Performance Evaluation of Rainwater Harvesting Systems

Toronto, Ontario

Prepared by: Toronto and Region Conservation

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Performance Evaluation of Rainwater Harvesting Systems
Toronto, Ontario

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NOTICE

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.

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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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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.

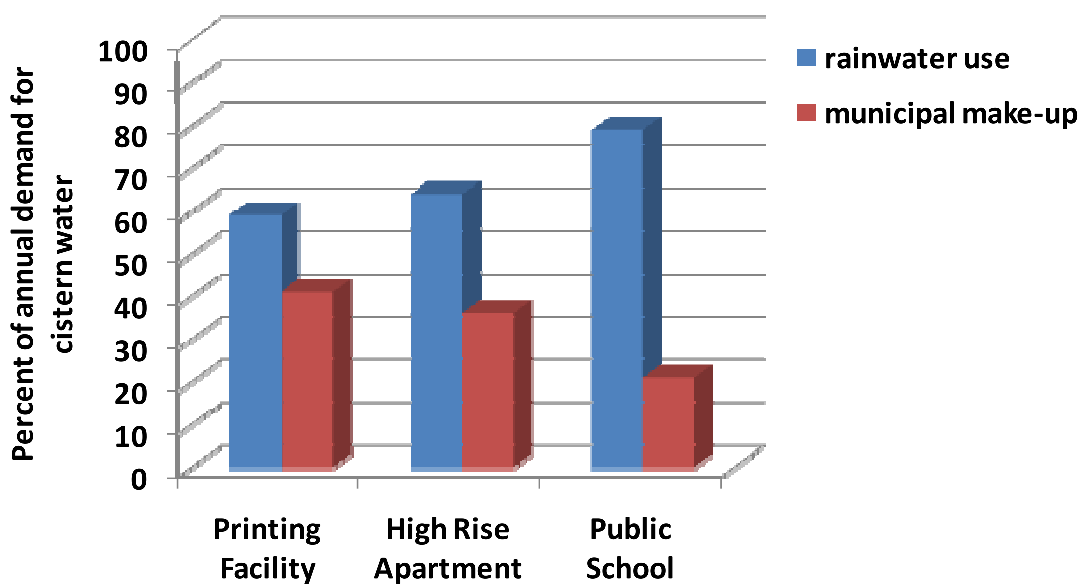

Figure 1: Rainwater use and municipal make-up as a percentage of total annual demand for non-potable water supplies during a 'normal' precipitation year.

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

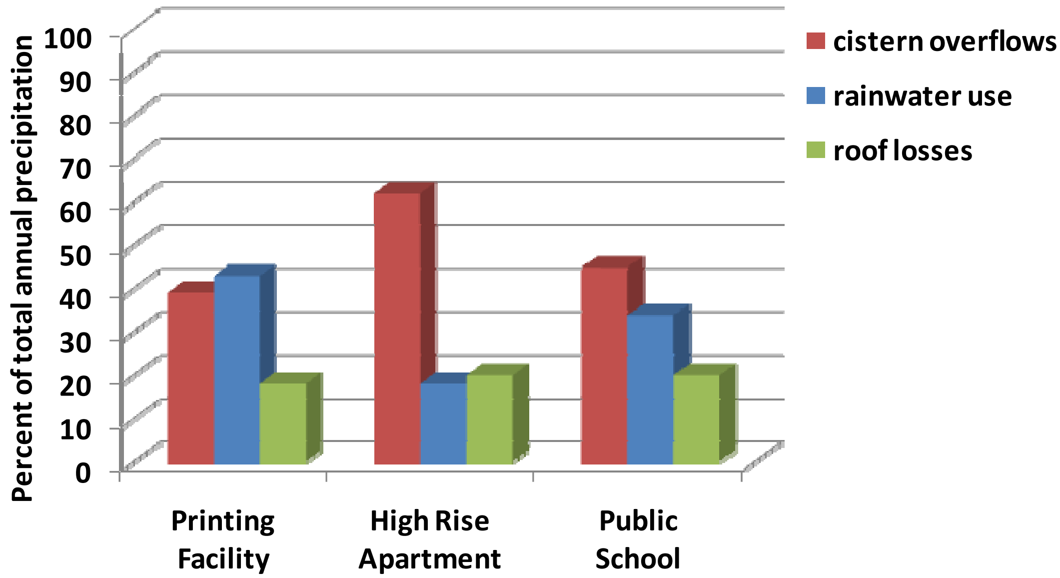

Figure 2: Rainwater use, overflows and direct losses from the roof (and patios where applicable) as a percentage of total annual precipitation inputs to rainwater catchment areas during a 'normal' precipitation year.

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.

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1.0 BACKGROUND

The ancient practice of collecting rainwater from roofs and using it to satisfy daily water needs has undergone a renaissance in the Greater Toronto Area (GTA) over the past few years as municipalities and building owners seek new and effective ways to conserve water and reduce the adverse effects of stormwater runoff on urban infrastructure and aquatic ecosystems. The most common uses of water captured through rainwater harvesting (RWH) systems include toilet flushing, landscape irrigation, vehicle washing and laundry, but if the water is treated, the systems can also be used to supply water for drinking, bathing and dishwashing (May and Prado, 2006; Lye, 2009). Industries may also use harvested water for cooling and in various production processes.

