

## Groundwater Drawdown and High-Rise Stormwater Harvesting for Urban Irrigation: Implementing Blue-Green Infrastructure in Frankfurt

### Rabattement de la nappe phréatique et collecte des eaux pluviales en hauteur pour l'irrigation urbaine: mise en œuvre d'infrastructures bleues-vertes à Francfort

Carlo Morandi<sup>1</sup>, Heidrun Steinmetz<sup>2</sup>

<sup>1</sup> Chair for Resource Recovery from Wastewater, RPTU University of Kaiserslautern-Landau, Germany (carlo.morandi@rptu.de); <sup>2</sup> Chair for Resource-Efficient Wastewater Technology, RPTU University of Kaiserslautern-Landau, Germany (heidrun.steinmetz@rptu.de)

#### RÉSUMÉ

La végétation urbaine souffre de plus en plus des effets négatifs liés au changement climatique, tels que le stress hydrique, ce qui diminue considérablement les services écosystémiques. Pour maintenir ces fonctions, l'irrigation artificielle est souvent inévitable, mais dépendre de l'eau potable n'est pas durable. Cette étude de cas à Francfort-sur-le-Main présente une mise en œuvre d'Infrastructure Bleue-Verte où la demande annuelle estimée en irrigation est assurée par des ressources alternatives. Le concept permet de récolter 4 800 m<sup>3</sup>/an d'eaux de ruissellement provenant des toitures et des façades, et utilise entre 10 000 et 35 000 m<sup>3</sup>/an d'eaux de drainage issues d'un rabattement permanent de la nappe phréatique. Comme l'eau de drainage présente une salinité élevée (conductivité > 1000 µS/cm), une stratégie de mélange avec l'eau de pluie est appliquée pour garantir une qualité d'eau adéquate pour l'irrigation. L'intégration d'un réservoir de stockage de 60 m<sup>3</sup> aux côtés du volume de rétention de 480 m<sup>3</sup> du bâtiment permet de substituer jusqu'à 70 % de l'eau potable. Cette approche améliore non seulement la résilience, mais réduit également les coûts opérationnels en minimisant les frais de rejet des eaux usées. À ce jour, le projet a reçu son avis de subvention de la ville de Francfort, faisant passer cette approche de gestion circulaire de l'eau du concept à la mise en œuvre.

#### ABSTRACT

Urban vegetation increasingly suffers from negative climate change-associated effects, e.g. drought stress, significantly diminishing ecosystem services. To sustain these functions, artificial irrigation is often unavoidable but relying on potable water is not sustainable. This case study in Frankfurt am Main presents a Blue-Green Infrastructure implementation where the estimated annual irrigation demand is secured through alternative resources. The concept yields 4,800 m<sup>3</sup>/year of harvested stormwater runoff from roofs and building facades and utilizes 10,000–35,000 m<sup>3</sup>/year of drainage water discharged from a sustained groundwater drawdown. As the pumped water from the groundwater drawdown exhibits elevated salinity (conductivity >1000 µS/cm), a blending strategy with rainwater is applied to ensure adequate irrigation water quality. Integrating a 60 m<sup>3</sup> storage tank alongside the building's 480 m<sup>3</sup> retention volume allows for a drinking water substitution of up to 70%. This approach not only enhances resilience but also reduces operational costs by minimizing wastewater discharge fees. As for now, the project has received its grant approval from the City of Frankfurt, transitioning this circular water management approach from concept to implementation.

#### KEYWORDS

Blue-Green Infrastructure, Climate Adaptation, Permanent Groundwater Lowering, Stormwater Harvesting, Urban Irrigation

---

## 1 INTRODUCTION

Climate change is accelerating the frequency of extreme weather events, including prolonged periods of drought and heatwaves, which severely threaten urban ecosystems (Brunetti et al., 2024). Urban trees, critical for mitigating the Urban Heat Island effect and providing biodiversity corridors, are increasingly susceptible to hydraulic failure and metabolic stress under these conditions (Savi et al., 2024). Consequently, artificial irrigation is becoming essential to preserve urban green infrastructure. However, relying on potable water is unsustainable as water scarcity affects already over 11% of the European population, a figure expected to rise (European Commission, 2024).

