TECHNICAL BRIEF

Sustainable Technologies
EVALUATION PROGRAM

Low Impact Development

Evaluation of the Stormwater and Biodiversity Benefits of an Extensive Green Roof

This three-year study, initiated in 2003, evaluated the hydrologic, water quality and biodiversity benefits of a green roof located on a multi-story building at York University in Toronto, Ontario. The performance of the green roof was compared to a conventional (control) roof through water quantity and quality analysis and hydrologic modelling. A biodiversity assessment conducted investigated flora, birds and bees on the green roof.

Continuous precipitation and runoff data collected over 18 months (excluding winter) indicated that the green roof discharged 63% less runoff than the adjacent control roof. The green roof's retention capacity varied with evapotranspiration, with the best retention rates observed in summer months, followed by the spring and fall. Loads of most chemical variables were lower in runoff from the green roof than the control roof. Exceptions included parameters like calcium, magnesium, and total phosphorus, which were either naturally present in the green roof media or added to promote plant growth. Total phosphorus concentrations were significantly higher in runoff from the green roof relative to the control, and regularly exceeded the Ontario receiving water objective. Phosphorus concentrations fell significantly after the first year, suggesting that the nutrient is being leached from the media. Flora monitoring showed that despite the fact that the original green roof seed mix was primarily non-native, its low-nutrient, low-competition environment would be conducive to the establishment of conservative or rare native plants of concern.

The Greater Toronto Area (GTA) consists of between 50 and 75% impervious land cover, while the city cores are comprised of closer to 95%. Within the City of Toronto, rooftops make up 21% of the total built surface area, offering the potential for green roofs to make a significant impact in reducing runoff and improving water quality.

As urban areas continue to expand, maintaining pervious areas and green spaces is an ongoing challenge. With the advent of the low impact development approach to stormwater management, innovative solutions have emerged for managing water in underused areas like rooftops in order to reduce the use of valuable land. One example is green roofing, which retains rainwater, promotes evapotranspiration, and results in lower runoff volumes and contaminant loads from the rooftop. They can also help improve air quality, reduce building energy use, increase biodiversity, mitigate the urban heat island, and create healthier, more attractive cityscapes.

INTRODUCTION

Green roofs have been widely recognized as providing significant private and public benefits to urban environments. Broader recognition of these benefits has been the driving force behind the growth of the Greater Toronto Area (GTA) green roof industry over the past two decades, and the City of Toronto's adoption of policies supporting green roof implementation. In 2009 the City became the first in North America to require green roofs on new buildings when the City Council adopted the *Green Roof Bylaw*.

Improved control of stormwater represents one of the most important public benefits of green roofs, and as such is the primary focus of this evaluation. Green roofs provide stormwater control by retaining precipitation and returning it to the atmosphere through evapotranspiration. This results in reduced stormwater peak flows, lower total runoff volumes from the roof, and less risk of channel erosion and impact to downstream aquatic habitat.

This three year study was initiated in 2003 to address the growing need for research on the stormwater management and biodiversity benefits of green roofs in cold climates. Specific objectives of the study were to:

- evaluate the potential of green roofs to reduce the quantity and improve the quality of stormwater runoff;
- quantify stormwater management benefits at a watershed scale through scenario modelling;
- assess the capacity of green roofs to improve urban biodiversity; and
- provide recommendations on green roof design and maintenance.

STUDY SITE

The study was conducted on a portion of the roof on the Computer Science and Engineering building at York University in the City of Toronto (Figure 1). Constructed in 2001, the building drains to Black Creek, a tributary of the Humber watershed.

Figure 1: Study area on the York University Computer Science and Engineering Building

The portion of roof used as the study area is covered by two surfaces: conventional shingles, referred to as the control roof, and the green roof (Figure 1). While both areas have a 10% slope, the green roof area is larger (241 m^2) than the control roof (131 m^2).

The green roof consists of 140 mm of growing media and is vegetated with wildflowers. The growing media is composed of crushed volcanic rock, compost, blonde peat, cooked clay and washed sand. It was designed to be light weight, retain water and resist compaction. An irrigation system was installed to facilitate watering when necessary.

APPROACH

Field Monitoring

All climate and hydrologic data were collected and archived in real time using a web-based monitoring system. Figure 2 shows the location of monitoring instruments.