Most large Canadian cities receive an average of 260 to 1,500 mm of precipitation annually, and have the potential to harvest this precipitation to lower domestic municipal water use by up to 50% (Brandes et al., 2006). In recognition of the multiple uses of rainwater, RWH systems offer a number of environmental, social, and economic benefits on the individual, business, and municipal level, including:

- *Lower municipal energy costs:* Roughly one third of municipal electricity consumption in Ontario is spent pumping and treating water, much of it for uses such as irrigation and toilet flushing, which do not require treated water (PAGI, 2008).
- *Reduced green house gas emissions and air pollution:* Less energy used in pumping water long distances can translate into lower emissions of air pollutants and gases that contribute to global climate change. Above ground gravity fed systems that do not require water pumps are particularly effective in this regard.
- *Delayed expenditures on new water treatment plants or existing plant expansions:* Water treatment plant expansions in Canada cost billions of dollars each year. Delaying these expansions can result in significant savings (Leidl, 2008).
- *Improved stormwater management:* Utilizing rainwater to supplement municipal supplies helps to reduce flood risk, stream erosion, infrastructure damage, and the pollution of waterways and beaches from stormwater runoff and combined sewer overflows.
- *Lower consumer water bills:* Supplementing potable supplies with rainwater can reduce water bills by as much as 50% in homes and up to 80% in industrial buildings.
- *Reduced demand on water resources:* Providing a reliable and renewable source of water to end users helps to reduce demand on water resources (such as groundwater aquifers and reservoirs) from which municipal water supplies are drawn.

In the past, high start-up costs and regulatory barriers discouraged broad implementation of RWH technologies in Ontario, but with recent changes to the Ontario Building Code, coupled with growing interest in green building technologies and new requirements for controlling stormwater runoff volumes, the context for adoption of the technology in urban areas has become considerably more favourable.

1.1 Rainwater Harvesting Technology

Residential or commercial RWH systems can vary widely in design from a simple rain barrel at the end of a roof downspout to complex industrial systems that purify collected water to potable water standards.

Typically, a RWH system consists of three basic elements: the collection system (such as a roof), the conveyance system (infrastructure that transports the water), and the storage system (above or below ground cistern); however in larger systems or ones designed to produce potable water, a pressurized or non-pressurized water discharge system and pre/post treatment unit is usually included (Farahbaksh et al., 2009). In most cases, a cistern overflow draining to an infiltration basin or municipal sewer system is necessary in order to prevent system backups. Figure 1.1 illustrates a typical RWH system for residential use.

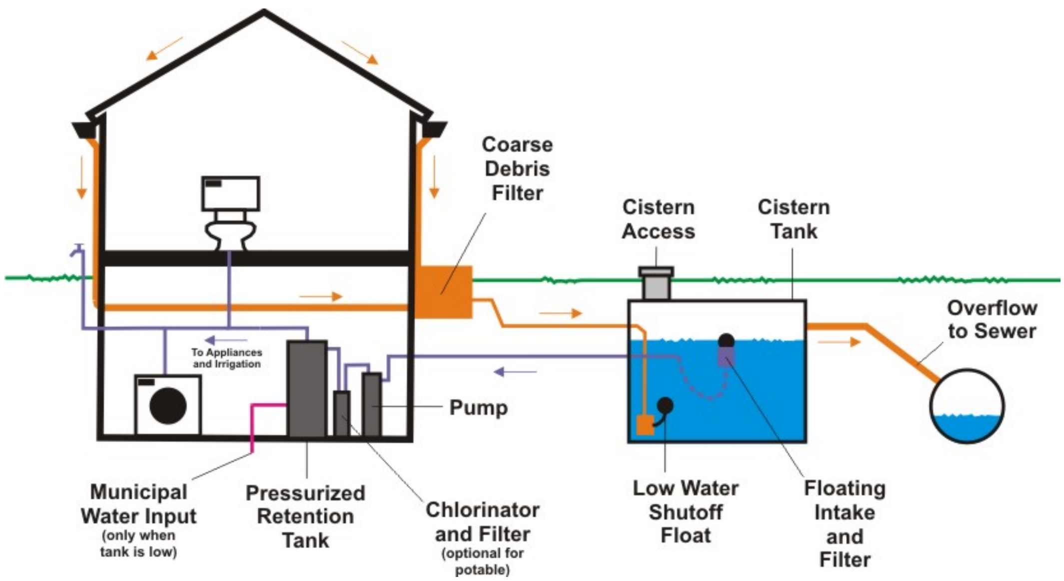

Figure 1.1: A typical domestic RWH system.

In order to prevent dust and debris from collecting in the cistern, the water must first pass through a coarse debris filter or first flush diverter. Finer particulates passing through the filter are settled out via sedimentation when the water enters the cistern. Filters can be placed in the cistern (e.g. floating suction filters), underground between the cistern and conveyance pipe and/or above ground. In cases where the water is used as a potable source, filters (*e.g.* sand and charcoal), ozone, and ultraviolet light can be used to further purify the water. In order to prevent ice accumulation and frost damage to the filter, devices should be installed either in a temperature controlled environment, buried below the frost line, or equipped with heat tracing.

The design and size of the system is ultimately determined by two factors: supply and demand. The volume of water that can be captured and stored (the supply) must be similar to, or exceed the volume of water used (the demand). An equation frequently used to determine the supply of a simple RWH system is:

$$Q_i = A\, r_i - \{(E_i + b_i)\, A + D_i\}$$

Where i represents a time interval, Q_i is the available rainwater volume (m^3), A is the catchment (roof) area (m^2), r_i is the rainfall depth (m) over the interval i, E_i is the evaporation abstraction (m), b_i is the initial loss (wetting, surface storage) in (m), and D_i is the consumed volume (m^3). This equation is typically used in a spreadsheet program using historical rainfall data as input in order to find a combination between D and Q that maximizes system efficiency (Exall, 2004). In urban areas, where mains top up supplies are readily available, it is not cost effective to size the cistern to meet 100% of the demand for nonpotable water. Instead, municipal water is used to supplement water supplies when the cistern is dry.

1.2 System Performance

1.2.1 Water Quantity

The performance of rainwater harvesting systems is measured both in terms of their capacity to conserve water as well as to reduce the volume of stormwater runoff leaving the site. These performance measures vary substantially depending on a number of factors, the most important of which are the pattern and quantity of rainfall and snow, the size of the catchment area, the size of the cistern and the pattern and demand for non-potable water. All other factors being equal, performance will tend to be higher when supply is not limited by cistern volume or catchment area, and the supply of water from precipitation closely matches the demand for water from the harvesting system. Southern Ontario climate conditions are well suited to rainwater harvesting because annual precipitation in large urban centres is typically between 750 and 950 mm and rainfall is higher in the summer when more water is used for irrigation.

