Balancing between Survival and Cooling: Defining Water Demand Thresholds for Blue Green Infrastructure under Drought Conditions

Survie ou refroidissement : seuils d’eau pour les infrastructures vertes et bleues en période de sécheresse

E. Andrusenko[1]*, J. A. van der Werf [1], A.M.J. Coenders-Gerrits[1], J.G. Langeveld[1,2]

[1] Department of Water Management, Delft University of Technology;
[2]Partners4urbanwater
*Corresponding author email: e.o.andrusenko@tudelft.nl

RÉSUMÉ

Les infrastructures vertes et bleues (IVB) sont largement utilisées pour gérer les eaux pluviales et réduire les risques d’inondation en milieu urbain. Toutefois, l’augmentation de la végétation en ville entraîne une demande en eau plus élevée, surtout en période de sécheresse prolongée, en raison d’une évaporation accrue.

Pour garantir la survie des plantes et renforcer la résilience climatique, il est essentiel d’identifier deux seuils critiques : la quantité minimale d’eau nécessaire pour éviter la mortalité végétale, et le niveau d’humidité du sol permettant un rafraîchissement optimal par évaporation. Mieux comprendre et quantifier ces seuils permettra de concilier verdissement urbain et gestion durable de l’eau, en maintenant l’efficacité des IVB face au changement climatique.

ABSTRACT

Blue Green Infrastructure (BGI) is widely adopted as an adaptive strategy for stormwater management, helping to reduce flood risk in urban areas. However, expanding urban greenery increases urban water demand during prolonged droughts, largely due to elevated evaporation rates. To sustain vegetation and enhance climate resilience, it is essential to understand the minimum water input required to prevent plant mortality, as well as the soil moisture thresholds needed to support effective evaporative cooling.

Defining these two critical thresholds is essential for effective urban water management in water-limited conditions. The first threshold ensures plant survival by providing the minimum necessary water to maintain physiological functions. The second threshold identifies the soil moisture levels required to maximize cooling efficiency, optimizing the evaporative benefits of urban greenery. Balancing these thresholds is particularly important as cities face increasing water constraints while expanding urban greening initiatives. Understanding and quantifying these ranges will support sustainable water management strategies, ensuring that BGI remains functional and effective in mitigating urban heat stress under changing climate conditions.

KEYWORDS

Blue Green Infrastructures, Climate Adaptation, Drought, Urban Water Demand

1 INTRODUCTION

Vegetation plays a key role in cooling urban environment through shading and evapotranspiration, making Blue Green Infrastructure (BGI) vital tool for climate adaptation. While the importance of soil moisture for plant transpiration is well established, the specific influence of substrate moisture on evaporative cooling performance in urban settings remains poorly understood (Gobatti et al., 2023).Although greenery is widely valued for its cooling potential, the soil moisture thresholds needed to maintain that function, especially under drought, are still unclear (Antoszewski et al., 2020). The knowledge gap becomes more crucial when considering the trade-offs between limited water availability and the need for Urban Heat Island (UHI) mitigation in urban areas that are prone to drought and heat.

In urban environments, managing water for vegetation is a challenge that is not as common as those in agricultural or forestry settings. While irrigation requirements in those sectors are well established, they are not fully transferable to urban green spaces, where vegetation structure and function significantly differ (Pereira et al., 2021). Agricultural guidelines typically follow seasonal growth cycles, with water demand rising during active crop development and declining before harvest (Allen et al., 2020). In contrast, urban landscapes are dominated by mature vegetation, leading to a more stable but context specific water demand. General recommendations, such as applying one-tenth of the reference evapotranspiration, often underestimate the needs of younger urban plants, whose water requirements are considerably higher (Hof & Wolf, 2014). Applying standards developed for other land uses can lead to inefficient water use, as these guidelines are tailored to different plant growth stages.

In agriculture and forestry, irrigation focuses on maximizing yield. In urban settings, particularly during drought, the priority shifts toward maintaining plant survival and preserving ecosystem functions such as microclimate cooling. The goal is to apply the minimum water necessary to sustain vegetation and reduce the UHI effect without overusing limited resources. Defining a threshold just above the wilting point is therefore essential for efficient irrigation planning. Drought impacts typically peak in midsummer, when soil moisture is lowest, intensifying plant stress and amplifying the UHI effect. Identifying minimum water ranges that support both survival and cooling is a prerequisite for effective strategies to reduce vapor pressure deficit (VPD) and alleviate water stress in urban vegetation (Gobatti et al., 2025).

To address this challenge, the study investigates two critical soil moisture thresholds in Blue-Green Infrastructure: the minimum level required to sustain plant vitality during drought and the level needed to maintain effective evaporative cooling. An experimental plot was set up with three compartments, each simulating a distinct water management strategy: A) free drainage, B) fixed water table, and C) controlled wilting point. Vegetation is consistent across all treatments, isolating soil moisture as the primary variable influencing plant survival and cooling performance. By tracking plant and soil responses under controlled conditions, the study defines functional thresholds for both survival and cooling. As cities increasingly rely on BGIs to manage drought and heat, quantifying these ranges is essential for informing sustainable water use and ensuring long-term climate resilience.