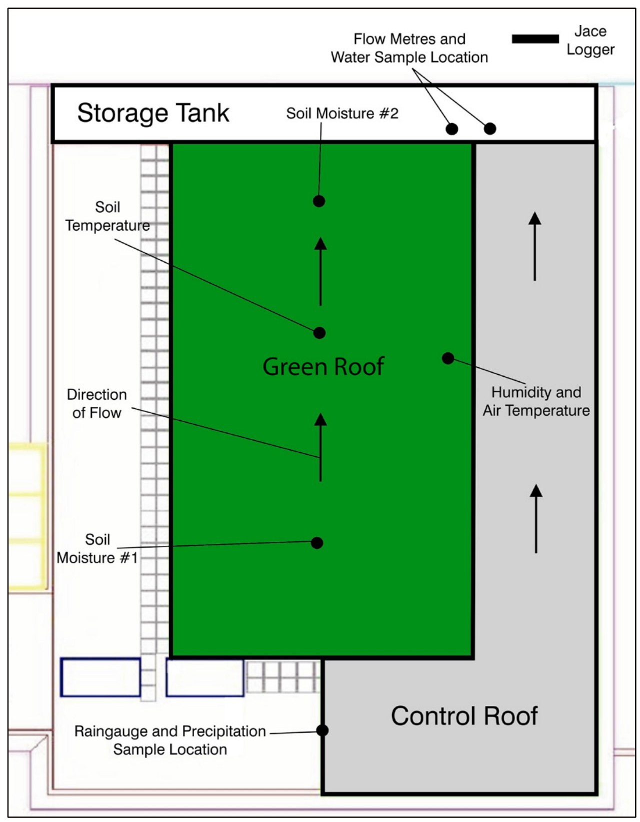

Figure 2: Locations of monitoring equipment at the study site

Parameters measured included runoff volumes, precipitation, soil moisture, relative humidity, and temperature of air, runoff, and the growing medium. Runoff flows from the green and control roofs were measured for three consecutive monitoring seasons (2003-2005) using electromagnetic flow metres. Runoff water temperature was measured continuously from July to August in 2005. Precipitation quantities were measured throughout the study using a tipping bucket rain gauge.

Runoff samples from the green and control roofs were collected for water quality analysis using two automated samplers (Figure 3). Precipitation was also sampled and analysed in order to quantify atmospheric deposition of contaminants on the roof during dry and wet weather. An open bag lining a 48 cm diameter bucket was used for collecting precipitation samples.

Figure 3: Automated water samplers installed at the study site

Water quality analysis was completed for a total of 21 events during the 2003 and 2004 monitoring seasons, and then for an additional 6 events in 2008 in order to determine whether runoff quality had changed over time. Samples were submitted to the Ministry of the Environment laboratories for analysis of general chemistry, nutrients, bacteria, metals, and polycyclic aromatic hydrocarbons.

Biologists conducted an inventory of flora and fauna species on the green roof during the 2004 and 2005 monitoring seasons. Botanical surveys included both a comprehensive species inventory of every plant found on the green roof and a quadrat study to analyze quantitative composition. An undergraduate student from York University also carried out a bee survey in order to evaluate the value of the green roof as bird and bee habitat.

Modelling

Data obtained from monitoring in 2003 and 2004 were used to model the stormwater management benefits of green roof implementation on flat roofs within the fully developed Highland Creek watershed. Using a typical rainfall year, the Hydrological Simulation Program in Fortran (HSP-F) model was run for current conditions and two green roof implementation scenarios.

Analysis of Green Roof Growing Media

The chemistry, grain size, and water leachate chemistry of 11 different green roof growing media were analyzed in order to determine their potential impact on the quality of green roof runoff. Samples were analysed for various parameters including general chemistry, nutrients, metals and particle size.

FINDINGS

Over the monitoring period, the green roof retained approximately 63% of runoff relative to the control roof. This is based on data collected from May 2003 through to August 2005, excluding the winter months from January to March. Assuming that retention rates during the winter were between 5 and 25%, the annual retention rate for the entire study period would be between 51 and 54%. Excluding winter, the green roof retained 54% of precipitation relative to the control roof in 2003, while in 2004 it retained 76% and in 2005 it retained 74% (Table 1). The lower retention rate for 2003 is attributed to higher precipitation levels and the nightly irrigation of the plants that occurred during that year. Seasonally, the green roof's retention capacity varied with evapotranspiration. The best retention rates occurred in the hot summer months, followed by the spring and fall (Figure 4).

