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YORK UNIVERSITY ROOFTOP GARDEN STORMWATER QUANTITY AND QUALITY PERFORMANCE MONITORING REPORT

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Abstract

In Toronto, there is ongoing effort to evaluate the effectiveness of greenroof infrastructure as a technique to reduce the quantity and improve the quality of stormwater runoff in Toronto's Remedial Action Plan (RAP) Area of Concern. In 2003, a research site was chosen on the York University computer science building where measurements of climate, soil, and runoff data are being taken to quantify the benefit of roof gardens for stormwater quality and quantity management in urban areas. Lessons learned in 2003 suggest that: 1) the garden is effective in reducing the total runoff volume and peak flow of rainfall runoff. 2) Performance varies depending on soil moisture and rainfall intensity, however, most of the time the loadings and concentrations are far less than Provincial and Canadian water quality standards.

Introduction

Research has shown that significant environmental benefits can be achieved from rooftop gardens in terms of stormwater runoff quantity and quality control. For example, at a greenroof site in Hannover-Herrenhausen, Germany it was determined that 5 to 10 cm soil layers retained approximately 65-70% of precipitation runoff during the summer and approximately 50% during the winter (6). Kennedy and Gadd (4) reported improvements in the quality of effluent from gardens relative to galvanized roofs, which can contain high concentrations of zinc and other metals.

The water quality of Lake Ontario reflects the health of the rivers and creeks that drain into it. The City of Toronto (the City) has experienced a significant loss of its permeable (i.e. naturally vegetated) surfaces to urban development. In Toronto, tree canopy and natural coverage is approximately 20%, whereas an ideal target for a city is 30% to 35% (7;2;5). While the City has been relatively successful in protecting natural areas, restoring the natural landscape displaced by development is more difficult. To date, rooftops cover as much as 30% to 35% of the land

surface including exsisting and proposed developments (7). By greening rooftops, the total impervious coverage in Toronto can be reduced and new green spaces can be created.

Currently, there is an ongoing effort to evaluate the effectiveness of greenroof infrastructure as a technique to reduce the quantity and improve the quality of stormwater runoff in Toronto's Remedial Action Plan Area of Concern (3). The City's involvement in greenroofs is one of the many storm water management recommendations in the City of Toronto Wet Weather Flow Management Master Plan (1). The potential implementation would consist of retrofitting existing structures and/or incorporating designs into new developments.

Study Area

A research site was chosen on the new York University computer science building where measurements of climate, soil, and runoff quantity and quality data are being taken to quantify stormwater the benefit of roof gardens in urban areas. The roof is covered by two surfaces: shingles (control roof) and a garden both of which have a 10% slope (Figure 1).
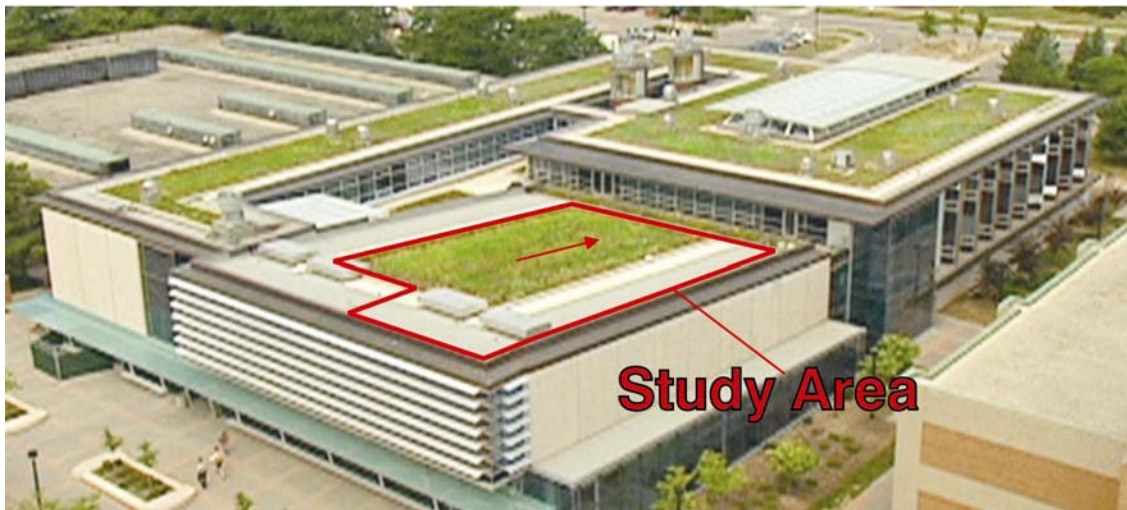

Figure 1: York University, Computer Science Building, Greenroof.