This is demonstrated by a monitoring study in the City of Guelph where a residential RWH system with an 8 m^3 cistern, a 100 m^2 shingled roof catchment area, and average daily water demand of 0.57 m^3/d was monitored over a one year period (Farahbaksh et al, 2009). The cistern provided non-potable water for a family of 5 for toilet flushing and laundry. Monitoring results showed that the RWH system reduced the total volume of runoff from the roof by 89%, and supplied approximately 85% of the demand for non-potable water uses (assuming that toilet flushing and laundry comprised 37% of total household demand). Had indoor uses in this residence been closer to the average five person household in the City of Guelph (1.32 m^3/d), the system would have performed significantly worse (Farahbakhsh et al, 2009).

1.2.2 Water Quality

The quality of water has been an important concern both for potable and nonpotable applications of RWH. It is affected by a variety of factors including climate, proximity to heavy industry, catchment material and various design elements of the RWH system itself (e.g. pretreatment, filtration). In the City of Guelph and surrounding area, Despins et al (2009) examined roof water quality from seven households with RWH systems, two of which used rainwater to meet the majority of household water uses. Results of cistern and point of use sampling showed low levels of turbidity (means < 2.6 NTU) and total nitrogen (mean < 2.0 mg/L), neutral pH and highly variable levels of TOC, colour and UV absorption. Total and fecal coliforms were above 1 CFU/100 mL detection limits in 30% and 14% of samples, but geometric means at all sites were at or below1 CFU/100mL. *Campylobacter* and *Legionella* were not detected. Catchment and storage materials were found to be the most important determinants of variations in sample quality among sites, with steel roofs providing better quality than asphalt roofs, and concrete cisterns having higher pH than plastic cisterns.

A three year study of water quality from four rainwater collection systems in the Netherlands also showed that collected water was faecally contaminated (Schets et al., 2010). Since the water did not meet Dutch or the World Health Organization standards for drinking water, treatment would be required before consumption. Regular cleaning of catchment, collection and distribution systems was recommended to reduce health risks associated with incidental contact.

1.3 Incentives and Policies

1.3.1 Canada and Ontario

Rainwater harvesting in Canada is considerably underutilized even though approximately 26% of Canadian municipalities reported water shortages due to seasonal drought, infrastructure problems and increased consumption between 1994 and 1999 (Environment Canada, as cited in Exall *et al*., 2004). Examples of RWH in Canada are mostly for residential use in rural areas where there is no access to centralized municipal supplies. Most urban examples are in buildings certified under one of the green building rating systems, in which points are earned for rainwater reuse and runoff reduction.

In 2006, a significant regulatory barrier to RWH in Ontario was removed with the release of a revised version of the Ontario Building Code (OBC). This version of the OBC includes an amendment allowing for the use of non-potable water for toilet and urinal flushing. The OBC does not specify the source of non-potable water, but simply requires that it be 'free of solids' (Leidl, 2008). Not surprisingly, there is more resistance to accepting rainwater as a potable supply than for low risk uses such as toilet flushing or irrigation. The water contamination disaster in Walkerton, Ontario in 2000 and the historical failure of decentralized water supply infrastructure has contributed to the reluctance of regulators to embrace another form of decentralized potable water supply infrastructure (Leidl, 2008). Researchers from the University of Guelph have helped to address these barriers by developing a detailed guidance document for the design and implementation of RWH (University of Guelph, 2010).

Several municipalities in Ontario currently view RWH as an important means of addressing water management problems. The City of Guelph, for instance, partnered with the University of Guelph, the Canada Mortgage and Housing Corporation, local developers and the Ontario Centres of Excellence to demonstrate residential applications of the technology and address cost and regulatory barriers in buildings across the city. The City of Toronto and the Regional Municipality of Waterloo have also been active in promoting the technology through stormwater and green building policies. A full scale demonstration of RWH technology is being constructed and monitored at Toronto's Exhibition Centre. The municipalities of Toronto, York and Peel also helped to support this monitoring evaluation of RWH systems in the GTA.

1.3.2 United States

Rainwater harvesting systems are much more common in the United States, especially where there are chronic water shortages (CWWA, 2002). State surveys suggest that there may be as many as 200,000 cisterns in use across the United States that supply water for individual households or small communities (Lye, 2002). Texas, for instance, has had property tax relief for commercial and industrial facilities using

RWH since 1993, and in 2001 a sales tax exemption was introduced for all RWH equipment (TRHEC, 2006). At the time of writing, the City of Austin were offering $500 for residential RWH systems and $5,000 for systems installed in buildings owned by public agencies or organizations in the non-profit sector. The Texas Water Board Manual on RWH (2005) is an excellent example of how the technology has been adopted and can be appropriately implemented under various circumstances.

The Cities of Portland and Albuquerque, and the States of Arizona, Ohio, Washington and Kentucky also have guidelines for designing and installing RWH systems. In Santa Fe, New Mexico RWH systems must be installed on all new residential buildings greater than 2,500 square feet (TRHEC, 2006, City of Albuquerque, 2007). The State of Virginia provides a tax rebate of up to $2000 for RWH systems.

1.3.3 Other Countries

In Europe, RWH is more widely accepted and practiced than in North America. Germany has been especially proactive in this regard. In 1980, Germany legalized rainwater utilization and by 1988 Hamburg became the first German city to provide subsidies for RWH adoption. RWH systems have since become part of mainstream building practice with roughly 100,000 systems being installed annually, hence the subsidies are no longer offered (Koenig, 2004). By 1993, Hessen became the first state to change its building regulations, giving local governments and communities the ability to enforce the use of RWH technology. The cities of Baden-Wurttemberg, Saarland, Bremen, Thuringen and Hamburg soon followed Hessen's lead (Brandes et al., 2006).

