Performance Evaluation of Rainwater Harvesting Systems

TECHNICAL BRIEF

Low Impact Development Series

The practice of collecting rainwater from roofs and storing it for later use has been employed in rural Ontario for well over a century. This practice is now being increasingly used in urban areas as municipalities and building owners seek new and effective ways to conserve water, delay costly expenditures on new water treatment plants, and improve stormwater management. Systems can range from small seasonal rain barrels on a residential lot to year-round plumbed systems with rainwater stored in underground cisterns.

> Roughly 33% of the City of Toronto's use of electricity is for pumping and treating water through a vast network of pipes and infrastructure. A substantial portion of that treated water is used to flush toilets, wash clothes and water lawns or gardens – uses that do not require highly treated water.

This study evaluated the performance of three commercial rainwater harvesting (RWH) systems in Toronto. The buildings included a printing facility, public school and high rise residential complex. All systems were designed to collect rainfall from the roof, store it in cisterns and distribute the water for toilet flushing and landscape irrigation. Results showed that, during a normal rainfall year, systems could supply between 59% and 79% of total demand for non-potable water, while diverting between 18% and 42% of annual precipitation on the roof catchment area from storm sewers.

During the winter, snowmelt contributed between 10% and 13% of total annual precipitation supply to the cisterns in the three buildings. Water quality sampling revealed that distribution water was suitable for non-potable uses, with low levels of turbidity and solids. Use of the systems for potable water would require treatment to remove low levels of bacteria and trace levels of polycyclic aromatic hydrocarbons and pesticides.

INTRODUCTION

Fuelled by a growing interest among homeowners and municipalities to conserve water and improve stormwater management, rainwater harvesting (RWH) is one of the many sustainable building practices being adapted across Canada. This three year monitoring project evaluates the benefits and limitations of a residential, commercial and institutional rainwater harvesting systems for water conservation and stormwater management under water use and precipitation conditions typical of the Greater Toronto Area.

STUDY SITES

Three buildings in Toronto with RWH systems were selected for the evaluation: (i) a commercial printing facility, (ii) a large public school, and (iii) a high rise residential building. All systems were designed to collect rainfall from the roof and/or patios, store it in cisterns and distribute the water for toilet flushing and irrigation. Overflows were directed to the municipal sewer. Other 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).

Metro Label Printing: The printing facility RWH system was designed to provide non-potable water for grounds irrigation and toilet flushing for 130 employees. The roof catchment area is 968 m^2 and the precast concrete underground cistern is 18 m^3 (6 m^3 settling chamber and 12 m^3 storage chamber). Municipal make-up water at the school is provided directly to the distribution system when cistern storage volumes are low.

Brookside Public School: The public school RWH system was designed to supply water to over 20 toilets, a drip irrigation system for the green roof and hosebibs. The roof catchment area is 2,879 m^2 with a 42 m^3 underground precast concrete cistern that includes a 13 m^3 settling chamber, and 29 m^3 storage chamber.

Minto High Rise Development: The high rise apartment RWH system is a simpler and is used primarily for irrigation during the summer and toilet flushing in common areas throughout the year. The 1295 m^2 catchment area for this system consists of roof and patio. The cistern is 24 m^3, of which roughly 19 m^3 is intended for rainwater storage and distribution, and the remaining 5 m^3 above the invert of the overflow pipe is used to provide temporary storage for controlled release of stormwater. Municipal water is used to top-up the cistern when the storage volume falls below a pre-set volume.

Table 1: Site drainage area and storage volume.

Site	Drainage Area (m^2)	Settling Chamber Storage Volume (m^3)	Rainwater Storage Volume (m^3)	Effective Rainwater Storage Volume (m^3)*	Stormwater Detention Volume (m^3)
Printing Facility	968	6	12	9	none
Public School	2879	13	29	26	none
High Rise	1295	none	19	9	5

* The 'effective rainwater storage volume' is the rainwater volume available for distribution, represented by the difference between the rainwater storage volume and minimum allowable storage volume in the cistern.

APPROACH

The monitoring program included continuous measurements of precipitation (rain and snow), cistern water levels, water volumes supplied from the cisterns (cistern water use), and municipal water volumes when cistern water storage volumes fell below preset levels (referred to as municipal make-up). Samples of water from the cistern and hose bibs, and sediment deposited in the cisterns were collected and submitted for lab analysis. Sample analysis included general chemistry, 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 cisterns were 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 under different scenarios.

Figure 1. The three study facilities that host rainwater harvesting cisterns. a)Metro Label printing facility; b) Brookside Public School; c) Minto high rise development.

FINDINGS

Model simulations during a 'normal' year of precipitation showed the systems could supply between 59% and 79% of total demand for non-potable water (Figure 2), while diverting between 18% and 42% of annual precipitation on the roof catchment area from storm sewers (Figure 3). Based on measured inputs to the cisterns, between 18 and 20% of annual precipitation was lost directly from the roof as a result of evaporation, roof overflows (through scuppers), and snow drift and blowoff.

Performance of the RWH systems was strongly influenced by the overall and seasonal patterns of demand for non-potable water supplies. 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 there. 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. Water use in the high rise apartment building was concentrated during the summer months when significant quantities of cistern water were used for irrigation and pavement washing. This pattern of use resulted in the cistern being undersized during the summer (mean water use of 3.0 m^3/day) , and vastly oversized during the rest of the year (mean water use of 0.2 m^3/day). 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, to 4.4 m^3/day during the busiest month of the school year.

