Performance Evaluation of Rainwater Harvesting Systems

Toronto, Ontario

Prepared by: Toronto and Region Conservation **Final Report 2010**

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A final report prepared by:

Toronto and Region Conservation Authority

under the

Sustainable Technologies Evaluation Program

May 2010
(Revised June 2011)

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A revision to this report was released in June 2011 incorporating minor changes and updates based on information provided since the original publication in May 2010.

PUBLICATION INFORMATION

Reports conducted under the Sustainable Technologies Evaluation Program (STEP) are available at www.sustainabletechnologies.ca. For more information about this study, please contact:

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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 was developed to provide the information, 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 for implementing technologies ;
- develop supporting 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 structures; 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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ACKNOWLEDGEMENTS

This project was made possible by funding support from the following organizations:

- Region of Peel
- City of Toronto
- Region of York
- Toronto and Region Remedial Action Plan (OMOE and Environment Canada)
- Government of Canada’s Great Lakes Sustainability Fund
- Ontario Ministry of the Environment (lab services)
- Fisheries and Oceans Canada
- Orlando Corporation
- Canada Mortgage and Housing Corporation

The following organizations provided information, site access and/or expertise:

Enermodal Engineering
Metro Label Company Ltd.
Minto Developments Inc.
Toronto District School Board

A special thanks to Pauline Beaupre from the University of Toronto for assistance with summarizing background information for the study.

EXECUTIVE SUMMARY

Rainwater harvesting refers to the ancient practice of collecting rainwater from roofs or other impermeable surfaces for future use in satisfying daily water needs. The practice helps to conserve water, reduce stormwater runoff, reduce municipal energy costs for pumping water, and delay costly expenditures on new water treatment plants or existing plant expansions. This study evaluates the benefits and limitations of commercial rainwater harvesting (RWH) systems from the perspective of water conservation, stormwater runoff control, water quality and overall operation and maintenance.

Study Sites

Three buildings in Toronto with RWH systems were selected for the evaluation: (i) a commercial printing facility, (ii) a high rise residential building, and (iii) a large public school. All systems were designed to collect rainfall from the roof, store it in cisterns and distribute the water for toilet flushing and irrigation. In addition to the RWH system, water use reduction features in the buildings include waterless urinals and low-flow toilets, fountains and faucets.

Although all buildings have similar end uses for non-potable water, the systems are configured very differently. Table 1 presents drainage areas and storage volumes sizes for the three sites.

Table 1: Site drainage areas and storage volumes

Site	Drainage Area (m^2)	Volumes (m^3)			
		Settling Chamber	Rainwater Storage	Minimum Storage	Effective Rainwater Storage [1]
Printing Facility	968	6	12	3	9
Public School	2879	13	29	3	26
High Rise Apartment	1295	none	24 [2]	10	9

1) “Effective rainwater storage volume” is the rainwater volume available for distribution, as represented by the difference between the rainwater storage volume and the minimum storage volume, that is set by the system operator and remains in the cistern at all times to prevent re-suspension and transport of previously settled solids.

2) Includes 5 m^3 of temporary storage above the overflow pipe to allow for slow release of stormwater during very large events

- The printing facility RWH system supplies non-potable water to 130 building occupants. The roof catchment area is 968 m^2 and the precast concrete underground cistern is 18 m^3. The cistern consists of a 6 m^3 settling chamber that is always full, and a 12 m^3 rainwater storage chamber that fluctuates with use.

- The public school RWH system supplies non-potable water to 826 occupants and has a roof catchment area of 2,879 m^2 with a 42 m^3 underground precast concrete cistern (13 m^3 settling chamber, and 29 m^3 rainwater storage chamber).

