Full-scale field trial for bioretention cells designed for cold climate conditions: establishment year

Essai à grande échelle de biorétentions conçues pour climat froid : année d'établissement

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RÉSUMÉ

Les villes en climat froid manquent de données sur les performances des biorétentions (BR) tant à l'échelle des cellules individuelles qu'à celle du sous-bassin de drainage. L'impact de l'implantation à grande échelle des BRs sur les sources d'eau potable est également inconnu. L'impact des substrats sur la performance, ainsi que les critères de choix des espèces végétales dans ce contexte restent à étudier. Ces lacunes entravent la mise en œuvre des BR. Le projet en cours a pour objectif d'effectuer le suivi de ces aspects des BRs. Cinquante-quatre BRs ont été construites sur un tronçon de 1,3 km d'une rue résidentielle de Trois-Rivières, Québec, Canada. Au total, 6 BRs (3 avec substrat commercial et 3 avec substrat fabriqué sur demande) sont instrumentées pour mesurer leurs performances en termes hydrologique et de qualité de l'eau et ce, au niveau de la cellule individuelle, du sous-bassin de drainage et des eaux souterraines. La croissance et l'état physiologique de quatre espèces ont été évalués. La saison d'établissement a permis le tassement du substrat et l'établissement des plantes. Les données collectées, les problèmes rencontrés et les observations faites au cours de cette période montrent l'importance des études sur le terrain pour améliorer la conception des BRs et la sélection des végétaux dans les climats froids.

ABSTRACT

Cities with cold winters lack data on the performance of stormwater bioretention cells (BRCs) both at the individual cell level and at the sub-catchment level. The impact of large-scale implementation of BRCs on sources of drinking water is also unknown. The impact of the media on the performance, and the criteria for choosing plant species in cold climates remains to be studied. These knowledge gaps impede the implementation of BRCs. The purpose of the current project is to monitor these variables. A total of 54 BRCs were built along a 1.3 km section of a residential street in Trois-Rivières, Québec, Canada. A total of 6 BRCs (3 with commercial and 3 with custom-made media) were studied and monitored to measure their performance in terms of hydrology and water quality at the system, sub-catchment and groundwater levels. Plant development and physiology were monitored in four plant species. The establishment season allowed settling of the media and establishment of the plants. The data collected, problems faced, and observations made during this period show the importance of field studies for finding optimal BRC design and plant selection for cold climates.

KEYWORDS

Bioretention cells, cold climate, green infrastructures, role of plants, urban stormwater

INTRODUCTION

A cold climate impacts stormwater management (Oberts et al., 2000). Nevertheless, few data exists on the performance of green stormwater infrastructures such as bioretention cells (BRCs) in a cold climate and on their appropriate design for this climate (Khan et al., 2012; Paus et al., 2015). Furthermore, little is known about their benefit and impact on drainage systems and water uses when implemented at full-scale (Autixier et al., 2014; Paus et al., 2015). Professionals also need guidance to choose proper media and plant species for northern climates both in terms of BRC performance and plant adaptation to the BRC environment (Payne et al., 2018). Standards and manuals do exist, but recommendations are not necessarily based on scientific evidence (Dagenais et al., 2018). To fill these gaps, a consortium of research teams developed a research project in collaboration with the City of Trois-Rivières (Quebec, Canada). The empirical data provided by this project will guide the large-scale implementation of BRCs in the city based on an adaptive design and planning strategy approach to resilience.

The main objectives of the study are to investigate: a) the impact of a special design of BRCs for cold climate conditions on stormwater hydrology and water quality; b) to study the effect of cold climate stormwater on media, mulch, plants and rhizosphere community; c) to assess the effect of BRC implementation at the sub-drainage area level, and d) to evaluate the impact of BRC on groundwater. However, this article will report on the results obtained and the lessons learned during the establishment year of the study. A complementary greenhouse experimental study is associated with this full-scale trial to examine the impact of plant species and traits on BRC's performance (Beral et al., submitted).

MATERIALS AND METHODS

Fifty-four BRCs were implemented along 1.3 km in a gently sloping section of a residential street, Saint-Maurice Street, in Trois-Rivières Quebec, Canada (Fig. 1). Trois-Rivières is a city in the southern part of the province of Quebec. Its climate is continental humid with maximal mean temperatures of 25.5ºC in July and minimal mean temperature of -17.1 ºC in January according to meteorological data. Mean precipitation is 1122.8 mm/y, 77% (i.e. 863.9 mm) falling as a rain and the rest as snow. Native soil in this location is a fine silty sand at least to a depth of 5m with an infiltration capacity of 66 to 132 mm/h. The depth of the groundwater table varies between 1.5 and 2.9 m (Marchand and Minguy, 2016). The BRCs were designed for cold climate conditions and were built behind sidewalks to protect them from being damaged by snow ploughing machines (Fig.1). The stormwater flows first to a sedimentation/infiltration pit under the sidewalk and then to the BRC. The unlined BRCs allow infiltration but each include additionally two 100 mm drains that are connected to the storm-sewer.

