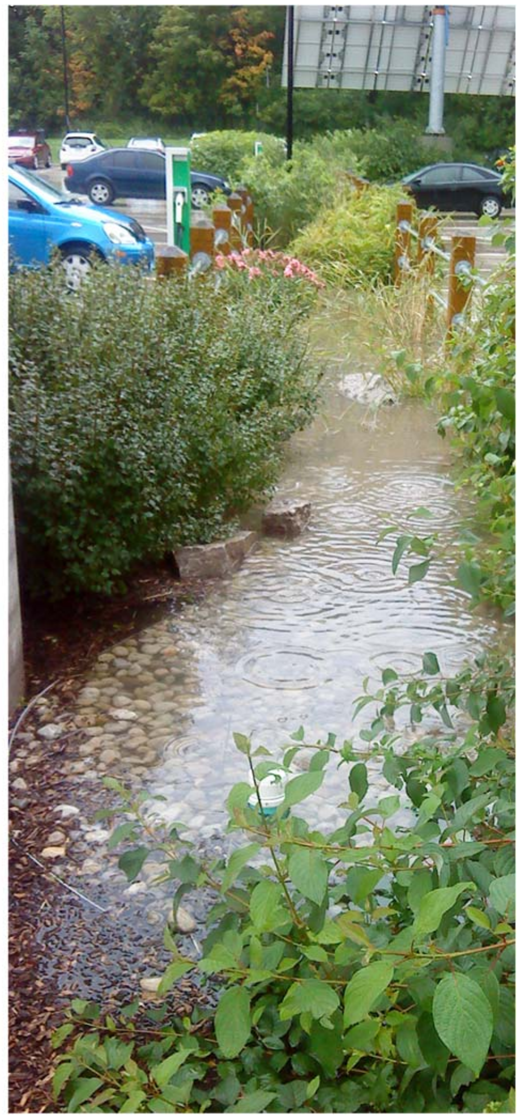
Performance Evaluation of a Bioretention System

Earth Rangers, Vaughan



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PERFORMANCE EVALUATION OF A BIORETENTION SYSTEM
Earth Rangers, Vaughan

Final Report

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NOTICE

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THE SUSTAINABLE TECHNOLOGIES EVALUATION PROGRAM

The Sustainable Technologies Evaluation Program (STEP) is a multi-agency program, led by the Toronto and Region Conservation Authority (TRCA). The program helps to provide the data and analytical tools necessary to support broader implementation of sustainable technologies and practices within a Canadian context. The main program objectives are to:

- monitor and evaluate clean water, air and energy technologies;
- assess barriers and opportunities to implementing technologies;
- develop tools, guidelines and policies, and
- promote broader use of effective technologies through research, education and advocacy.

Technologies evaluated under STEP are not limited to physical products or devices; they may also include preventative measures, alternative urban site designs, and other innovative practices that help create more sustainable and liveable communities.

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EXECUTIVE SUMMARY

Low Impact Development (LID) has emerged as an alternative to sole reliance on conventional urban stormwater management approaches. LID consists of a series of decentralized micro-controls at or near the source of drainage networks that supplements traditional detention facilities. This more distributed approach attempts to reproduce the pre-development hydrologic regime through site planning and engineering techniques aimed at infiltrating, filtering, evaporating and detaining runoff, as well as preventing pollution.

Bioretention is a common LID practice that uses the natural properties of soils, plants and associated microbial activity to infiltrate water and remove pollutants from stormwater runoff. It consists of a shallow, excavated depression with layers of stone, prepared soil mix, mulch and specially selected native vegetation that is tolerant to road salt and periodic inundation. Bioretention systems installed on less permeable native soils may include an underdrain to facilitate drainage. They remove pollutants from runoff through filtration by soil media and uptake by plant roots. Runoff volumes are reduced through evapotranspiration and full or partial infiltration depending on the underlying soil permeability. The practice provides aesthetic benefits and can easily be modified to fit a wide variety of space and drainage contexts, making it one of the more common LID practices for reducing runoff volumes and achieving groundwater recharge targets on development sites.

This study evaluates the performance of a bioretention system that treats runoff from a commercial parking lot. Key parameters examined include runoff volumes, runoff reduction, surface ponding and infiltration, water quality, surface soil and effluent water temperatures and soil moisture. The study also documents key operation and maintenance requirements.

Study Site

The site for this study is a bioretention facility installed in April 2010 on a new parking lot owned by Earth Rangers at the TRCA’s Living City Campus at Kortright in the City of Vaughan. The bioretention area was configured as a 123 m^2 linear island in the centre of the parking lot, with 128 m^2 bump outs on either end. A second 84 m^2 swale section to the east was connected to the island via an underdrain, which joins the cells and conveys subsurface flows to a sampling vault along the eastern end of the cell. The sampling vault houses various instruments used to measure flow rates, volumes, water quality and water temperature.

