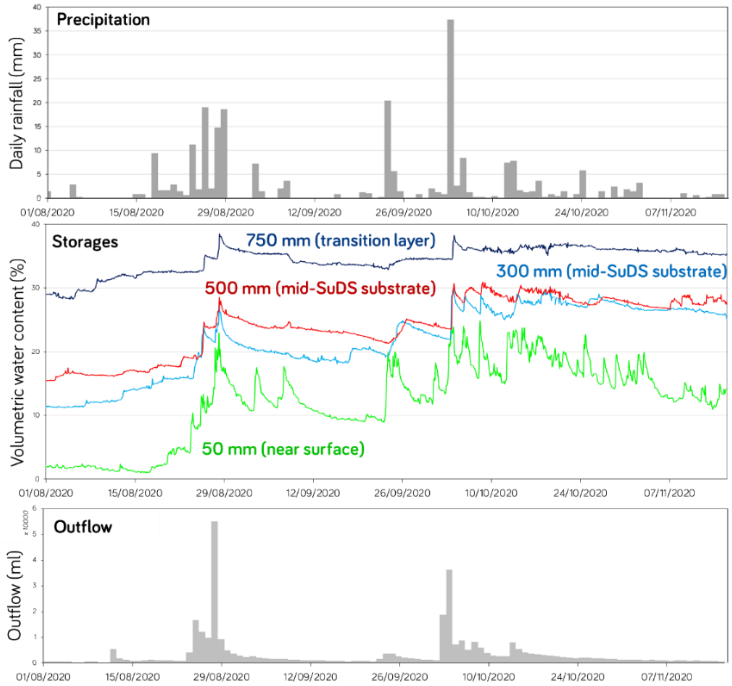

Figure 3: (a) aggregated data from the unrestricted outflow (Cell B) shrubbed lysimeter (*Deschampsia Goldtau, tufted hairgrass)* showing hydrological data trends through soil profile following rainfall events of varying magnitude.

All data from the NGIF is freely available in real-time from the NGIF data app, which can be accessed via the QR code in Figure 1b. The lysimeters presented within this study are coded as NGIF Lysimeters 3 (bare earth), 4 (amenity grass), 7 (*Iris Sibirica)* and 8 (*Deschampsia Goldtau*) on the NGIF data app. Weather and ET estimations data is collected from the weather station at Lysimeter 6.

Conclusions and future work

The commissioning, monitoring and preliminary data analysis of a large-scale lysimeter study being conducted at the NGIF(UK) is presented. Ongoing monitoring is enabling the hydrological performance of bioretention cells to be assessed under a range of rainfall conditions (both natural and simulated extreme events), free-drainage and restricted outlet design conditions, and to determine changes in long-term efficiency and performance associated with clogging, plant stress (drought/inundation), changes in soil-water retention capability and the efficiency of various planting styles and their comparative evapotranspiration behaviour. Working together with a range of stakeholders involved in UK SuDS schemes and international advisors, this work is helping to inform design criteria and anticipated performance using a quantified, physically derived evidence base to assist in numerical model development.

References

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