Table 1: Monthly flow volumes and performance of green vs. control roof for 2003-2005 monitoring seasons.

	Season	Rain (mm)	Inflow (L)[a]		Outflow (L)		Outflow per unit area (L/m^2)		% runoff retention relative to precipitation[b]		% runoff retention relative to control[b]	Average runoff co-efficient	
			Green	*Control*	*Green*	*Control*	*Green*	*Control*	*Green*	*Control*		*Green*	*Control*
2003	*Spring / Summer*	316.4	76252	41448	18152	40564	75	310	76.2	2.1	75.6	0.24	0.98
2003	*Fall*	347.4	83723	45509	55293	47960	229	366	34	-5.4	37.4	0.66	1.05
2003	*Totals*	663.8	159976	86958	73445	88524	305	676	54.1	-1.8	54.9	0.46	1.02
2004	*Spring / Summer*	325.5	78446	42641	17355	36434	72	278	77.9	14.6	74.1	0.22	0.85
2004	*Fall*	117.6	28342	15406	8708	14480	36	111	69.3	6	67.3	0.31	0.94
2004	*Totals*	443.1	106787	58046	26063	50914	108	389	75.6	12.3	72.2	0.24	0.88
2005	*Spring / Summer*	303.5	73144	39759	18497	35247	77	269	74.7	11.3	71.5	0.25	0.89
Total (all monitoring seasons)		**1410.4**	**339906**	**184762**	**118005**	**174686**	**490**	**1334**	**65.3**	**5.5**	**63.3**	**0.35**	**0.95**

[a] Inflows calculated based on measured precipitation and the total catchment area. [b] All percent runoff retention values are calculated based on total inflow and outflow measurements.

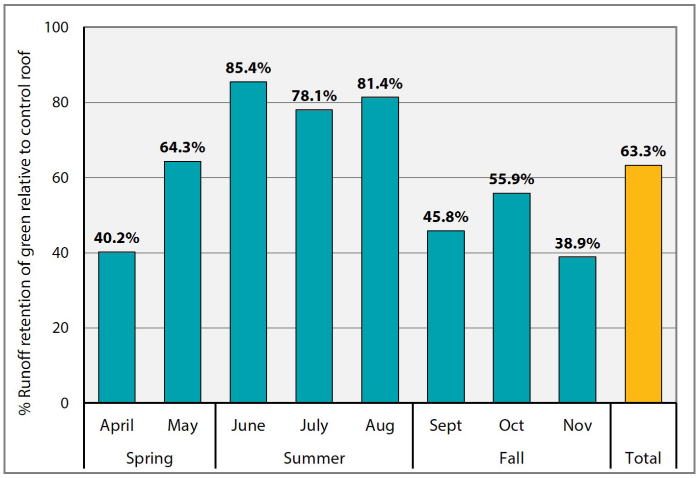

Figure 4: Average percent runoff retained by the green roof relative to the control on a monthly basis.

During individual events, variations in green roof retention were influenced primarily by antecedent soil moisture levels, and event size, duration and intensity. The green roof ceased to retain water once the substrate was saturated. Figure 5 shows precipitation and runoff flows from the control and green roofs for two consecutive events from Aug. 28 to 29, 2004, with an inter-event period of about 11 hours. During the first event - which was 8.8 mm - the control roof responds immediately, while the runoff response from the green roof is delayed and much smaller in magnitude, as the majority of rain is absorbed by the soil. During the second (24.2 mm) event, the runoff response from the green roof is more immediate than for the first event, due to higher soil moisture content and rainfall intensity. While the green roof response starts to mirror that of the control by the end of the second event, the volume reduction of the green roof over both events was still almost 40% relative to the control.

