

## Open-source infiltrometer prototype (INFLOW) for multi-site assessment of Nature-Based stormwater solutions

Prototype d'infiltromètre open-source (INFLOW) pour l'évaluation multi-sites de solutions fondées sur la nature pour la gestion des eaux pluviales

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### RÉSUMÉ

La majorité des solutions fondées sur la nature (SfN) pour le traitement des eaux pluviales en ville repose sur le principe d'infiltration de l'eau. Des estimations fiables de paramètres hydrauliques clés, comme la conductivité hydraulique à saturation ( $K_{sat}$ ), sont alors essentielles pour comparer et évaluer ces SfN. Cependant, les techniques traditionnelles pour mesurer ces paramètres restent difficiles à mettre en œuvre sur le terrain, et les infiltromètres commerciaux sont coûteux et propriétaires. Cette étude présente INFLOW (INFiltration characterization avec Low-cost Open-hardware Water infiltrometer), un dispositif open-source fournissant des mesures d'infiltration à haute résolution temporelle avec des contraintes de terrain minimales. INFLOW associe des composants modulaires et une documentation complète pour faciliter un accès large et permettre à l'utilisateur de monter et réparer le dispositif de façon autonome. Les retours opérationnels ont montré un faible bruit de mesure, une description précise des phases d'infiltration, un échantillonnage autonome et rapide, la portabilité et une reproductibilité robuste. Les limites incluent la nécessité d'améliorer la stabilisation du niveau d'eau et le débit d'alimentation pour mesurer l'infiltration dans des sols très perméables. Couplé au modèle BEST (Beerkan Estimation of Soil Transfer parameters), INFLOW permet d'estimer les paramètres hydrauliques des milieux poreux. Les résultats préliminaires multi-sites montrent qu'INFLOW est une alternative évolutive et peu coûteuse, capable de comparer les paramètres hydrauliques des NBS, contribuant à leur caractérisation standardisée et accessible.

### ABSTRACT

Many nature-based solutions (NBS) for urban stormwater management rely on the principle of gravity-driven water infiltration. Reliable estimates of key hydraulic parameters, such as saturated hydraulic conductivity ( $K_{sat}$ ), are therefore essential to compare and assess these NBS. However, traditional techniques for measuring these parameters remain difficult to implement in the field, and commercial infiltrometers are costly and proprietary. This study presents INFLOW (INFiltration characterization with Low-cost Open-hardware Water infiltrometer), an open-source device providing high temporal resolution infiltration measurements with minimal field constraints. INFLOW combines modular components and comprehensive documentation to enable broad access and allow users to assemble and repair the device independently. Operational feedback shows low measurement noise, precise depiction of infiltration phases, rapid autonomous sampling, portability, and robust reproducibility. Limitations include the need to improve water-level stabilization and supply rate to measure infiltration in highly permeable soils. Coupled with the BEST model (Beerkan Estimation of Soil Transfer parameters), INFLOW enables estimation of hydraulic parameters in porous media. Preliminary multi-site results show that INFLOW is a scalable, low-cost alternative capable of comparing NBS hydraulic parameters, contributing to their standardized and accessible characterization.

### KEYWORDS

Hydraulic conductivity, Infiltration, Low-tech instrumentation, Nature-based solutions, Stormwater  
Conductivité hydraulique, Eaux pluviales, Infiltration, Instrumentation low-tech, Solutions fondées sur la nature

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## 1 INTRODUCTION

Bringing back 'nature' into cities has led to real change in urban stormwater management, with the widespread implementation of nature-based solutions (NBS). Many types of NBS for stormwater management, such as vegetated bioretention/biofilter basins, swales and infiltration trenches, rely on infiltration through an engineered substrate (Chocat *et al.*, 2022). Key hydraulic parameters such as saturated hydraulic conductivity ( $K_{sat}$ ), sorptivity, and operational porosity are obtained from infiltration measurements and hydrological models. Furthermore, these parameters may change over time, e.g. due to clogging (Yang *et al.*, 2022). Consistent and reproducible hydraulic parameters estimates are thus needed to follow this phenomenon and can also be used to size facilities (transfer capacity, unsaturated-zone storage), model dynamic behaviour (partial saturation, transient infiltration), compare system types (vegetation, conditions, filter media), and explicitly integrate spatial variability in stormwater management.