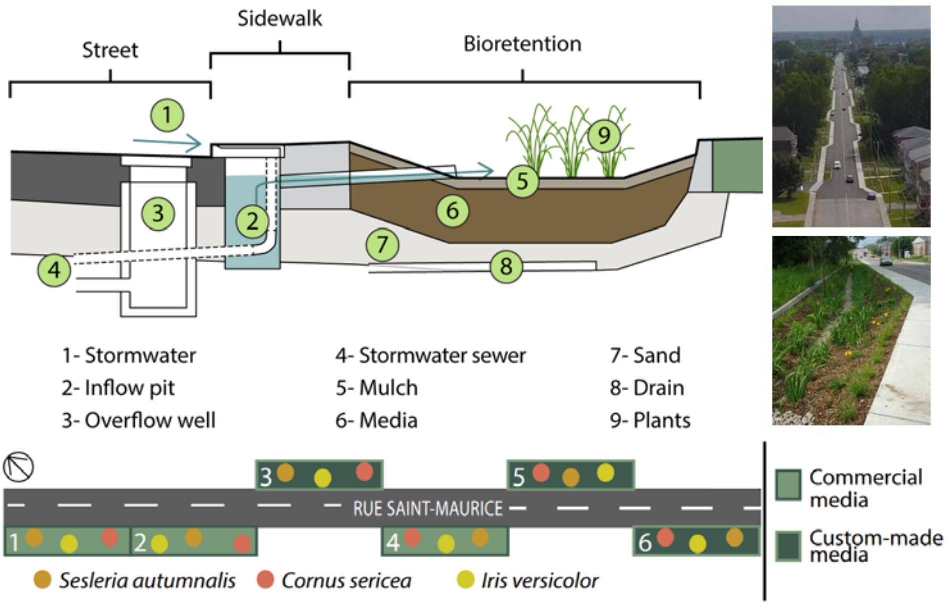

Figure 1. Top. From left to right: sectional drawing of a BRC; Saint-Maurice Street after BRC implementation; view of BRC with *Sesleria autumnalis*, *Hemerocallis* 'Stella de Oro' and *Iris versicolor*. Bottom: distribution of 6 BRCs on the street with location of root cameras and monitored plant individuals.

In total, 6 BRCs covering 775.5 m^2 are monitored from summer 2018. Three are filled with commercial media (BRC 1, 2, 4) and three with custom-made media (3, 5, 6). The six BRCs have a similar planting design and contain four plant species: two native species *Iris versicolor* (IV), *Cornus sericea* 'Kelseyi' and latter 'Arctic fire' (CS) and two exotic species *Sesleria autumnalis* (SA), and *Hemerocallis* 'Stella de Oro' (last one not monitored in this project). In addition to full-scale study, a complementary greenhouse mesocosm experiment (Beral et al., submitted) is performed with IV, CS, SA and native *Juncus effusus* (JE). Therefore, JE plants are also monitored on two other full-scale BRCs in Trois-Rivières. All species monitored in this study are recommended for BRCs in Canada, used in local municipal plantation designs, and present desirable and contrasting functional traits (e.g. type of root system) with regards to BRCs performance. The plantings were completed by the end of July 2018. Plants were watered by the contractor when needed to ensure proper establishment. No fertilizers were used in the BRCs. Weeds were removed when needed.

All sampling, analyses, and monitoring of stormwater, media and plants that is presented here will be continued during years 2019 and 2020. For runoff volume measurements flowmeters will be installed. Samples are taken from the BRCs inflow and outflow of the same rain event. The following water analyses will be done by an accredited laboratory during the study: TSS, TOC, COD, TN, NH_4-N, NO_3-N, TP, PO_4-P, Mg, K, Ca, Fe, Cr, Mn, Ni, Cu, Zn, Cd, Pb, chlorides, hydrocarbons (C10-C50), E. coli, viruses and chemical markers (acetaminophen, caffeine, theophylline, carbamazepine).

Two soil media and the mulch were sampled before planting and will be sampled again during the study. The following analyses of the soil media were made by the city prior to planting: water pH, buffer pH, organic matter (OM%), available P, K, Mg, Ca and cation exchange capacity (CEC). Permeability tests were performed on site. In addition, during our study pH, OM%, TN, NH_4-N, NO_x, P, K, and the main metals (e.g. Ca, Zn, Cd, Ni, Pb, etc.), salinity and chlorides will be analysed for all media.

