# Influence of soil and vegetation cover in the hydrological performance of bioretention cells in cold maritime climate

## Influence du sol et du couvert végétal sur les performances hydrologiques de la bioremédiation en climat marin froid

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## RÉSUMÉ

La mise en place de bassins de biorétention en climat froid peut être compromise par le gel et la neige en hiver. Bien que la texture du sol influence souvent leurs performances, la littérature suggère que les cycles fréquents de gel-dégel entraînent des modifications structurelles, tandis que l'infiltration et le développement des systèmes racinaires peuvent créer des voies d'infiltration préférentielles. Cette étude vise à évaluer les performances de bassins de biorétention recouverts d'une végétation diversifiée (arbustes et herbacées) par rapport à ceux recouverts d'une végétation dominée par le gazon, en climat froid. Quatre bassins de biorétention pilotes ont été construits et testés à Reykjavik, en Islande, lors d'une campagne de terrain menée de décembre 2024 à décembre 2025, avec 25 épisodes de pluies synthétiques équivalents à une période de retour de 1 à 2 ans. Les bassins recouverts d'arbustes et d'herbacées ont permis d'obtenir des réductions de débit de pointe légèrement supérieures à celles des bassins recouverts d'une végétation dominée par le gazon. Cependant, cette amélioration des performances hivernales s'est faite au détriment de temps de latence plus courts, ce qui pourrait impacter l'efficacité du traitement dans des applications pratiques. Tous les systèmes de biorétention ont présenté des performances adéquates en conditions hivernales, malgré le gel et la neige. Les résultats présentés s'inscrivent dans le cadre d'une recherche en cours.

## ABSTRACT

Bioretention cell implementation in cold climates can be detrimentally affected by frost and snow covers in winter. Although soil texture often determines their performance literature suggests structural changes caused by frequent freeze-thaw cycles, frequent infiltration and root systems can create preferential infiltration paths. In this study, we seek to assess the performance of bioretention cells with functionally diverse turf cover (shrubs & forbs) against those with a grass-dominated turf cover in cold climate. Four pilot-scale bioretention cells were built and tested with 25 synthetic stormwater events equivalent to 1–2 year return period in the city of Reykjavík, Iceland in a field campaign from December 2024 to present date (December 2025). Bioretention cells with shrubs & forbs turf covers reached slightly higher peak-flow reductions than those with grass-dominated turf covers. However, this increase in winter performance came at the cost of shorter delay times that could potentially impact treatment performance in practical applications. All the bioretention systems showed adequate performance during winter conditions in the presence of frost and snow cover. The results presented are part of an ongoing research.

## KEYWORDS

Bioretention, cold climate, stormwater, SUDS, turf

# 1 INTRODUCTION

The development of urbanization increases impervious areas contributing to surface runoff which coupled with intensifying weather exerts additional pressure in stormwater management structures (Shuster, et al. 2007). Such impacts can be deterred by the implementation of Low Impact Developments such as bioretention cells (Dietz and Clausen 2008). Although texture of the filter media, which determines storage-related parameters, has been studied extensively, it relies on the assumption of uniform pore space distribution (Skorobogatov, et al. 2020). Nonetheless, the ultimate available pore space and shape, which contributes to infiltration and reactivity, is rather determined by soil structure instead of texture (Skorobogatov, et al. 2020). This is particularly important in cold climates where different types of frost can form depending on the porosity and moisture of the soil (Muthanna, Viklander and Thorolfsson 2007). While all types of frost usually decrease infiltration compared to unfrozen conditions, porous frost allows for higher infiltration rates compared to concrete frost because of their different structures (Stoecker and Weitzman 1960). In a similar way, soil structure alterations by successive frost-thaw cycles (Ding, et al. 2019) and/or deep root systems (Zaqout, Andradóttir and Arnalds 2022) can prove beneficial for infiltration in cold climates. Thus, the present study focuses on determining the and effect of initial soil conditions a functionally diverse turf cover (deep root system) in bioretention cell performance in cold climate compared to bioretention cells with a grass-dominated turf cover (shallow root system).

# 2 METHODS

## 2.1 PILOT-SCALE BIORETENTION CELLS

Four raised bioretention cells were built on the campus of the university of Iceland. The area of each cell was 1.20 m2 using 45 cm deep loamy sand media obtained from a local supplier. As it is common in cold climate regions, the soil media was selected because of its high hydraulic conductivity which allows for proper infiltration capacity (Kaus, Muthanna and Braskerud 2016). Laboratory tests were carried out to characterize the soil as a loamy sand (according to ASTM D422-63(2007)), determine its bulk density (1.11 – 1.48 g/cm3), and saturated hydraulic conductivity (0.91 – 1.10 m/h). A 25 cm deep gravel drainage layer was set below the soil media with the respective drainage pipe (DN 75 mm, S = 5.00%). The bioretention cells were divided in pairs, that is, two cells with a 5 cm grass dominated turf cover and the next pair with functionally diverse turf cover (grass turfs + forbs & shrubs). Each cell was equipped with three water content reflectometers located at 5, 15, and 35 cm of depth into the soil media to continuously monitor moisture content and temperature (type CS650, Campbell Scientific Inc., accuracy ± 1%,). As the bioretention cells were built above ground level, rock wool and cladding were used as insulators to replicate underground conditions.