- The high rise apartment RWH system is located in the underground garage and does not include a settling chamber. Rainwater is used primarily for irrigation during the summer and for toilet flushing in common use areas throughout the year. The 1295 m^2 catchment area for this system includes both roofs and patios, and the cistern is capable of storing 24 m^3 of water. Approximately 19 m^3 of the cistern volume is intended for retention of harvested rainwater, and the remaining 5 m^3 above the invert of the overflow pipe is used to provide temporary storage for controlled release of stormwater. Unlike the other two systems, municipal water is used to top-up the cistern, rather than being provided directly to the distribution system when cistern storage volumes are low. Although the cistern is considerably larger than that of the printing facility, the effective rainwater storage volume available for distribution is the same (see Table 1) because the minimum storage volume required to prevent re-suspension of bottom sediments was set by the operator at 10 m^3, rather than the more typical level of 3 m^3 at the printing facility.

None of the three systems include soakaways or trenches for infiltration of overflows. Instead, all overflows are directed to the storm sewer.

Study Approach

The monitoring program included continuous measurements of precipitation (rain and snow), cistern water levels, water volumes supplied from the cistern (cistern water use), and water volumes supplied from the municipal line when cistern supplies were not available (referred to as municipal make-up). Samples of water from the cistern and hose bibs, and sediment deposited in the cistern were collected and submitted for analysis by the Ministry of the Environment laboratory in Toronto. Sample analysis included the following major variable groups: general chemistry (e.g. pH, conductivity, suspended solids), metals, major ions/anions, bacteria, nutrients and polycyclic aromatic hydrocarbons.

Models for each of the sites were developed to assess hydrologic performance under different scenarios (i.e. ‘normal’ precipitation, various cistern sizes), and provide estimates of cistern water use and overflow volumes during periods when the cistern was not in operation. The primary measured inputs to the model were precipitation (supply to cistern) and combined flow from the municipal and cistern lines (demand from cistern). The rainfall catchment area, cistern specifications and pipe elevations together with equations simulating snow melt and roof evaporative losses provided the basis for determining cistern water levels, overflows to the storm sewer and the need for municipal make-up water.

The models were validated based on monitored data at the printing facility and high rise apartment, where rain water harvesting systems were operating for at least one year. At the public school, the cistern pumps were not operating regularly for reasons that were being investigated at the time of writing. Hence, model inputs for this site included precipitation and actual demand for non-potable water in the building (i.e. use from hose bibs and toilets), together with system specifications and calibrated parameter values for roof losses (e.g. snow blowoff, direct roof evaporation) derived from monitoring data collected at the other two sites. Good matches between measured and simulated water use from the cistern and municipal lines at the two fully operational sites showed the models to be effective tools for predicting system performance under alternative scenarios.

Study Findings

Monitoring and modelling results from these sites indicate that rainwater harvesting systems have the potential to provide significant water conservation and stormwater management benefits. Model simulations during a 'normal' year of precipitation[1] showed the systems to have supplied between 59 and 79% of total demand for non-potable water (Figure 1), while diverting between 18 and 42% of annual precipitation on the roof catchment area from storm sewers (Figure 2). Annual losses from evaporation, direct roof overflows, and snow blowoff were estimated based on measured inputs to the cisterns at between 18 and 20% of annual precipitation.

At the printing facility, demand for non-potable water increased from 1.0 m^3/day in 2007 to 1.5 m^3/day in 2009 due to an increase in the number of employees working at the facility. When modeled under 'normal' precipitation conditions, this growth in demand resulted in a 71% increase in municipal make-up and a 13% decrease in overflows to the storm sewer over the three year period, The number of days the cistern could act as the sole supply of non-potable water also fell from close to 8 days in 2007 to only 6 days in 2009. Time series data showed that the cistern supply needed to be supplemented with municipal water to meet building demand primarily during extended cold periods over the winter, long spells with limited or no rain, and days with heavy use during the fall.

