Can it be this simple? Three soil-based NBS-elements for aboveground management of roof runoff demonstrated in Copenhagen

Est-ce vraiment si simple ? Trois éléments de NBS à base de sol pour la gestion aérienne du ruissellement de toiture, démontrés à Copenhague

Marina Bergen Jensen [a], Emilia Danuta Lausen [a*], Ulrik Hindsberger [b],

a Department of Geosciences and Natural Resource Management, Landscape Architecture and Planning – Design, University of Copenhagen - *emze@ign.ku.dk
b Danish Technological Institute

RÉSUMÉ

En utilisant l'énergie potentielle des pluies de toiture, les eaux pluviales peuvent être acheminées par gravité vers des NBS aériennes et non intrusives, permettant une gestion compacte et sans excavation, même lors d'événements extrêmes. Depuis 2019, cette approche, dite NBS d'eaux pluviales sous pression, est démontrée dans le Green Climate Screen de Copenhague, qui gère une toiture de 240 m² tout en servant de barrière acoustique. Cet article présente la conception, la construction et les premières performances de trois éléments : le *Rain Dyke*, le *Rain Mound* et le *Raised Rainbed*, installés dans une cour résidentielle et recevant le ruissellement de trois toitures (≈190 m²). Une méthode de dimensionnement en trois points équilibre stockage quotidien, évapotranspiration, infiltration jusqu'au niveau de service et stockage temporaire lors d'événements centennaux. Tous les éléments sont fondés sur le sol, garantissant un bilan pédologique positif ou nul. L'acheminement utilise des tubes en PE résistants au gel et un filtre en laine minérale. Les observations confirment l'efficacité du sol comme éponge et matériau de construction dans les NBS basées sur l'évaporation, ainsi que leur intégration harmonieuse dans les espaces de loisirs. Le suivi continu documentera le bilan hydrique et l'entretien. La démonstration souligne le potentiel de cette approche comme solution évolutive, bas carbone et économique pour les villes denses.

ABSTRACT

By using the potential energy of rooftop rainfall, stormwater can be gravity-conveyed into aboveground, non-invasive NBS_{sw}. This enables space-efficient, no-dig management of even extreme events. Since 2019, the approach, which is known as pressurized stormwater-NBS, has been demonstrated in Copenhagen's Green Climate Screen, which manages a 240 m² roof while doubling as a noise barrier. This paper describes the design, construction, and early performance of three novel elements for pressurized stormwater-NBS: the Rain Dyke, the Rain Mound, and the Raised Rainbed, implemented in a residential courtyard and receiving runoff from three roofs (≈190 m²). A three-point sizing method balances daily storage with evapotranspiration, infiltration up to the service level, and temporary aboveground storage for 100-year events. All elements are soil-based, maintaining a positive or even zero soil balance. The conveyance system uses frost-tolerant PE tubing and a mineral-wool filter. Observations confirm soil's suitability as a sponge and construction material in evaporation-based-NBS and show seamless integration into residents' recreational areas. Continued monitoring will document water balance and maintenance. The demonstration highlights pressurized stormwater-NBS as a scalable, low-carbon, low-cost solution for dense cities.

KEYWORDS

nature-based stormwater management; the rain dyke, the rain mound, the raised rainbed, pressurized conveyance

1 INTRODUCTION

Despite nearly two decades of attention to nature-based stormwater management (NBS_{sw}) in Denmark, climate adaptation of cities to more extreme precipitation is still largely dominated by conventional pipe-based capacity upgrades (Municipality of Copenhagen, 2024). To position NBS_{sw} as the preferred climate adaptation pathway, several technical and governance-related barriers must be overcome (Martin *et al.*, 2025; Zarei and Shahab, 2025). A key technical barrier is the restricted space in existing cities, limiting the use of e.g. curb extensions in streets and rain gardens in courtyards, despite their aesthetical and ecological co-benefits (Bjørn and Howe, 2023).

With the invention of the Green Climate Screen (Lausen et al., 2022) a new category of space-efficient NBS_{sw} has emerged. By using gravity-driven conveyance in a pressurized pipe, exploiting the principle of communicating vessels, rooftop stormwater can be managed in aboveground vertical configurations, allowing for evapotranspiration to dominate the annual water balance, and for extreme events to be detained on multifunctional neighbouring areas (Figure 1).

This paper presents new designs of aboveground evaporation-based NBS_{sw} for T = 1 y events (15 mm) with the combined capacity to handle extreme events (T = 100 y events (90 mm) by means of infiltration.

2. METHODS

The new elements jointly create a complete stormwater solution for Zone A, a part of the 0.4 ha Copenhagen courtyard designated as demonstration area for aboveground NBS_{sw} (Figure 1). The courtyard is bordered by approximately 0.2 ha of roofs, connected to the public combined sewer through 40 downpipes. Zone A now manages stormwater from 190 m² of roof area, captured by four of these downpipes (Figure 1). The solution emerged from a landscape design process aimed at creating a cohesive and holistic courtyard that responds to residents' needs while meeting technical hydrological requirements, as defined by the Three Points Approach (3PA) (Fratini *et al.*, 2012; Randall *et al.*, 2025). In addition, the design process incorporated selection of construction methods and materials to ensure a low carbon footprint, integrating environmental responsibility with functional and aesthetic objectives.

