

Analyse des performances et résilience d'une solution fondée sur la nature innovante pour la gestion des eaux pluviales urbaines : retours d'expérience issus d'une démarche collective au sein du projet européen GreenStorm

Exploring the performance and resilience of an innovative nature-based solution for urban stormwater management: lessons from a collective thinking process in the European GreenStorm project

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RÉSUMÉ

Dans le cadre du projet européen GreenStorm, un modèle hydrologique conceptuel a été développé afin de simuler, pour différentes variantes de conception, le fonctionnement de Vertuo©, une solution innovante fondée sur la nature (SfN) combinant un module de stockage étanchéifié et un espace de pleine terre. L'objectif était d'évaluer le fonctionnement hydrologique de cette SfN et d'orienter son dimensionnement dans différents contextes climatiques (climat tempéré à Paris et climat méditerranéen à Athènes), sous des conditions actuelles et futures (RCP8.5). Un atelier a réuni une vingtaine d'experts, chercheurs et ingénieurs de collectivités de Paris, Copenhague et Athènes afin de tester l'outil et d'explorer des stratégies d'optimisation. Les scénarios analysés révèlent plusieurs éléments : difficultés à accroître l'évapotranspiration en raison des limites imposées par l'évapotranspiration potentielle, exfiltration difficile à maîtriser, et alternance marquée entre des périodes de sécheresse et de saturation. Les modifications de paramètres (type de sol, répartition Vertuo©/naturel, hauteur de drain) n'apportent que des améliorations limitées, notamment sur le bilan hydrologique, sans qu'un compromis clair ne se dégage. Ce travail constitue une première étape vers une approche intégrée de conception et de gestion de SfN multifonctionnelles et résilientes face aux extrêmes climatiques.

ABSTRACT

As part of the European GreenStorm project, a conceptual hydrological model was developed to explore the performance of a nature-based solution (NbS) under a range of design and implementation contexts. This solution, Vertuo©, is an innovative NbS that combines a lined storage module and a natural soil area. The objective is to assess the hydrological behaviour of this NbS and to guide its design across different climatic contexts (temperate in Paris and Mediterranean in Athens), under both actual and future (RCP8.5) conditions. A workshop brought together around twenty experts, including researchers and municipal engineers from Paris, Copenhagen, and Athens, to test the tool and explore potential optimization strategies. The scenarios analysed revealed several key issues: the difficulties of increasing evapotranspiration due to limits imposed by potential evapotranspiration, exfiltrations that remains challenging to control, and a marked alternation between periods of dryness and saturation. Parameter modifications (soil type, Vertuo©/natural distribution, drain height) provided only limited improvements, particularly in terms of the overall water balance, and no clear compromise emerged. This work represents a first step toward an integrated framework for the design and management of multifunctional, climate-resilient NbS.

MOTS CLÉS

Extrêmes climatiques, dimensionnement, modélisation, solutions fondées sur la nature, ruissellement

1 INTRODUCTION

The European GreenStorm project (<https://arceau-idf.fr/en/projects/greenstorm>), initiated in 2024 and funded under the Driving Urban Transitions partnership, aims to better design and facilitate the deployment of the diverse Nature-based Solutions (NbS) dedicated to urban stormwater management. It addresses the performance and resilience of these NbS, with a focus on various climate extremes, including storms, heatwaves, and droughts, for future and current conditions. The project promotes close collaboration between researchers and practitioners to bridge the gap between scientific investigation and real-world NbS implementation and management. One of the GreenStorm tasks concern the development and evaluation of a unified modeling framework for predicting the performance of the NbS at the facility scale (Berthier et al., 2025).

Within this context, the Vertuo© system was identified as one of the innovative NbS that the City of Paris intends to implement for stormwater management and associated multiple benefits. However, its effective implementation requires a clear understanding of its hydrological behaviour under varying climatic and hydrological conditions. This highlights the need for a modelling framework capable of representing its key processes and informing design choices. The objective of this contribution is therefore to present the modelling approach developed for this purpose and to illustrate how it can support the design and performance assessment of the Vertuo© system, based on the outcomes of a collaborative workshop conducted with practitioners and researchers.

2 THE CASE STUDY

The selected case study is located on Rue de la Jonquière in Paris, France, where the municipality has initiated a street pedestrianization project integrating two micro NbS (Figure 1.a). Each NbS unit measures approximately 10 m in length, 2.5 m in width, and 1 m in depth, and is designed to collect runoff from a street catchment area of about 150 m². A NbS combines artificial modular units (Vertuo©) with natural vegetated infiltration zones. A Vertuo© module consists of a lined cubic structure divided into two connected compartments: one half composed of a void space designed to store stormwater, and the other half filled with vegetated substrate supporting plant growth. Runoff is first collected within the Vertuo© module and can then be transferred to the adjacent natural module via a drain at a controlled flow rate, allowing gradual infiltration and providing passive irrigation to the vegetated soil. This hybrid configuration is supposed to optimize both hydraulic performance and vegetation health, while maintaining a balance between engineered storage and natural but controlled infiltration processes. For these NbS deployment, the objectives of the municipality regarding stormwater management are to reduce overflow discharge to the sewer network, control exfiltration to mitigate potential geotechnical risks, minimize irrigation demand, and maintain favorable conditions for vegetation health and resilience.