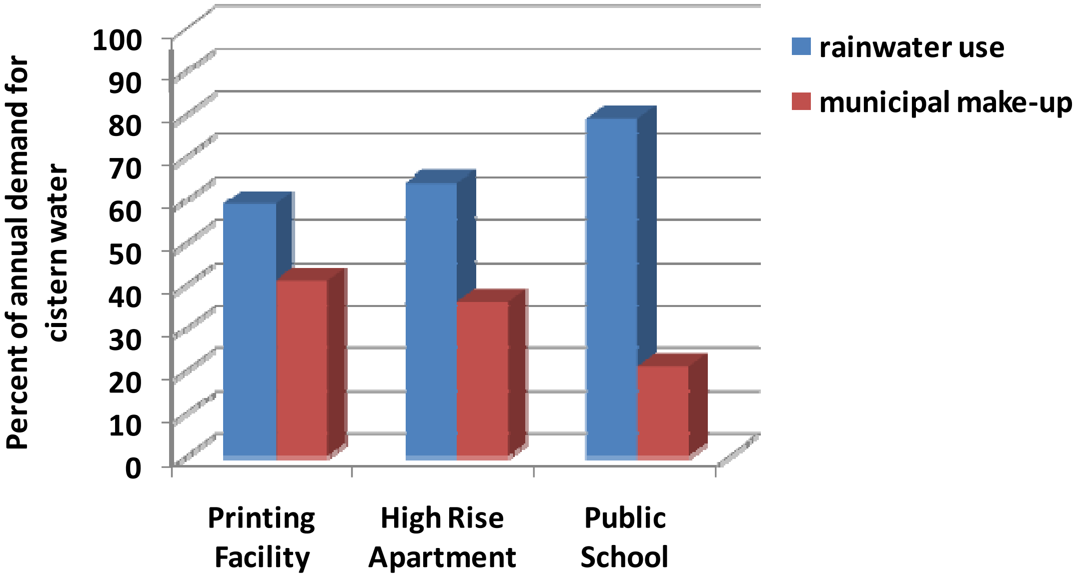

Figure 1: Rainwater use and municipal make-up as a percentage of total annual demand for non-potable water supplies during a 'normal' precipitation year.

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[1] Refers to a daily historical precipitation data set derived from Pearson Airport normals (1971 to 2000).

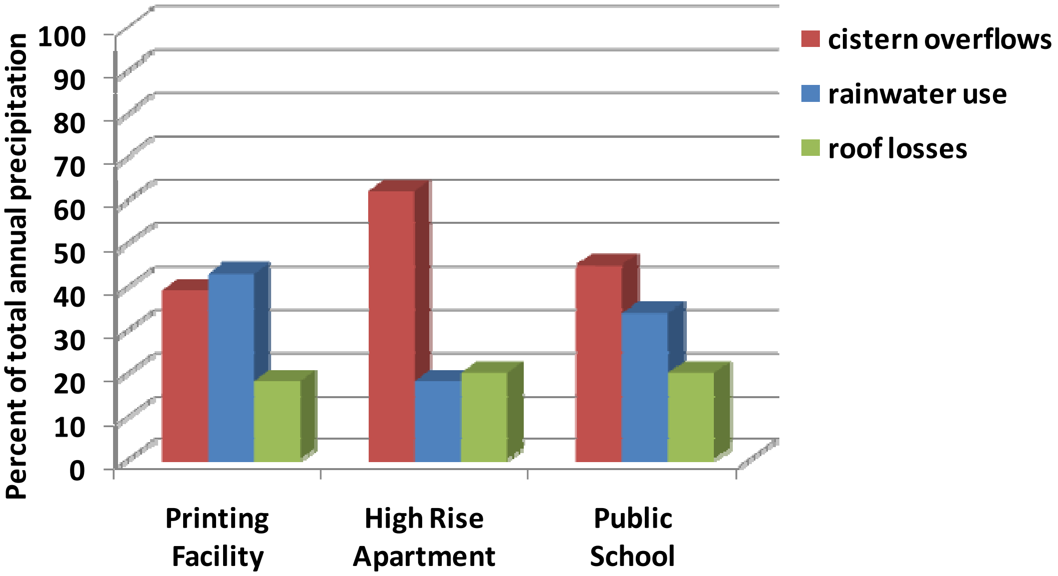

Figure 2: Rainwater use, overflows and direct losses from the roof (and patios where applicable) as a percentage of total annual precipitation inputs to rainwater catchment areas during a 'normal' precipitation year.

