Spatial and temporal variability in bioswale infiltration rate observed during full scale infiltration tests. Case Study: Riga Latvia

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Highlights

- First time in the Baltic States, full-scale infiltration tests performed in 8 bioswales in Riga, Latvia.
- High temporal and spatial variability of hydraulic performance observed even in similar designs.
- Most bioswales empty several times within one day, questioning effectiveness of water retention.

Introduction

As part of the solution to make Baltic States climate adaptive, the first nature based solutions have been implemented in recent years that enable rainfall infiltration and evapotranspiration of stored water to mitigate the effects of drought and heat stress, but also intensive rainfall events causing floodings. The long-term efficiency of Green Infrastructure is however not mainstream and often questioned, moreover there is high degree of spatial and temporal variability in the hydraulic performance of NBSs of the same design observed elsewhere, for example Boogaard (2022), Kasprzyk et al. (2022), Venvik and Boogaard (2020). As a part of a project to collect local data on the performance of stormwater NBSs to inform research om water-balance-optimal bioswale design, full-scale infiltration tests were performed in July and October 2023 in 8 bioswales installed in the period 2017-2022 in Riga, Latvia.

Methodology

Study site selection and description

A quickscan research was conducted starting with mapping over 25 locations with green infrastructure implemented in Riga. Basic information, such as location, characteristics and photos and videos are uploaded to the open-source database ClimateScan. From these, 8 bioswales in 3 sites (see figure 1) installed in the period 2017-2022 are selected for hydraulic testing measuring the infiltration capacity of bio retention solutions.

Figure 1. Location of study sites in the context of North-Eastern Europe and the city of Riga

Sites 1 and 2 are residential developments constructed in 2020-2021 by the same developer with the bioswales implemented to the same design with the only exception being presence of underdrains at the site 2. Site 3 is a parking lot of a shopping centre SPICE Home with two symmetrical bioswales. See figure 2 for bioswale location within the study sites.

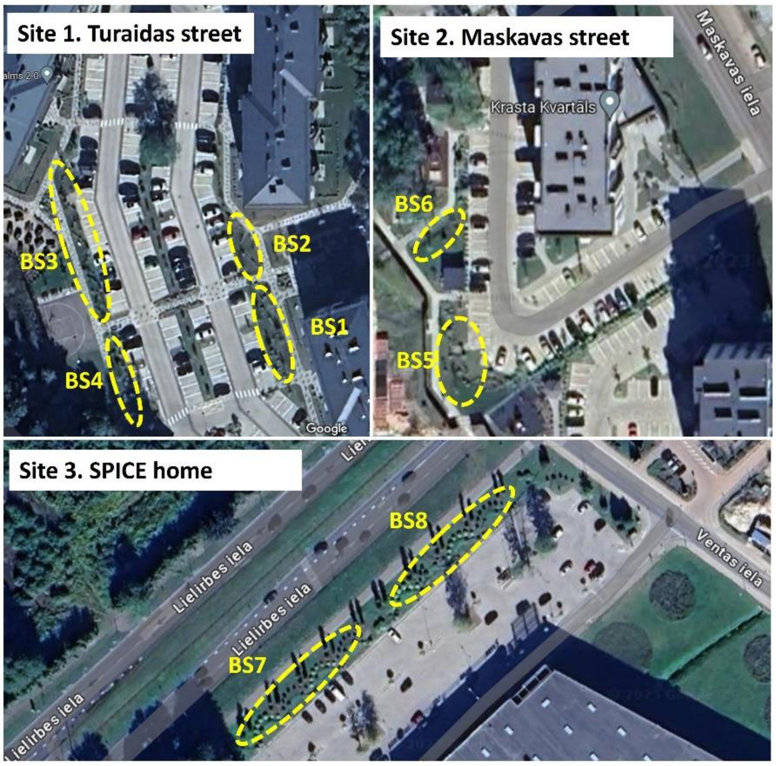

Figure 2. Location of bioswales (BS) within the study sites.