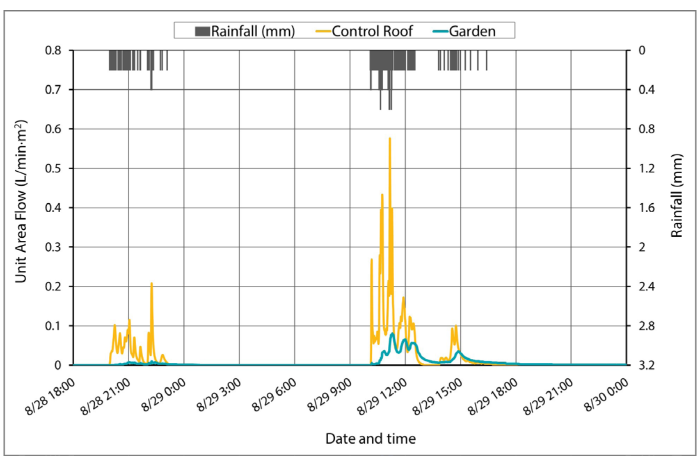

Figure 5: . Hydrograph and hyetograph for two consecutive events from Aug. 28-29, 2004. The events are 8.8 and 24.2 mm, and inter-event period is approx. 11 hours.

Average peak flow reduction of the green relative to the control roof decreased with increasing precipitation event volumes. The green roof attenuated peak flows less effectively during subsequent storm events and during individual large events. Average peak flow reductions for rainfall depths between 10 and 29 mm, 30 and 39 mm, and over 40 mm were 87, 68 and 50%, respectively. Within the City of Toronto, approximately 98% of rainfall events that occurred between 1970 and 2002 were less than 30 mm (Klassen, 2005). Assuming that peak flow reduction during events smaller than 10 mm are as high or higher than 87%, it may be concluded that the green roof could provide at least an 87% reduction in peak flows for 98% of rainfall events in Toronto.

The green roof continued to provide stormwater management benefits during the cold season. These benefits include runoff retention, peak flow reduction and increased runoff lag times. During one snowmelt event on December 16, 2003, the green roof provided 35% runoff retention and 15% peak flow reduction relative to the control roof. There was also a 5 hour lag in peaks between the two surfaces. These peak flow characteristics help to prevent stream erosion and reduce the frequency of overflows in areas where there are combined sewers.

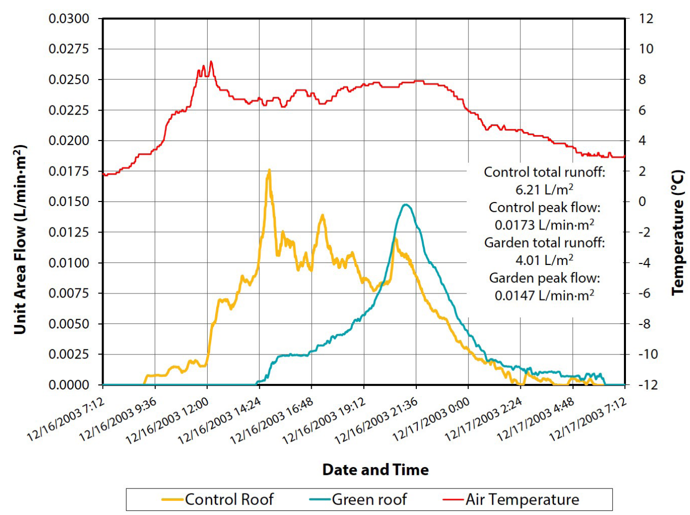

Figure 6: Hydrograph showing control and green roof flows during a of a snow melt event on December 16, 2003. Red line represents air temperature.

Hydrologic simulations of green roof implementation on 100% of available flat roofs in the Highland Creek watershed showed a 4% reduction in annual runoff volume. Flat roofs that were capable of being greened accounted for 9% of the watershed. The results also showed that this extent of green roof implementation in that watershed would cause a 15% reduction in peak flows (for events between 20 and 30 mm) and a 37% increase in evapotranspiration.

Total loads for most pollutants of concern were lower from the green roof than from the control, largely because the green roof had much smaller runoff volumes. Table 2 shows the 'percent difference' in unit area loads from the control and green roofs. Positive values indicate higher control roof loads and negative values indicate higher green roof loads. The green roof did have higher loads of several chemicals that form part of the growing medium, such as potassium, magnesium, calcium and phosphorus. Among these, only phosphorus posed a threat to receiving waters since, at elevated concentrations in rivers and lakes, it can stimulate algal and aquatic plant growth. As these plants decompose they contribute to the depletion of oxygen levels, resulting in adverse effects on aquatic organisms.