The control roof is approximately half the size of the garden measuring 131 m^2 and 241 m^2 respectively and drains into a storage tank. The tank is used to reduce peak flow discharges to the existing municipal storm drainage system (Figure 2).

The garden consists of a 140mm substrate and is vegetated with wildflowers. Since April 2003, both roofs are being continuously monitored for rainfall, runoff quantity and event runoff quality,

air temperature, soil temperature, humidity, and soil moisture. To prevent freezing during cold weather, all monitoring equipment was wrapped with both insulation and heat tracing cable to take measurements of snowmelt. All of the monitoring devices excluding the water samplers have been networked to a single logger and network that statistically calculates and communicates measured data via the internet. The internet connection also provides real-time measurements of activities (e.g. rainfall) that can be accessed from anywhere in the world.

Methodology

The automated data collection system uses a web-based monitoring system for real-time monitoring and archived data of all climate and hydrometric parameters. The system logs all sensor measurements in one minute intervals and the data are stored and reported through a specially designed website (www.sustainabletechnologies.ca). The website provides the means to view the ongoing progress as well as facilitate the remote operation of the equipment. Archived logs are uploaded to a central web server at Seneca College for long term storage and automatic processing of point values into user selectable report formats.
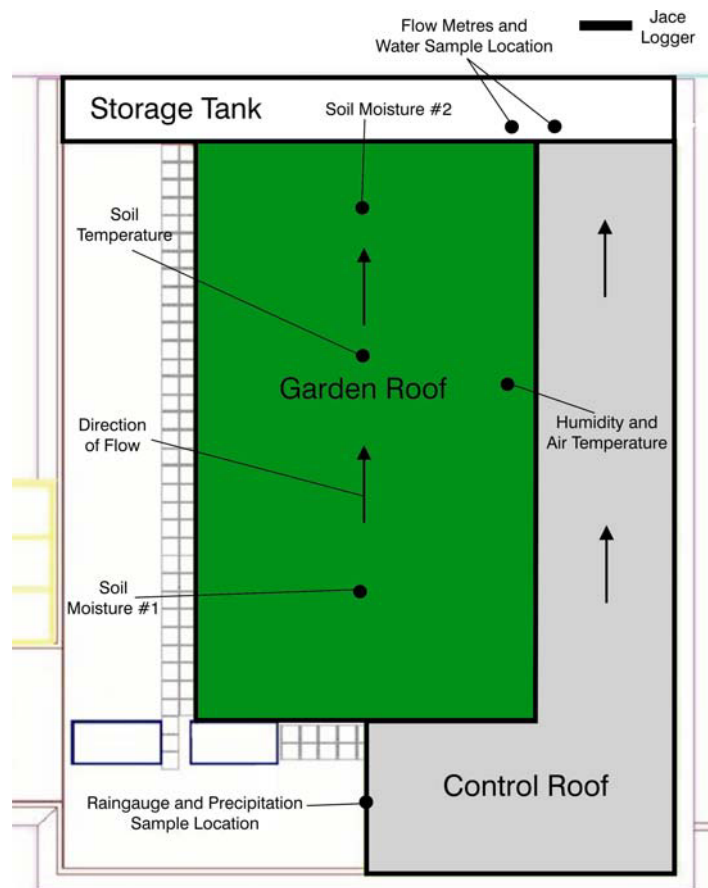
Figure 2: Monitoring design for 2003 season

Flow from both roofs have been isolated and drain to separate eves troughs at the end of the sloped roof, which in turn, is piped through two 2" diameter Endress and Hauser Promag 50 flow metres, and ultimately to the storage tank. The flow metres determine flow rates and volume via the water conductivity (Figure 3).

