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Determining the recharge potential of a Low Impact Development system under seasonally frozen conditions

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Summary

Urbanization increases the rapid runoff of meltwater and rainwater across the landscape through the conversion of land from permeable pre-development surfaces to impermeable post-development surfaces via the construction of roadways, parking lots, and rooftops (Bannerman et al., 1993). Low-Impact-Development (LID) technologies aim to mitigate the adverse effects of urbanization on stormwater runoff and try to return the urban hydrologic system to pre-development conditions by mimicking the natural infiltration, runoff, and evapotranspirative processes while simultaneously treating stormwater for urban contaminants (Vogel and Moore, 2016). A component of this technology involves naturally recharging infiltrated water into the groundwater system. The recharge potential of a vegetated bioswale (bioretention) system in the Town of Okotoks, Alberta was investigated using a water-balance method and through the application of a modified version of the groundwater mounding equation of Hantush (Hantush, 1967; Swamee and Ojha, 1997). Of the 19 storm events measured, the largest event produced an observed mounding height of 14 cm beneath the first inlet of the vegetated swale system, indicating a maximum recharge rate of 4.9 mm/day and an average recharge rate of 3.5 mm/day for the largest summer storms. The next step in this project will be to compare the summer recharge rates to recharge rates observed during the spring melt season in order to examine any fundamental discrepancies. Understanding the recharge potential of these LID systems in seasonally frozen soils will be paramount in helping to guide water resource management decisions in urbanized centers in Canada.

Background

The study site for this project was built in collaboration with the Town of Okotoks and Source2Source Inc. as part of a larger study on the effectiveness of bioretention systems. The site consists of two main components; (1) a small-scale study area with self-contained beds of bioretention media comprised of varying organic, loam, and clay content isolated from the natural system through use of impermeable liners, and (2) a full-size bioretention system that consists of a series of interconnected vegetated depressions infilled with 0.6 m of a 60/30/10 unscreened loam, hardwood mulch, and compost mixture (Skorobogatov & Albers, 2015). The full-scale system was the focus for this study. The full-scale system is situated directly above the alluvial, gravel and sand aquifer along the northern bank of the Sheep River and is fully integrated with the natural hydrologic system as it does not make use of impermeable liners. This lack of an impermeable liner is a feature rarely found in bioretention studies due to the difficulties associated with study of the percolating waters. Stormwater runoff from a parking lot and surrounding areas is collected and diverted into this full-scale system, where it infiltrates through the system and eventually percolates down into the alluvial aquifer.

Theory and Methods

Two vegetated depressions were fitted with 90-degree V-notch weirs and accompanying pressure sensors deployed in a PVC housing to automatically measure inflowing water at five-minute intervals. Vertical profiles of soil moisture sensors were installed from groundwater surface to 1.0 m depth beneath the centers of each vegetated depression and recorded soil moisture at half-hour intervals. Water table wells drilled directly adjacent to the vegetated depressions were used to monitor fluctuations in the position of the water table directly below the swale, and a well further away from the depressions was used to determine background regional fluctuations in water table elevation. The position of the water table in each well was recorded every hour using a pressure transducer. Figure 1 shows the conceptualized water balance for a single swale.

Slug and bail tests were performed in December of 2019 to obtain hydraulic conductivity estimates of the aquifer material below the two vegetated depressions. This value is required to calculate the required infiltration rate to produce the observed localized mounding height beneath the vegetated depression. That infiltration rate was then multiplied by the observed duration of mounding to determine the total recharge for each mounding event.

A hydrometeorological station installed at the site was used to obtain measurements of wind speed, air temperature, precipitation, incident solar radiation, and relative humidity. These data were used to calculate the daily potential evapotranspiration at the site using the Food and Agricultural Organization (FAO) modifications to the Penman-Monteith evapotranspiration equation (Allen et al. 1998). All data, including precipitation, runoff, evapotranspiration, and soil moisture were used to construct a water budget on a seasonal timescale to estimate potential groundwater recharge.

Results and Observations

A total of 19 storm events with inflow volumes greater than one cubic meter were measured for the summer monitoring period from July to September of 2019. Stormwater volumes varied in magnitude between 4 m^3 and 290 m^3 per event. These will be compared to the data from the spring melt monitoring period in early 2020.