Standard tools to make infiltration measurements — such as double ring (ASTM, 2009), Guelph permeameter (Reynolds & Elrick, 1985), and disc infiltrometers (Perroux & White, 1988)—, show recognised limitations: poor portability, heavy logistical requirements, non-autonomous sampling, difficulty achieving exploitable transient regimes (low temporal resolution), and difficulty in field implementation. This is of special importance for NBS, which often have higher intended infiltration capacity than many natural or agricultural soils, for which the mentioned devices have been developed originally. Automated commercial devices exist, such as Upstream Technology MPD Infiltrometer, Decagon/Metergroup SATURO automated double-ring infiltrometer, Eijkelkamp Automated Infiltration Meter, ICT International Infiltrometer Series. However, these often involve high costs (€10,000–15,000), do not allow autonomous repair, and depend on the manufacturer for updates, batteries, sensors, and firmware. Proprietary elements prevent modification, make internal algorithms inaccessible and turn the devices into a black box and limited scientific appropriation. For many field-oriented projects, this material opacity limits reproducibility, weakens inter-site comparability, and imposes maintenance constraints incompatible with scientific sustainability.

To overcome these obstacles, open-source instrumentation can be an alternative addressing major needs: transparent schematics, code and algorithms, full reproducibility, adaptability to local teams' needs, cost reduction, as well as user-managed repair and maintenance. This open-source development aligns with recent discussions on sustainable instrumentation, as highlighted by Clément *et al.* (2025), emphasising modifiable, auditable, repairable and transmissible equipment. Furthermore, it aims to promote transparent, reproducible, and accessible research—conditions needed to widely understand and compare hydrological performances for NBS across temporal, ecological and climatic contexts.

This abstract presents (i) a detailed description of the INFLOW infiltrometer (INFiltration characterization with Low-cost Open-hardware Water infiltrometer), (ii) how to process the collected data, and (iii) preliminary results from a first application during a sampling campaign on five Swedish and one French experimental sites.

## 2 METHOD

### 2.1 INFLOW device

The INFLOW infiltrometer (*Fig.1*) is an automated device adapted from the Beerkan test. Using the Best (Beerkan Estimation of Soil Transfer parameters) modelling process developed by Lassabatère *et al.* (2006), which is under continuous development (Lassabatère *et al.*, 2023), it is possible to calculate the key hydraulic parameters of porous media. This model relies on the Haverkamp model (Haverkamp *et al.*, 1994).

INFLOW consists of a pressurized (3 bar) 7-liter water tank mounted on a tripod, equipped with an electronic heightening hook that records the water tank's mass (resolution:  $10^{-4}$  g). The mass data are collected by a battery-powered, Arduino-based data acquisition system at fixed intervals (every 2 s). Mass loss from the water tank corresponds to infiltrated water volume and is recorded on an SD card. A water-level regulator maintains a constant 3 cm water head in a metallic infiltration ring (*Fig.2*).

The single steps for an infiltration essay are as follows (*Fig. 1*): (i) fill the water tank with drinking water, (ii) insert the metallic ring into soil or media with a depth of 0.5 cm, (iii) degas the hose and fix the level regulator to the cylinder, (iv) pressurise and suspend the reservoir, (v) start data acquisition by activating the pressurization button, and (vi) open water inlet valve. The measurement is now starting. During the measurement, the

decreasing weight in the water tank can be followed via the LCD screen. When there is no water left in the tank, the valve has to be closed, and the acquisition button turned off. A soil sample is collected to measure relative humidity, particle size distribution and bulk density. After the acquisition of data, they need to be entered in the model to obtain estimated hydraulic parameters with the BEST method (Lassabatère et al., 2006). An easy-use interface is available on Sci-lab software to support processing of infiltration data with the BEST method.