## 2.2 SYNTHETIC RUNOFF EVENTS

Synthetic runoff events were selected instead of natural rainfall events because of the high magnitude-dependency and variability of performance in similar field studies (Nazarpour, Gnecco and Palla 2023). The four bioretention cells were tested using a 2 hour long 0.2 l/s event representing a 1–2 year return period for a 1% infiltration area ratio for the city of Reykjavík with a catchment area of 120 m2 (Af/Ai = 1%). The experiments started in December 2024 and are still ongoing with a biweekly frequency. Each event was classified into neutral, snow and frost depending on the initial surface and soil conditions throughout the seasons (figure 1).


Figure 1 Vegetated cover of the functionally diverse turf cells throughout the first year of measurements; Spring 2024 (leftmost); Fall 2024 (left); Winter 2024 (right); Spring 2025 (rightmost)

The runoff was applied using a constant-head elevated tank that delivered the water into two ½ inch diameter hoses with 0.78 cm2 holes spaced every 15 cm (figure 2). The water level in the tank was recorded using a pressure transducer (Solinst 3001, 5m range, accuracy ± 0.05 % of full range) while ensuring such level remained constant for a uniform inflow during the events. The outflow of each cell was equipped with 45-degree v-notch weirs with pressure transducers to collect outflow data (figure 2). To ensure accuracy in the measurements, the water level was also measured every 10 minutes using a measuring tape during each synthetic runoff event.

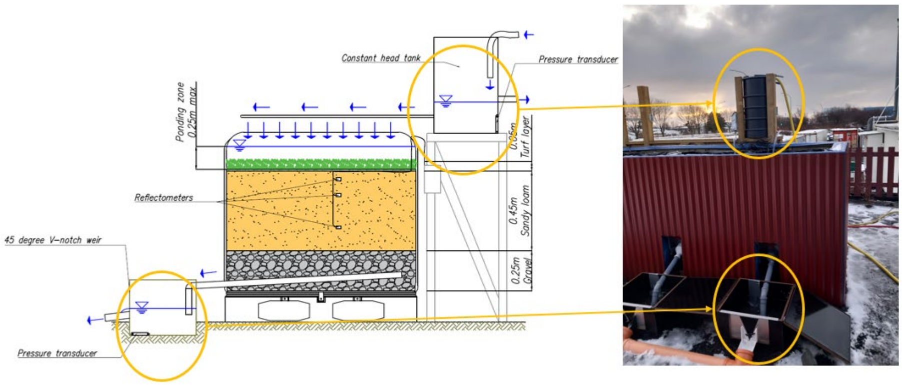


Figure 2 Descriptive diagram of the experimental setup; design drawing (left),field picture (right)

## 3 PRELIMINARY RESULTS

During the experimental period from December 2024 to November 2025, 14 neutral events, 6 snow events, and 5 frost events were recorded with the upcoming winter season of 2025 – 2026 expected to deliver relevant data in frost and snow events. The performance was evaluated by determining their peak flow reduction, volume reduction, delay time, and drainage capacity. During non-frozen conditions (Neutral, March 2025 – September 2025, Figure 3), both pairs of cells showed similar performance, with maximum peak flow reduction of around 50% with the cells with diverse turf reaching 54%. The bioretention cells with shrubs & forbs slightly outperformed the pair with a grass turf cover which could be attributed to such pair having a consistent lower initial moisture content. A considerable range in performance was observed. During winter frost, a similar behaviour was observed, the frost observed was granular allowing infiltration as opposed to concrete frost. Lastly, the peak flow reduction was consistently lower during events with 3 – 34 cm deep snow cover, and again the cells with functionally diverse turfs slightly outperforming the others while performing significantly better in deep snow covers of 20 – 30 cm (figure 4). Overall, these initial results suggest that the bioretention cells are performing well in winter. The addition of forbs and shrubs does not seem to add any significant benefits to the hydrological performance for practical applications.

