Urban infiltration in cold climate

Infiltration urbaine en climat froid

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RÉSUMÉ

La mise en œuvre du Système de Drainage Durable Urban dans l'hémisphère Nord est confrontée au problème de baisse d'inflitration pendant l'hiver, en raison des sols gelés. Le but de cette étude était d'évaluer la capacité d'infiltration en hiver des noues et fossés ainsi que des couverts végétaux naturels lors des fréquents cycles de gel-dégel. L'inflitration a été mesurée avec huit infiltromètres à anneau unique, et par l'analyse de mesures continues de la teneur en eau dans le sol à différentes profondeurs, BREEAM garantie le quartier d'Urriðaholt, situé sur une colline aux pentes de 13 à 16%. Les résultats suggèrent que la formation et la capacité d'infiltration du sol ont été influencées par le couvert végétal : une dense couverture herbeuse est efficace quelque soit la saison, alors qu'à travers une vegetation moins dense l'infiltration diminue de 11-54% en hiver par rapport à l'été. Le gel a été mesurée pendant quelques jours dans le sol à une profondeur de 5cm, et du gel inhibant toute infiltration ne s'est pas formé. Les résultats présentés ici font partie d'une étude en cours.

ABSTRACT

The implementation of Sustainable Urban Drainage Systems (SUDS) in the northern hemisphere is confronted with the problem of decreased infiltration during winter because of frozen soils. The goal of this research was to assess the winter infiltration capacity of a grass swale and natural vegetation cover during frequent freeze-thaw cycles. Infiltration was measured with eight single-ring infiltrometers, and by analysing continuous water content measurements in the soil at different depths in the steep (13-16%), BREEAM certified neighbourhood Urriðaholt. Results suggest that frost formation and infiltration capacity were influenced by vegetation cover: dense grass cover performed equally on a seasonal basis, while infiltration through less dense vegetation covers decreased by 11-54% during winter as compared to summer. Frost was measured for a few days at 5 cm depth in the soil, and concrete frost completely inhibiting infiltration did not form. The results presented are part of an ongoing research.

KEYWORDS

Cold climate, infiltration, SUDS, stormwater, snowmelt

1 INTRODUCTION

Urbanisation is exerting increasing pressure on cities and their infrastructure. Additionally, extreme events are expected to increase due to climate change. Thus, the conventional strategies of urban drainage systems are no longer sustainable (Ramos et al., 2017). Sustainable Drainage Systems (SUDS) have gained increasing attention as an alternative or to complement the traditional drainage system (Zhou, 2014). SUDS differ from the conventional underground piping systems by reducing runoff volumes close to source via infiltration, detention, and retention, and by enhancing water quality and recharging the groundwater reserves (Rujner et al., 2016). Nevertheless, the implementation of SUDS in northern cities faces many obstacles. Snow covers on top of frozen or semi-frozen ground can drastically inhibit the infiltration capacity of soils in swales, detention ponds, rain gardens, permeable pavements, and green roofs. In addition to seasonal frost, frequent freeze-thaw cycles have an effect on soil structure by redistributing soil particles, especially in soils with high moisture content (Ding et al., 2019). However, the decrease in the infiltration capacity of soils depends mostly on the type of frost formed in the soil profile. In particular, concrete frost prevents infiltration completely whereas porous or granular frost permits infiltration (Paus et al., 2015).

The goal of this study was to assess the infiltration capacity of grass swales and natural terrains undergoing successive precipitation (250 days per year) and frequent freeze-thaw cycles (10-20 cycles over a snow season), the latter of which is unique in Iceland. Specifically, do frequent whether cycles promote the formation of concrete ice, which drastically decreases permeability. Or, do green surfaces retain their functionality due to the short frost periods and type of frost formed?

2 METHODS

The study area is the developing Urridaholt neighbourhood, in which SUDS were implemented from the beginning in the project's design and planning to protect the water quality of the nearby shallow lake. The site is situated on a hill with very steep terrain, which is unique in the case of SUDS implementation. The neighbourhood is integrated with a network of grass swales and detention ponds designed to recharge the groundwater table, enhance water quality, and to attenuate runoff.