The bioretention surface contains a combination of plants and river rocks. Runoff drains into the bioretention cell and east swale as sheetflow from a 2,272 m^2 impermeable interlocking concrete pavement, where it infiltrates into the native soils, is returned to the atmosphere as evapotranspiration, or is conveyed downstream through perforated underdrains approximately 1.3 m below the cell surface. During large rain events, excess ponded runoff is conveyed across the surface to a catchbasin that drains to an outlet to prevent water from backing up onto the parking lot. Native soils in the area consist of silty clay glacial till.

Study Approach

The monitoring program consisted of co-ordinated measurements of precipitation, flow, water quality, water temperature and soil moisture. Evapotranspiration was estimated based on actual measurements over the same period in a well vegetated field less than 1 km from the study site. Flows entered the cell as sheetflow and therefore could not be measured directly. Therefore, inflows to the system were estimated from precipitation, using an abstraction factor to account for direct losses from the parking surface. Outflows, water quality and water temperature were monitored in the sampling vault at the outlet. The difference between total inflows and total outflows was used as the basis for calculating the volume of runoff reduced through infiltration and evapotranspiration.

The capacity of the bioretention system to improve water quality was assessed through statistical analysis of the quality of outflows from the bioretention system outlet and the quality of untreated runoff from a nearby asphalt pavement with similar traffic density and sources of contamination. Samples at both locations were volume weighted to account for changes in water quality over the course of the monitored events. Load reduction factors were estimated based on median concentrations and measured runoff and outflow volumes. Water quality variables included solids, chloride, general chemistry, nutrients and metals.

Soil moisture was measured over a two month period at 20 vegetated and non-vegetated locations throughout the cell to assess contributions of vegetation to runoff reduction and the need for irrigation during dry periods in the summer. Soil moisture was measured at 2 and 10 cm depths on a daily basis before and after rain events using a soil moisture meter. Measurements of vegetated and non-vegetated areas at the two depths were analyzed statistically to assess differences.

Study Results

Site observations and monitoring data collected over the two year study period showed that the bioretention system is capable of substantially reducing runoff volumes and improving the quality of stormwater drainage from the parking lot. The main study findings were as follows:

1. *Hydrology:* Over 90% of the runoff directed into the facility from the paved drainage area either infiltrated or was returned to the atmosphere as evapotranspiration, indicating that this practice can provide effective stormwater treatment and runoff control even on low permeability soils. Runoff reduction levels were similar in cold (December to March) and warm seasons (April to November) despite slower infiltration during the winter.
2. *Surface Ponding and Infiltration:* Throughout the summer, surface ponding occurred only during large or high intensity rain storms, and rarely for more than 20 minutes, indicating rapid infiltration. During winter, ponding was less frequent but lasted longer, particularly when snow melt events were combined with rain. Surface temperature measurements and direct observations revealed that winter ponding was caused by the formation of a thin layer of ice at the surface. In all cases, the parking lot remained free of standing water because the overflow elevation was below that of the pavement surface.

3. *Evapotranspiration:* Evapotranspiration estimates derived from actual measurements over the same period in a well vegetated field less than 1 km from the study site indicated that approximately 8.9 and 9.6% of total runoff inputs were evapotranspired between April and November in 2011 and 2012, respectively.
4. *Water Quality Loads*: On a per unit area basis, the mass of contaminants discharged from the bioretention facility was estimated to be between 65 and 92 percent less than that discharged from the conventional asphalt control.
5. *Water Quality Concentrations*. The concentrations of most constituents in bioretention underdrainage were significantly lower than in asphalt runoff (α=0.05), including total suspended solids, total phosphorus, ammonia nitrogen, total kjeldahl nitrogen, lead, iron, and aluminum. Exceptions included nitrate nitrogen, which was higher in bioretention effluent, as well as copper and zinc, which were not significantly different (α=0.05). The concentration of some constituents in bioretention effluent, such as zinc, copper and phosphorus, exceeded receiving water objectives more than 60% of the time.
6. *Nutrient Concentrations*. Previous studies have often found elevated nutrient concentrations in bioretention effluents. These elevated levels have been attributed to high phosphorus concentration in soils or leaching from organic soil amendments. In this study, phosphorus concentrations exceeded the Provincial receiving water guideline 69% of the time, but were similar to concentrations observed in local receiving waters (median = 0.05 mg/L). Although slightly elevated above asphalt runoff, nitrate nitrogen concentrations were always below the Canadian Environmental Sustainability Indicator for nitrate of 2.93 mg/L.
7. *Soil Moisture*: The moisture content of soils at 2 and 10 cm depths was significantly greater (α=0.05) in the non-vegetated (*i.e.* river stone) than vegetated areas of the bioretention cell. This suggests that bioretention cells without vegetation will have less capacity to reduce runoff through temporary soil moisture storage and evapotranspiration. Rain and runoff from the parking lot maintained soil moisture within the root zone at levels sufficient for plant survival and growth.
8. *Surface Temperature*: Relative to the asphalt pavement, average surface temperatures of the bioretention cell were warmer during the winter and considerably cooler during the summer. In the summer, peak bioretention soil temperatures were just over 25°C, compared to above 40°C on the asphalt. An ice layer formed on the surface of the cell during the winter, but further below the surface, temperatures were approximately 5°C warmer. These results show the benefit of bioretention in reducing urban heat island effects, and creating conditions that allow snow and ice to melt quickly during the spring.
9. *Effluent Temperature*: The reduction in runoff and cooler temperature of bioretention outflows helped to mitigate the thermal impact of urbanization on downstream aquatic communities. The maximum temperature of bioretention underdrain outflows during hot summer periods was just over 20°C, which was over 10°C lower than peak asphalt runoff temperatures during the same events.
10. *Operation and Maintenance*: Vegetation maintenance was conducted as part of the larger landscape maintenance activities at the site. Regular maintenance of the parking lot bioretention and bump-outs accounted for approximately $1500 of the annual budget. Manual irrigation was almost never required to supplement parking lot sources of water. Pipes and outlets remained clear of debris during the first 4 years of operation and there was no evident damage to vegetation from snow plowing and maintenance activities.

