# Evaluation of the long-term hydrologic performance of a rain garden in Trondheim, Norway

Évaluation de la performance hydrologique à long terme d'un jardin de pluie à Trondheim en Norvège

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## RÉSUMÉ

Les zones de rétention des eaux pluviales, telles que les jardins pluviaux, sont utilisées pour capter les eaux de ruissellement et les relarguer plus lentement afin de réduire les conséquences de l'urbanisation sur les infrastructures existantes d'évacuation des eaux. Les jardins pluviaux font partie des systèmes de traitement à succès et font l'objet de nombreux travaux de recherche. Cependant, ceux-ci sont menés la plupart du temps immédiatement après leur construction. La question se pose de leur capacité à maintenir leur efficacité de traitement à long terme. Un jardin pluvial à Trondheim, en Norvège, a fait l'objet d'un suivi hydrologique pendant sept ans. La capacité à long terme d'infiltration n'a pas changé. Le jardin pluvial a permis d'infiltrer et de traiter complètement 79% des évènements pluvieux observés. De 2012 à 2016, la conductivité hydraulique à saturation moyenne est passée de 1,4 à 16,1 cm/h. On suppose que c'est la végétation qui modifie la structure du sol et sa teneur en matière organique, et qui augmente la capacité d'infiltration du sol du jardin pluvial. Les données observées seront utilisées pour calibrer un module jardin pluvial dans DRAINMOD. Ce modèle, initialement conçu pour le drainage, a déjà été utilisé et avec succès pour ces systèmes aux États-Unis. Le modèle évaluera les performances à long terme des jardins pluviaux et évaluera de nouveaux designs de fonctionnement sur les performances hydrologiques. L'analyse hydrologique à long terme montre qu'avec une maintenance adéquate, les jardins pluviaux constituent une solution durable à long terme pour atténuer les impacts hydrologiques de l'urbanisation et du changement climatique.

## ABSTRACT

Stormwater control measures, such as rain gardens, are used to capture and slowly release stormwater runoff to ease the increasing burden of urbanization on existing drainage infrastructure. Rain gardens are a popular stormwater control measure and have been research extensively; however, most field scale research on rain gardens is conducted immediately following their construction. As a filter based practice, there are many questions about the ability of rain gardens to sustain hydrologic performance over time. A rain garden in Trondheim, Norway was monitored for hydrology for seven years. Long-term ability to infiltrate runoff volumes did not change. The rain garden was able to fully infiltrate, and treat, 79% of observed storm events. From 2012 to 2016, mean saturated hydraulic conductivity increased from 1.4 to 16.1 cm/hr. It is hypothesized that vegetation growth changes soil structure and soil organic matter content which increases infiltration capacity in the rain garden soil media. Observed data will be used to calibrate a model of the rain garden in DRAINMOD, a software used in previous research to successfully model rain gardens in the United States. This model will provide predictions on future performance, and will be used to assess the impact of design changes on hydrologic performance. Long-term hydrology analysis shows that with proper maintenance, rain gardens can be a long-term solution to mitigating the hydrologic impacts of increasing urbanization and climate change.

## KEYWORDS

Bioretention, DRAINMOD, hydrology, infiltration, rain gardens

# 1 INTRODUCTION

The importance of urban stormwater management continues to be amplified globally as urbanization of populations continues and climate change impacts are more pronounced. The United Nations World Urbanization Prospect (2018) projects that 68% of the world's population will live in an urban area by 2050, a 13% increase compared with today. This urbanization, coupled with increases in global temperature and extreme weather events, will stress existing infrastructure with increased urban stormwater runoff volumes and peak flow rates (Berggren et al. 2012; Kristvik et al. 2018; Semadeni-Davies et al. 2008).

A key component of urban stormwater management is the use of stormwater control measures (SCMs) to mitigate these impacts by capturing a designed volume of runoff and slowly releasing it to ease the capacity burden on existing drainage infrastructure. A popular SCM used in North America and Australasia, and growing in popularity in Europe and Asia, is the rain garden, also known as bioretention or biofiltration. Rain gardens have been researched extensively with respect to hydrologic mitigation and have shown the ability to successfully meet hydrologic goals across a wide range of climate conditions (Davis et al. 2009; Hunt et al. 2012; Paus et al. 2016).