Bioswales 1 – 6 are constructed to a similar design: storage depth up to 50 cm with overflow at typically 30 cm above the bottom of the swales. Bioswales 1 – 4 (Site1) are implemented without underdrains and thus lose water only through exfiltration and evapotranspiration, whereas bioswales 5 – 6 are equipped with underdrains below filter media, losing water additionally through drainage. Bioswales 1 – 2 and 3 – 4are connected through overflow pipe. Bioswales 7 and 8 have a depth of up to 45 cm and overflow pipe 15 cm above the bottom of the swales, connected to the municipal storm sewer. All bioswales have annual and perennial plants. Figure 3 illustrates performance of infiltration tests in bioswale 2 and bioswale 7.

Figure 3. Infiltration tests in bioswale 2 and 8.

Full scale infiltration testing

Bioswales were filled up repeatedly up to the point of overflow (overflow structures were closed off with plastic sheets and duct tape) through firefighting hose, connected to the street fire taps. Then the drop of water level to the empty or nearly empty level was registered with TD-Diver/CTD-Diver pressure sensor data loggers by Van Essen Instruments. To back-up the data, measurements were made with several sensors as well as supplemented with visual observations using measurement tape and time lapse photography. Infiltration test at one site was carried out during one full day, filling up the swales repeatedly when these were empty or half empty. Data loggers were left in the swales for a certain amount of time to register emptying of the swales after the end of the day, where possible. Infiltration tests were performed in bioswales 1-4 on July 13, 2023, in bioswales 5-6 on July 14, 2023 and then repeatedly in bioswales 1-4 on October 16 and additionally in bioswales 8-9 on October 17.

Data processing

Pressure sensor readings were compensated with the atmospheric pressure data to calculate the water level above the sensor. Time series of specific emptying sequences (water level drop) were extracted from subsequent tests and analysed using linear regression. The resulting slope of the linear regression was used to calculate infiltration rate in m/d.

Results and discussion

Figure 5 shows infiltration rate calculation for bioswale 2 for infiltration tests on July 13 and October 16.

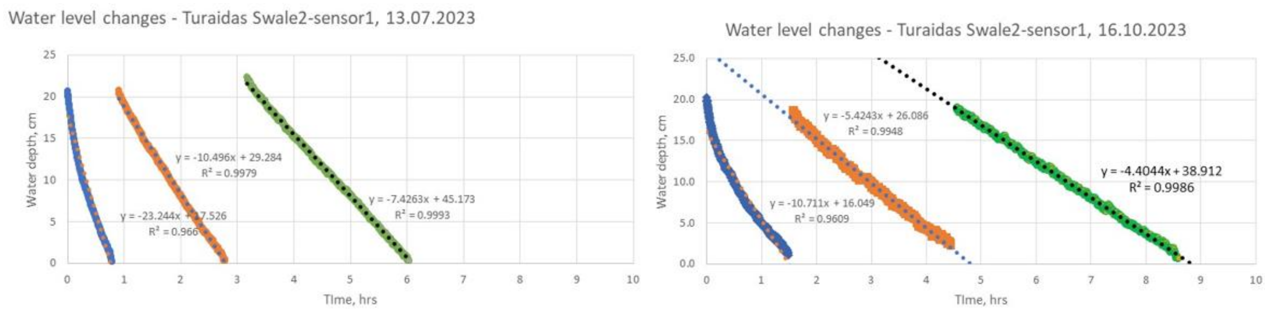

Figure 4. Water level changes in bioswale 2 during July 13 and October 16 infiltration tests. Regression coefficient (slope) shows infiltration rate in cm/h

Figure 6 shows infiltration rate calculation for bioswale 5 for infiltration tests on July 14.