Two ISCO 6700 automated water samplers were installed to collect runoff water samples from both the control roof and the garden roof. The samplers were connected to the flow meters which in turn were used as a triggering mechanism. Because there is virtually no lag time on the control roof, the sampler was programmed to take samples when 0.1L/s were measured by the flow sensor. Samples were then collected every 5 minutes until all 24 1L bottles were collected. Samples collected from the garden roof were taken every 10 minutes and had a 30 minute delay (average lag time) from the initial flow measurement of 0.1L/s.

Samples consisted of both composite and discrete event samples. Composite samples had all 24 bottles combined while discrete event sampling broke down the event in 4 parts. Each part represented the early, middle (1), middle (2), and end of a storm. In this case, if 24 bottles were collected, the first 6 were combined to represent the early part of the storm; the next 6 would be middle (1) and so on. This was done in order to observe if concentrations changed throughout the event.
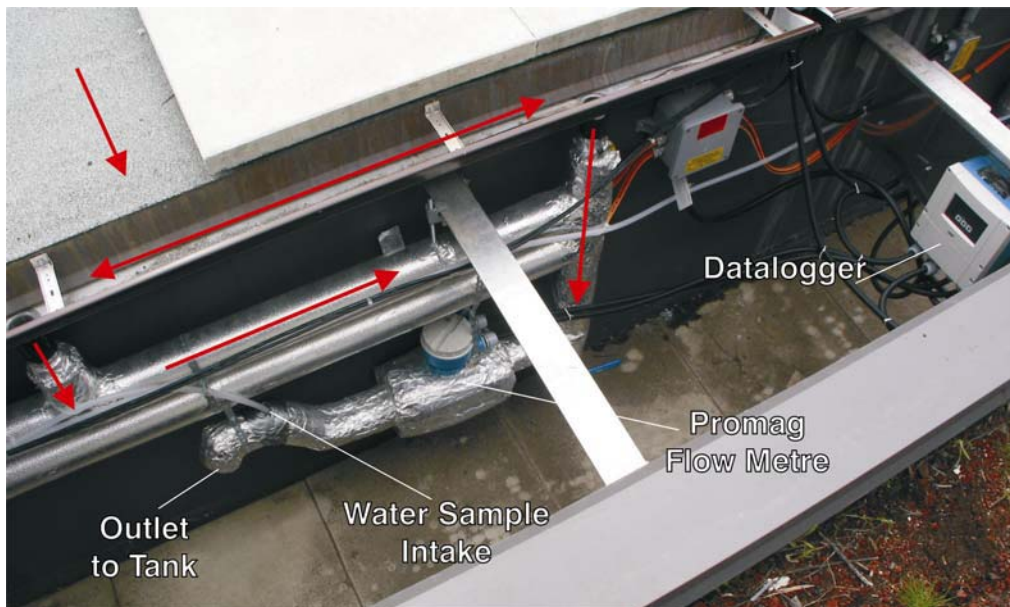

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Figure 3: Flow collection and metering design.

One Hydrological Services tipping bucket raingauge has been installed on site. It has a bucket measurement of 0.2mm, with a measuring range of 0 to 500mm/hr and an accuracy of ±2% at 100mm/hr. Backup measurements are being taken by two separate gauges owned by the TRCA and York University and are located within 5 km from the study area. Precipitation was collected into an open Teflon bag lining a bucket with a diameter of 48cm. All precipitation samples were submitted to the lab as composites. Samples were analyzed for similar parameters to directly compare pollutant concentrations and loads in precipitation and roof runoff. Because precipitation is relatively clean, samples could only be analyzed for certain parameters. These parameters include:

- Metals
- Nutrients
- Conductivity
- Cations
- Chloride
- Turbidity
- Anions
- PAHs
- Bacteria
- CODs
- Suspended solids
- Alkalinity
- BODs
- pH
- Phenolics

All samples were submitted to the Ontario Ministry of the Environment (MOE) for testing.