Rain gardens have been shown to effectively reduce runoff volumes via exfiltration to in-situ soils and evapotranspiration dependent upon drainage configuration, system and catchment size, and filter media depth (Davis et al. 2012). However, research has yet to explore the impacts of continuous usage and aging on hydrologic mitigation. As a filtration based practice, rain garden soil media characteristics may change over time resulting in changes in infiltration and performance. The research presented herein provides a first look at a long-term analysis of the hydrologic performance of a rain garden by examining seven years of hydrology data and uses that data to calibrate a model to predict future performance.

# 2 METHODOLOGY

## 2.1 Site Description

A rain garden receiving runoff from an 8,300 $m^2$ multi-family residential development at Risvollan, Trondheim, Norway was monitored for hydrology from 2011 until 2017. Built specifically for research in 2010, the 40.0 $m^2$ rain garden is described in detail by Paus et al. (2016). The rain garden included 75 cm of soil filter media comprised of a mix of sand, topsoil, and leaf compost. The rain garden has a bowl ponding depth of 16 cm and is drained by two lateral 100 mm drain pipes. As it was originally constructed for research, the rain garden included an impermeable liner to prevent exfiltration of treated runoff into in-situ soils and to better quantify treated volumes. The rain garden was vegetated with shrubs and perennials.

## 2.2 Data Collection

The rain garden was monitored for seven years (2011-2017). To monitor hydrology of the RIS rain garden, 150°, 90°, and 120° v-notch weirs were installed at the inlet, outlet of the subsurface drain, and at the bypass elevation of the rain garden, respectively. Water levels were monitored with AquiStar ® PT-12 pressure transducers and stage-discharge relationships for each weir were used to calculate flow rates and volumes. Sensors and data were collaboratively managed by the Norwegian University of Science and Technology and the Norwegian Water Resources and Energy Directorate (NVE). One-minute resolution precipitation data were obtained from an onsite NVE weather station. Hydraulic conductivity of the soil media was also measured during the seven year monitoring period. Hydraulic conductivity tests were performed using the Modified Philip Dunne (MPD) infiltrometer (ASTM International 2018).

## 2.3 Data Analysis

Due to the piling of cleared snow from parking areas near the rain garden and the impacts of freezing and thawing on hydrology data and sensors, data between the months of November and March were removed before analysis. Storm events were defined as at least 2.5 mm of rainfall and a minimum ADP of 6 hours. Rainfall events were discretized based on size for further analysis.

Following previous research by Paus et al. (2016), infiltrated volumes were calculated as the difference of observed inflow and bypass flow as the presence of an impermeable liner would preclude exfiltration of runoff into in-situ soils. Data were inspected for normality and log-normality. Data were uniformly non-normal resulting in the use of non-parametric statistical analysis.

# 3 RESULTS AND DISCUSSION

## 3.1 Rainfall

During the seven year monitoring period, reliable data were collected for 135 rainfall events from April 2011 through November 2017. Due to equipment malfunctions, data were not available for 2012. A total of 2055.3 mm of rainfall was observed during the monitoring period. Average rainfall during the annual monitoring period (April – November) in Trondheim is 602 mm. The median rainfall was 10.70 mm with events ranging from 2.6 to 69.5 mm of rainfall. Median peak 5-minute intensity and average intensity were equal at 0.70 mm/hr. Median antecedent dry period between rain events was 2.4 days and median rainfall duration was 16 hours.

## 3.2 Hydrology

629.9 $m^3$ of inflow was observed during the monitoring period. Of this inflow, 208.1 $m^3$ bypassed treatment via the bypass weir, resulting in 67% of all runoff receiving treatment via infiltration through the rain garden's soil media. Bypass flow was observed during 28, or 21%, of the 135 observed storm events. In comparison, Paus et al. (2016) reported an infiltrated volume rate of 55% and observed bypass flow during 26% of storm events. No significant trends were detected in infiltrated volume over time. Infiltrated volume appears to follow seasonal rainfall patterns, with the greatest occurrence during late summer and early fall (Figure 1).