The aquifer material below the vegetated swales showed underdamped to critically damped slug test response behaviour with recovery times of approximately four seconds, indicative of a very high hydraulic conductivity material. Preliminary analysis suggests hydraulic conductivities on the order of 10^{-2} m/s. The resulting mounding heights were relatively small, and indicated small changes in mounding height corresponded to relatively large changes in infiltration rate. The maximum observed mounding height was 14 cm, which would suggest maximum recharge rates of around 4.9 mm/day.

Comparison of recharge estimates from the water balance method and the groundwater mounding method provided an estimate of the error and bias inherent within each method, and comparison between the summer and spring-melt seasons provided insights into how the recharge potential of these systems changed seasonally. Understanding the seasonal impacts on the effectiveness of these systems will be paramount in helping design water management best-practices for both the retrofitting of current urban developments, and in planning for future urban expansion in these seasonally frozen climates. Continued study of LID systems is guided by the ultimate goal of helping to mitigate the adverse effects of urbanization on water quality, quantity, and sustainable use.

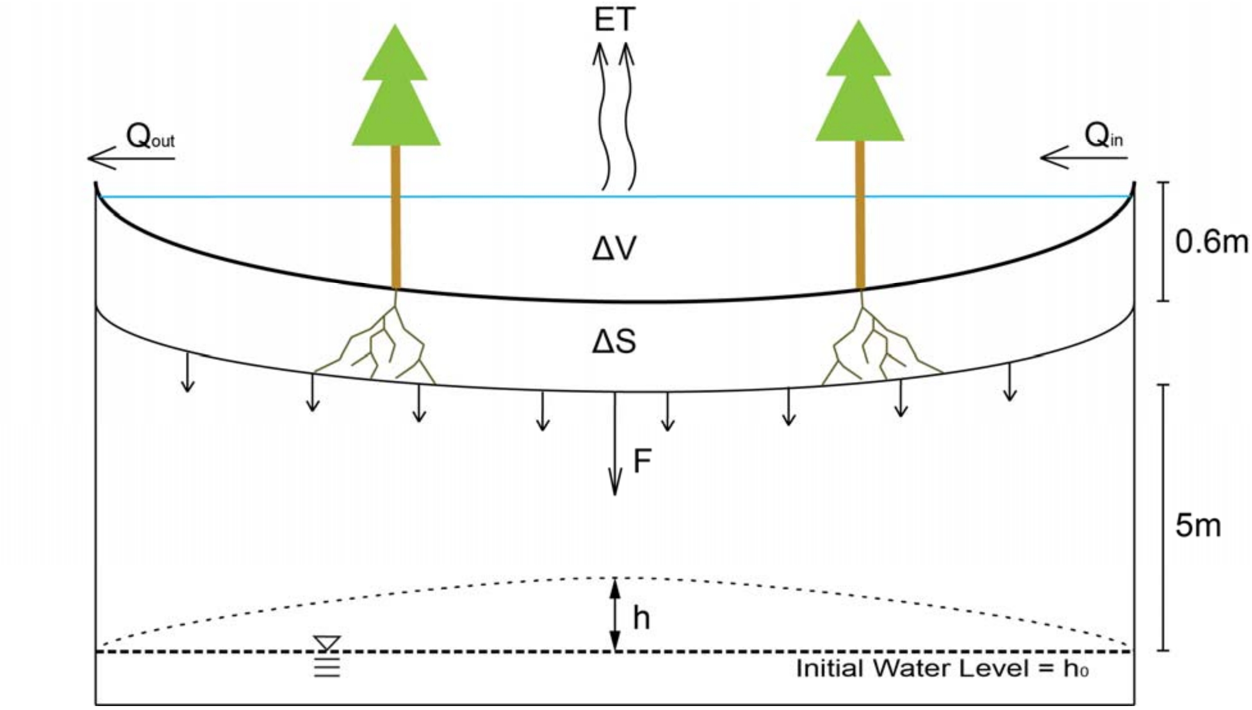

Figure 1 - Conceptual model of the water balance components beneath the vegetated swales at the study site (not to scale). Q_{in} *and* Q_{out} *are volumetric inflow and outflow, respectively, ΔV is the change in the volume of ponded water in the swale, ET is the evapotranspirative loss, ΔS is the change in soil moisture, F is percolation, and h is the localized mounding height due to recharge.*

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