2 METHODOLOGY

To investigate the relationship between water availability and cooling performance in urban greenery, an experimental plot was constructed in Delft, the Netherlands (51.985338, 4.389456), to simulate three distinct water management strategies. The setup consists of a reinforced concrete container of 6 × 3 meters, divided into three equal compartments using wooden dividers lined with a plastic membrane to ensure hydraulic separation **(Figure 1)**. Each compartment represents a specific irrigation condition: free drainage, representative of droughts (A), keeping fixed wilting point, representing minimum plant survival (B), and a fixed ground water table, representing maximum cooling effect (C). These regimes allow for the comparison of soil moisture availability effects on plant survival and cooling performance under controlled conditions.

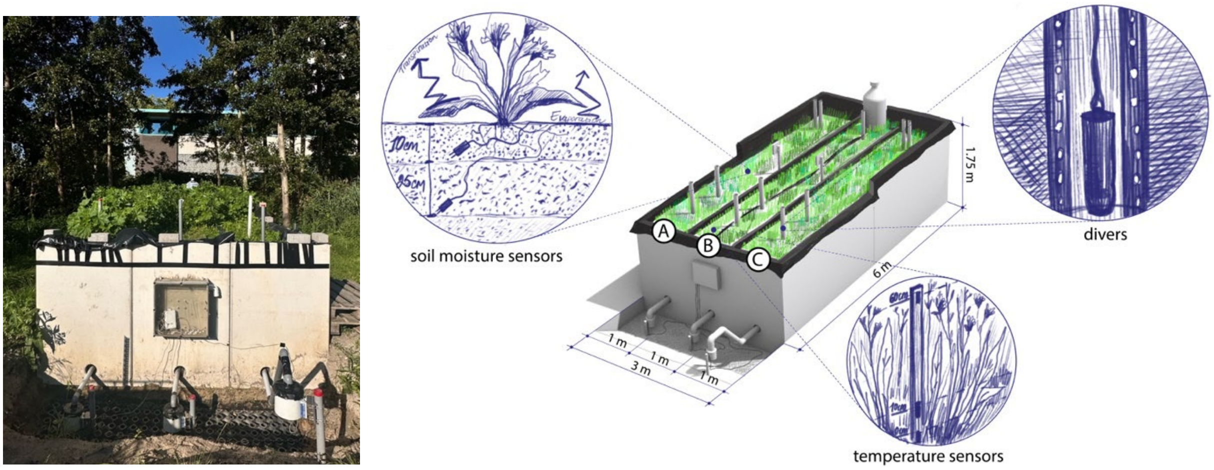

Figure 1. Experimental setup: photo (left) and axonometric view with dimensions and sensor close-ups (right).

All compartments share the same vegetation mix and soil layering to ensure comparability. The planting palette consists of a diverse selection of flowering herbaceous species commonly applied in BGI across the Netherlands. This wildflower mix comprises a range of herbaceous species commonly used in Blue-Green Infrastructure. The soil profile begins with an impermeable LDPE lining (0.5 mm) to isolate the substrate from the concrete base and prevent leakage. Above this, a 30 cm drainage layer is installed using a plastic drainage board and underdrain system (50 mm PVC), followed by 75 cm of sandy clay loam soil selected for its low infiltration capacity (~0.25 cm/h), and topped with a vegetation substrate.

Each water regime is controlled via distinct drainage configurations. The free drainage compartment includes open outlet drains with a 45° PVC bend directing water to a tipping bucket (ECRN-100). The fixed water table is maintained at 50 cm using a vertical outlet pipe system with a 90° elbow, also connected to the tipping bucket for overflow capture. In the wilting point setup, irrigation is applied manually using a 60 L water can to keep soil moisture near the plant stress threshold.

A network of sensors was installed across all compartments to monitor soil moisture, temperature, and other water balance components. Soil moisture sensors (METER TEROS 12, Decagon 5TM, and ECHO EC-5) are placed at two depths (10 and 25 cm), with four sensors per compartment to capture vertical moisture profiles. Water levels are tracked using Van Essen TD-Divers (two per section), positioned 20 cm from the compartment walls. Temperature is measured using thermal sensors located at three heights: ground level, 10 cm above the vegetation, and 60 cm above the canopy, allowing assessment of evaporative cooling across vertical layers. A control setup without vegetation, equipped with reference sensors at three heights, is used to isolate the greening effect. All sensors are connected to ZL6 data loggers, which receive input from tipping buckets and support remote data access and thermal image analysis.