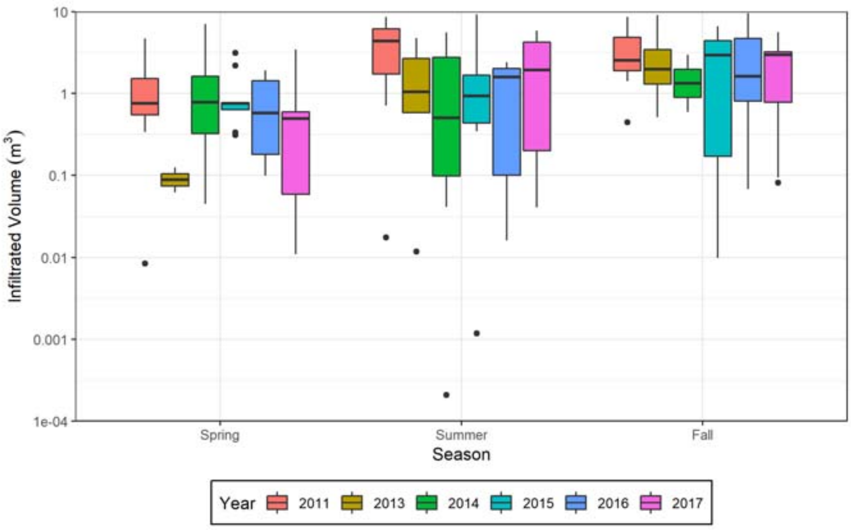


Figure 1. Seasonal effects on volume of runoff infiltrated.

To assess changes in long term performance, the fractional volume of runoff infiltrated into the soil media was analysed. This fractional volume (fv) is the ratio of infiltrated volume to inflow volume. A decreasing trend over time would indicate that less runoff is receiving treatment compared to post-construction. Changes in soil media over time due to compaction and surface clogging could lower the hydraulic conductivity of the soil media and result in more runoff volume bypassing the system. Trend analysis did not detect any significant trend in infiltrated volume or bypass occurrence with time. Further, fv averages remained fairly constant throughout the monitoring period (Table 1). Exceedance probability analysis predicts complete infiltration of runoff volumes for 80% of storm events.

Table 1. Annual infiltrated fractional volume (fv) summary statistics and observed bypass events.

| Characteristic | 2011 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|
| Observed Storms | 34 | 18 | 14 | 18 | 21 | 30 |
| Mean | 0.89 | 0.91 | 0.98 | 0.99 | 0.95 | 0.93 |
| Median | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Standard Deviation | 0.25 | 0.23 | 0.07 | 0.04 | 0.19 | 0.18 |
| Bypass Events | 9 | 4 | 2 | 2 | 3 | 8 |
| Bypass % | 27% | 22% | 14% | 11% | 14% | 27% |

To better understand the continuation of hydrologic performance, saturated hydraulic conductivity ($k_{sat}$) measurements over the monitoring period were examined. From 2012 to 2016, mean $k_{sat}$ values increased from 1.4 ± 7.9 cm/hr to 16.1 ± 21.8 cm/hr, respectively. These increases in $k_{sat}$ over time are supported by recent research by Muerdter et al. (2016) and Paus et al. (2014), who both found higher $k_{sat}$ values for aging rain gardens. It is hypothesized that increases in organic matter and changes in soil structure due to the proliferation of vegetation in rain gardens over time increases the conductivity and infiltration capacity of rain gardens, which may concomitantly ameliorate any negative impacts due to fine sediments imported from the watershed via runoff on surface infiltration rates.

## 3.3 Modelling

Results of hydrologic modelling will be used to provide the longest calibration of a DRAINMOD model for rain gardens to date. Rain gardens have been successfully modelled using DRAINMOD software, as underdrained systems function similar to tile drained agricultural fields, which DRAINMOD was designed to simulate (Brown et al. 2013). Soil samples were taken from the rain garden and soil water characteristics from those samples will be used to model long-term performance of the rain garden under various climate scenarios. Further, changes in rain garden design, including bowl storage depth, exfiltration to in-situ soils, and surface area will be modelled to provide options for adaptability to future climate change. Results of the model will be presented alongside monitoring results.

# 4 CONCLUSION

A rain garden in Trondheim, Norway was monitored for hydrology from 2011 to 2017. 79% of observed rain events were completely infiltrated into the rain garden soil media, providing hydrologic mitigation and potential for treatment of pollutants in runoff. Trend analysis did not detect any significant changes in infiltration, indicating that rain garden performance was not impacted by aging and the import of sediment from the watershed. These findings provide key evidence to support the implementation of rain gardens, with maintenance, as a long-term solution to mitigating the hydrologic impacts of increasing urbanization and climate change.

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