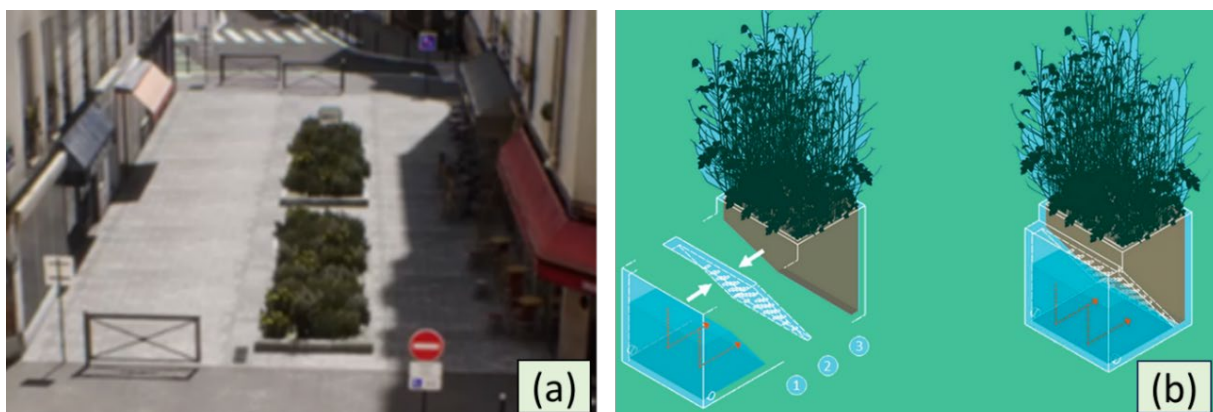


Figure 1: (a) Photo montage of the project site and (b) representation of the Vertuo© module triangular prism geometry (<https://www.vertuo.city/>).

3 THE NUMERICAL APPROACH

A numerical model and a tool have been developed to simulate the hydrological behavior of this specific NbS, with the objective of assessing its performance and exploring design considerations regarding its efficiency

The model is based on a conceptual representation of the system as a set of interconnected reservoirs simulating the main hydrological processes in a Vertuo© module and the adjacent natural area (Figure 2). Evapotranspiration (ET) is assumed to be equal the potential evapotranspiration (PET) when the water level exceeds 0 mm in the Vertuo© reservoir, whereas in the natural area ET is limited by soil water availability. The type of substrate for Vertuo© module and of soil for natural one defines the storage capacity of each, and overflow occurs when water level exceeds these storage capacities. The hydraulic connection between the Vertuo© module and the natural area is modeled through a drain characterized by its conductivity, its length, and its level from the bottom. Within the natural component, exfiltration to the underlying soil is driven by its hydraulic conductivity, represented by the water-content-dependent function $K(\theta)$. Two additional reservoirs represent the interception of rainfall by vegetation on all the solution and the surface storage on the natural area. Rainfall interception is simulated using a canopy model parameterized by the leaf area index (LAI), the soil cover factor (SCF), and the crop coefficient (K_v). The potential evapotranspiration (PET) is given by the product of K_v and a reference evapotranspiration (ET_0).

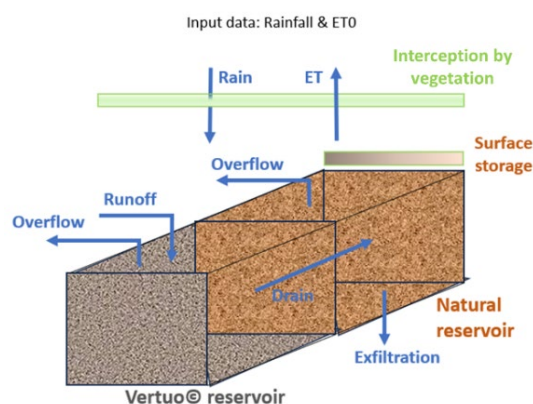


Figure 2: Conceptual diagram of the hydrological processes simulated in the NbS.

A simple, user-friendly Windows executable interface was developed to facilitate the use of the model by allowing users to specify the main parameters and directly run the corresponding simulations. For the GreenStorm application, meteorological data from two sites were considered: the Météo-France station in Trappes, France (approximately 30 km from Paris), and the station of the Agricultural University of Athens, Greece. For both climates, the analysis covers the period January 2012 to December 2018, using rainfall data at a 5-minute resolution and daily ET_0 computed with the FAO-56 Penman–Monteith method. Future climate conditions were also considered under the RCP8.5 scenario for 2085–2100. For each site, rainfall series were available at a 5-minute time step (Pons et al., 2025), and daily ET_0 values were estimated using the Hargreaves equation (after verifying consistency with Penman–Monteith under current climates). Daily ET_0 values were then disaggregated to an hourly time step using a Gaussian distribution based on sunshine duration.