The experimental setup follows the hydrological mass balance modeling approach described in previous work (Andrusenko et al., 2025) and is designed to support a simplified hydrological analysis based on the principle of mass balance. Each of the three compartments is treated as an individual hydrological unit, with a temporal resolution of five minutes, enabling a detailed assessment of short-term dynamics. The underlying assumption is that the sum of inflows equals the sum of outflows and changes in storage over time(Meng et al., 2022). In this context, precipitation measured at the site (P) is treated as the primary inflow, while outflows include surface runoff (R), subsurface drainage, and evaporation. Here, evaporation refers collectively to water loss through transpiration and interception evaporation. Changes in soil water storage (S_{soil}) are tracked using soil moisture sensors placed at two depths (10 cm and 25 cm), along with pressure transducers (divers) to monitor water table fluctuations. Evaporation, the only unmeasured variable, is estimated as the residual of the mass balance equation. This framework enables a comparative assessment of the three water management strategies by linking water availability to cooling performance and plant response.

3 RESULTS

The experimental setup has been designed to assess two crucial thresholds over the course of the plant growing season, from spring through autumn, with particular focus on drought periods, when water demand is high and the effects of water scarcity on both plant vitality and cooling performance are most prominent.

Before the growing season, an initial monitoring phase was carried out during the winter period to establish a baseline water balance and verify system functionality. This phase provided an opportunity to validate sensor performance, check mass balance consistency across compartments, and ensure that the observed data align with the intended water management strategies. The absence of active vegetation allowed a clear assessment of system behavior without biological influence, offering a reference point for near-zero evaporation under cold conditions. These data form a critical benchmark for interpreting seasonal changes in water demand and cooling performance.

Monitoring data from the October test period show clear inflow–outflow dynamics across the compartments, enabling early assessment of system behavior and hydrological response. As vegetation is largely inactive during this period, compartments A (free drainage) and B (controlled wilting point) are expected to show similar outflow behaviour, since wilting point control is not maintained without plant water demand.Both compartments indeed show low cumulative outflows relative to total rainfall, with B displaying slightly higher values that remain within a realistic range for its drainage configuration. Compartment C behaves distinctly, as expected from its fixed water-table configuration: its cumulative outflow remains negligible while cumulative storage increases steadily during rainfall events. This reflects the regulated drainage design, where water is retained until the controlled overflow level is reached **(Figure 2)**.

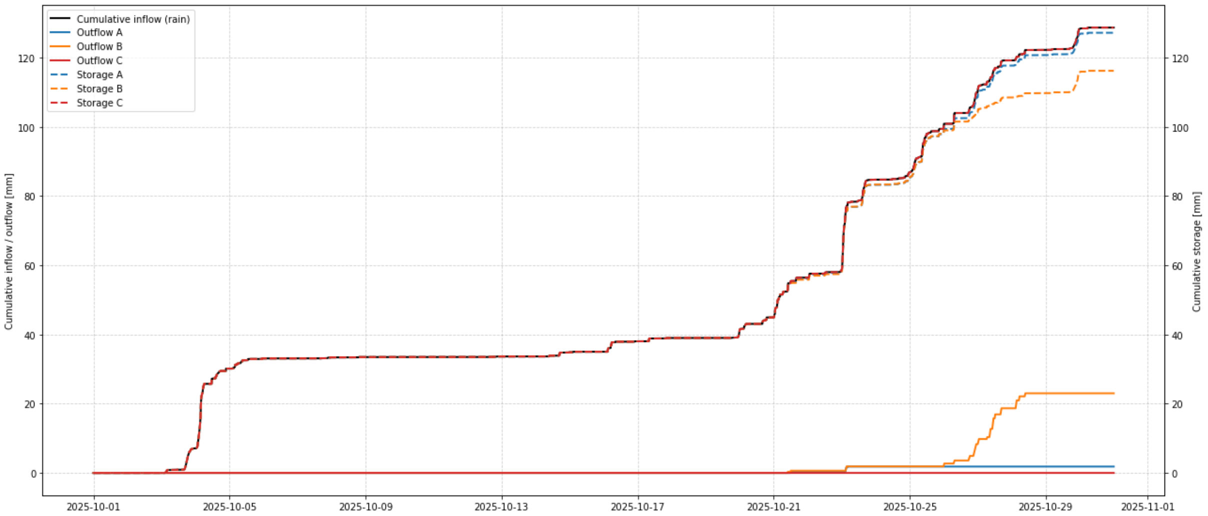

Figure 2. Cumulative inflow–outflow dynamics and storage values for compartments A (free drainage), B (controlled wilting point), and C (maintained water table).

At this stage, the setup remains under refinement, and the winter period is being used to test mass-balance assumptions, adjust sensor and drainage components, and establish a reference point for near-zero evaporation under cold conditions. The preliminary results presented here therefore reflect an ongoing testing and calibration process. By the time of the Novatech conference, the full growing season will be underway, allowing for a detailed evaluation of evaporation dynamics and cooling performance under active vegetated conditions. Combined with the mass-balance framework, these results will clarify the effectiveness of the three tested water-management strategies and support more efficient water use in future BGI applications.

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