Developing Capacity for Large-Scale Rainwater Harvesting in Canada

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Rainwater harvesting (RWH) is the ancient practice of capturing rainwater from impervious surfaces and storing it for future use. Harvesting roof runoff for domestic purposes has historically been prevalent in rural areas of Canada and the practice is currently experiencing revived interest and uptake in the urban environment. When implemented on a wide scale, RWH can contribute to both stormwater abatement and water conservation, serving to relieve pressure on existing infrastructure and potentially delay the need for infrastructure expansion. While such benefits are known, there remain several barriers that impede widespread implementation. These include cost, liability concerns, and a lack of clear policy for RWH. This paper outlines the benefits of RWH and describes findings of recent research that has attempted to develop some of the technical, administrative, and market capacity needed to overcome these barriers, focussing on water quality, design practices, economic analysis, and policy development.

Key words: rainwater harvesting, stormwater management, low impact development, integrated water resources management

Introduction

Rainwater harvesting (RWH) is an ancient practice of capturing rainwater from roofs and other hard surfaces for future beneficial uses. In Canada, RWH was a common practice at the turn of the century and is still practiced in rural areas. Centralized municipal water supplies and building code requirements have significantly reduced the urban use of RWH and relegated it, in most parts, to green building-type demonstrations. Combined effects of climate change, rapid urban population growth, water security, and stormwater management challenges have given new impetus to RWH. Use of small (~200 L) rain barrels for outdoor watering, for example, has picked up considerably in the past few years, and many municipalities in Ontario provide financial incentives to home owners towards the purchase of rain barrels. Components of a RWH system include a catchment surface (a roof for example), conveyance and storage system, pressurized or non-pressurized water discharge system, and pre or posttreatment unit processes. Storage can range from as little as 200 L (typical rain barrels) to as high as several thousand litres. This paper deals mainly with large-scale RWH (>1,000 L).

The use of rainwater for domestic purposes is playing an important role in a broader movement towards more sustainable urban drainage practices and land development. In Australia, RWH is a component of water sensitive urban design (WSUD); in North America it is included in low impact development (LID); while in the U.K. it contributes to sustainable drainage systems (SUDS). In addition to the traditional role that rainwater has played in providing a decentralized supply of fresh water, these practices are recognizing the important contribution rainwater capture and reuse can make to municipal stormwater management. In Canada, RWH is only beginning to be promoted for these purposes, as seen by its inclusion in the City of Toronto *Wet Weather Flow Management Guidelines*, which took effect in 2007 (City of Toronto 2006). In places like Germany, it is becoming an entrenched practice as stormwater fees are often prorated based on the total volume of rainwater entering the storm sewer, thereby providing significant incentive for RWH (Koenig personal comm. 2008).

This paper reports the results of a comprehensive research project that aimed to fill in key research gaps that exist for large-scale RWH and build capacity for its broader implementation. First, the impacts of RWH on both stormwater management and water conservation are reported, based on both computer modelling and observations of a demonstration site located in the City of Guelph, Ontario. Major barriers for RWH, identified through stakeholder interviews, are then offered. Finally, work undertaken to address these barriers is described, focussing on water quality, design, economic analysis, and policy development.

Modelling the Impacts of Rainwater Harvesting

A model was developed to evaluate the impact RWH systems could have on both stormwater flows and municipal water conservation (Leidl 2008). The model uses a 60-year historical record of daily precipitation for the City of Guelph, Ontario, provided by Schroeter et al. (2006). The frequency of major rainfall events

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over a 24-h duration in this data set is consistent with predictions from IDF (intensity, duration, frequency) curves for the Guelph area (Environment Canada 2007b). The model assumes that rainwater is collected from a 160-m^2 catchment area (roof), and stored in a 6,500-L cistern that supplies rainwater to a three-person residence. Three end-use scenarios were modelled: the use of rainwater for outdoor applications and toilet flushing (141 L/household/day); for outdoor use, toilet flushing and laundry (246 L/household/day); and the maximum use scenario where rainwater is used for all household uses except kitchen use (507 L/household/day). The end-use patterns assumed for this analysis correspond to a typical water efficient home in North America (Vickers 2001), with particularly low outdoor usage. Output from the model indicates performance parameters such as the volume of rainwater utilized and the volume of overflow from the system.

Results from the model were compared with the observed performance of a RWH system installed in Guelph, Ontario, from October 2006 to September 2007. Daily rainfall data during this time were compared with the average monthly rainfall data from Environment Canada (2004) historical records (1971 to 2000) as presented in Fig. 1.

Normal annual rainfall for the City of Guelph is 770 mm, a figure slightly lower than the 790 mm observed during the period studied, October 2006 to September 2007. As seen in Fig. 1, observed rainfall during five months of the study was similar to historical normals with the exception of October, December, and January, where larger than normal rainfall accumulations took place, and the period from June to September, where drought-like conditions were observed (Despins 2008). Since precipitation patterns in the observed year were more extreme than average, the average stormwater mitigation and rainwater consumption can be expected to be higher in the modelled system than in the observed system, due to a more even distribution of precipitation throughout the year.
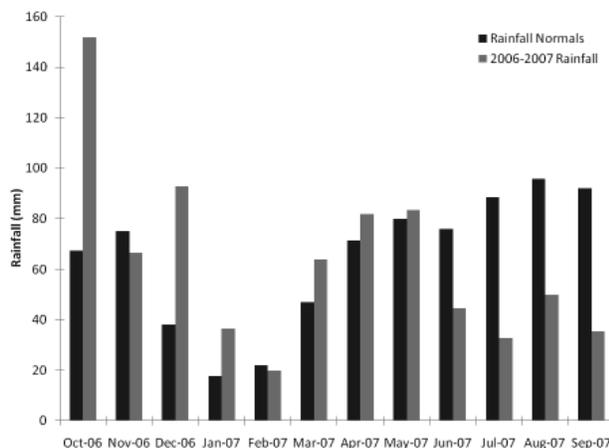

Fig. 1. Comparison of the normal and observed monthly rainfall accumulations for the City of Guelph during the research project.