The experimental setup includes eight 22.5 cm in diameter, 40 cm long single ring infiltrometers in four different terrains (Figure 1): S1 and S2 in the grassed swale, L1 and L2 in the lupine field, H1 and H2 in the heath, and B1 and B2 in the barren. The rings were hammered down to 15-17 cm depth perpendicular to the slope of the terrain. A hole was drilled in each ring to prevent water accumulation during winter. The rings were placed 3 m apart in the grass swale and the barren, 2.5 m apart in the lupine field and 5 m apart in the heath. Measurements were conducted monthly in the winter (October to March) and two times during summer at all sites except H2, which had the highest infiltration rate consistently. The heath seemed to have very gravelly underlying strata, reflected in a high difficulty to hammer the ring into the ground. The accuracy of the infiltration experiments involve in maintaining a steady water level, estimated as ±0.1 mm/minute.

Figure 1 Infiltration rings in four vegetation covers: Grass swale (S1, S2); Heath (H1, H2); Lupine (L1, L2); Barren (B1, B2).

The study swale section was instrumented with five water content reflectometer probes (Type CS650 Campbell Scientific, Inc.). Each probe has two parallel sensors 30 cm long. The probes were placed horizontally in the swale at 10-centimetre intervals at 5, 15, 25, 35, and 45 cm depths from the soil surface below the turf layer (Figure 2). Readings were logged by a multiplexer data logger (Campbell Scientific Inc.) every 1 minute. Weather data was obtained from the Icelandic Meteorological Office (IMO).

Figure 2 Setup of the water content reflectometer probes.

3 RESULTS AND DISCUSSION

The infiltration measurements carried out from June to March (**Erreur ! Source du renvoi introuvable.**), show considerable spatial variations: With the exception of one of the heath site (H2), the two lupine sites (L1, L2) had consistently the highest infiltration, while the two barren sites (B1, B2) the lowest. Measurements carried out in June, July, and October showed almost no significant changes in infiltration within each site. These three months were characterised with high precipitation (50-85 mm per month), mild air temperatures (2-14 °C). During winter (November-March), however, infiltration decreased by an average of 11-54% compared to summer at all measuring points, except those at the grass swale. The highest decrease was measured at the lupine field and the barren, while the reduction at the heath field was only 11-15%, except for the measurement at H1 on March 13th, when infiltration increased. At the first grass swale site (S1), infiltration increased significantly (105%) during winter, while it increased moderately by 10% at the second swale site (S2). Such variations can be attributed to the differences in vegetation cover and due to the type of frost formed. On one hand, the grass swale has a dense vegetation cover that can isolate the soil underneath it, which can undermine frost formation. Moreover, formation of frost in the presence of thick roots near the surface, which is the case for grass, can lead to the creation of channel-like routes within the soil, and to the formation of large ice crystals, which in some cases can even enhance infiltration. On the other hand, sparse vegetation covers, which is the case at the lupine and the barren fields, the soil surface is similar to a bare ground, which can enhance the formation of thin ice lenses, which inversely affects infiltration. Whereas at the heath field, where the vegetation cover is relatively denser than the ones at the lupine and the barren fields, the decrease in infiltration is lower.

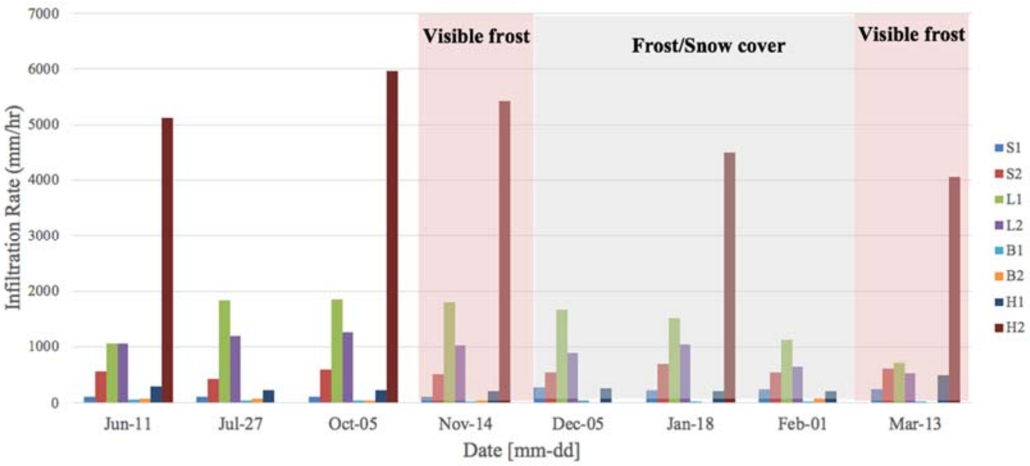

Figure 3 Infiltration rates measured at Urridaholt from June to March 2018. S1 and S2 were measured in the grass swale, L1 and L2 were measured in the lupine field, B1 and B2 were measured in the barren, and H1 and H2 were measured in the heath.