Table 2: Unit area loads and percent difference of control roof vs. green roof for the 2003 and 2004 monitoring seasons

Variable	Unit Area Load (mg/m^2)		% Difference control vs. green roof
	Green Roof	Control roof	
Total suspended solids	763.2	6752.0	88.7
Potassium	2463.2	2091.5	-17.8
Nitrogen; nitrate	40.8	450.1	90.9
Nitrogen; nitrite	7.5	31.4	76.2
Nitrogen; ammonia +ammonium	6.1	245.7	97.5
Nitrogen; total Kjeldahl	575.3	677.7	15.1
Phosphorus; phosphate	207.2	26.1	-694.1
Phosphorus; total	241.7	69.5	-247.6
Aluminum	19.6	63.1	68.9
Calcium	9510.4	5300.2	-79.4
Copper	15.6	110.8	85.9
Iron	14.3	38.5	62.8
Lead	1.62	3.45	53.0
Magnesium	2329.0	904.1	-157.6
Zinc	3.37	11.02	69.5

Total phosphorus and phosphate concentrations in green roof runoff significantly decreased in from 2004 to 2008. Phosphorus is the limiting nutrient to plant growth, and because is it needed in only very small amounts, elevated concentrations can stimulate algal and aquatic plant growth, which deplete oxygen levels as they decompose resulting in adverse effects on aquatic organisms. During monitoring in

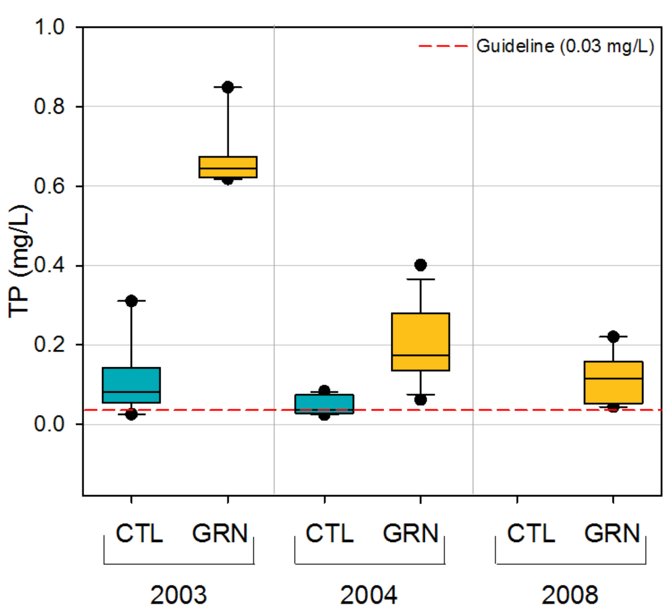

Figure 7a: Box plot depicting concentrations of total phosphorus (TP) in control and green roof runoff. Guideline is a Provincial Water Quality Objective (OMOE, 1994).

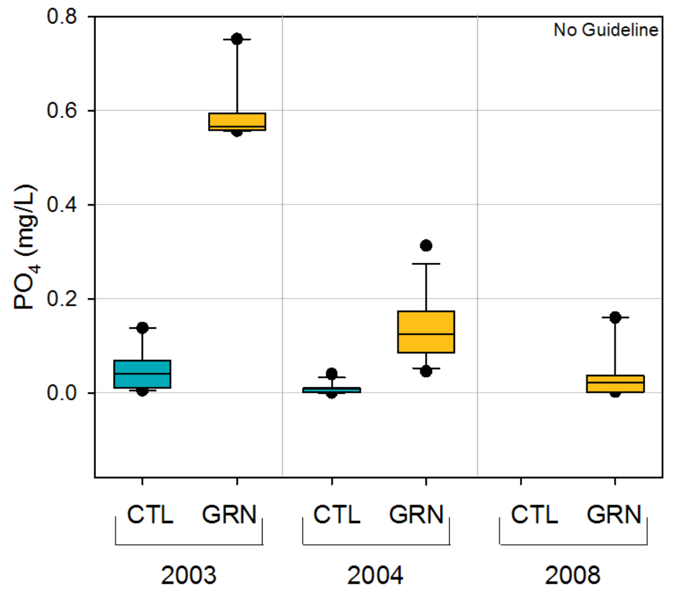

Figure 7b: Box plot depicting concentrations of phosphate (PO_4) in control and green roof runoff during different monitoring seasons.