Treatment efficiency was determined on the basis of pollutant mass differences. Load-based median efficiency was calculated as:

$$LE\sum = (V_{in} \times EMC_{in} - (V_{out} \times EMC_{out}) / V_{in} \times EMC_{in}) \times 100$$

1 =1

Where:
- LE = Load Efficiency
- V = Volume
- EMC = Event Median Concentration

Measurements are also being taken to characterize both the micro climate and garden soil attributes. The climate was monitored for relative humidity (RH), air temperature, and rainfall and the garden was monitored for soil moisture and soil temperature. Two sensors were positioned at the high and low points in the garden soil. From the flow metres, the high point was near the top of the 10% slope. Measurements are being collected to assist in calculating the residual water content that is being stored in the soil, the antecedent soil moisture condition, and to assess potential improvements to the system. Measurements will provide valuable information for the final water balance and analyzing the performance of the garden area in terms of moisture retention and storage capacity.A Veris Industries digital RH, air and soil

temperature sensor was installed with a measurement accuracy of ±2% and ±0.25% respectively. Soil temperature measurements are being collected at the centre of the garden. They will be used to assess the potential evapotranspiration in the final water balance. Similar to soil temperature, air temperature measurements were taken as a control for future efficiency calculations. Relative humidity was measured for two reasons: to confirm storm event occurrences and for future use in a water balance modelling analysis.

The roof flow balance was determined by calculating the percent difference between the volumes of precipitation that fell on both roofs against the volume measured at the control and garden roof downspouts. In order to quantify the extent to which greenroofs may reduce the amount of stormwater runoff, a water balance model will be developed. The model will reflect the following:

$$Precipitation - Evapotranspiration \pm Storage - Runoff = 0$$

For this study, evaporation is defined as occurring from soil, plant, and impervious surfaces. While storage is water held as soil moisture and plant uptake, as well as, water that is stored in the runoff storage tank. By monitoring all of the previously mentioned parameters, evapotranspiration can be determined as the residual in the water balance equation. It is expected that the water balance will be calculated at the end of the monitoring program.

2003 Monitoring Results

Water Quantity

Over the monitoring season (May to November), the garden reduced the total runoff volume per area (m^2) by approximately 55% and peak flow rates by up to 85% for storm events ≤10mm. During the spring/summer months, the garden reduced runoff volume by 76% and by 37% in the fall. This suggests that garden performance is affected by seasonality (Table 1 and 2). On June 25, 2003 the garden irrigation system was activated by York University. Connected to a timer, the system was activated daily for 118 days from 5:30am to 6:00am until October 20, 2003. The total runoff volume for each day of watering was subtracted from the event flow and was not included in the flow balance. However, observations suggest that the continuous saturation of the garden soils decreased the storage capability and therefore garden performance.

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Selected events with similar precipitation volumes were observed for effectiveness in peak flow reduction. Table 2 depicts the percent difference between unit area volumes from the control and garden roofs, all of which, from storm events ranging between 10mm and ≥40mm. Observations suggest that peak flow reductions decrease with larger storm events. In this case, storms ranging in sizes from 10-19mm, 20-29mm, 30-39mm, and ≥40mm had an average peak flow reduction of 85%, 82%, 68%, and 46% respectively.

	Month	Total Rainfall (mm)	Rainfall Volume (L)		Runoff Volume (L)		Runoff L/m^2		% Diff. Rainfall Volume vs. Runoff Volume		% Diff. Garden vs. Control Runoff (L/m^2)
			Garden	Control	Garden	Control	Garden	Control	Garden	Control	
Spring / Summer	May	121.8	29353.8	15590.4	11202.1	14933.7	46.5	114	61.8	4.2	59.2
	June	87.8	21159.8	11238.4	3489	12175.1	14.5	92.9	83.5	-8.3	84.4
	July	44.2	10652.2	5657.6	749.3	5263.2	3.1	40.2	93.0	7.0	92.3
	August	62.6	15086.6	8127.4	2711.9	8192	11.3	62.5	82.0	-0.8	81.9
	Total	**316.4**	**76252.4**	**40613.8**	**18152.3**	**40564**	**75.4**	**309.6**	**76.2**	**0.1**	**75.6**
Fall	September	143.6	34607.6	18811.6	21435.6	18977.3	88.9	144.9	38.1	-0.9	38.6
	October	55	13255	7205	7950.5	7567.9	33	57.8	40.0	-5.0	42.9
	November	148.8	35860.8	19492.8	25906.5	21414.9	107.5	163.5	27.8	-9.9	34.3
	Total	**347.4**	**83723.4**	**45509.4**	**55292.6**	**47960.1**	**229.4**	**366.2**	**34.0**	**-5.4**	**37.4**
	Total	**663.8**	**159975.8**	**86123.2**	**73444.9**	**88524.1**	**304.8**	**675.8**	**54.1**	**-2.8**	**54.9**