The period with the longest recorded frost in the soil and two rainfall events was 11th of November to the 13th of December (Figure 4). Measurements of soil water content and soil temperature at the different depths in the study swale suggest that the top layer at 5 cm depth was susceptible to changes in air temperature and rainfall, while the probes at the deeper layers were less affected: Firstly, during the largest rainfall event in 2018 (47.7 mm, November 18), the top soil water content increased almost instantly by 30% and the soil temperature by 8 °C. Secondly, when the air temperature decreased to sub-zero, frost was only recorded during short time intervals, the longest being between the 2nd and the 6th of December. At this time, the soil water content in the top layer decreased substantially due to the change of phase from liquid to solid water. During the second and largest rainfall event in December (13.3 mm, December 12) the water infiltrated through the frozen soil surface and through the entire soil profile, seen by a significant increase in both water content and soil temperature at all depths (Figure 4, right and left, respectively). From this, we conclude that concrete frost did not form in the swale and infiltration was not inhibited during the winter season 2018-2019. In addition, the largest winter rainfall events in Iceland are accompanied by high air temperatures, which may help warm up the soil and promote winter infiltration. Frequent warm rainfall and freeze-thaw cycles may, therefore, prevent the formation of deep frost in the soil.

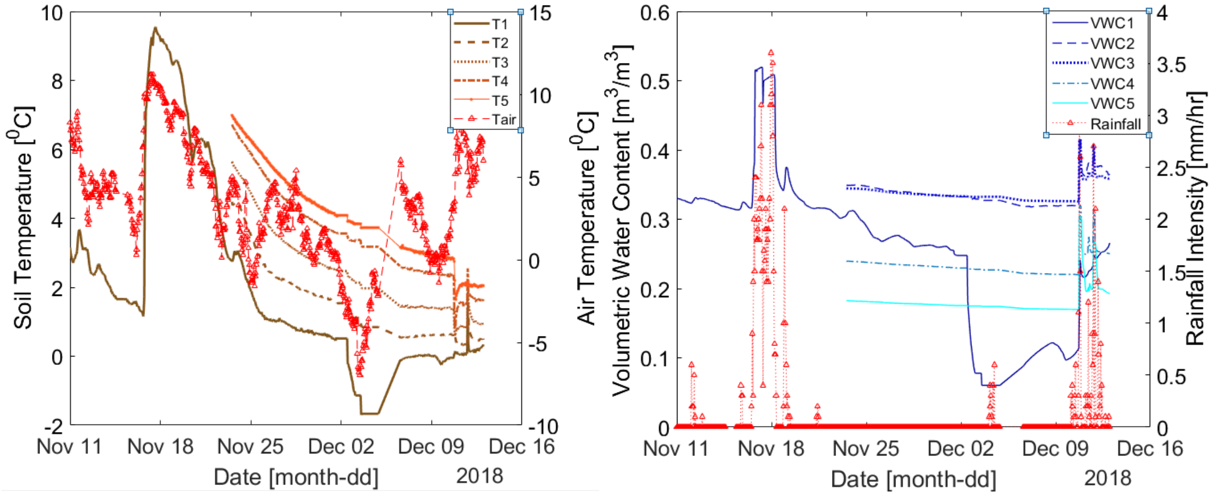

Figure 4 Soil temperature and air temperature (left). Air temperature in red (Station 1, Reykjavik), and soil temperature. Volumetric water content and precipitation (right). Both between 11.11.2018 – 13.12.2018.

4 CONCLUSIONS

Field measurements, soil observations and meteorological data collection were carried out to understand better the processes and changes that occur in regards to infiltration in cold climates. Variations in infiltration can be observed between summer and winter, and in different vegetation covers. In dense vegetation cover (grass swale) infiltration increased during winter, indicating porous frost in the soil, whereas in sparse vegetation covers (lupine, barren, and heath) infiltration decreased. Moreover, during winter, soil water content and soil temperature data revealed that the swale maintained its infiltration capacity.

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