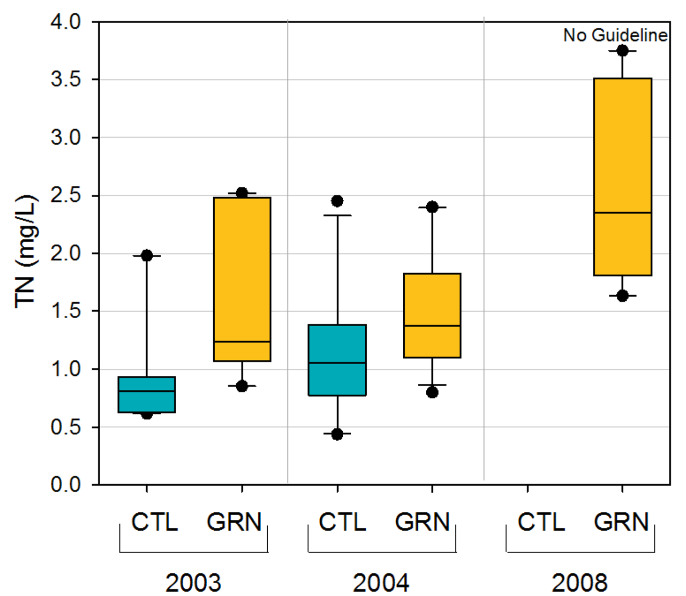

Figure 7c: Box plot depicting concentrations of total nitrogen (TN) in control and green roof runoff during different monitoring seasons.

Box Plots

Also known as whisker diagrams, box plots are used to display key statistics from a data set in a standardized way. They show how data are distributed, which gives an indication of the data set's symmetry or the extent to which it is skewed.

The data presented in the box plots of Figures 7a to 7e are concentrations of nutrients in runoff from the two roof surfaces. In these box plots, the horizontal line across the box is the median, the bottom and top of the box are the 25th and 75th percentiles, and the whiskers extending below and above the boxes are the 5th and 95th percentiles. The dots are the maximum and minimum concentrations observed.

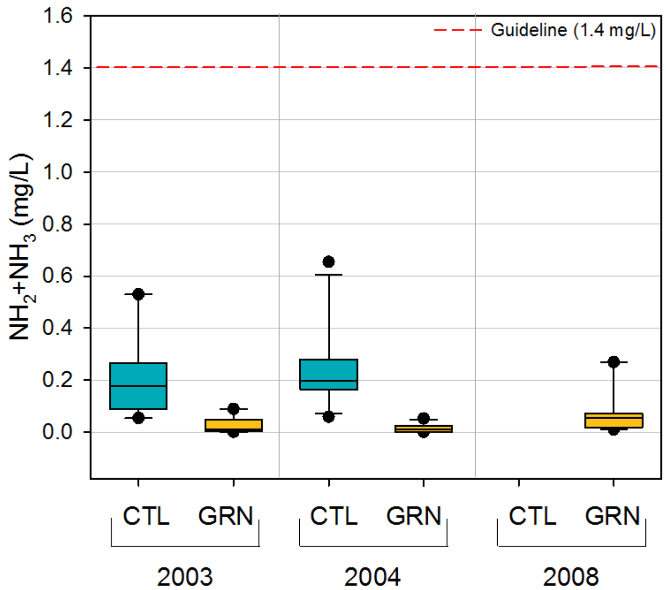

Figure 7d: Box plot depicting concentrations of nitrogen present as ammonia + ammonium (NH_2+NH_3) in control and green roof runoff during different monitoring seasons. Guideline is a Provincial Water Quality Objective (OMOE, 1994).

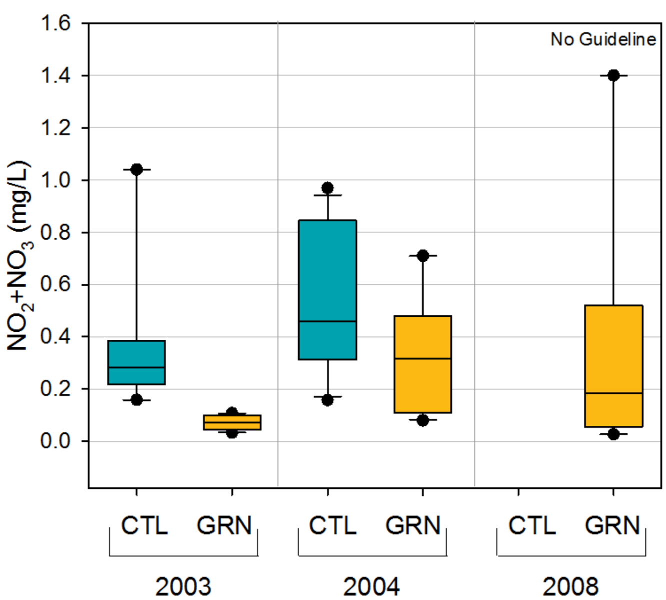

Figure 7e: Box plot depicting concentrations of nitrogen present as nitrite + nitrate (NO_2+NO_3) in control and green roof runoff during different monitoring seasons.