Belgium has national legislation which requires all new construction to incorporate RWH systems for flushing toilets and external water uses (CWWA, 2002). Tax credits or rebates on RWH equipment are also offered in the United Kingdom and France (de Gouvello *et al*., 2005). While RWH practice in the UK remains in its infancy, markets for the technology have grown considerably since 2005. Several countries in Europe are considering legislative requirements for incorporation of RWH systems in new buildings for the purposes of flushing toilets and external water uses (Lye, 2009)

RWH systems are also being installed across Australia, with some help from government incentive schemes. South Australia has the highest percentage of households (51%) with cisterns, of which 36% use the harvested rainfall as drinking water (Diaper, 2004). Through Community Water Grants the Australian Government Water Fund gives communities up to $50,000 towards projects that will save, recycle, or improve their local water resources as part of a five year $200 million program (AGWF, 2006). Further encouragement is given through state-wide programs mandating energy and water efficiency measures in new buildings.

1.4 Start-up Costs in Canada

The costs for rainwater harvesting systems will vary considerably depending on the catchment roof area, size and complexity of the system, the quality of system components, and whether the system is being retrofitted into an existing building or constructed as part of a new building. In general, retrofits will be more expensive because some existing infrastructure or plumbing components will need to be replaced, and equipment and contractors will need to be brought in specifically for this task.

Start-up costs for retrofitting a rainwater harvesting system into a 20 year old Bungalow in the City of Guelph were estimated at approximately $8,100 (Despins et al, 2006). The 8 m^3 cistern and excavation constituted over half of the total system and installation cost. The pump and constant pressure system kit cost another $1,600, although cheaper models are available.

By comparison, a larger rainwater harvesting system (18 m^3 cistern including the settling chamber) at a commercial labelling facility in Toronto cost approximately $18,000, excluding piping in the building. An even larger system with a 45 m^3 cistern (including the settling chamber) installed in the Brookside Public School in Toronto cost roughly $40,000. These examples suggest that, as a general rule of thumb, dual use RWH systems in Ontario cost roughly $1 per litre of cistern storage.

In Victoria, British Columbia, costs are lower because climate conditions allow for cisterns to be installed above ground, which eliminates excavation costs. A residential system with a 8 m^3 cistern supplying roughly 140 m^3/year for all end uses was estimated to cost about $5000. A smaller 5 m^3 cistern with 90 m^3/yr supplied for toilets and laundry would cost about $3000 as treatment components would not be required (CRD, 2007).

2.0 STUDY OBJECTIVES

This three year monitoring project evaluates the benefits and limitations of three commercial and institutional rainwater harvesting systems for water conservation and stormwater management under water use and precipitation conditions typical of the Greater Toronto Area. Based on monitoring data, a model was developed and calibrated to assess hydrologic performance under different cistern sizing and precipitation scenarios. Sampling of water quality from the cistern and distribution system was conducted to determine the suitability of the water as a source of non-potable water source. Special attention was directed towards performance of the system under cold climate conditions as there are few studies that address this topic. Results of the study will be used to develop tools, educational materials and guidelines for application of this technology in new and existing buildings.

3.0 STUDY SITES AND SYSTEM DESIGNS

Three RWH systems were monitored as part of this study. These include: (i) a commercial printing facility in Scarborough (East Toronto); (ii) a high rise apartment building near the intersection of Eglinton Ave. and Yonge Street in Central Toronto, and (iii) a newly constructed public school, also in Scarborough. The three RWH systems represent a good cross section of different designs for varying applications. Monitoring of the RWH systems were conducted over a three year period at the printing facility, and for one year at the other two buildings.

3.1 Commercial Printing Facility

3.1.1 Site

The printing facility owned by Metro Label is a 12,260 m^2 warehouse containing label press equipment, adjoining office space, truck loading docks and parking (Figure 3.1). The facility is located at 999 Progress Avenue, Scarborough, Ontario and is certified as 'silver' under the LEED™ (Leadership in Energy and Environmental Design) green building rating system. Their operations have also been certified to meet ISO 14001 environmental management standards. This new building design incorporates sustainable site planning, innovative wastewater technologies, a heat recovery system, use of recycled construction materials, and indoor environmental quality (CaGBC 2006, Enermodal, 2006).

Figure 3.1: Metro Label printing facility, 999 Progress Avenue, Scarborough, Ontario.

3.1.2 Rainwater Harvesting System

Part of Metro Label's water conservation plan includes the use of an 18 m^3 rainwater collection cistern (12 m^3 storage chamber and 6 m^3 settling chamber) to reduce municipally supplied potable water for flushing toilets and manual irrigation. Rainwater collected from a 968 m^2 section of the roof is directed to 4 pressurization tanks and then to 6 toilets and 2 external hose bibs, resulting in a reduction in water use for sewage conveyance. Other water use reduction features include waterless urinals and ultra low-flow fountains and faucets (Enermodal, 2006). The cistern distribution network is depicted in Figure 3.2.