Table 1. Monthly volume totals from May to November, 2003.

Lag time is the time from the centre of a mass of rainfall to the peak of the hydrograph, while a runoff coefficient is the ratio of runoff to precipitation. The control roof performed as expected during the monitoring season, where short runoff lag times and runoff coefficients nearing 1 are typical of a standard roof with no runoff controls (Table 3). By contrast, garden coefficients progressively increased over the monitoring period (i.e. July = 0). By November, a co-efficient of 1 was averaged for the month, suggesting that the garden was providing little storage and was characteristic of an impermeable surface. The decrease in storage performance during the fall (September to November) was a result of cooler temperatures, plant dye off, irrigation in September and October and decreased evapotranspiration rates, which in turn, increased soil moisture content.

Date	Range	Rainfall (mm)	Peak Flow (L/min)		Peak Flow L/m^2		Difference (L/m^2)	Peak Flow Reduction (%)
			Control	Garden	Control	Garden		
5-May-03	10-19mm	10.8	3.472	0.600	0.027	0.002	-0.024	-90.6
5-May-03		13.8	30.800	7.400	0.235	0.031	-0.204	-86.9
20-May-03		12.2	14.100	0.921	0.108	0.004	-0.104	-96.4
4-Jun-03		13.2	6.500	0.600	0.050	0.002	-0.047	-95.0
13-Jun-03		17.6	60.228	6.435	0.460	0.027	-0.433	-94.2
15-Jul-03		11.6	136.275	7.571	1.040	0.031	-1.009	-97.0
22-Jul-03		11.2	111.670	5.300	0.852	0.022	-0.830	-97.4
10-Aug-03		10.6	195.706	14.385	1.494	0.060	-1.434	-96.0
11-Aug-03		10.6	199.870	187.756	1.526	0.779	-0.747	-48.9
14-Oct-03		15.7	94.771	29.080	0.723	0.121	-0.603	-83.3
26-Oct-03		15	9.914	5.246	0.076	0.022	-0.054	-71.2
2-Nov-03		18.4	26.846	8.574	0.205	0.036	-0.169	-82.6
12-Nov-03		15.6	42.457	19.143	0.324	0.079	-0.245	-75.5
19-Nov-03		14.6	53.541	25.718	0.409	0.107	-0.302	-73.9
Average							**-0.443**	**-84.9**
8-Jun-03	20-29mm	21.6	39.857	2.604	0.304	0.011	-0.293	-96.4
29-Jun-03		26.4	196.365	76.954	1.499	0.319	-1.180	-78.7
2-Aug-03		24.4	220.247	42.837	1.681	0.178	-1.504	-89.4
3-Nov-03		22	52.203	34.288	0.398	0.142	-0.256	-64.3
Average							**-0.808**	**-82.2**
16-May-03	30-39mm	30.6	32.176	14.385	0.246	0.060	-0.186	-75.7
23-May-03		33.6	34.069	24.605	0.260	0.102	-0.158	-60.7
Average							**-0.172**	**-68.2**
27-Sep-03	≥40mm	41.6	124.044	122.812	0.947	0.510	**-0.437**	**-46.2**

Table 2. Peak flow reduction and percent difference for storm events between 10mm to >40mm.