3. RESULTS

The landscape design of the stormwater management system follows the minimal impact approach. To limit the disruption to the recreational lawn in Zone A, commonly used by residents for barbecues and chess, the stormwater features were placed along the outer edges of the area. Their positioning follows the natural curves of the space, preserves the root zones of existing trees, and enhances the sense of an enclosed and safe environment (Figure 1).

The stormwater scheme consists of the Rain Dike, the Rain Mound and the Raised Rainbed (Figure 2). All elements are built from mineral soil and dimensioned in accordance with the 3PA to: (1) store and evapotranspire everyday rain (15 mm, T = 1 y) assuming a 25 % volumetric water holding capacity of the soil, (2) to infiltrate technical rain I (additional 35 mm, T = 10 y) assuming a saturated hydraulic conductivity of the soil beneath and next to the elements of 10^{-6} m/s, and (3) to retain technical rain II (additional 40 mm, T = 100 y) on the lawn by means of the Perimeter Dike, allowing the lawn to be turned into an aboveground basin, and to divert extreme events (> 90 mm, T > 100 y) towards public street by a controlled overflow in the Perimeter Dike. The treatment train thus consists of evapotranspiration of everyday rain, infiltration of technical rain, and safe diversion of extreme rain.

The simple principles for the conveyance system and runoff utilization mechanism are illustrated in detail for the Rain Dike in Figure 3, right. Details on the connection of the downpipe to the pressurized conveyance system is illustrated in Figure 3, left.

While the Rain Dike and the Rain Mound are both constructed from uncontaminated excess soil obtained from a soil waste facility, the Raised Rainbed is created by reconfiguring the local soil: the bottom of the raingarden is lowered, and the excavated soil used to build the surrounding dike, resulting in a net-zero soil balance.

Figure 1: Overview. Left: Demonstration courtyard with roofs to be connected to aboveground NBSsw (dotted line); Right: Stormwater scheme for Zone A with Rain Dike, Rain Mound, Raised Rainbed and 100-y Perimeter Dike (light green line).

Figure 2: Left: Photo of the Rain Dike, receiving runoff from 45 m^2 of roof. Middle: Photo of the Rain Mound, receiving runoff from 65 m^2 of roof. Right: Raised Rainbed, receiving stormwater from 80 m^2 of roof. Flow marked with blue arrows.

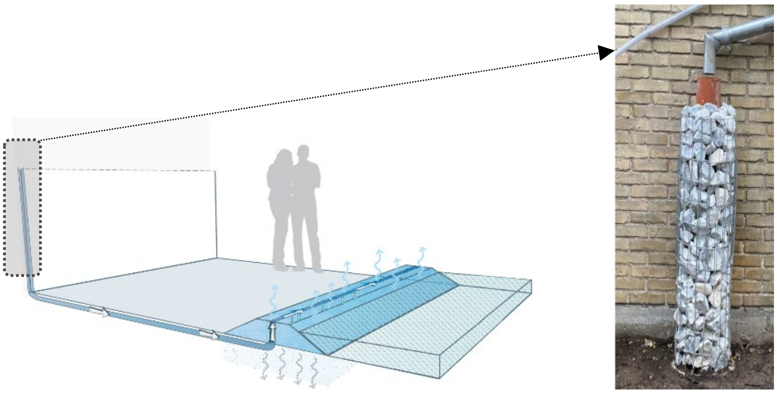

Figure 3: Left: Gravity based stormwater management principle. Right: Photo of element for pressurized conveyance. A mineral wool filter is inserted in the red tile pipe. The stone filled gabion serves aesthetical purposes and hides a 50 mm PE-tubing with good frost resistance.

4. DISCUSSION

With pressurized NBS_{sw}, the resulting aboveground solutions can effectively overcome typical urban constraints: insufficient space, limited volume capacity, and conflicts with underground utilities. The ability to shape elements vertically and horizontally and the advantage of double programming of areas offers architectural flexibility. This enables non-invasive interventions that can be implemented by small landscaping companies and entrepreneurs. Compared with conventional belowground and depression-based systems, the pressurized approach reduces CO_2 footprint, avoids deep excavation in the urban landscape, and simplifies maintenance. However, some aspects require attention: sensitivity to inlet blockage (though this is likely mitigated with the mineral wool filter), the need for careful level-setting of perimeter dikes, and potential frost risks if unsuitable materials are chosen.

Future work should include long-term hydraulic monitoring to establish the impact of local water balance, including particularly seasonal evapotranspiration measurements, and evaluation of resident engagement with multifunctional green spaces.

5. CONCLUSION

Pressurized conveyance opens the door to robust, low-cost, low-carbon and flexible climate adaptation in dense urban areas. With aboveground design and double programming of areas, the range of design options is manifold. The elements demonstrated in Copenhagen confirm that simple soil-based constructions can manage extreme storms, while integrating seamlessly into community green spaces, without the need to import or export soil, but relying on terrain reconfiguration. This approach shows strong potential for broader urban application and scalable nature-based climate adaptation strategies.

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