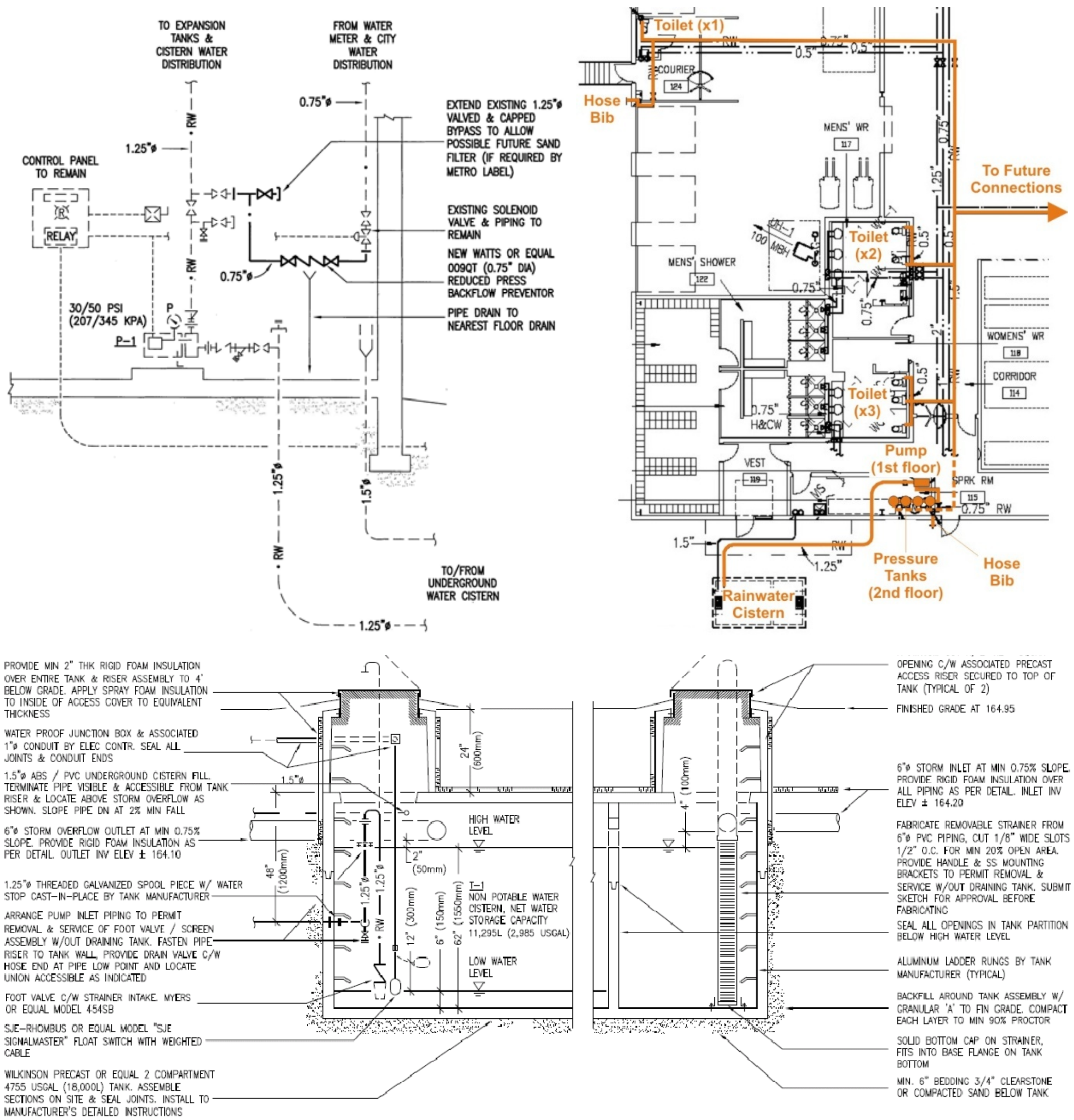

Figure 3.2: Metro Label printing facility pump and pressurization schematic (top left), distribution network (top right), and cistern (bottom).

Using a cistern float switch and controller (relay) to trigger a solenoid valve, the system is designed to automatically by-pass the cistern and use municipal water when the cistern storage volume falls below three cubic metres. When this occurs, potable water is sent directly to the pressurized tanks for distribution within the building. The cistern only receives roof runoff. A filtration system (*e.g.* sand filter) can be added to supply potable water if there is a future need for this application.

3.1.3 Design Model

In January 2006, prior to construction, the system was modelled to determine its LEED™ credit weight for potable water use reduction. The model included a reference and design case. Parameters and daily water demand for the two cases are presented in Table 3.1. In the reference case all fixtures have standard water flow rates and use municipal water. In the design case all fixtures, except hose bibs, have low flow rates and water for the toilets and one hose bib is provided by rainwater. Toilets in the design case are 6/3 dual flush and urinals are waterless. The water conservation measures represent a total water consumption savings of 44% relative to the design case (29% if the cistern is not included).

Based on the design model, it was estimated that 257 m^3 of cistern water would be used each year, with an annual cost savings of \$386/yr at a local municipal rate of \$1.50/m^3. The total water demand on the cistern was estimated to be 391 m^3/yr, but rainfall and water use simulations indicated that only 66% of this demand would be met by the cistern because of inadequate rainwater supply during dry periods in the summer and cold weather in the winter. Thus 34% of the demand would need to be supplemented by municipal water supply. Only a small amount of irrigation was included in the modelling because the cistern does not supply a permanent irrigation system (only manual use via hose bibs). Landscape irrigation is supplied by an automated system connected to the municipal supply. Actual rainwater and municipal water supply use at the facility from 2007 to 2010 are presented in Chapter 5.

Table 3.1: Estimated annual water use for the Metro Label printing facility

Fixture Type	Number of Occupants	Number of Daily Uses per Occupant	Water Use Rates	Units	Water Use Duration	Units	Water From Cistern?	Daily Water Demand [m³/day]
Reference Case								
Toilets (Women's)	65	3	6.1	L/flush	1	flush	N	0.972
Toilets (Men's)	65	1	6.1	L/flush	1	flush	N	0.324
Urinals	65	2	3.8	L/flush	1	flush	N	0.404
Lavatory Faucets	130	3	9.5	L/min	0.5	min	N	1.517
Showerheads	130	0.25	9.5	L/min	5	min	N	1.264
Hose Bibb	130	0.01	18.9	L/min	5	min	N	0.101
Hose Bibb	130	0.01	18.9	L/min	5	min	N	0.101
Daily Water Consumption [m³/day]:								**4.681**
Design Case								
Toilets (Women's)	65	3	4.5	L/flush	1	flush	Y	0.728
Toilets (Men's)	65	1	4.5	L/flush	1	flush	Y	0.243
Urinals	65	2	0	L/flush	1	flush	N	0.000
Lavatory Faucets	130	3	7.2	L/min	0.5	min	N	1.154
Showerheads	130	0.25	7.6	L/min	5	min	N	1.015
Hose Bibb	130	0.01	18.9	L/min	5	min	N	0.101
Hose Bibb	130	0.01	18.9	L/min	5	min	Y	0.101
Daily Water Consumption [m³/day]:								**3.342**