Month	Total Rainfall (mm)	Average Runoff lag (min)		Average Runoff Coefficient	
		Control	Garden	Control	Garden
May	121.8	3.4	88.7	0.8	0.2
June	87.8	4.5	16.5	1	0.1
July	44.2	4.0	10.8	0.8	0
August	62.6	1.4	4.3	0.9	0.1
September	143.6	1.0	3	1	0.6
October	55.0	-2.6	29.6	1	0.8
November	148.8	3.4	17.5	1.2	1

Table 3. Average monthly runoff lag time and co-efficient from May to November, 2003.

Nonetheless, during the spring/summer months (May to August), warmer temperatures, plant growth, and increased evapotranspiration rates generated low coefficients nearing 0. Unlike the previous, run off lag time varied from 4 to 88% during the spring/summer months and 3 to 18% during the fall months. The variable lag times are a direct result of antecedent conditions, event precipitation volumes, and irrigation contribution. Antecedent conditions significantly affect the

performance of the garden. Soil moisture, warm temperatures, and evaporation rates regenerate or deteriorate the gardens storage capability. For instance, events that occur "back to back" increase the soil moisture content and in turn, increase runoff volumes and rates because of the reduction in storage.

In general, the garden performs better during the spring/summer months than in the fall. When selected events were sorted into ascending order (6.3mm to 41.6mm) and separated into spring/summer and fall events, it was observed that the garden exceeded its storage capacity for storms ≥30.0mm during the spring/summer and ≥20.0mm during the fall (Figure 4). For rainfall amounts less than 25.0mm, coefficients were generally low (0.1 to 0.7) during the spring/summer months. During the fall months, runoff from the garden was more prominent and coefficients ranged from 0.4 to 1.0. lower spring/summer runoff volumes reflected both by regular periods of dry weather, variable rainfall intensity, warmer temperatures, and living garden vegetation evapotranspiration, while fall performance reflected cooler temperatures, minimal soil dryness, variable rainfall intensity, and plant die-off.

Runoff Volume for Various Storm Sizes, York University Greenroof, 2003.