Recent literature emphasizes the transition towards a Circular Economy in the water sector, advocating for the reuse of non-conventional water sources to close the urban water loop (Frijns et al., 2024; Smol et al., 2025). While the reuse of treated wastewater is currently widely discussed (Kakwani & Kalbar, 2024) – driven notably by the new EU Regulation on Water Reuse (2020/741) which focuses almost exclusively on treated wastewater – other local sources remain underutilized. Specifically, drainage water from Permanent Groundwater Drawdown, which is often required for building protection in high groundwater tables, is frequently discharged into sewer systems, wasting a valuable resource derived largely from infiltrated stormwater.

This study presents a case study in Frankfurt am Main where PGL water, combined with harvested stormwater runoff from high-rise roofs and facades, is used for irrigation. This aligns with recent calls for "Water-Sensitive Urban Design" that integrates multiple water sources—freshwater, stormwater, and drainage—to enhance climate resilience (Balkrishna et al., 2024).

## 2 THE FRANKFURT WALLANLAGEN CASE STUDY

The "Wallanlagen" (rampart gardens) encircle Frankfurt's city center as a vital green corridor. Currently, the "Taunusanlage" section relies on a 25-year-old irrigation system fed exclusively by potable water. This practice is increasingly unsustainable given Frankfurt's severe hydrological imbalance: Frankfurt am Main consumes approximately 400% more drinking water than it can produce within its own municipal boundaries (Harting, 2016; Michels, 2014). Consequently, the city is heavily dependent on long-distance water imports from surrounding regions, specifically the Hessisches Ried, Kinzigtal, and Vogelsberg (Harting, 2016).

However, groundwater availability in these external extraction areas is also declining due to climate change impacts, leading to ecological stress and potential conflicts over resource allocation. To secure the water supply for the park's green areas and trees without exacerbating this regional strain on drinking water reserves, a project was initiated to substitute potable water with local alternative sources (Morandi et al., 2023).

### 2.1 Identification of Stormwater-Derived Resources

Two primary water sources were identified, both intrinsically linked to the urban catchment's precipitation:

- **Drainage Water from Sustained Groundwater Drawdown:** The groundwater drawdown system at a high-rise building site continuously pumps (shallow) groundwater to protect the building structure. In urban hydrology, this water is heavily recharged by infiltrated stormwater and is currently discharged unused into the combined sewer system.
- **Roof and Facade Runoff (Stormwater Harvesting):** Rainwater from the roofs and facades of the adjacent planned high-rise is captured. This resource is of high quality but discontinuously available.

## 3 WATER QUALITY AND BLENDING STRATEGY

### 3.1 Quality Assessment of PGL Drainage Water

A critical step in the feasibility study was the detailed assessment of the PGL drainage water quality. A measurement campaign was conducted to evaluate its suitability for irrigation against established standards, specifically DIN 19684-10 (2009; German standard for irrigation water) and ISO 16075-1 (2020).

An extract of the parameters analyzed is presented in Table 1. The results indicate that while many parameters are within acceptable ranges, the water exhibits elevated salinity markers.

Table 1: Detailed water quality parameters of the PGL Drainage Water compared to irrigation standards (Source: adapted from Ludwig et al., 2021; Morandi et al., 2023).

Parameter	Unit	Mean Value ± SD (Min to Max)	DIN 19684-10 Limit	ISO 16075-1 Limit
pH-Value	-	7.5 ± 0.1	6.0–8.0	-
Electrical Conductivity	µS/cm	1041 ± 159	300–800	< 1,400
COD (dissolved)	mg/l	(>15 to 18)	< 0 (COD total)	-
Chloride	mg/l	121 ± 14	< 70	< 250
Sulfate	mg/l	211 ± 24	< 250	-
Sulfide (dissolved)	mg/l	(<0.04)	< 0.5	-
Ammonium-N (NH4–N)	mg/l	(<0.04 to 0.15)	< 1	-
Borate	mg/l	0.08 ± 0.03	< 1	-
Sodium	mg/l	63 ± 6.8	< 30	< 150
SAR	(mmol/l) <sup>0.5</sup>	2 ± 0.2	0–6	-