Impact of RWH on Stormwater Management

It is estimated that percent impervious cover in urban environments can range from 41% in high density residential areas to as high as 96% in downtown commercial settings (Bowles 2002). Of this, as much as 70% can be attributed to roof surfaces. As such, capturing rainwater that falls on roof surfaces can be an important strategy for stormwater management in urban environments. RWH has the potential to significantly contribute to stormwater management by both reducing the volume of water entering the storm sewer system and, in some cases, by minimizing the peak flow generated by the storm. The effectiveness of RWH in mitigating storm flows depends primarily on the severity of the storm and the end use patterns for the RWH system.

Figure 2 shows the results of modelling stormwater flows based on rainfall intensity and rainwater demand patterns. The rainfall data is separated into six different categories, based on total rain height in one day. The total volume of rainwater discharged as overflow from the cistern is compared with the volume of runoff that would otherwise have been discharged from the roof surface in the absence of a RWH system. This difference in volume is represented as percent stormwater reduction.

The first trend indicated in Fig. 2 is the wide degree of variation in the reduction of roof runoff volumes, ranging from 0 to 100% in many cases. This is due primarily to varying antecedent dry periods and suggests that RWH is most effective when used in combination with other onsite stormwater management techniques to provide some redundant capacity to accommodate overflow. Coombes (2002), for example, integrated RWH with infiltration trenches and a recharge basin as part of a water sensitive urban design (WSUD) approach. This resulted in zero discharge from the property and the elimination of traditional stormwater systems.

A second obvious trend common for all end-use scenarios is that the percent reduction in stormwater decreases with greater rainfall levels when cisterns fill to capacity and overflow the excess volume. However, as indicated by the "*n*" values for each rainfall height, rain events with greater than 40 mm occur only about once per year. Considerable reduction is therefore achieved for a large majority of rain events for each of the end-use scenarios.

Finally, greater reductions in stormwater flows are achieved when the end uses for rainwater are expanded, as seen by the increasing percent reductions seen with each of the three consecutive graphs. A larger number of end uses allows cisterns to be drawn down more quickly and to accommodate greater volumes of rainfall. A large reduction in overflow volume is seen just by adding laundry to toilet flushing and irrigation as end-use applications. This suggests that the maximum possible range of end uses should be promoted.

To evaluate the potential of RWH systems to mitigate stormwater flows with these expanded end uses (laundry and toilet flushing) under actual use conditions, a
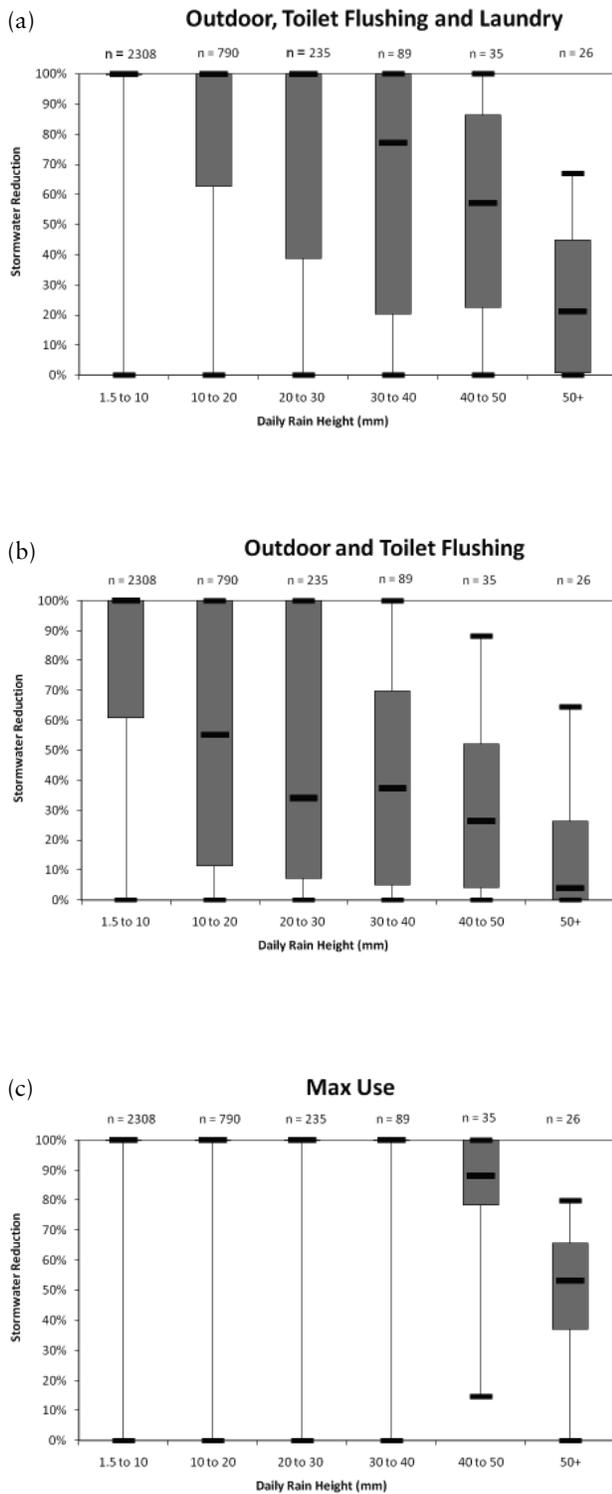
Fig. 2. Reduction in roof runoff volumes from April to October for three end-use scenarios: outdoor and toilet flushing [top]; outdoor, toilet flushing, and laundry [middle]; and max use [bottom]. Each grey box represents the first and third quartile, and the ends of the 'whiskers' indicate the minimum and maximum; "*n*" is the number of events for each daily rain height range, throughout 60 years of rainfall data (Leidl 2008).

