# Calibration and Validation of a Large-Scale Dripper-Based Rainfall Simulator for Experimental SUDS Evaluation

## Calibrage et validation d'un simulateur de pluie à grande échelle pour l'évaluation expérimentale des techniques de gestion durable des eaux pluviales

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## RÉSUMÉ

Ce travail présente le processus de calibrage et de validation d'un simulateur de pluie à grande échelle basé sur un système de goutteurs, développé pour l'évaluation expérimentale des techniques de gestion durable des eaux pluviales (SUDS). L'équipement a été conçu pour reproduire des intensités de pluie comprises entre 5 et 70 mm/h avec une grande stabilité et une bonne homogénéité spatiale sur une large surface d'essai. Trois maillages de distribution, différant par matériau et diamètre d'orifice, ont été testés afin d'identifier la configuration offrant les meilleures performances hydrauliques. Les essais de calibrage ont montré des écarts inférieurs à 3 mm/h et des coefficients d'uniformité supérieurs à 87 %, confirmant la robustesse du système goutteurs-maillage en conditions contrôlées. Le maillage le plus performant a été retenu pour la validation à pleine échelle. Les résultats ont mis en évidence une reproduction fiable des intensités cibles, avec une uniformité comprise entre 75,6 % et 83,2 %, valeurs cohérentes avec celles attendues pour des simulateurs extérieurs de grande taille. Le dispositif fournit ainsi des conditions pluviométriques suffisamment homogènes et répétables pour les études de ruissellement, de mobilisation de polluants et de performance hydraulique des SUDS dans des scénarios contrôlés mais réalistes.

## ABSTRACT

This work presents the calibration and validation of a large-scale dripper-based rainfall simulator designed for experimental assessment of Sustainable Urban Drainage Systems (SUDS) by Canal Isabel II at Madrid. The infrastructure was developed to reproduce rainfall intensities between 5 and 70 mm/h with high stability and spatial consistency across a large test area (around 200 $m^2$). Three flow-distribution meshes—differing in material and orifice size—were evaluated to determine the configuration providing the best hydraulic behavior. Calibration tests showed deviations below 3 mm/h for all intensities and Christiansen Uniformity Coefficients above 87%, confirming the robustness of the dripper-mesh system under controlled conditions. The best-performing mesh was subsequently installed for full-scale validation. Validation results demonstrated that the simulator reliably reproduces target intensities, with uniformities ranging from 75,6% to 83,2%, values consistent with expectations for large outdoor simulators where boundary and wind effects are more pronounced. Overall, the simulator provides sufficiently homogeneous and repeatable rainfall conditions for studies on runoff generation, pollutant mobilization and the hydraulic performance of SUDS under controlled and realistic scenarios.

## KEYWORDS

Calibration, Rainfall simulator, SUDS, Uniformity coefficient, Urban drainage.

Étalonnage, Simulateur de pluie, SUDS, Coefficient d'uniformité, Drainage urbain.

## 1 INTRODUCTION

Urban drainage systems increasingly rely on Sustainable Urban Drainage Systems (SUDS) to mitigate flooding and reduce pollutant loads transported during storm events. Experimental evaluation of SUDS performance traditionally depends on natural rainfall, which limits reproducibility and prolongs monitoring periods. Rainfall simulators offer a controlled alternative capable of generating precise intensities and repeatable conditions.

In addition to enabling reproducible hydraulic conditions, rainfall simulators represent a key asset for experimental SUDS research because they allow testing under event-based scenarios that are difficult to capture in real rainfall conditions. Medium to high intensities, typically above 30 mm/h, are particularly relevant for the assessment of overflow mechanisms, infiltration capacity loss, and the wash-off of accumulated pollutants on impervious surfaces (Cerdà, 1997; Fernández-Raga et al., 2010). However, reproducing these intensities uniformly over large areas remains challenging for many existing devices. Dripper-based simulators offer an advantageous alternative to nozzle-based systems due to their lower sensitivity to pressure fluctuations, reduced maintenance and more stable droplet formation. For these reasons, the present work focuses on the development of a large-scale system (Figure 1) specifically tailored to the hydraulic requirements of SUDS experimental testing.

Figure 1. Overview of the large-scale rainfall simulator (left) and mesh location (right).

This study reports on the calibration and validation of a large-scale dripper-based rainfall simulator developed in a pilot research facility in Meco (Madrid, Spain) by Canal Isabel II water company (see Figure 1). The system was designed to reproduce intensities between 5 and 70 mm/h over a large testing area. This extended abstract focuses on the calibration/validation methodology and its main results.