Annual Indoor Use	**Municipal Only**	**Municipal with Cistern**	**Savings**	**Percent Savings (Relative to Reference)**
Total Water Consumption for Sewage (m³/year)	620	354	266	43%
Potable Water Consumption for Sewage (m³/year)	620	122	498	80%
Total Water Consumption (m³/year)	1709	1220	489	29%
Potable Water Consumption (m³/year)	1709	963	745	44%
Cost of Potable Water Consumption ($/year)	$2,563	$1,445	$1,118	44%
Potable Water Displaced by Cistern (Design Case Only) [m³/year]:				**257**

Assumptions 1) Water & Sewer Rate [$/m³]:= $1.50 and 2) Ratio of full-occupancy days to total days in a year: 0.82. Adapted from Enermodal Engineering Ltd.

3.2 High Rise Apartment

3.2.1 Site

Completed in early 2007, Minto Development's high rise residential apartment building located at 150 Roehampton Avenue in Toronto is the first multi-residential building to achieve LEED™ Gold certification (Figure 3.3). The building is 16 stories high with 148 suites. As the storm sewer serving Roehampton Avenue has limited capacity, the City of Toronto required on-site stormwater detention to be implemented to maintain or reduce pre-development flows. Under these requirements, allowable discharge to the street sewer was not to exceed the peak runoff rate under the pre-development condition for the 2 year event. In addition, an over land flow route was to be provided to direct runoff in excess of the 5 year event to an overland flow outlet. The flow volume difference between the 2 and 5 year events was to be detained on site.

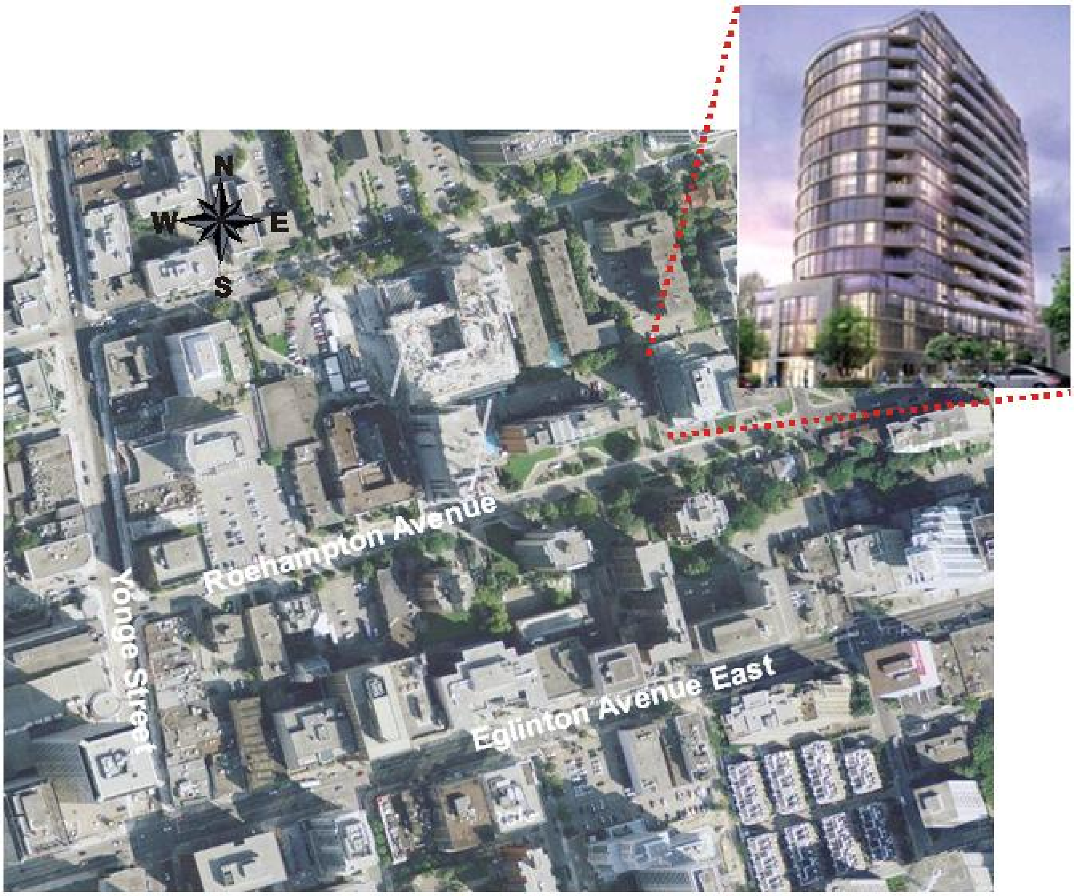

Figure 3.3: High rise apartment building, 150 Roehampton Avenue, Toronto, Ontario.

3.2.2 Rainwater Harvesting System

In order to meet City requirements and enhance building sustainability, the building includes a simplified domestic style RWH system to flush 3 toilets in public use areas, provide water for grounds irrigation, cool heated street level runoff (with overflows) and provide temporary stormwater detention for rooftop drainage. The RWH system was designed as a pilot project to assess the effectiveness of the technology, and to determine whether or not the design could be scaled up for larger applications in future Minto developments and retrofits.

Measurements and monitoring of the site indicated that the cistern located in the parking lot below the building has a storage capacity of 24 m^3 (Figure 3.4). The lower portion of the chamber (19 m^3) is used for the retention of harvested rainwater and the upper active portion (5 m^3) for stormwater detention, as required by the stormwater management plan for the site. The invert of the stormwater overflow pipe is located at the bottom of the detention storage depth and is sized to allow slow drainage of the detained water after a precipitation event.