domestic RWH system was installed and monitored for a one-year period, from October 2006 to September 2007. The RWH system was comprised of an 8,000-L cistern which stored rain runoff from an asphalt shingle roof with a 100-m² catchment area. Rainwater was pumped into the home and used for flushing toilets and laundry in a five person household. The performance of the RWH system was monitored using a rain gauge installed at the site, a water level sensor and temperature sensor placed inside the rainwater cistern, and a water meter installed on the rainwater plumbing line. The volume of rainwater in the cistern and the rainfall at the site during the one year study period is provided in Fig. 3.

One of the trends immediately evident from Fig. 3 is the variable nature of the cistern volume. This repeating cycle is characterized by sharp inclines in the volume following rainfall, followed by a slower decline in volume as a result of normal demand. Throughout the monitoring period, the cistern volume varied from a minimum volume of 1,250 L to a maximum of 7,650 L. Above the 7,650-L threshold, the cistern overflowed into the storm sewer connected to the property. Overflows from the cistern were recorded on eight days throughout the one-year monitoring period. As seen in Fig. 3, it is evident that, like the stormwater modelling projections, the majority of these overflows took place during days with large amounts of rainfall, when the rainfall exceeded 35 mm. The number of overflow events and the total losses associated with them are summarized in Table 1.

During the study period, overflows were observed on eight occasions and resulted in an approximate loss of 8,000 L from the system, contributing to stormwater runoff from the site. Comparison of these losses with the 65,000 L of rainwater runoff that was collected and utilized at the site indicates that the use of the RWH system decreased the total volume of runoff from the site by 89%. This demonstrates the significant stormwater mitigation potential of RWH systems with an expanded range of end-use applications.

Another important consideration with RWH systems is their potential for capturing snowmelt during winter months. This potential was evaluated at the household test site during the winter of 2007. From January 14 to
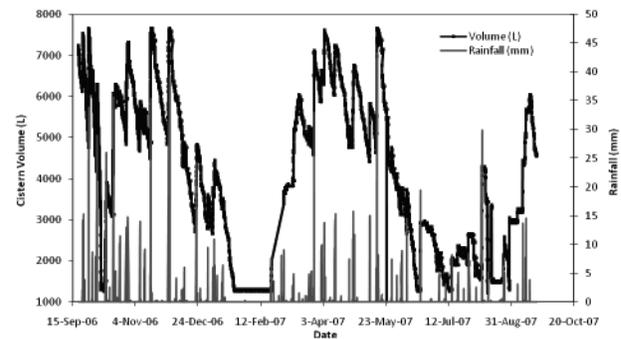

Fig. 3. Cistern volume and rainfall of RWH demonstration site (Despins 2008).

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TABLE 1. Annual rainfall, overflow and water use characteristics of the household RWH system monitored

Rainfall (mm)	Number of days without available rainwater	Number of overflow events	Overflow volume (L)	Household rainwater use (L)	Household mains water use (L)
790	55	8	8,000	65,000	142,000

February 18 the maximum daily ambient air temperature ranged from a low of -15.4°C to a high of -0.8°C. Throughout this period, 39 cm of snow fell and remained on the ground because of the low temperatures. The water equivalent of this snowfall, estimated by melting the snow while it fell, was 43.2 mm (Environment Canada 2007a). Evident from the negligible volume of stored rainwater during this time (see Fig. 3) the snowfall appears to have had a negligible impact on increasing the volume of water stored in the cistern. However, with warmer temperatures in late February, a portion of this snowfall contributed to the stored water volume.

From February 19 to March 4, 2007, the daily temperature periodically rose above 0°C, prompting the melting of snow (snowmelt) that had accumulated on the roof surface during this time. During this period, a 2,560-L increase in the volume of stored water was recorded by the sensor placed in the rainwater cistern. If this cistern input is considered with respect to the 43.2-mm water equivalent reported by Environment Canada (2007a), about 60% of snowfall (as measured by water equivalents) contributed to the cistern during snowmelts. The 40% snowmelt loss factor is likely due to winds that blow a portion of the accumulated snow from the roof surface onto the property surrounding the home. Another potential cause of this loss is the restriction of snowmelt flow because of frozen water inside the gutters and downspouts. This restriction in flow forces the snowmelt

to overflow from the guttering, reducing the total volume of water that could be captured by the rainwater cistern.

In addition to capturing snowmelt, some rainfall runoff was also collected during the warmer "thaw" periods in the winter. During the coldest months monitored, January and February, the rain gauge at the site recorded 36 and 19 mm, respectively. Thus, these findings show that even during periods of cold weather, RWH systems can continue to mitigate stormwater flows by collecting and utilizing both snowmelt and rainfall.