Recommendations

This study has demonstrated the viability of bioretention as a stormwater practice under Greater Toronto Area soil and climate conditions. The following recommendations on bioretention design and further research needs are offered based on the results of this study.

<u>Facility Design</u>

- The soil filter media is a critical component of bioretention design that controls infiltration rates, surface ponding, water quality performance and long term maintenance needs. In this facility, the correct bioretention media was specified and purchased, but in situ tests revealed the media to have a finer texture than specified, suggesting that it was mixed or supplemented with other native materials and/or contaminated during the construction process. Soil media in bioretention facilities should be tested for grain size and permeability as part of the facility commissioning to ensure that the appropriate soil media has been used and that its properties have not been compromised by construction site runoff. Contracts with soil mixing companies should include clauses that guarantee that the material delivered meets required specifications.
- Despite the presence of a high percentage of silt and clay in the soil media, runoff infiltrated extremely well through the surface, with ponding occurring for less than 20 minutes during most large events. While further investigation is needed, this finding may lend support to reducing the high sand content in the current specification (from 88% to approximately 75 - 80%). The sand was specified to ensure good drainage, but it can also inhibit the establishment of some plant species and necessitate more manual irrigation than may otherwise be required.
- Underdrains should always be raised at least 30 cm in the cross section, even on low permeability soils, to provide the storage and hydraulic head needed to maximize infiltration. Further reductions in discharge volumes and peak flows can be achieved by restricting flow through the underdrain outlet, allowing treated water to discharge slowly over a 72 to 96 hour period.
- The bioretention cell evaluated in this study was surfaced primarily with river stone and some plants and shrubs. Vegetated area soils were shown to have lower soil moisture contents and higher capacities to retain runoff than neighbouring non-vegetated areas. Wherever possible, vegetation should be used in bioretention systems both to improve runoff retention and create the living soil conditions that help trap contaminants and maintain the long term infiltration capacity of the soil media.
- Current TRCA/CVC guidelines on bioretention systems recommend that the drainage area to bioretention facilities should be no more than 15 times the size of the facility footprint to ensure optimal performance over the life of the facility. In this study, the bioretention cell functioned well with a drainage-to-facility area ratio of 13:1, confirming that an area at least this size can be effectively treated without erosion or pre-mature sediment clogging.
- Gravel diaphragms or sediment forebays are often recommended in bioretention facilities to dissipate energy and provide pre-treatment of runoff. In this facility, runoff was directed across the full length of the cell with vegetation providing a pre-treatment filtering function prior to entering the filter media. The absence of soil erosion and strong growth of vegetation along the cell edges suggest that this method can be a viable alternative to other techniques that may require more space and offer less aesthetic appeal.

<u>Further Research Needs</u>

- Further research on the long-term performance of bioretention facilities is needed to provide better data on the required frequency of maintenance, the interval at which full scale rehabilitation may be needed, and changes in functional performance over time.
- The role of vegetation and associated microbial processes in maintaining infiltration in bioretention facilities is not well understood. Further research is needed to identify the types of vegetation best suited to meeting the stormwater treatment and runoff control functions of bioretention, and how the selected cover types influence long term maintenance.
- The sandy filter media used in bioretention systems is designed to remove contaminants, support healthy plant growth, and allow rapid infiltration of runoff. In areas where plant growth is not a key consideration, however, clear stone filtration systems can be designed to infiltrate water at much higher rates while consuming less land area and providing similar runoff volume reductions. The performance of high flow rate systems from a water quality and overall operation and maintenance point of view requires further assessment in cold climate urban settings.

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