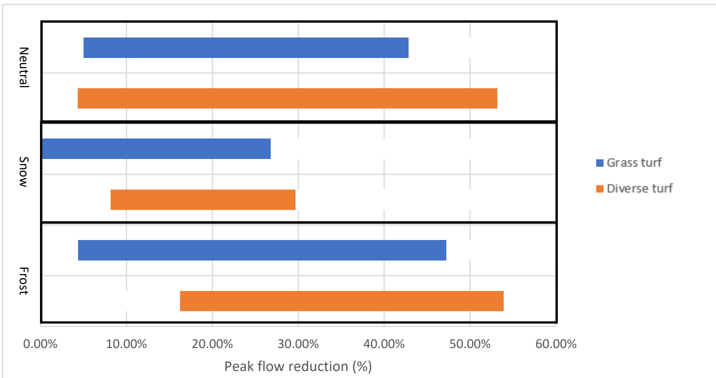


Figure 3 Peak flow reduction range observed in the field campaign; neutral (top); snow cover (middle); frost (bottom)

This increased performance trend was also observed in terms of volume reduction where the bioretention cells with diverse turfs performed better. Nonetheless, the delay times (difference between hydrograph centroids) were shorter by around 10 minutes (figure 4). Although the difference in delay time was not overly pronounced in the study it might prove detrimental for water quality purposes (Furén 2025) in practical applications with potential higher density of deep-rooted vegetation or by the formation of preferential paths through long-term use.

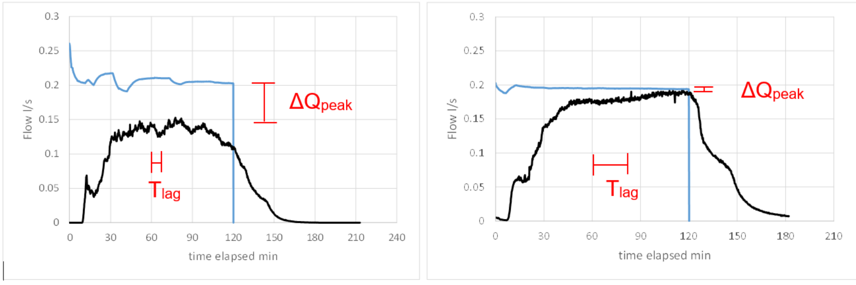


Figure 4 Hydrographs from an event on the 30th of October 2025 snow (30 cm) event illustrating differences in peak flow reduction and delay time; diverse turf cover (left); grass dominated turf cover only (right); Inflow (blue); outflow (black)

## 4 CONCLUSIONS

- The preliminary results suggest that the effect of using functionally diverse turf covers could have a minor improvement on the performance of bioretention cells in cold climate as it has been suggested in the literature pointing out that their deep-rooted systems affect the structure of the underlying filter media.
- All of the bioretention systems showed adequate performance during winter conditions indicating the systems were resistant to the formation of concrete frost. The systems performed at worse during snow events with depths above 20 cm in the pair with grass dominated turf cover where they did not provide significant peak flow reductions.

## LIST OF REFERENCES


Dietz, Michael E., y John C. Clausen. (2008). *Stormwater runoff and export changes with development in a traditional and low impact subdivision*. Journal of Environmental Management., 87(4), 560-566.

Ding, Brenden, Fereidoun Rezanezhad, Behrad Gharedaghloo, Philippe Van Cappellen, y Elodie Passeport. (2019). *Bioretention cells under cold climate conditions: Effect of freezing and thawing on water infiltration, soil strucutre, and nutrient removal*. Science of the Total Environment., 649, 749-759.

Furén, Robert. (2025). *Stormwater bioretention systems: Water quality treatment and long-term pollutant accumulation*.

Kaus, Kim H, Tone M. Muthanna, y Bent C. Braskerud. (2016). *The hydrological performance of bioretention cells in regions with cold climates: seasonal variation and implications for design*. Hydrology Research., 47(2), 291-304.

Muthanna, T. M., M. Viklander, y S. T. Thorolfsson. (2007). *Seasonal climatic effects on the hydrology of a rain garden*. Hydrological Processes., 2(11), 1640-1649.

Nazarpour, Shaahin, LLaria Gnecco, y Anna Palla. (2023). *Evaluating the Effectiveness of Bioretention Cells for Urban Stormwater Management: A Systematic Review*., Water, 15(5), 913.

Shuster, W. D., J. Bonta, H. Thurston, E. Warnemuende, y D. R. Smith. (2007). *Impacts of impervious surface on watersehd hydrology: A review*. Urban Water Journal., 2(4), 263-275.

Skorobogatov, Anton, Jianxun He, Angus Chu, Caterina Valeo, y Bert van Duin. (2020). *The impact of media, plants and their interaction on bioretention performance: A review*. Science of the Total Environment. 715.

Stoecker, J. H., y S. Weitzman. (1960). *Infiltration rates in frozen soil in Northern Minnesota*., Soil Science of America Journal, 24, 137-139.

Zaqout, Tarek, Hrund Ólöf Andradóttir, y Ólafur Arnalds (2022). *Infiltration capacity in urban areas undergoing frequent snow and freeze–thaw cycles: Implications on sustainable urban drainage systems*., Journal of Hydrology, 607,