Impact on Water Conservation

Like stormwater management, the impact of RWH on water conservation is greatest when the number of end-use applications is maximized. Toilet flushing and laundry are two low-risk, nonpotable applications, which together comprise approximately 37% of household demand in a conserving home (Vickers 2001). This volume, along with any water used outdoors, can theoretically be replaced with rainwater. In addition to end-use patterns, however, actual water savings also depend significantly on catchment area and tank size. The same model used by Leidl (2008) to generate Fig. 2 was also used to produce Fig. 4, which illustrates the impact of these three parameters on water conservation in typical residences in Guelph, Ontario (Leidl 2008).
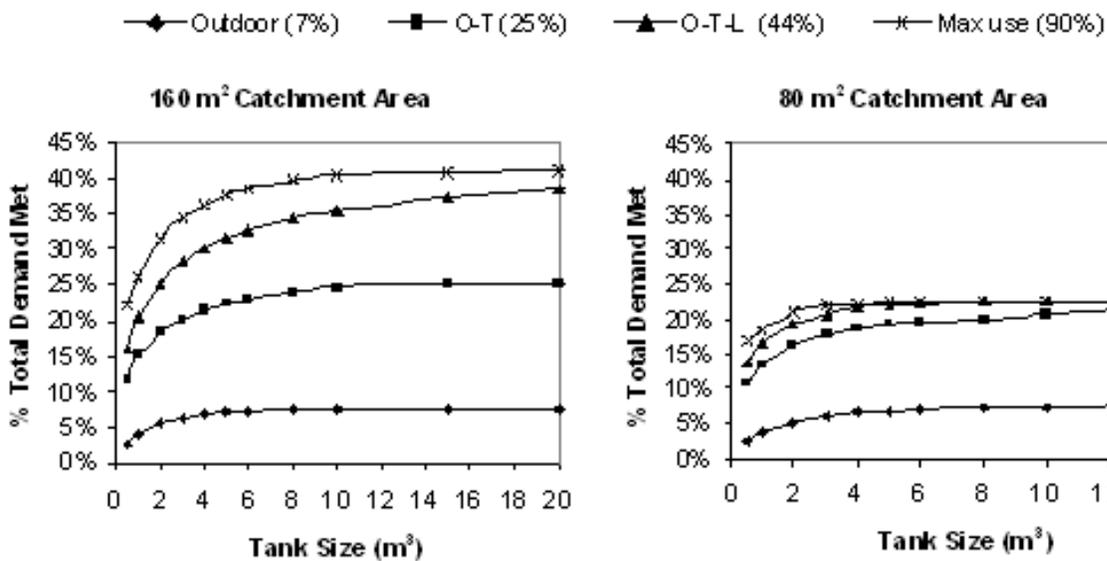

Fig. 4. Impact of rainwater end-use pattern on water conservation for two different catchment areas (O = outdoor; T = toilet flushing; L = laundry. Percentage shown is of total household consumption).

From Fig. 4, catchment area appears to be the most important parameter affecting maximum water savings, followed by end-use patterns. If the catchment area is sufficiently large, a greater number of end-use applications for RWH will result in greater water savings, as seen in the left-hand graph for a 160-m² catchment area (typical of a single detached house). However, if the catchment area is small (a typical attached townhouse), only a limited volume of water can be captured and water savings will only marginally increase with expanded end uses (right-hand graph). Tank size is also important, but due to the other two factors, it is quickly subject to diminishing returns.

In Fig. 4, the maximum water savings are 40 and 23% for the 160- and 80-m² catchment areas, respectively. However, when designing a system, one must consider the incremental advantage of increasing tank size and expanding end uses, and balance that with the associated incremental cost. A cost-effective design for the larger catchment area may be a 6- to 8-m³ cistern serving outdoor uses, toilets, and laundry. For the smaller catchment area, a reasonable design would be a 2- to 4-m³ cistern serving only outdoor uses and toilet flushing. These systems would produce water savings of approximately 34 and 17%, respectively.

When RWH is implemented on a wide scale, significant water savings can be achieved at the municipal scale. Leidl (2008) projected that the implementation of the above systems in an all new residential development in the City of Guelph (Ontario) would result in an 18% reduction in total residential demand by 2054. This value varies with changes in population growth rate, housing size, and occupancy.

As previously discussed, the performance of a domestic RWH was monitored for a one-year period. This performance monitoring program not only provided data regarding the stormwater reduction impacts of RWH, but also data for evaluating the ability of RWH systems to reduce dependence on municipal water supplies.

The performance monitoring program revealed that a significant reduction in municipal water use could be achieved from the use of a RWH system. The RWH system yielded 65 m³ of water from 790 mm of rainfall during the one-year study for a 120 m² catchment area. This volume of rainwater provided approximately 178 L per day (36lpcd) for toilet flushing and laundry. The remaining household demands were met, on average, by 389 L of mains water per day (78lpcd). Of note is that this average rainwater demand includes the days for which rainwater was unavailable. Examination of rainwater use exclusively on days where rainwater was available reveals that the daily mean rainwater demand was higher at 272 L/day (54lpcd). This finding indicates that if rainwater was always available, rainwater use could have offset mains water use by as much as 47%.

It is important, however, to qualify these reductions in mains water use as those to be expected at water-conserving homes. The mean daily water use in the five-person household was 62% lower than 1,320 L/day (264lpcd), which is the average water use of a five-person household residing in the City of Guelph (City of Guelph 2006). If the rainwater use at this site (36lpcd) were applied to a five person household with average water use, 13% of municipal water would be conserved when dry periods are included.

These statistics demonstrate that the use of rainwater for flushing toilets and laundry could reduce the average water demands of households from a low of 13% to as much as 47%. Since many households in Canada have characteristics that are similar to those of the site studied, it is likely that this range of water savings would be applicable to a large proportion of Canadian homes. For homes that are significantly different from the one studied, the water conservation potential of a RWH system would depend upon factors such as the amount of supply (rainfall and/or snowmelt), the size of the catchment area, the capacity of the cistern, and the amount and pattern of demand.

Identifying Barriers for Large-Scale Rainwater Harvesting

Despite the benefits that RWH has for both stormwater management and water conservation, several barriers impede its further development and wide-spread implementation. Leidl (2008) conducted a series of stakeholder interviews to identify key barriers, from the perspective of municipal representatives, building professionals, and RWH product suppliers. Barriers were identified from interview content, assigned a significance ranking (0 = insignificant; 1 = significant; 2 = very significant), and redistributed to the respondents for confirmation. The significance rankings for all sixteen respondents were then summed to indicate the overall perceived severity of the various barriers. The results of this work are shown in Fig. 5.