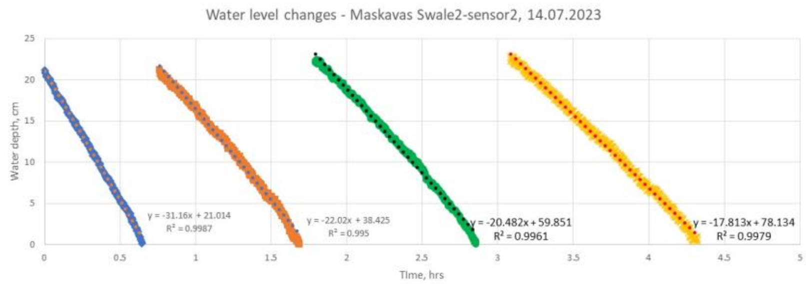

Figure 5. Water level changes in bioswale 5 during July 14 infiltration test. Regression coefficient (slope) shows infiltration rate in cm/h

It was observed that infiltration rate decreased with the subsequent infiltration tests, with saturated infiltration rate being 60-65% lower compared to the unsaturated infiltration rate. Infiltration rate varied greatly for the bioswales with the same design in Site 1 and Site 2.

Table 1 shows summary results for all infiltration tests on July 13-14, 2023 and table 2 shows summary results for all infiltration tests on October 17-18, 2023. The tests showed infiltration rate decrease in October 16 tests as compared to July 13 (BS1 – BS4) by 25-50%, which can be explained by varying antecedent rainfall patterns and differences in initial water content in the biofilter media.

Table 1. Infiltration test results summary for July 13 – 14, 2023 tests (Sites 1 and 2)

Infiltration rate, m/d	**BS1**	**BS2**	**BS3**	**BS4**	**BS5**	**BS6**
Test1-Sensor1	1.3	5.6	1.6	0.3	3.3	7.8
Test1-Sensor2	1.3	5.4	1.0		3.2	7.5
Test1-average	**1.3**	**5.5**	**1.3**	**0.3**	**3.3**	**7.7**
Test2-Sensor1	0.9	2.5			1.8	5.1
Test2-Sensor2	0.9	2.6			1.8	5.3
Test2-average	**0.9**	**2.5**			**1.8**	**5.2**
Test3-Sensor1		1.8				4.7
Test3-Sensor2						4.9
Test3-average		**1.8**				**4.8**
Test4-Sensor1						4.1
Test4-Sensor2						4.3
Test4-average						**4.2**

Table 2. Infiltration test results summary for July 13 – 14, 2023 tests (Sites 1 and 3)

Infiltration rate, m/d	**BS1**	**BS2**	**BS3**	**BS4**	**BS7**	**BS8**
Test1-Sensor1	1.03	2.54	0.67	0.14	0.16	0.17
Test1-Sensor2						0.18
Test1-average	**1.03**	**2.54**	**0.67**	**0.14**	**0.16**	**0.18**
Test2-Sensor1	0.69	1.35			0.09	0.11
Test2-Sensor2						0.11
Test2-average	**0.69**	**1.35**			**0.09**	**0.11**
Test3-Sensor1		0.99				
Test3-Sensor2						
Test3-average		**0.99**				

It should be noted that most bioswales targeted at infiltration empty several times within one day therefore greatly exceeding recommended maximum emptying time. The bioswales with underdrain (BS5 and BS6) generally have higher infiltration rate although also bioswales without underdrain (BS2) have comparable high infiltration rate.

Conclusions and future work

The results showed high variation in infiltration rates in the bioswales implemented both with different design and with the same design. Most swales targeted at infiltration operate in the recommended margins, although it could be argued that the infiltration rate is unreasonably high, decreasing potential water retention and evapotranspiration and stormwater treatment. Full-scale infiltration tests have been proven to be both an effective research instrument and community communication tool for the benefits on nature-based solutions.

Future work will concentrate on parameters for optimising water balance in the swales, emphasising interactions between biofilter media, plants, infiltration and evapotranspiration and optimisation not only for design events but also for frequent rainfall.

References

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