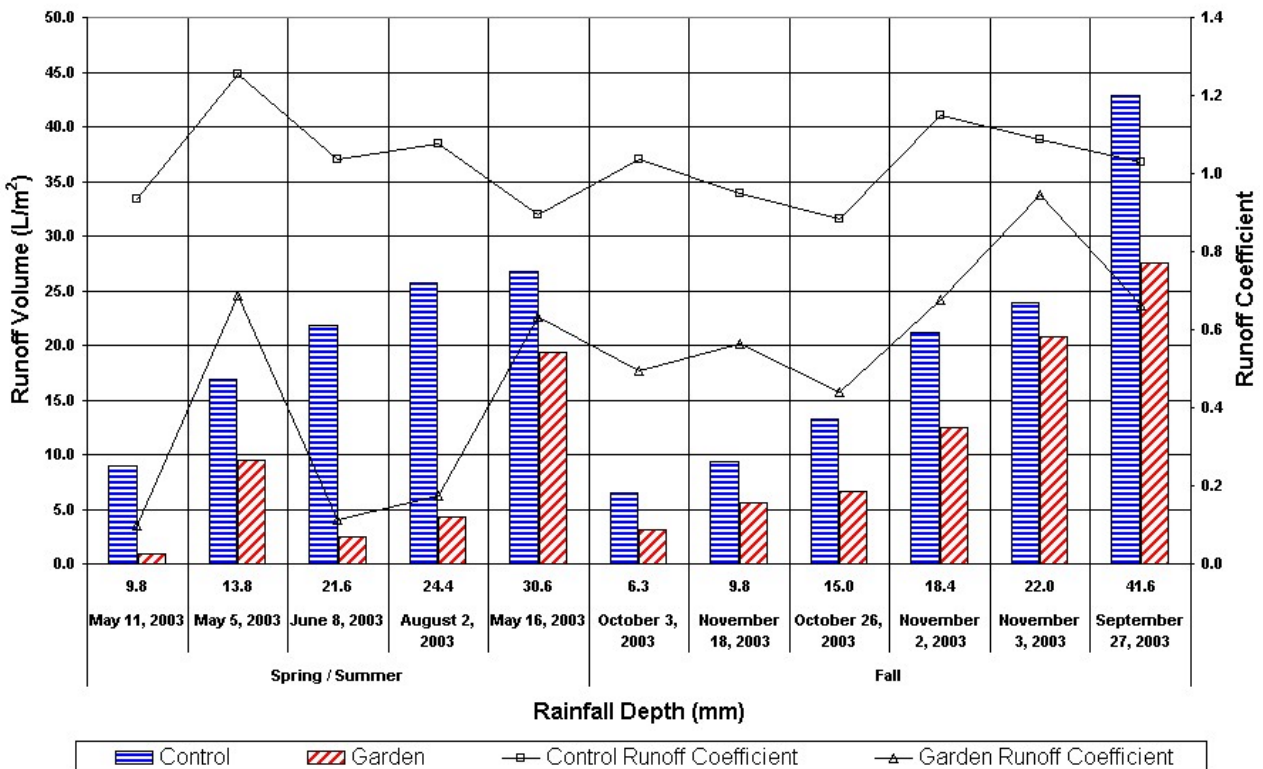back to main topic   previous   next

Figure 4. Event performance for various sized storms. Chart is arranged by events from smallest to largest and by season.

During the spring/summer months, warmer temperatures, decreased rainfall, and increased evaporation rates dried the soil and decreased soil moisture content. The increase in soil void space availability allowed the garden to absorb more precipitation during an event and in turn generated low runoff volumes during this time. It was observed that when soil moisture reached 33% or greater, runoff from the garden in most cases, would equal or exceed the control runoff. In this case, little retention and storage was provided by the garden.

Water Quality

For this study, events collected on September 15, 22, 27, October 14, and 18 were used. Results from several other events were not available at the time of writing. Generally, garden runoff had higher concentrations than both the control roof and rainfall. Of the 60 water quality parameters monitored most concentrations met PWQO and CWQG guidelines. However, the garden had 7 parameters exceed PWQO concentrations and 3 exceeded CWQGs. These parameters included: phenolics, total phosphorous, *Ecoli*, cadmium (both guidelines), copper (both guidelines), lead (both guidelines), and fluoranthene. Generally, the garden increased concentrations for most metals, cations, anions, bacteria, and several nutrients. Surprisingly, rainfall exceeded PWQO and CWQG guidelines for pH (5.3), lead (4.6 µg/L), and copper (6.8 µg/L), however, for all other parameters rainfall concentrations were well below guidelines.

Typically, the garden had larger pollutant loadings. Compared to the control roof, the garden had larger loadings for phosphate (97%), total phosphorous (95%) most metals, cations, anions, and COD (91%). However, the garden was effective in reducing loadings of suspended solids (172%), nitrogen complexes such as ammonia/ammonium, nitrite, and nitrite/nitrate (852%, 79%, and 212% respectively), aluminium (26%), copper (147%), BOD (93%), manganese (224%) and most PAHs.

It should be noted that irrigation from municipal waterworks may have influenced some parameters by diluting or increasing concentrations and loadings. Furthermore, hardness values were much larger from the garden than the control roof. This could contribute to a reduction in the toxicity of metals in garden runoff.

Climate and Garden Soil

In all cases, the maximum monthly soil temperature was less than the maximum monthly air temperature. On the other hand, minimum soil temperature observations suggested that soil temperatures were higher than minimum air temperature values. This is most likely because of the increased density and insulation characteristic of the garden soil. In several cases mean temperatures for soil exceeded air temperature, the lower values were a result of slower temperature fluctuations in the soil, and larger, more rapid changes in the air temperature (Table 3). During July, and most of the spring/summer, air temperature was consistently greater than the soil temperature, suggesting that the soil acted as an insulator during night and daytime temperatures. The garden also typically generated a temperature inversion lag which saw air temperatures changing more rapidly than soil temperatures.