Cost was by far the most significant barrier identified in the interviews, expressed by over 80% of respondents. Liability was the second most significant barrier; however, it was felt predominantly by the municipal representatives. The third and fourth largest barriers (limited end uses for rainwater and poor differentiation between grey water and rainwater, respectively) were expressed by just over half of the participants and are both related directly to provisions in the Ontario Building Code. While addressing the latter requires only minor modifications to the Code, the former requires important revisions to the Code to allow for additional end uses and may necessitate additional specifications. Finally the last major barrier, a lack of public awareness and acceptance, was observed by half of the participants. They felt public education was necessary to "grow demand" and encourage both market and regulatory development.

Recent work by both Despins (2008) and Leidl (2008) has aimed to address many of the barriers identified in Fig. 5. Despins et al. (2009) conducted an extensive water quality monitoring program for RWH

systems to generate data that would support additional end uses of rainwater, such as laundry. While anecdotal evidence exists regarding rainwater quality and end uses, there is little scientific evidence and few documented cases from the Canadian context. These data are necessary to facilitate public acceptance and encourage regulatory advances for RWH and address issues associated with liabilities. Despins also designed and installed several demonstration sites, using the resulting experiences as a basis for the development of a design manual and cistern sizing model. These tools will help to clarify technical and regulatory requirements and best practices for designers, installers, and inspectors of RWH systems.

Although cost is perceived as a major barrier, it is rarely investigated beyond simple payback analysis. Leidl (2008) performed an in-depth economic analysis from various perspectives and used an alternative approach that allowed emerging technologies such as RWH to be more equitably compared with conventional water supply alternatives. This new approach, combined with innovative incentive measures, can assist in addressing the cost barrier. Finally, Leidl (2008) conducted a review of the existing regulatory framework for RWH in Ontario and other jurisdictions (Germany and Australia, for example), and based on the outcome of the above work regarding barrier identification, water quality, design, and economics, provides recommendations for policy advancement.

The following sections discuss each of these areas of work:

Water Quality Considerations

Despite the significant water conservation and stormwater management potential for RWH, concern regarding the real and perceived health risks associated with the quality of harvested rainwater is a major barrier that has impeded the adoption of large-scale RWH in Canada. These concerns have created great resistance on the part of regulatory authorities in development of policy or legislation that promotes RWH implementation.

One of the greatest areas of concern with regards to rainwater quality is microbiological contamination. In a study of the microbiological quality of cistern-stored rainwater in Kentucky, Lye (1991) detected total coliforms in a range of 0 to 300 CFU/100 mL. Higher figures were reported by Fujioka et al. (1991) for rainwater systems in Hawaii. Fujioka et al. (1991) found that the rainwater collected from the cistern contained 0 to 520 CFU/100 mL, with a mean of 103 CFU/100 mL of fecal coliforms. A more comprehensive study by Crabtree et al. (1996) evaluated the presence of fecal coliforms as well as *Cryptosporidium* and *Giardia* in rainwater samples collected from cisterns in the U.S. Virgin Islands. The study found a range of 0 to 308 CFU/100 mL of fecal coliforms, and detected one or both of the protozoa in 47% of the samples collected.

To address concerns regarding rainwater quality, and determine specifically whether levels of microbiological
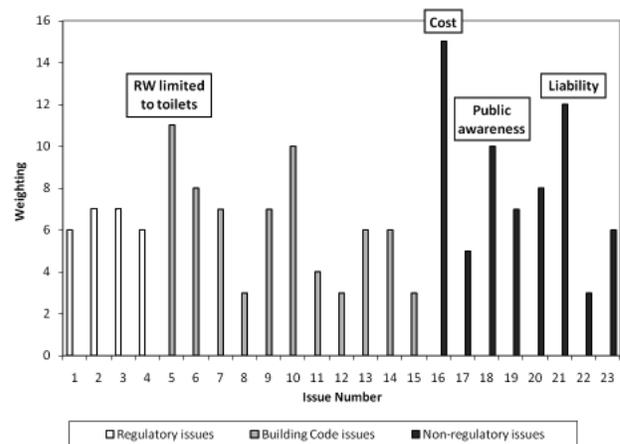
Fig. 5. Summary of barriers identified by various stakeholders.

contamination similar to those found by Fujioka et al. (1991) and Crabtree et al. (1996) were present in rainwater harvested in Canada, a rainwater quality assessment program was carried out. The one-year program took place from October 2006 to October 2007, during which time rainwater samples were collected from seven sites (six households and one industrial site) located in and around the City of Guelph. The majority of the sites used rainwater to service, at the minimum, toilet flushing and outdoor use, with two sites (Site 1 and Site 3) meeting nearly all household water demand with rainwater.

At each of the sites, samples were collected directly from the cistern [cistern-stored samples (CS)] as well as at the point-of-use (POU) from a hose bib or other suitable location downstream of any post-cistern treatment units employed at the sites. The only exceptions to this method were Site 5 and Site 7, where only POU samples could be collected. In total, 360 individual samples were collected and tested for the presence of total and fecal coliforms, as well as a number of physicochemical parameters including pH, turbidity and total organic carbon. Further details regarding the sites participating in the quality assessment program and methods used in sample collection and analysis are provided in Despins et al. (2009).