Using a small pump to pressurize and distribute the non-potable water, the cistern water is passed through a filter before water is distributed for building uses. Depending on water demand, a float switch inside the cistern is used to activate a solenoid, which allows municipal water to fill the cistern when the water level is low. The 'low' water level sensor was set to pump 5.4 m^3 of municipal water when cistern water volumes fell below 10 m^3. It is assumed that the lower 10 m^3 was needed as a quiescent settling area to prevent resuspension and transport of solids deposited during previous events in the bottom of the cistern.

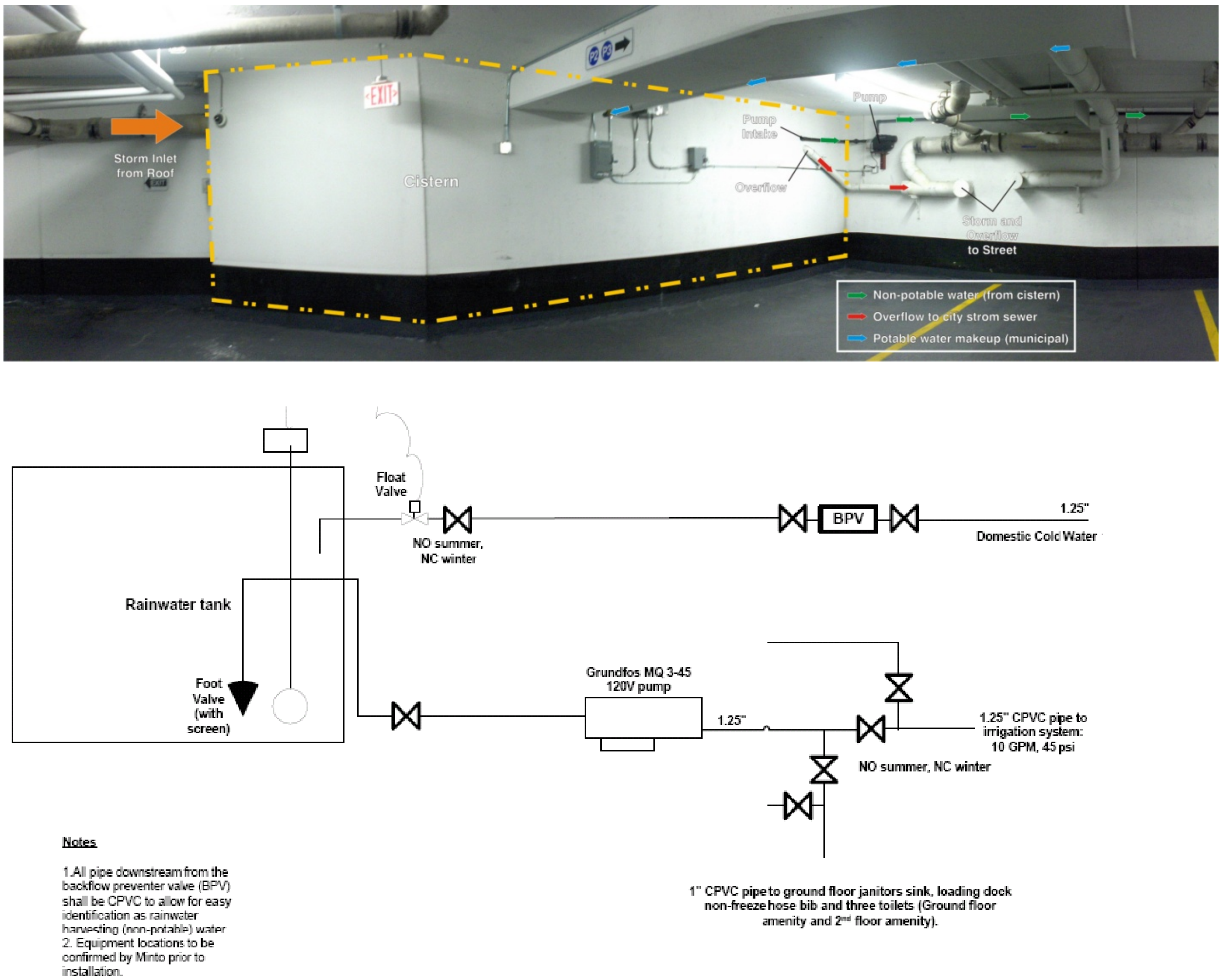

Figure 3.4: RWH system schematic, cistern (top) and pump schematic (bottom).

3.2.3 Design Model

Unlike the commercial and institutional rainwater harvesting systems, the Minto facility was sized based on a more general set of calculations, rather than a model. The reason for the simpler sizing methodology relates both to the relatively small demand on the system (only 3 toilets and hosebibs) and the dual use of the system both for rainwater retention and stormwater detention. The overall rainwater capacity of the system could be considered generous relative to expected non-potable water demand.

3.3 Public School

3.3.1 Site

Completed in August 2007, the Brookside Public School located at 75 Oasis Boulevard in Scarborough is rated as LEED™ gold (Figure 3.5). It consists of radiantly heated and cooled slabs, with a displacement ventilation system. The materials are specified to be low-VOC with high recycled content, and a green education program is integrated into the school classroom curriculum. Low flow fixtures and waterless urinals result in an overall projected water savings of 35% for indoor uses. The school is also aligned to get optimal light and heat from the sun and has a large bike rack area and limited parking spots to encourage walking and cycling to school. A RWH system is used to collect runoff precipitation for flushing all toilets and to irrigate the surrounding grounds (CaGBC, 2008 and TDSB, 2008).

Figure 3.5: Brookside Public School, 75 Oasis Boulevard, Scarborough, Ontario (Google Maps, 2010).