Cistern supplies needed to be supplemented with municipal water to meet building demand primarily during extended cold periods over the winter, dry spells, and during days with heavy use. With the increase in workforce at the printing facility, the number of days the cistern could act as the sole supply of non-potable water fell from close to 8 days in 2007 to only 6 days in 2009. The public school cistern had more capacity, and could serve as the sole source of water supply for an average of 10 days without rain. The high rise complex required municipal make-up only during the summer. Low use during the 8 cooler months resulted in most of the rainwater overflowing (Figure 3).

Snowmelt provided a relatively reliable source of water throughout most of the cold season. In cold climates, the contribution of snow to cistern supply is often overlooked or underestimated. However, this study showed that, during a normal year of precipitation, the contribution from snowmelt represented between 10% and 13% of total annual precipitation supply to the cisterns in all 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. Heat from the building combined with solar radiation resulted in melt occurring even when average daily temperatures were as low as -5°C.

Models assessing the effect of cistern size on system performance showed performance to increase with cistern size, but at a diminishing rate. Since municipal top up supplies are readily available in urban areas, 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 was oversized by roughly 13 m^3 and the printing facility and high rise apartment cisterns were undersized by approximately 4 and 5 m^3 , respectively. The public school system has the capacity to incorporate additional future uses if available.

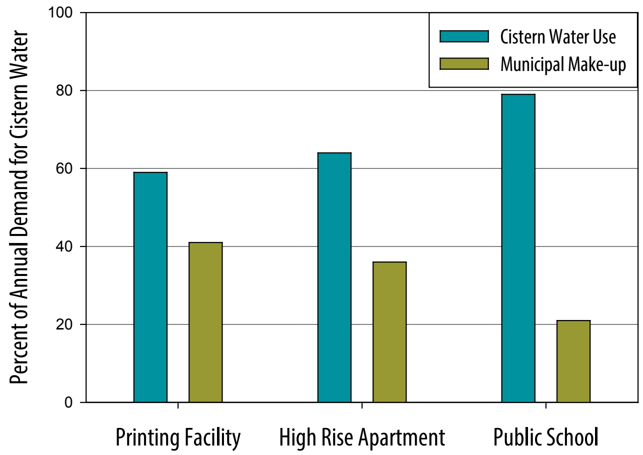

Figure 2: Cistern and municipal water use as a % of total annual demand.

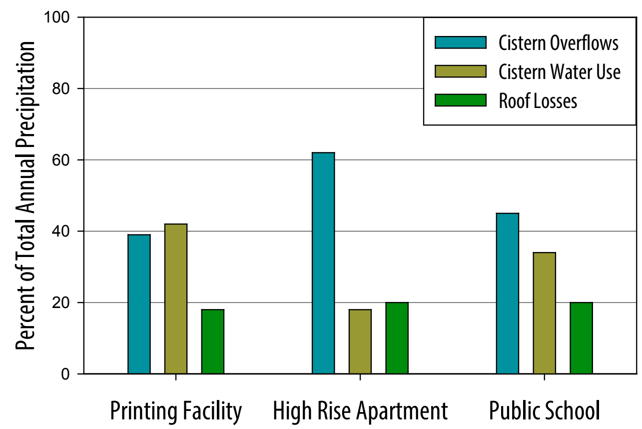

Figure 3: Cistern water partitioning as a % of annual precipitation input to cistern.

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 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 visually comparable to that of municipal water. Using that water for potable supply would require treatment to remove low levels of bacteria and trace levels of polycyclic aromatic hydrocarbons and pesticides. 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.

A number of operational issues were encountered with the systems, including leaky cisterns, broken pipes and pump failures. These problems appear to have stemmed largely from inexperience and inadequate institutional capacity, rather than a lack of technological knowhow. 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.

The cost of the three systems was not well documented but estimates from available information suggest initial capital costs of $1/L of storage. With a municipal water rate of $1.6/m^3$ and water savings for a typical precipitation year, the pay back for the printing facility, high rise apartment and public school would be 35, 41 and 37 years, respectively. These calculations do not take into account annual maintenance, annualized discount rates, LEED point benefits, and other factors such as the rising cost of municipal water and providing equivalent stormwater detention elsewhere.

CONCLUSIONS AND RECOMMENDATIONS

The study indicates that RWH is both technically and socially feasible, even in cold Canadian climates. RWH systems have the potential to offset the majority of a building's non-potable water needs, as well as help municipalities manage stormwater runoff. Optimally sized systems in Ontario should reduce annual roof runoff by at least 40% and provide approximately 80% of annual demand for non-potable water supplies.

There is a wide variety of reasons why building owners are considering implementing RWH systems to supply non-potable water. RWH systems provide a buffer against rising water prices, and the presence of a storage tank can supply water for landscape irrigation when municipal watering restrictions are in place. RWH can play an important role in helping urban centres become more sustainable.

Typical maintenance activities associated with RWH systems include clean out of sediment from settling chambers, seasonal cleaning of drain and debris filters, pump maintenance and valve and system pressurization checks. If the water system is intended for potable supply, regular inspection of treatment filters and water sampling would also be required. Most rainwater harvesting systems are under warranty for at least a year after installation and should be inspected by an experienced person.

RWH systems should be part of a larger package of measures that aim to reduce the water use of buildings. Demand management measures such as low flow fixtures, waterless urinals and conservation approaches to irrigation are less expensive than RWH per unit of water conserved and should be implemented with RWH as part of an integrated water efficiency plan for buildings.

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For more information on STEP's other LID initiatives, or to access the full report for this study, entitled Performance Evaluation of Rainwater Harvesting Systems, visit us online at www.sustainabletechnologies.ca

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