The microbiological quality of the CS rainwater and POU rainwater reported by Despins et al. (2009) is provided in Fig. 6. The number of fecal coliforms detected in the rainwater cisterns ranged from <1 (below detection limit) to 400 CFU/100 mL. Despite this range, the median number of fecal coliforms was <1 CFU/100 mL at each site, with the exception of Site 4, which had a median of 2 CFU/100 mL of total coliforms. Fecal coliforms were detected above 1 CFU/100 mL in only 52 out of 360 (14%) samples. The figure shows that the CS rainwater at Site 4 tended to have higher levels of coliforms than the other sites. This site, located in an older neighbourhood of downtown Guelph, is thought to have poorer quality due to the presence of a greater number of mature trees on the property. The RWH systems at the other sites tended to have been installed in newer

homes which had no or little overhanging tree branches contributing plant matter and permitting animal activity above the catchment surface.

Another important trend reported by Despins et al. (2009) (and discernible in Fig. 6) is the improved quality of the POU samples when compared with the samples collected from the rainwater cistern. The degree of post-cistern treatment varied from no treatment at Site 6, treatment by storage in a residential hot water tank at Site 3, to extensive treatment by slow sand filtration and activated carbon at Site 1. The most prevalent method of postcistern treatment, however, was the combination of a 20-micron particle filter and ultraviolet (UV) disinfection, which was used at Sites 1, 2, and 4. Following these postcistern treatment techniques, the number of samples with >1 CFU/100 mL was reduced by 97% on average for fecal coliforms, and 96% on average for total coliforms (Despins et al. 2009).

On two occasions during the quality assessment program, the microbiological analysis was expanded to include detection of the pathogens *Legionella* and *Campylobacter* in the CS rainwater. Despite fecal coliforms being present in quantities as high as 79 CFU/100 mL (at Site 4) when sample collection took place, neither pathogen was detected above 1 CFU/100 mL in the CS water. In addition to this microbiological analysis, the levels of polycyclic aromatic hydrocarbons (PAHs) and the metals present in the rainwater were investigated. Several studies, such as those by Förster (1996, 1998) and Van Metre and Mahler (2003) have identified these quality parameters in rain runoff, and have expressed concerns regarding the risks of rainwater contamination from roof surfaces. The samples collected in this study, however, showed little contamination from the roof or other components of the RWH system, as none of the 22 PAHs analyzed (including benzo[a]pyrene, benzo[b]fluoranthene, benzo[j]fluoranthene, benzo[k]fluoranthene, and indeno[1,2,3-cd]pyrene) were detected above detection limits, and none of the 34 metals were above the maximum acceptable concentrations or aesthetic objectives of the *Guidelines for Canadian Drinking Water Quality* (Health Canada 2007).

The absence of *Legionella*, *Campylobacter*, and PAHs, and the minor levels of metals and fecal coliforms, indicates that that there is minimal risk associated with the nonpotable use of rainwater for toilet flushing, laundry, and outdoor purposes. The significant improvement in quality observed from the use of particle filtration and UV disinfection suggests that, given additional postcistern treatment, the end uses for which rainwater is utilized could be further expanded. Because of the high quality of rainwater, it is recommended that these expanded end-uses be pursued, as the greater the amount of rainwater use, the greater the associated municipal water savings and reduction of stormwater flows.
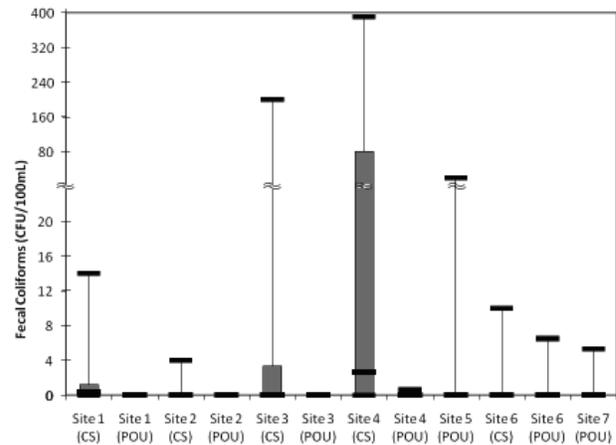

Fig. 6. Levels of fecal coliforms in cistern-stored (CS) and point of use (POU) rainwater samples. Each box represents the bounds of the first and third quartile, the median is marked by a horizontal line inside the box, and the ends of the 'whiskers' represent the minimum and maximum.

Design Considerations

Concerns regarding the quality of rainwater also influence the design of RWH systems, specifically with regards to indoor plumbing in settings where a municipal water supply is available. To prevent contamination of the municipal water supply, many jurisdictions and documents pertaining to the design of RWH systems specify that an independent rainwater supply line must be used, and physical connections (cross-connections) between the two water supplies are prohibited unless accompanied by an approved backflow prevention device (DIN 2002; Standards Australia/Standards New Zealand 2005; TWDB 2005; Ontario Ministry of Municipal Affairs and Housing 2006). In the event of insufficient rainwater, the storage cistern must be topped up with mains water to ensure continued operation. These mains top-up systems often require that a backflow prevention device (preferably in the form of a simple air gap) be installed to prevent contact between rainwater and municipal supply during the top-up process.

Another aspect that must be considered when designing RWH systems, particularly in cold climates like Ontario, is the performance of RWH systems during periods of cold weather. RWH systems must be designed to prevent ice from accumulating in the conveyance network between the catchment surface and the cistern, or in any treatment devices located prior to the cistern. The design, and most importantly the placement, of the rainwater cistern must also take into consideration the risks associated with stored rainwater freezing during periods of cold weather. To address this issue, precistern treatment devices and rainwater cisterns should not be located outdoors or above ground due to the risk of freezing (unless they are drained prior to the onset of cold weather). Instead, these should be placed below the local frost penetration depth, or located in a temperature

controlled environment (such as a basement) to ensure that freezing does not take place.