To evaluate the plant development, measurements of leaf area, plant volume, photosynthetic rate and stomatal conductance were taken on three specimens of IV, SA, and two of CS once a month on BRCs 1-6. In addition, 6 JE specimens were evaluated for the same parameters on BRC7 and three on BRC8. The BRC7 and BRC8 are located next to BRC5 and are filled with the commercial media. One transparent root camera pipe per species was installed on each BRC for root development assessment. In the beginning of the study the above- and belowground biomass of each plant species was dried and weighted. From the collected biomass of plant replicates, the following analyses were performed: TN, TC, P, K, Ca, Mg, Na, Al, B, As, Cu, Fe, Mn, Zn, Cd, Co, Cr, Hg, Ni, Pb, Se.

RESULTS AND DISCUSSION

According to meteorological data, the summer of 2018 was hot and dry with temperature above normal in August (21.6ºC; normal 20.0ºC) and September (16.2ºC, normal 14.2ºC). A total of 72.3 mm of rain fell in August with a maximum of 7 days without rain. In September the total rainfall was 91 mm with a maximum of five days without rain. Hydrological results are expected in 2019. Pilot inflow and outflow grab sampling was done in August, September and October 2018. The first water quality results for the inflows show typical pH values (average 7.7). Average concentrations of many runoff pollutants from Saint-Maurice Street are lower than average stormwater concentrations according to Duncan (1999) (e.g. TP: 259 versus 560 µg/L, TOC: 8.5 versus of 19 mg/L; COD: 7.9 versus 47 mg/L, Pb: 1.8 versus 110 µg/L, Zn: 33 versus 260 µg/L; Mn: 39.9 versus 370 µg/L). This is probably since this street section is newly built and the runoff quality is different from typical residential runoff. Moreover, some results show a great variability. Outflow TOC, DOC, TN, NO_3-N, TP, Mg, Ca, Mn, Fe and Cd concentrations were higher than in runoff. This result was expected during the establishment period of the BRCs because of initial leaching and compaction from stabilizing soil with 4-6% of OM content (Hunt et al., 2012). However, in the absence of volume data, it not possible to determine the magnitude of the pollutant load from the substrate. Outflow Fe and Mn content will be followed with great attention since their concentrations in groundwater are a concern in the Trois-Rivières region. Canadian drinking water standards for Mn are 50 ug/L for organoleptic reasons (Health Canada, 1979). However, no well or groundwater recharge are present in that part of the city. From year 2019 automatic samplers will be used for representative water sampling.

The custom-made soil media was lower in OM (4.8% versus 5.9%) and K (133 versus 375 µg\L), Ca (2000 versus 2500 µg\L), Mg (229 versus 277 µg\L) and CEC (14 versus 19.4) than commercial soil but had higher P content (212 versus 119 µg\L), and more fines (<0.8 mm particles; 34.2% versus 13.8% for the commercial media). Results from the initial soil and mulch samples taken by the research team are expected soon.

Overall the JE and SA plants showed the healthiest growth during the first season. CS cultivar 'Kelseyi' was initially used but was rapidly infested with flea beetles, so this cultivar will be replaced with 'Arctic

Fire', a more vigorous variety, which showed better growth and less damage by the insects. IV was infected with a rust that can have an impact on the photosynthesis of the plants and hence their growth and winter survival potential.

As expected, of the monitored species CS had greatest leaf area (CS ($\bar{x}$=17 536 cm^2) > IV ($\bar{x}$=9684 cm^2) > SA ($\bar{x}$=3456 cm^2) $\geq$ JE ($\bar{x}$=3154 cm^2). CS and JE had more constant photosynthetic rate from July to October. However, at the beginning of August, SA had the highest mean photosynthetic rate of $\bar{x}$=18202 μmol/m^2/s compared to only $\bar{x}$=7286 μmol/m^2/s for CS. It could be due to the insect damages or to transplant shock which is greater for woody plants. An ANOVA showed no interactions between species and media. Adjustments in year 2019 will be made to the leaf area equation to better represent the actual shape of the leaf. More control of insects and diseases might change the observed order of the species. Plant density will be considered as leaf area per BRC area will be measured next year to accurately account for the performance of the plant per m^2. This data will be useful to assess to the potential contribution of different species to the BRC performance at different moments of the growing season. IV showed the most visible root growth according to root pictures taken in August and September. CS specimens were located further from the camera which might explain the apparent weak root development combined with insect damages and transplant shock. SA root systems were small and not visible. More data are needed to confirm and explain these observations.

CONCLUSION

The establishment season allowed settling of the media and establishment of the plants. The data collected, and observations made during this period pointed towards areas that will need further investigation or fine-tuning in upcoming years. The establishment phase should be over for herbaceous plants but could continue for CS. Volume data will help us determine if leaching is taking place from BRCs or if it is just an artefact of reduced outflow volumes. Data on groundwater quality will also allow evaluation of its contamination by the filtrate from the BRCs. The two media were designed to be similar; additional data are necessary to confirm if the difference in composition has an impact on the performance of BRC or growth of the plants. Subsequent years will help us validate our preliminary results.

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