## 2 MATERIALS AND METHODS

### 2.1 Simulator configuration

The simulator includes four dripper lines supplying different flow rates, each of which spans the entire testing area, allowing the rainfall contributions from all lines to overlap and generate a uniform combined pattern. A flow-distribution mesh positioned 0,70 m below the emitters homogenizes the droplets before impact. Initially, three meshes were tested: Mesh 1 (M1), a plastic mesh with 1,9 mm orifices; Mesh 2 (M2), a plastic mesh with 5,0 mm orifices; and Mesh 3 (M3), a metallic mesh with 3,0 mm orifices.

The choice of a 0,70 m distance between emitters and mesh was based on previous studies (Meyer and Harmon, 1979; Naves et al., 2020) reporting that this range supports the development of drop terminal velocity while maintaining spatial consistency. Larger distances tend to increase horizontal dispersion and accentuate edge effects, while shorter ones reduce the kinetic energy of droplets, potentially altering runoff initiation processes. The selected spacing between dripper lines was optimized to ensure overlapping rainfall footprints without producing over-concentration zones. These considerations were fundamental to ensuring that the simulator could operate robustly across the entire rainfall-intensity spectrum required by the project.

### 2.2 Calibration and validation methodology

A preliminary calibration consisted of 12 tests combining the three drop-forming mesh materials and orifice sizes, and four target rainfall intensities (5, 10, 20 and 40 mm/h), selected because they correspond to the nominal intensities delivered by each dripper line and their most frequent operational combinations. Water was collected in metal containers arranged in a 2×2 grid beneath each mesh section; intensity and Christiansen Uniformity Coefficient (CU) were derived from collected volumes.

After selecting the best-performing mesh, full-scale validation was performed (Figure 2) with 120 containers placed in a regular 15 x 12,5 $m^2$ mesh. Tests used intensities of 5, 20, 40 and 70 mm/h, using the same methodology as the calibration procedure.

Figure 2. Validation setup showing container grid.

# 3 RESULTS

## 3.1 Calibration results

The calibration was performed with the three different meshes. Measured intensities showed deviations from theoretical values below 8 mm/h for all meshes. Uniformity coefficients were consistently above 87%. Results are summarized in Table 2.

Table 2. Calibration results for the three mesh configurations

| Test id. | Theoretical intensity (mm/h) | Measured values | M1 | M2 | M3 |
|---|---|---|---|---|---|
| Cal_1 | 5 | Intensity (mm/h) | 7,9 | 8,2 | 8,4 |
| | | Uniformity (%) | 94,6 | 87 | 93,2 |
| Cal_2 | 10 | Intensity (mm/h) | 11,9 | 12,2 | 12,3 |
| | | Uniformity (%) | 97,1 | 94,2 | 95,4 |
| Cal_3 | 20 | Intensity (mm/h) | 19,4 | 18,4 | 19,8 |
| | | Uniformity (%) | 97,2 | 95,2 | 94,1 |
| Cal_4 | 40 | Intensity (mm/h) | 48,3 | 47,5 | 48,1 |
| | | Uniformity (%) | 94,8 | 95,4 | 96,2 |

Mesh M1 (plastic with 1,9 mm size) demonstrated the most consistent performance across intensity levels, balancing uniformity and hydraulic stability. It was therefore selected for its installation in the whole simulator for its validation.

## 3.2 Validation results

Full-scale validation with the mesh M1 confirmed that the system reproduces intensities reliably (5,9, 19,8, 37,8 and 67,3 mm/h for target values 5, 20, 40 and 70 mm/h respectively), with deviations below 3 mm/h. Uniformities ranged from 75,6% to 83,2%, consistent with expectations for large rainfall simulators where edge effects reduce homogeneity. Results are summarized in Table 3. Furthermore, a heat map representing the spatial distribution of the intensities measured was developed (Figure 3).

Table 3. Validation results for selected intensities.

| Test id. | Theoretical Intensity (mm/h) | Mean Intensity (mm/h) | Uniformity Coefficient (%) |
|---|---|---|---|
| Val_1 | 5,0 | 5,9 | 81,9 |
| Val_2 | 20,0 | 19,8 | 75,6 |
| Val_3 | 40,0 | 37,8 | 81,3 |

| Test id. | Theoretical Intensity (mm/h) | Mean Intensity (mm/h) | Uniformity Coefficient (%) |
|---|---|---|---|
| Val_4 | 70,0 | 67,3 | 83,2 |