To improve the quality of harvested rainwater, the design of RWH systems can incorporate precistern and/or postcistern treatment devices to improve the quality of rainwater. Precistern treatment devices are incorporated as part of the conveyance network and rely upon gravity flow to facilitate the treatment process. Alternatively, postcistern treatment devices rely upon pressurized flow and/or electricity to aid in the treatment process, and thus, tend to be more rigorous than precistern treatment. As shown in the previous section, the use of a particle filter and UV disinfection was quite effective at improving rainwater quality.

Another issue that must be addressed in the design of RWH systems is the handling of overflows during large rainfall events. Methods for handling overflow may include onsite infiltration (above- or below-grade) as well as discharging to an existing storm sewer infrastructure, where allowed.

Economic Analysis

Water supply systems have traditionally been assessed using conventional economic methods, namely cost-benefit analysis. These methods suffice when the options being considered are similar in form, scale, ownership, and approach (e.g., when all of the options consist of large, centralized infrastructure owned by a municipal utility and aim to supply a bulk volume of water). However, economic and environmental constraints are forcing decision makers to consider new approaches to urban water management, which include options for demand management, source substitution, and varying scales of decentralization. RWH is one technology that represents this new approach. As these new solutions are introduced, it is critical that they are accurately represented by the methods of economic analysis applied, and that such methods allow for an equitable comparison between conventional and nonconventional alternatives.

The method of cost-benefit analysis was evaluated for its ability to appropriately reflect the unique benefits offered by water conservation or source substitution alternatives (Leidl 2008). While the basic process stays the same, certain components take on added significance or require slight modification to ensure the equitable comparison of conventional and nonconventional solutions. These include the following:

- Avoided costs such as water and wastewater operational savings and delayed infrastructure expansion should be included;
- The unit cost ($/m^3) for water supply options should be calculated using the projected volume of water utilized each year as opposed to the theoretical capacity of the system;
- Due to the different forms of ownership and/or funding mechanisms that characterize many emerging technologies and approaches, analysis should be conducted from several cost perspectives to best determine how different parties are affected;

- The same discount rate and time horizon should be applied to both conventional and nonconventional options. Discount rate refers to the interest rate used to determine the present value of a future cash flow, representing the time value of money;
- A thorough sensitivity analysis should be conducted whereby the cost of key variables is altered to indicate the economic performance of the systems under a range of possible future scenarios.

When conducting an economic analysis for RWH, the homeowner perspective and societal perspective are most important. The homeowner analysis draws on assumptions and expectations common for private investment. For example, higher discount rates may be utilized over a shorter time frame. Trends in home mortgages are often used to determine these parameters (Pickering et al. 2007). This perspective indicates the cost born by the individual over a time span relative to a single user. In the societal perspective, lower discount rates and a longer time period are used, reflecting broader, intergenerational interests and responsibilities. In addition, transfer payments from one perspective to another are not included (Mitchell et al. 2007). Examples of such payments would be the developers' mark-up on capital costs or savings in municipal water tariffs from reduced consumption of mains water. Calculations for the homeowner perspective generally result in a much higher cost compared with those for the societal perspective.

Distributed technologies like RWH are often evaluated from the homeowners' perspective, while conventional infrastructure for municipal water supply is usually considered from the societal perspective. Because the underlying economic assumptions are different, the resulting costs from these two analyses cannot be compared. However, despite this incompatibility, such comparisons are often made. This is largely because distributed source substitution or conservation technologies are considered as private infrastructure producing only private benefit, with little recognition of broader community implications. Further, such measures are often not considered as an integral part of water supply planning, but rather as an afterthought after major decisions about water supply planning have been made. The public benefit of such infrastructure should be recognized, and as such, systems like RWH should first be evaluated as public infrastructure, following the societal perspective. Only then can these emerging technologies be equitably compared with conventional supply-side alternatives, and only then will the most sustainable solutions emerge.

Leidl (2008) performed a cost-benefit analysis for RWH, considering both the homeowner and societal perspective. Cost estimates for various RWH configurations were determined for the southern Ontario context, the most cost-effective of which was a buried concrete cistern serving outdoor use, toilets, and laundry. The capital cost was then reduced by 30% to account for future market development and economies of scale. The net present value (expressed as $/m^3) was determined

for both the homeowner and societal perspectives, and then compared with the societal cost of two water supply alternatives proposed in the City of Guelph *Water Supply Master Plan* (2006). The primary assumptions used in this analysis are given in Table 2.

It was determined that, from the homeowner perspective, a RWH system would cost approximately $4.57/m³. The same system, when considered from the societal perspective, would be only $1.47/m³. For comparison, the development of new surface water supplies was found to be $0.75/m³ for a local source and $1.43/m³ for a regional source, calculated from the societal perspective. It is obvious that RWH would be immediately dismissed as cost prohibitive if only the homeowner perspective is considered, but it becomes a potentially viable option when it is subject to the same economic methods as the options with which it is being compared. These results are shown in Fig. 7.

Development of Progressive Policies

The promising results discussed above regarding the quality of rainwater, emerging design best practices, and economic feasibility are contributing to a growing interest in RWH. As such, the practice of RWH is increasingly demanding recognition and accommodation by regulatory authorities. However, before considering the need for additional regulatory measures, it is important to first understand the existing regulatory framework for RWH and how it developed. A recent review identified three key components of the regulatory framework for Ontario, all of which are equally important and mutually reinforcing (Leidl 2008):

