



# Performance Evaluation of Rainwater Harvesting Systems

Toronto, Ontario





# **Performance Evaluation of Rainwater Harvesting Systems Toronto, Ontario**

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## PUBLICATION INFORMATION

Reports conducted under the Sustainable Technologies Evaluation Program (STEP) are available at [www.sustainabletechnologies.ca](http://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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## 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. The printing facility RWH system was designed to provide non-potable water for 130 occupants. The roof catchment area is 968 m<sup>2</sup> and the precast concrete underground cistern is 18 m<sup>3</sup> (6 m<sup>3</sup> settling chamber and 12 m<sup>3</sup> storage chamber). The public school RWH system is designed to supply non-potable water for 826 occupants and has a roof catchment area of 2,879 m<sup>2</sup> with a 40 m<sup>3</sup> underground precast concrete cistern (12 m<sup>3</sup> settling chamber, and 28 m<sup>3</sup> storage chamber). The high rise apartment RWH system is a much simpler system that is used primarily for irrigation during the summer and only occasionally for toilet flushing in public areas throughout the year. The roof catchment area for this system is 1,388 m<sup>2</sup> and the cistern is 21.7 m<sup>3</sup>, of which roughly 14.5 m<sup>3</sup> is intended for rainwater storage and distribution. Unlike the other two systems, municipal water is used in the high rise to top-up the cistern when the storage volume falls below a pre-set volume, rather than being provided only during times when cistern storage volumes are low. None of the three systems include a soakaway or trench for infiltration of cistern overflows.

### 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.

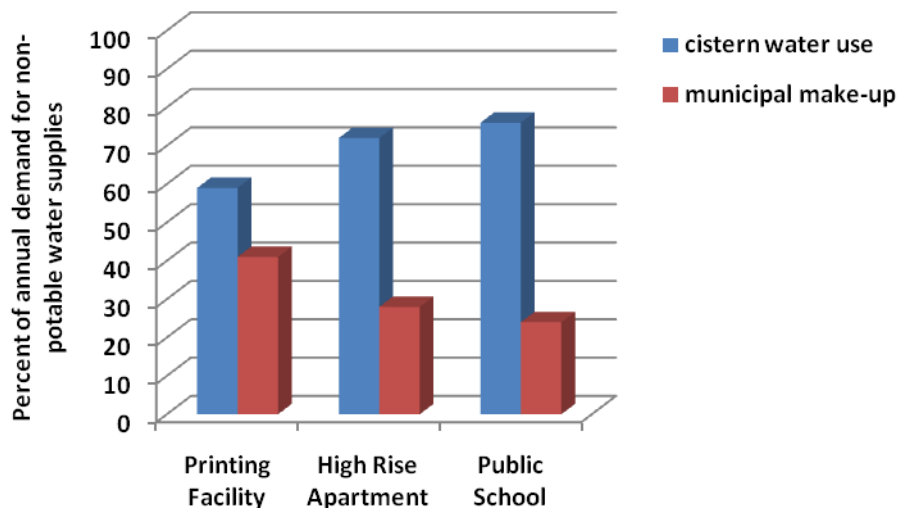
Models for each of the sites were developed to assess hydrologic performance under different scenarios (i.e. 'normal' precipitation, various cistern sizes), and provide estimates of cistern water use and overflow volumes during periods when the cistern was not in operation. The primary measured inputs 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.

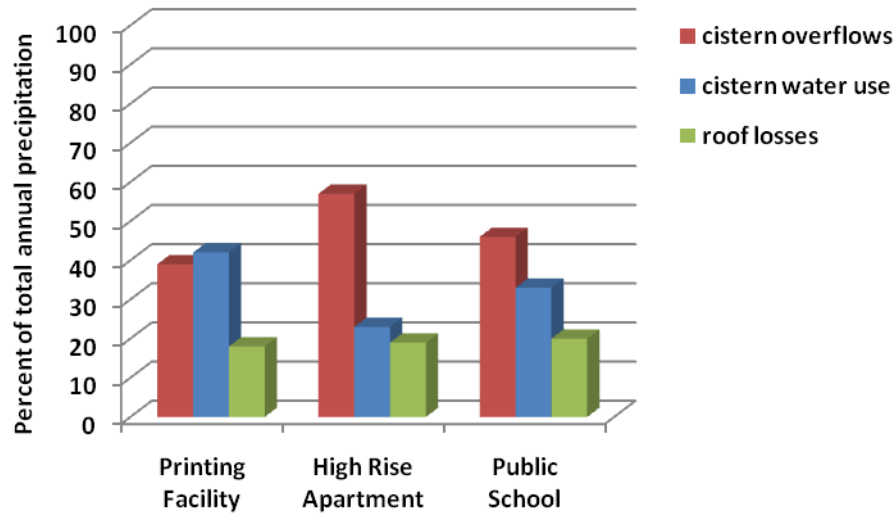
### Study Findings

Monitoring 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<sup>1</sup> showed the systems to have supplied between 59 and 76% of total demand for non-potable water (Figure 1), while diverting between 23 and 42% of annual precipitation on the roof catchment area from storm sewers (Figure 2). Annual losses from roof storage, evaporation, direct roof overflows, and snow blowoff were estimated based on measured inputs to the cisterns at between 18 and 20% of annual precipitation.



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

<sup>1</sup> Refers to a daily precipitation data set derived from Pearson Airport normals (1971 to 2000).



**Figure 2:** Cistern water use, overflows and roof losses as a percentage of total annual precipitation inputs to roof catchment areas during a 'normal' precipitation year

At the printing facility, demand for non-potable water increased from 1.0 m<sup>3</sup>/day in 2007 to 1.5 m<sup>3</sup>/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.

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<sup>3</sup>/day, compared to an average of only 0.2 m<sup>3</sup>/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 effective at reducing stormwater runoff because 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<sup>3</sup>/day, with average monthly use ranging from 1.5 m<sup>3</sup>/day during the summer, when the building is occupied less frequently, and 4.4 m<sup>3</sup>/day during the busiest month of the school year. At the average annual daily 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 heavy use.

In cold climates, the contribution of snow to cistern supply is often overlooked or underestimated. Even the original design and sizing of the printing facility and school systems assumed no inputs from snow. However, this study showed snowmelt to provide a relatively reliable source of water throughout most of the cold season. During a normal year of precipitation, the contribution from snowmelt represented between 10 and 13% of total annual precipitation supply to the cisterns in the three buildings. 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  $-5^{\circ}\text{C}$ .

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  $1\text{ m}^3$  in storage capacity. By this rule the printing facility cistern was undersized by approximately  $5\text{ m}^3$  (based on 2009 water use) and the high rise apartment and public school cisterns were oversized by roughly 4 and  $13\text{ m}^3$ , respectively. Both the high rise and public school systems have the capacity to incorporate additional future uses if available.

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 ( $< 5\text{ NTU}$ ). 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.