As can be inferred from Table 1, the electrical conductivity, chloride, and sodium concentrations exceed the strict limits of the German DIN 19684-10 (2009), although they generally fall within the broader limits of the international standard ISO 16075-1. While direct, short-term application might be tolerable under ISO standards, long-term application poses a risk of secondary soil salinization and damage to salt-sensitive urban vegetation (Zhang et al., 2025; Gao et al., 2025). Conversely, problematic substances often found in deeper groundwater in Frankfurt, such as sulfide, were not found in critical concentrations in this shallow PGL water.

### 3.2 The Blending Concept

To mitigate the salinity risk without implementing energy-intensive desalination technologies (like reverse osmosis), a blending strategy was developed. By mixing the saline PGL water with the low-salinity harvested stormwater (or drinking water as a backup), the electrical conductivity is reduced to plant-compatible levels. The concept is depicted in Figure 1.

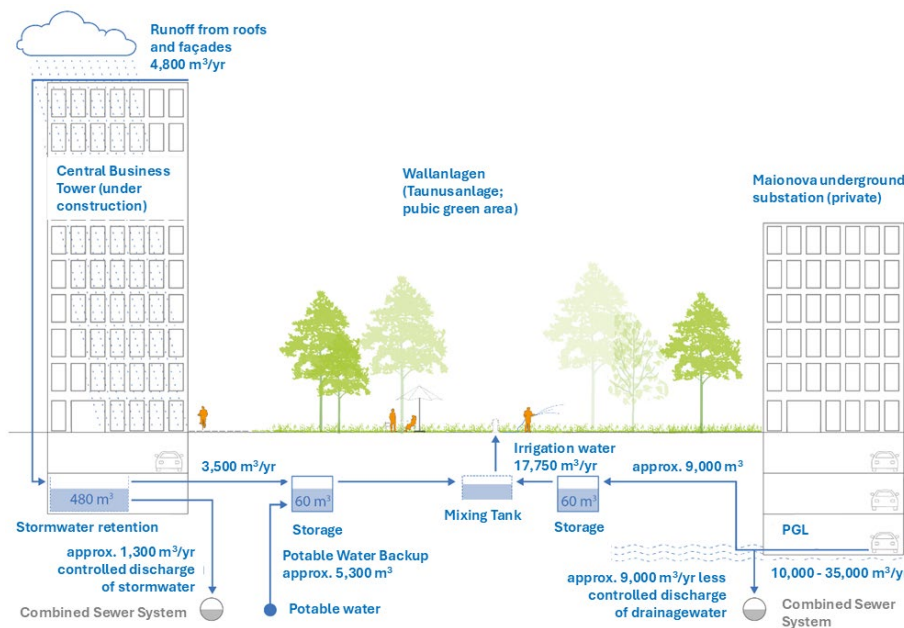


Figure 1: Irrigation concept for public green spaces combining drainage water from the sustained groundwater drawdown (permanent groundwater lowering ; PGL) and stormwater runoff from high-rise roofs and façades.

---

Calculations indicate that a mixing ratio of 40% rainwater to 60% drainage water is required to safely meet irrigation standards. This approach effectively dilutes the critical parameters identified in Table 1.

## 4 TECHNICAL IMPLEMENTATION AND REALIZATION

### 4.1 The Blending Concept

To manage the temporal mismatch between the continuous (but variable) PGL supply, the intermittent stormwater supply, and the seasonal irrigation demand, storage capacity is required, as illustrated in Figure 1:

- A 480 m<sup>3</sup> retention tank collects the building's stormwater runoff.
- An additional 60 m<sup>3</sup> storage tank is dedicated to the blending process, decoupling supply from peak demand.

This system allows for a potential substitution of up to 70% of drinking water previously used for irrigation.