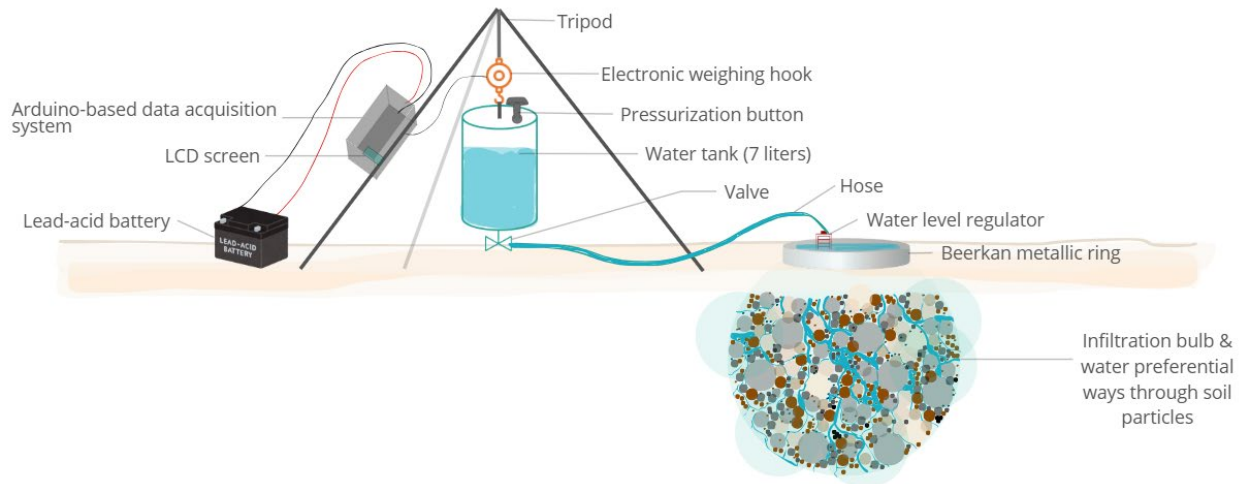


Figure 1. INFLOW infiltrometer schematic representation



Figure 2. INFLOW infiltrometer prototype photos in field use in Växjö, Sweden

## 2.2 Field sampling campaign

Real-scale experiments were performed on five sites in Sweden, including a bioretention basin in Sundsvall, infiltration trenches in Växjö, and swales in Malmö. In France (Chassieu), two contrasting zones of a large (8000 m<sup>2</sup>) and 25 years-old infiltration basin were sampled. The first zone, according to EUNIS terminology (Gayet et al., 2018), is an ecological habitat similar to a “dry, xeric, oligotrophic habitat”, and the second zone is similar to a “reed beds and large helophyte fringe formations”. For the French site, random quadrats were selected within each vegetation zone. Three to four infiltration tests were performed in and around each quadrat when feasible. Bulk density, relative humidity, and particle size distribution (measured with a Mastersizer 3000, Malvern) were then collected for BEST modelling. For the Swedish sites, the same protocol was applied, except that quadrats were not stratified by vegetation zones, as such zones were absent.

### 3 PRELIMINARY RESULTS & DISCUSSION

Primary results are presented, which still require BEST modelling. To obtain key hydraulic parameters, bulk density, relative humidity, and particle size distribution must be incorporated, and these analyses are currently being performed.

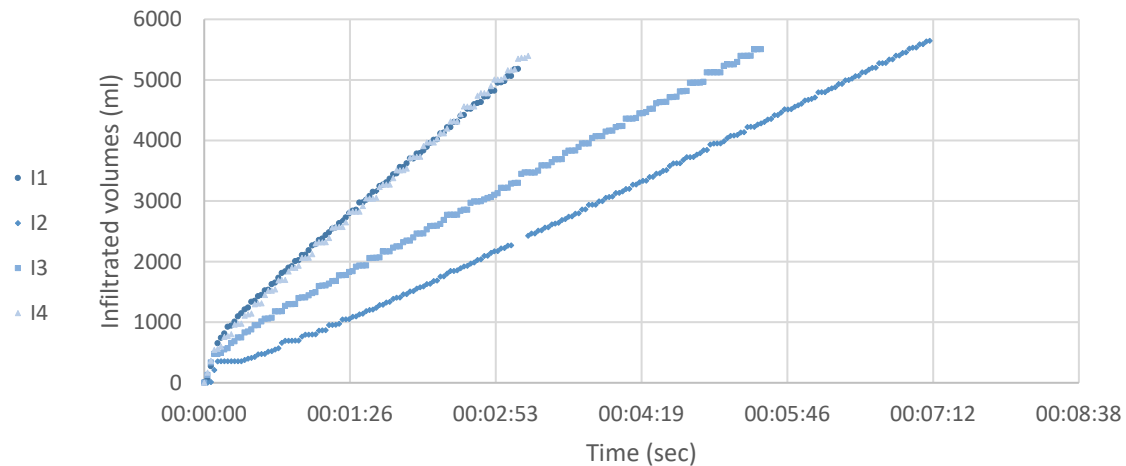


Figure 3. Example of infiltrated volumes of water, using INFLOW (dry grassland dominated by Poaceae in infiltration basin in Chassieu, France). Four infiltrations tests were performed around and in the quadrat: I1 to I4. Measures of water mass (represented as volumes) were taken automatically every 2 seconds.

Field feedback confirms several operational strengths of the developed infiltrometer, including low measurement noise (due to measurement uncertainties associated with the electronic weighting hook, the oscillatory motion of the suspended water tank, and the regulation of inflow volumes into the metal cylinder by the water-level control system) and detailed characterisation of infiltration dynamics enabled by high temporal resolution (Fig. 3). Additionally, the device is easy of transport, allows autonomous and rapid sampling, and strong reproducibility between replicated measurements. The instrument also has a fully accessible and comprehensive documentation. However, some limitations remain. These include the need for broader validation against commercial devices, enhanced stabilisation of the water head, and technical upgrades to improve performance in highly conductive soils where infiltration rates exceed the device's maximum flow capacity. The prototype offers a low-cost (approximately 350 euros), reproducible, open-source alternative to conventional infiltrometers. When combined with BEST modelling, it enables a robust estimation of key hydraulic parameters. Preliminary measurements collected across six sites demonstrate the capacity of the device to compare NBS hydraulic functions under varying vegetation, climatic, and pedological conditions. Overall, the instrument provides an important contribution towards harmonising and scaling hydraulic characterisation methods for nature-based stormwater systems.

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