Water use in the high rise apartment building was concentrated during the summer months when significant quantities of cistern water were used for irrigation of vegetated areas surrounding the building. During this period, water use averaged 3.0 m^3/day, compared to an average of only 0.2 m^3/day during the rest of the year. This pattern of use resulted in the cistern being undersized during the summer, and vastly oversized during the rest of the year. In addition, the system was not as efficient as other sites at reducing stormwater runoff because the effective rainwater storage volume was small relative to the drainage area (see Table 1 above), municipal make-up water was provided to the cistern rather than directly to the distribution system, and most of the rainfall and snowmelt inputs to the cistern during the 8 cooler months overflowed (Figure 2).

Demand for non-potable water recorded at the public school over a one year period averaged 2.7 m^3/day, with average monthly use ranging from 1.5 m^3/day during the summer, when the building is occupied less frequently, and 4.4 m^3/day during the busiest month of the school year. At the average annual daily use rate, the cistern could serve as the sole source of non-potable water supplies for close to 10 days without rain. As at the printing facility, periods requiring municipal make-up supplies occurred mainly during cold and dry periods when rainfall supplies were low, and during periods of infrequent heavy use.

In cold climates, the contribution of snow to cistern supply is often overlooked or underestimated in the design and sizing of RWH systems. This study showed snowmelt to provide a relatively reliable source of water throughout most of the cold season. During a normal year of precipitation, roughly 50 to 64% of snowfall on the catchment areas drained to the three cisterns, representing between 10 and 13% of total annual precipitation supply to the cisterns. This source of water was often more efficiently distributed than rain because accumulated snow on the roof melted gradually during peak sun periods over several days, resulting in a more even supply that generated smaller volumes of cistern overflow. Heat from the building combined with solar radiation resulted in melt occurring even when average daily temperatures were as low as -5°C.

The models were run to assess the effect of cistern size on system performance. As expected, performance increased with cistern size, but at a diminishing rate. Since municipal top up supplies are readily available in this area, it would not be cost effective to design the system to supply 100% of rainwater demand. Under these conditions, an optimally sized cistern will provide a balance between collection efficiency and cistern cost. To achieve this balance, the Ontario manual for residential RWH systems suggests that the cistern should be sized to provide at least a 2.5% improvement in the water collection efficiency following an increase of 1 m^3 in storage capacity. By this rule, the public school cistern was oversized by roughly 13 m3, while the printing facility and high rise apartment cisterns were undersized by approximately 5 and 4 m^3, respectively (based on 2009 water use). The public school system has the capacity to incorporate additional future uses if available. The apartment system was undersized overall, but oversized during low use periods in the cold seasons. This system would operate more efficiently during the summer if the trigger for supplying municipal water to the cistern (i.e. minimum storage volume) was reduced from the existing $10m^3$ to a lower volume.

Water quality sampling from the cisterns and hose bibs of the printing facility and high rise apartment revealed that water from the system was suitable for non-potable water use. Total suspended solids and turbidity levels were generally low (< 5 NTU). Water collected at the high rise apartment had higher colour values (15 TCU) than the printing facility site (5 TCU), but the water at both sites was still visually comparable to that of municipal water. At the high rise, increases in some heavy metals (e.g. lead, zinc, iron) from the cistern to hose bibs indicated that the distribution system was a source of these constituents. The highest levels of these metals were observed in the initial samples collected in May before the outdoor taps had been used for irrigation. Subsequent hose bib samples collected later in the summer after the system had been flushed showed much lower concentrations. At both sites, use of the systems as potable water sources would require treatment to remove low levels of bacteria and trace levels of polycyclic aromatic hydrocarbons and pesticides.

A number of operational issues were encountered with the systems, including leaky cisterns, broken pipes and pump failures, some of which had still not been fully resolved at the time of writing. These problems appear to have stemmed largely from inexperience and inadequate institutional capacity, rather than a lack of technical knowhow. As the technology becomes more widespread in Canada, the incidence of similar problems would be expected to decline. To help ensure operational issues are identified and addressed in a timely manner, strict procedures for commissioning, inspecting and post construction monitoring should be established and implemented for all new systems.