2003 and 2004, when the green roof was newly constructed, runoff contained significantly higher TP and PO4 concentrations than the control runoff (Figure 7). The main source of phosphorus on the green roof is the growing medium itself, which may have contained phosphorus-rich fertilizers to help initiate plant growth. Chemical analysis of the substrate shows that this particular substrate (which is no longer commercially available) had higher soil phosphorus concentrations than 10 of the 11 other tested substrates. Green roof total phosphorus and phosphate concentrations in 2004 were less than half of what they were in 2003, and they continued to decrease as measured in 2008. This decrease likely represents a process of leaching whereby soil phosphorus is gradually flushed out during initial operation. If this is the case, continued leaching over time may bring phosphorus levels from the green roof down to control roof levels and/or receiving water objectives, a trend already initiated during the 2008 sampling period.

Total nitrogen from green roof runoff exceeded control runoff concentrations and showed an increase over time. It is common for green roofs to have higher concentrations of TN compared to a control roof initially following construction completion. This is associated with the growing media composition, similarly to the observed higher levels of TP and PO_4 (Figure 7). Although it is expected that TN would eventually leach out of the green roof over time, this was not observed for the study site, as the TN concentrations sharply increased in the 2008 measurement season. Thus, the continuously high concentrations of TN may be attributed to release by roots of particular plant species. Nitrite and nitrate experienced a decrease over time, although the variance increased. This decrease shows that green roofs are effective in removing nitrite and nitrate from the stormwater runoff before it enters the ecosystem. This is important, as nitrite is a major concern in surface runoff from urban environments, as increasing nitrogen concentrations facilitate plankton production which leads to algal blooms.

Results of the water leachate chemical analysis from various growing media confirmed that green roof growing media can be a significant source of copper and phosphorus in runoff. The leachate quality of samples from most media tested exceeded receiving water standards for several water quality variables, including phosphorus, aluminum, copper, iron and vanadium. Whether these same variables would be elevated in runoff under field conditions depends on a number of factors, including the type of media, storm size and age of the greenroof. This study showed that while phosphorus may be a concern in green roof runoff, only long term monitoring can determine how long this issue may persist. As described above, phosphorus concentrations in runoff from the York University green roof did in fact drop from 2004 to 2008. Metals in green roof runoff are generally not a concern since conventional roof runoff typically contains much higher concentrations of these constituents. While the mobility of some metals appeared to increase with subsequent leaching of the fresh growing media products tested, this trend would not necessarily be expected to continue in the long term. Runoff from the York University green roof showed no significant upward trend in concentrations of metals over time.

Watershed modeling results indicate that due to the reduced runoff volumes, the implementation of green roofs would result in lower pollutant loads. Hydrologic modelling of 100% green roof implementation in the Highland Creek watershed (representing 9% of the watershed area) indicated that water quality loads would be reduced for almost all variables, primarily due to decreased flow volumes. The only notable exceptions were total phosphorus and total Kjeldahl nitrogen, for which levels increased moderately from baseline conditions. It should be noted that the data used for the modelling were from the 2003 monitoring season during which the green roof was at its peak nutrient leaching rate.

The maximum temperature of green roof runoff (34°C) was greater than that of the control roof runoff (31.5°C). The average runoff temperature was also higher for the green roof (27°C) than for the control roof (22°C), and both exceeded the cold water fisheries target temperature of 21°C. The higher green roof runoff temperatures may be attributed to the ability of soil substrates to store heat and slowly release it back to the atmosphere. Moisture in the green roof substrate heats up during inter-event periods and then mixes with rain water, eventually being discharged as runoff. By contrast, the control roof can cool down quickly on cloudy rainy days, resulting in runoff that is closer to the temperature of the rain. Despite the fact that green roof runoff is warmer, its thermal impact on receiving water may still be less than that of the control runoff, simply because it discharges approximately 80% less runoff than the control during the hot summer months.