### 4.2 From Concept to Implementation

Building upon the concept initially developed during the research project INTERESS-I, funded by the German Ministry for Education and Research, the initiative has now successfully moved into the realization phase. The Parks and Green Spaces Office of the City of Frankfurt has officially secured significant funding for the implementation. The project, titled "Tanusanlage Blau-Grüne Infrastruktur," received a federal grant from the "Adaptation of Urban and Rural Areas to Climate Change" program, covering approximately 75% of the total project costs. With this funding secure (received in July 2025), the project is set to construct a small underground "waterworks" in the Tanusanlage.

Construction is planned to begin in late 2026, finishing in 2028. This facility will integrate two new cisterns (170 m<sup>3</sup> for rainwater and 60 m<sup>3</sup> for drainage water) beneath existing paved surfaces to store and blend the water sources. The implementation will build a new underground cistern for stormwater instead of using the building's internal retention tank. Once operational, the system is expected to replace approximately 12,900 m<sup>3</sup> of drinking water per year, establishing the site as a lighthouse project for climate adaptation (Biener, 2025).

This transition establishes the site as a lighthouse project for integrating PGL water into urban stormwater management strategies, proving that drainage water can be re-valued as a resource for climate adaptation rather than a burden on wastewater infrastructure.

## LIST OF REFERENCES

- Balkrishna, A. et al. (2024). Circular economy policies for water and wastewater. *Water Policy*, 27(10).
- Biener, B. (2025). Gießwasser vom Hochhaus (*German: Irrigation Water from the High-Rise*). *Frankfurter Allgemeine Zeitung*.
- Brunetti, C. et al. (2024). Phenotypic plasticity of urban trees under water stress. *Conservation Physiology*, 8(1).
- DIN 19684-10 (2009). *Bodenbeschaffenheit - Chemische Laboruntersuchungen - Teil 10: Untersuchung und Beurteilung des Wassers bei Bewässerungsmaßnahmen*.
- EC (2014). European Commission: Eine grüne Infrastruktur für Europa (*German: A green Infrastructure for Europe*).
- EU (2020): EU Regulation on Water Reuse (2020/741).
- Frijns, J. et al. (2024). Recommendations for circular water management. *International Journal of Water Resources*.
- Gao, Y. et al. (2025). Optimizing Irrigation and Drainage Practices to Control Soil Salinity. *ResearchGate Preprint*.
- Kakwani, N. & Kalbar, P. (2024). Review of 5Rs in water recycling. *Journal of Environmental Management*.
- Kowarik, I., Bartz, R. & Brenck, M. (Eds.) (2016). *Ökosystemleistungen in der Stadt – Gesundheit schützen und Lebensqualität erhöhen (German: Ecosystem Services in the City – Protecting Health and Enhancing Quality of Life)*. Naturkapital Deutschland-TEEB DE.
- Ludwig, F. et al. (Eds.) (2021). *Integrierte Planung blau-grüner Infrastrukturen – Ein Leitfaden (German: Integrated Planning of Blue-Green Infrastructures – A Guideline)*. Technische Universität München.
- Morandi, C., Well, F., Ludwig, F. & Steinmetz, H. (2023). Bewässerung städtischer Vegetation mit alternativen Wasserressourcen: Fallstudie Wallanlagen in Frankfurt am Main (*German: Irrigation of Urban Vegetation with Alternative Water Resources: Case Study Wallanlagen in Frankfurt am Main*). *ANLiegen Natur*, 45(2).
- Potz, H. (2016). *Green-blue grids: Manual for resilient cities*. atelier GROENBLAUW.

- Savi, T. et al. (2024). Drought-induced dieback of urban trees: mechanisms of hydraulic failure. *Conservation Physiology*, 7(1).
- Smol, M. et al. (2025). Transitioning to circular management in the water and wastewater sector. *Journal of Cleaner Production*.
- Zhang, L. et al. (2025). Effects of Continuous Saline Water Irrigation on Soil Salinization Characteristics. *MDPI Agronomy*, 15(8).