4 A WORKSHOP TO PRACTICE THE NBS OPTIMIZATION

During the GreenStorm General Assembly held in Athens in June 2025, a workshop focusing on the case study was organized with two main objectives: (i) to assess the functioning of the NbS with respect to its design and climate conditions, and (ii) to evaluate how the tool supports—or fails to support—this assessment. Around twenty participants, mainly researchers and a few local government engineers, were brought together and introduced to the case study, the model, and the tool. Four subgroups were then formed, each supervised by a facilitator trained in using the tool. For one hour, each subgroup discussed and tested different design scenarios, after which all participants reconvened for a collective debriefing. The activity was not intended as a numerical optimization exercise, such as those described in Oberascher et al. (2025), but rather as a collaborative moment to share considerations and reflections on NbS design and optimization.

Active participant engagement during the workshop led to the development of various strategies. The first group compared the forcings and model results under current versus future climate conditions, focusing on the relationship between stress conditions and the annual water budget. Group 2 first worked on a configuration with only the natural component (to reduce the carbon footprint), then attempted to reduce exfiltration by reintroducing the Vertuo© module, and ultimately sought to reduce overflow events by enhancing ET. The third group focused on vegetation physiology through hydric stress indicators, examining the partitioning between the Vertuo© and natural modules and, in a second step, the influence of soil type. The last group sought to reduce periods of hydric stress particularly dry days, in order to limit irrigation needs. They tested configurations using only the Vertuo© module, as well as different drain heights, soil types, and vegetation coefficients.

Because multiple strategies were explored, the approach cannot be reduced to the identification of a single optimal solution. Instead, Table I illustrates the diversity of configurations tested and the associated hydrological trade-offs. The strategies aimed at limiting exfiltration and overflow were confronted with the difficulty sometimes the near impossibility of enhancing ET because of the natural limitation imposed by PET (especially under the Paris climate). Dry days appeared as a significant issue across many of the tested scenarios, particularly in Athens, even though these same scenarios also exhibited substantial saturation periods, which can also be harmful to plants. The link between storage strategies and exposure to stress conditions was also highlighted, revealing the challenging balance between dry and saturated states. Two groups noted that modifications to the design parameters produced only limited improvements, especially regarding the overall water budget, leading some participants to doubt the possibility of identifying an acceptable solution. One group even suggested that changes in the fundamental design principles might be necessary, although without certainty regarding the potential outcomes.

Table 1: Results for scenarios tested during the workshop. The reference scenario uses a silty clay loam soil, equal Vertuo© and natural surface areas, and the current climate of Athens, and drain high of 280 mm; all other scenarios differ by a single parameter change. ET, exfiltration, and overflow are expressed as percentages of total inflow (rainfall + runoff). Extreme conditions are reported through the number of dry and saturation days in both the Vertuo (VTU) and natural areas (NAT). For each indicator, blue indicates the maximum value and green the minimum.

Scenario	Rainfall / PET (in mm/year)	ET (%)	Exfiltration (%)	Overflow (%)	Dry days (VTU, NAT)	Saturation days (VTU, NAT)
Reference	388/1109	0.34	0.27	0.39	(57,90)	(24,182)
Only Vertuo© module	388/1109	0.42	-	0.57	(38, -)	(140, -)
Only Natural module	388/1109	0.19	0.0	0.81	(-, 171)	(-, 3)
Athens Future climate	220/1361	0.48	0.23	0.28	(149,155)	(10,122)
Paris climate	601/ 690	0.18	0.42	0.39	(0, 0)	(75, 336)
Paris Future climate	644/944	0.23	0.37	0.39	(0,0)	(77, 347)
Sandy soil type	388/1109	0.31	0.38	0.31	(63, 132)	(23, 0)
Drain high of 250 mm	388/1109	0.36	0.25	0.38	(63, 23)	(23,175)

All groups also provided feedback on the tool, addressing both its user interface—with suggestions for enhanced visualisation (not shown here) and its underlying modelling framework. They noted that certain model components could be improved, in particular by incorporating a physical model to more accurately represent vegetation responses under water stress conditions. In addition, one group recommended including the ET/PET ratio in the outputs as a diagnostic indicator to support design optimization.

5 CONCLUSION AND PERSPECTIVES

In support of the operational work of the City of Paris within the GreenStorm project, a conceptual model and tool were developed to assist in the design of an innovative multifunctional NbS that horizontally couples a lined storage module and a natural one. The use of the numerical tool by twenty experts in a workshop illustrated its practical relevance, by enabling users to explore different design options and climate conditions, as well as the challenges in identifying an optimal solution, including potential contradictions between the corresponding objectives. The work represents a first step towards a more global approach to the design and management of innovative, climate-resilient NbS systems adapted to diverse contexts. While the present work does not address model adequacy and uncertainties, current efforts within GreenStorm project are focused on developing a robust modelling framework, evaluated across a variety of NbS, to simulate their behaviour under climate extremes.

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