Soil moisture was collected from May to August, 2003. Sensor malfunction made data collected between September and November unreliable. Observations suggest that because of the sloped roof, water collected in the lower 1/3 of the garden (sensor 2). In almost all cases, percent moisture for sensor 2 was greater than sensor 1. Mean relative humidity suggested that humidity gradually increased between spring/summer and fall. During the spring/summer months, warmer temperatures, decreased rainfall, and increased evaporation rates dried the soil and decreased soil moisture content. The increase in soil void space availability allowed the garden to absorb more precipitation during an event and in turn generated low volumes during this time. It was observed that when soil moisture reached 33% or greater, runoff from the garden in most cases, would equal or exceed the control runoff. In this case, little retention and storage was provided by the garden.

	Air Temperature (ºC)			Soil Temperature (ºC)			Soil Moisture 1 (%)			Soil Moisture 2 (%)			Relative Humidity (%)		
	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
May	28.2	5.3	14.6	24.2	9.1	14.3	33.7	29.2	24.5	42.6	29.9	38.3	98.7	8.7	66.1
June	38.6	6.3	21.1	36.3	11.2	21.2	32.4	6.2	21.6	36.7	8.4	25.8	95.7	19.2	61.6
July	37.1	13.3	24.0	35.3	16.7	25.2	20.0	6.8	10.7	33.1	18.0	26.4	94.7	22.7	63.1
August	36.5	12.4	24.2	30.4	15.3	23.7	23.9	6.5	16.9	41.4	21.2	32.2	98.7	20.6	68.4
September	33.3	6.2	19.3	25.4	8.2	18.0	-	-	-	-	-	-	99.4	25.8	70.5
October	30.6	1.5	11.3	19.0	2.4	8.7	-	-	-	-	-	-	100.3	32.4	74.6
November	19.0	-4.2	6.7	12.7	0.2	4.4	-	-	-	-	-	-	100.4	39.0	81.7

Table 3. Monthly maximums, minimums, and means for soil moisture, temperature, and relative humidity, for 2003.

Conclusions and Recommendations

The key findings of the monitoring to date are:

- Overall, the garden resulted in a 55% reduction in runoff volume from May to November, 2003.
- Seasonality did affect the performance of the garden. During the spring/summer months, the garden reduced the total runoff volume by 76% and by 37% in the fall. Typically, storm events ≤30mm had reduced flow and volume during the spring/summer months, while in the fall it was approximately ≤20mm.
- Antecedent conditions (i.e. % soil moisture and dry weather) can degrade or improve garden performance by adjusting storage capabilities (Appendix B).
- The performance of the garden at reducing peak flow rates varied from 85% reduction for storm events up to 10mm, to 46% reduction for 40mm storm events.
- Irrigation significantly reduced the performance of the garden by continually saturating the soil and increased plant die-off rates.
- The garden provided no quantity control benefit when soil moisture reached 33% or greater.
- Of the 60 water quality parameters monitored most concentrations from the garden met PWQO and CWQG guidelines. However, the garden had 7 parameters exceed PWQO concentrations and 3 exceeded CWQGs. These parameters included: phenolics, total phosphorous, *Ecoli*, cadmium (both guidelines), copper (both guidelines), lead (both guidelines), and fluoranthene. Generally, the garden increased concentrations for most metals, cations, anions, bacteria, and several nutrients.
- Typically, the garden had larger pollutant loadings. Compared to the control roof, the garden had larger loadings for phosphate (97%), total phosphorous (95%) most metals, cations, anions, and COD (91%). However, the garden was effective in reducing loadings of suspended solids (172%), nitrogen complexes such as ammonia/ammonium, nitrite, and nitrite/nitrate (852%, 79%, and 212% respectively), aluminium (26%), copper (147%), BOD (93%), manganese (224%) and most PAHs.

The following outlines the recommendations for the 2004 monitoring period.

- The irrigation system should be regulated by soil moisture sensors that trigger the system only when necessary. Over watering not only decreased the performance of the garden, but it contributed to increased plant dye off.
- Testing of chemical makeup of all contact surfaces (i.e. garden soil, eves trough plumbing) to determine the magnitude these surfaces are contributing to runoff quality changes.
- Complete a full water balance for 2003 and 2004 seasons.
- Undertake hydrologic modelling analysis using monitored data to calibrate model.
- Evaluate benefits of vegetation versus substrate.

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