1) Overarching policy provides high-level direction and sets expectations. There are several policy references for water conservation, at both the provincial and municipal levels; however, only the *Places to Grow* provincial growth
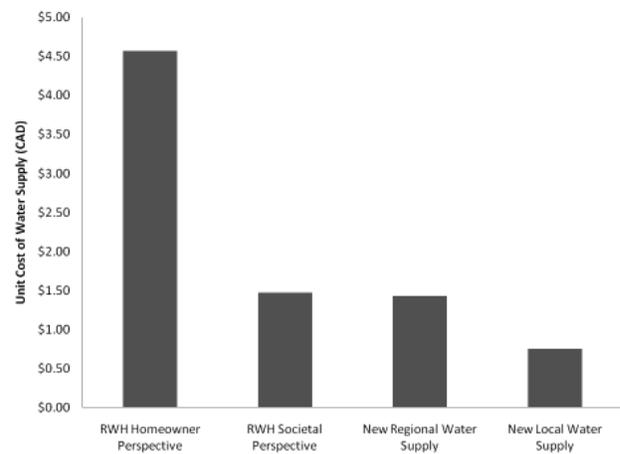

Fig. 7. Comparison of unit cost for RWH and conventional water supply options.

management legislation goes beyond conservation and mentions source substitution (Ontario Ministry of Public Infrastructure Renewal 2005). No explicit mention of RWH could be found, except for briefly in the Toronto *Wet Weather Flow Guidelines* (City of Toronto 2006). Further, conservation policies are largely couched in broader planning documents and receive little attention on their own. Apart from conservation, however, several of these policy statements do encourage sustainable stormwater management.

2) Regulatory devices are legally binding tools that allow for enforcement. In the Ontario context, The Ontario Building Code (OBC) is the most significant piece of regulation and in 2006 was amended such that rainwater could be used to flush toilets and urinals, regardless of the availability of potable water. This makes the OBC one of the most progressive building codes in Canada, with

TABLE 2 . Primary assumptions for cost-benefit analysis

	Time frame (yrs)	Discount rate [a] (%)	Included costs and savings	Other assumptions
RWH Homeowner Perspective	25	6.2	Savings: water and sewer rates, softening salt Costs: capital cost + 30% developer mark-up, operation and maintenance	30% reduction in capital cost [b]
RWH Societal Perspective	50	5	Costs: capital cost, operation and maintenance	30% reduction in capital cost [b]
New regional water supply	50	5	Costs: capital cost, operation and maintenance	As per City of Guelph, 2006, except annual projected demand was used instead of total system capacity
New local water supply	50	5	Costs: capital cost, operation and maintenance	

[a] Real discount rate, not including assumed 2% inflation.
[b] Cost reduction assumed due to improved markets and economies of scale.

respect to nonpotable water use. However, advocates for RWH are urging the expansion of permissible end uses to include washing machines and the development of more detailed technical specifications. In general, regulatory advances in Ontario seem piecemeal and reactionary, with little collective strategy for advancing RWH or similar technologies.

3) Support mechanisms are aimed at end users and provide the information, encouragement and incentive that allow for widespread implementation. This may include design manuals, education campaigns, financial incentives, or demonstrations, etc. In 2006, the Canadian Standards Association (CSA) produced a standard for the installation and maintenance of nonpotable plumbing systems. While these standards are not yet recognized in the Building Code, their development represents the start of positive advances in the sector. Apart from the CSA standards, however, no sources of information or guidance could be found for RWH in Ontario. Relevant information seems to be the most fundamental form of support that is missing.

After reviewing the existing regulatory framework for RWH, we must then consider the current approach to policy development in general. The purpose of policy is viewed differently by different stakeholders. Some feel that minimizing liability or mitigating risk should be the primary role, while others suggest that encouraging innovation and enabling implementation must take priority (Leidl 2008). Given the sustainability concerns that mark the water sector and the uncertainty posed by factors such as climate change, it is evident that what is needed is the ability to adapt quickly. As change requires risk and risk implies liability, any policy that narrowly aims to minimize risk or liability is inherently resistant to change and cannot be considered progressive. Policy must therefore be designed to advance innovation and implementation. Alternative means of risk management must then be developed that do not detract from this end. An excellent example of this can be found in the Gulf Islands of British Columbia. Although the Building Code has very little reference to RWH, systems, including those used for potable purposes, are approved by municipal inspectors as long as the designs are stamped by a professional engineer (Burgess personal comm. 2008). This alleviates municipal liability and ensures a level of risk management, meanwhile promoting innovative designs.

There are many policy initiatives that can be undertaken to advance RWH, which must be tailored to local circumstances. However, in all cases and across all locations, the three components (overarching policy; regulatory devices; support mechanisms) must be considered. Further, the need to focus on innovation and implementation remains universal. The following measures have been suggested as priorities for the case of Ontario (Leidl 2008):

- Overarching Policy: Explicit, stand-alone policies are required for sustainable water management, including stormwater management, conservation, and source substitution, both at the provincial and municipal levels;
- Regulatory Devices: RWH should be more explicitly addressed in the Ontario Building Code. Grey water and rainwater should be dealt with separately, and the permissible end uses for rainwater should be expanded to clearly include both laundry and irrigation;
- Support Mechanisms: Design guidelines should be developed through a collaborative process and should be endorsed by the Ministry of Municipal Affairs and Housing (administrators of the Building Code).

Conclusions and Recommendation

RWH shows significant promise, both as a sustainable stormwater management strategy as well as a water conservation and source substitution approach. Although the need for sustainable stormwater management such as RWH is pressing, a lack of adequate capacity at the societal, institutional, and individual levels has thus far limited their widespread uptake. Capacity development for RWH and other sustainable water management practices must be undertaken systematically in Canada. For RWH this includes development of overarching policies and progressive regulations, availability of design guidelines and supporting documents, and an enabling environment (including market readiness and technical capacity). New approaches for economic assessment of alternative water management approaches should be reinforced and individual capacity must be enhanced to ensure their effective use. Furthermore, stormwater and overall water management plans should encourage a diversity of approaches and avoid "silver bullet" solutions.

Acknowledgments

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