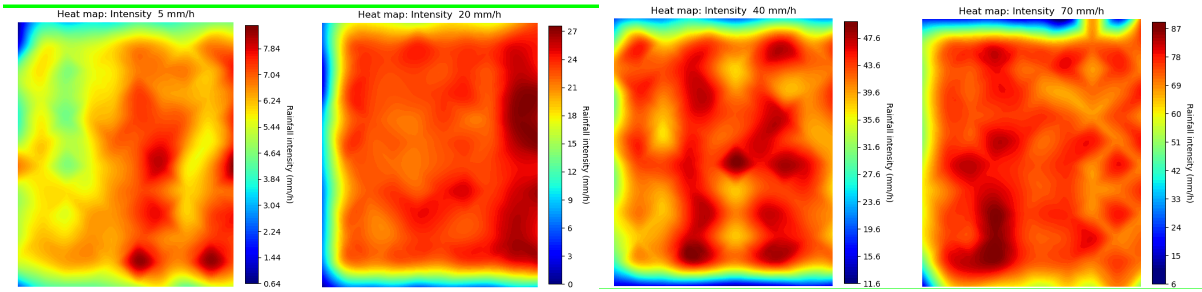


Figure 3. Measured rainfall spatial distribution for validation intensities

## 4 DISCUSSION

The calibration results showed that all tested meshes were capable of reproducing the target rainfall intensities with deviations below 8 mm/h, confirming the robustness of the dripper-based technique. Among them, Mesh M1 demonstrated the greatest hydraulic stability, achieving Christiansen Uniformity Coefficients up to 97% and maintaining consistent behavior across all intensities. These findings validate the suitability of the selected configuration for controlled experimental conditions and support its adoption for full-scale testing. In addition, the simulator exhibited strong temporal stability during all experiments, an essential characteristic for ensuring reproducibility in long-duration SUDS evaluations, where small variations in rainfall input can significantly affect infiltration and wash-off dynamics.

During the full-scale validation phase, lower uniformity values (75,6% to 83,2%) were observed, mainly due to boundary effects and wind-exposure effects in the outdoor experimental area. Despite these reductions, the values remain above commonly accepted thresholds for hydrological field studies (Tarjuelo et al., 1999), and spatial analyses (Figure 3) confirmed that most variability was concentrated in the peripheral zones, while the central region—where measurements are typically performed—maintained stable rainfall distribution (see Figure 3). Overall, the results demonstrate that the simulator reliably reproduces a wide range of rainfall intensities and provides sufficiently homogeneous conditions for experimental studies on runoff generation, and SUDS performance under controlled hydrological scenarios.

## 5 CONCLUSIONS

The rainfall simulator successfully reproduced intensities from 5 to 70 mm/h with deviations <3 mm/h and uniformities between 75% and 97% depending on scale. Calibration identified the optimal mesh (plastic, 1,9 mm), and validation confirmed the system's operational reliability. The equipment is now ready for upcoming campaigns assessing SUDS hydraulic and pollutant-retention performance under controlled hydrological conditions. Beyond the specific context of the pilot platform, the insights gained from the design and tuning of this simulator provide a replicable framework for other large-scale experimental facilities focusing on urban hydrology. The methodology described here can support the development of future testing infrastructures aimed at advancing our understanding of SUDS behavior under controlled yet realistic rainfall events. Also, the project includes the deployment of a runoff simulator, which will expand the range of possible experiments.

## LIST OF REFERENCES


Cerdà, A. (1997). Rainfall simulation with a simple portable sprinkler design in the Mediterranean Basin. *Soil Technology*, 11(2), 163–170.

Fernández-Raga, M., Palencia, C., Keesstra, S., Jordán, A., Fraile, R., Angulo-Martínez, M., & Cerdà, A. (2010). Splash erosion: A review with unanswered questions. *Earth-Science Reviews*, 104(1–3), 27–32.

Iserloh, T., Ries, J.B., Arnáez, J., Boix-Fayos, C., Butzen, V., Cerdà, A., … & Wirtz, S. (2013). European small portable rainfall simulators: A comparison of rainfall characteristics. *Catena*, 110, 100–112.

Meyer, L.D., & Harmon, W.C. (1979). Multiple-intensity rainfall simulator for erosion research on row sideslopes. *Transactions of the ASAE*, 22(5), 100–103.

Naves, J., Anta, J., Suárez, J., & Puertas, J. (2020). Development and calibration of a new dripper-based rainfall simulator for large-scale sediment wash-off studies. *Water*, 12(1), 152.

Tarjuelo, J.M., Montero, J., Honrubia, F.T., Ortiz, J.J., & Artes, M. (1999). Irrigation uniformity with medium-size sprinklers: Part II—Influence on crop yield. *Agricultural Water Management*, 40, 71–86.