The original seed mixes applied to the green roof had a significant influence on its native biodiversity. In 2005 the green roof had 91 vascular plant species, of which 32% were native. Because the green roof was originally seeded with non-native grasses and forbs, it was found to have relatively low native biodiversity. Despite the influence of the original seed mixes, subtle, gradual changes were observed. Native biodiversity increased between 2004 and 2005 from 29 to 40 species.

Overall, the green roof is a low-nutrient, low competition environment that can support conservative or rare native plants of concern. While green roofs cannot be a substitute for conserving and restoring forested or wetland habitats on the ground, or large patches of intact landscape in the Greater Toronto Area, they can likely contribute to the conservation of some of our more sensitive flora, especially those adapted to exposed, low-nutrient habitats such as some prairie, meadow, thicket, and fen-like meadow-marsh types. The exposed environment of the green roof would be conducive to certain habitat-specialist native plants while limiting the competitiveness of most invasive species.

The fauna survey conducted in 2004 and 2005 found a total of six bird species on the green roof. The Canada goose and house sparrow were found to be breeding, while the European Starling was the most frequent species observed at the site. To assess the effectiveness of the green roof as a bee habitat the site was compared to other ground level habitats located nearby. The findings indicate that bee community structure on the green roof is not significantly different than most other ground level sites surveyed. As succession occurs on the green roof, bee nesting and foraging may occur.

Figure 8: York University green roof plants pictured in 2003.

CONCLUSIONS

Results of this study showed that green roofs provide significant environmental benefits in terms of flow control, water quality improvement and the creation of healthy green spaces. By retaining flow, reducing peak flows, and creating habitat for plants and animals, the roof mimics many of the life sustaining features of the natural environment. The green roof has the ability to reduce runoff by up to 87% for rainfall events that are less than 30 mm in depth, which occur 98% of the time in Toronto. The runoff reduction benefits are reflected in the water quality results, as loads for majority of runoff constituents were well below the loads generated within the control roof runoff. Additionally, concentrations of phosphorus decreased over time through the process of leaching, which indicates that following a stabilization period, their initially high concentrations do not pose a threat to receiving waters. In addition to water quantity and quality benefits, the green roof was used as a habitat by numerous flora and fauna within an otherwise urban environment. As such, green roofs are feasible and sustainable alternatives to conventional roofs that help mitigate inevitable urban sprawl.

RECOMMENDATIONS

• On buildings with sufficient structural support, flow restrictors should be used in conjunction with green roofs to help attenuate runoff peaks in the winter and early spring, when the green roof is not retaining as much runoff.

• As green roof substrates can be a significant source of phosphorus, growing media containing phosphorus-rich fertilizers or excessive nutrient levels should be avoided.

• Construction materials surrounding the green roof should be selected to minimize leaching of chemicals into runoff.

• To maximize green roof biodiversity, a range of different substrate types, depths and irrigation regimes should be used. Fertilization of green roof soils should be avoided since the low-nutrient status on green roofs is beneficial to biodiversity.

• Minimizing green roof runoff temperatures may require the use of more shading plants or another method that minimizes the exposure of the green roof substrate to direct solar radiation.

• Green roof irrigation should be minimized through appropriate plant and substrate selection. Irrigation schedules should be based on substrate moisture levels.

• This study and current green roof literature suggest that during the first season of installation plant growth and survival should be monitored carefully. Thereafter, the number of maintenance visits required will range from 3 to 10 per year.

• Runoff retention capacity of green roofs during winter rainfall and snowmelt events requires further study

• Long term monitoring of green roof water quality is needed to determine how successive leaching of the growing media may lead to reductions in contaminant loads, and whether or not these reductions are reversed as contaminants build-up in the substrate.

• Long term monitoring of green roof flora and fauna populations should be conducted to determine whether flora biodiversity increases over time, and whether migrating and locally breeding birds will frequent green roofs.

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Visit us at www.sustainabletechnologies.ca to access the full report for this study - titled *Evaluation of an Extensive Green Roof* - and explore our other resources on green infrastructure.

About STEP

The water component of the Sustainable Technologies Evaluation Program (STEP) is a partnership between Toronto and Region Conservation Authority, Credit Valley Conservation, and Lake Simcoe Region Conservation Authority. Contact us at STEP@trca.on.ca.

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