3.3.2 Rainwater Harvesting System

The Brookside RWH system was designed to supply water to over 20 toilets and several hose bibs. Unlike the printing facility system, where a small pump is used to pressurize several large storage tanks, the Brookside system uses two large variable frequency drive (VFD) pumps and one small expansion tank to keep the water flowing throughout the building (Figure 3.6). The roof catchment area for the 42.3 m^3 cistern (28.8 m^3 storage chamber and 13.5 m^3 settling chamber) is 2,879 m^2. Several water use reduction features have been added to the building, including waterless urinals, low flush toilets and ultra low flow fountains and faucets.

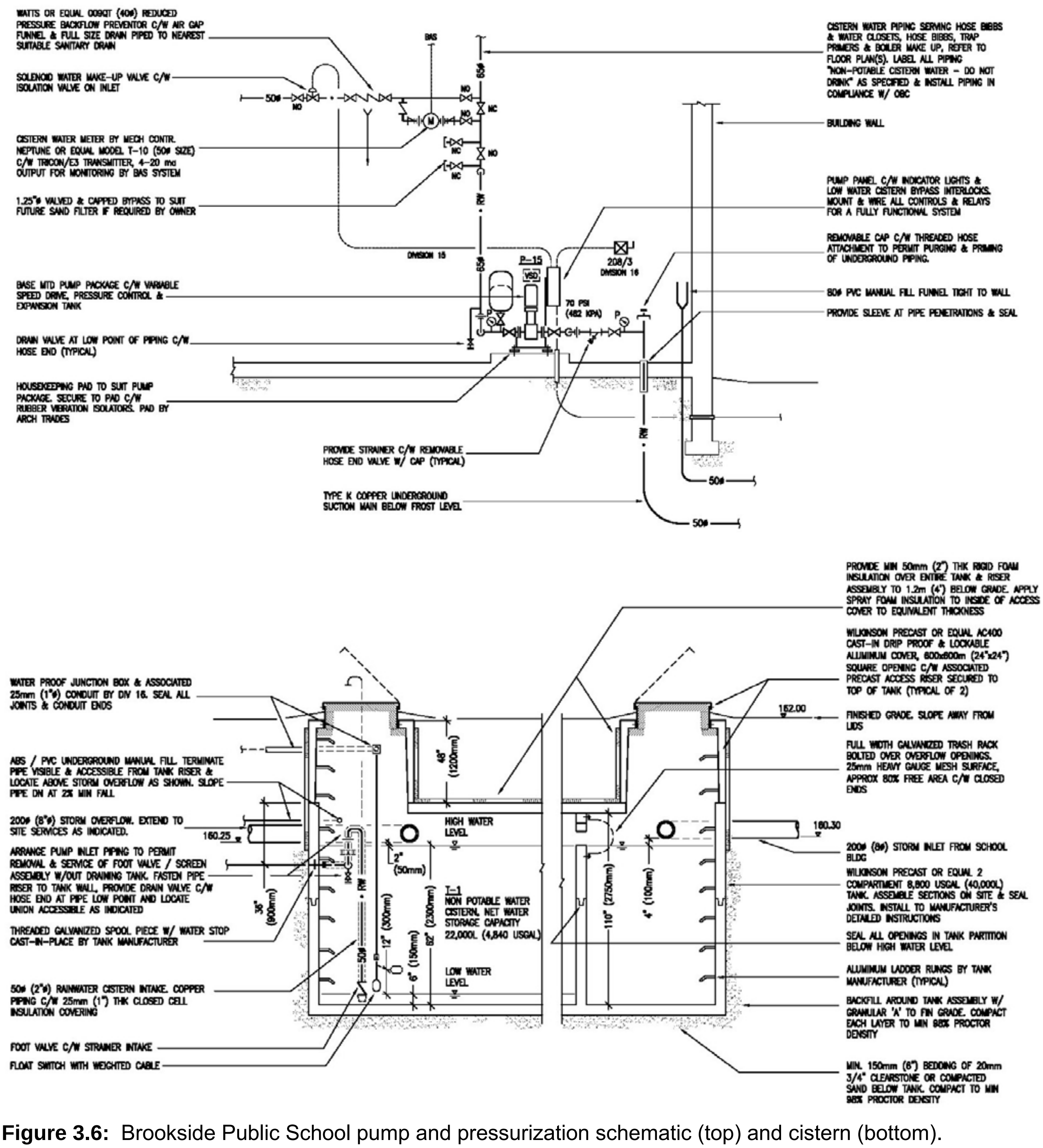

Figure 3.6: Brookside Public School pump and pressurization schematic (top) and cistern (bottom).

3.3.3 Design Model

Like the system at the commercial printing facility, the Brookside school RWH system was modelled with reference and design scenarios to determine its LEED™ credit weight for potable water use reduction.

The reference case includes standard water flow rates. The design case includes various water conservation initiatives, and considerable lower levels of irrigation. Parameters and daily water demand for the two cases are presented in Tables 3.2 and 3.3.

When modelled, the total water demand on the cistern was estimated to be 1,844 m^3/yr, but rainfall and water use simulations indicated that only 49% of this demand (903 m^3/yr) would be met by the cistern. This reflects lower supplies during the winter when cold weather reduces water inputs to the cistern. The annual savings on water supplied by the cistern (903 m^3/yr) was estimated to be $1,355, assuming a water rate of 1.50/m^3. Note that these are very conservative estimates as the cistern demand values do not include soccer field irrigation and precipitation does not include potential supplies from snowmelt.

Table 3.2: Estimated annual indoor water use at Brookside public school

Fixture Type	# of Occupants	# of Daily Uses per Occupant	Water Use Rates	Units	Water Use Duration	Units	Water From Cistern?	Daily Water Demand [m^3/day]
Reference Case								
Toilets (Women's)	413	3	6.0	L/flush	1	flush	N	3.951
Toilets (Men's)	413	1	6.0	L/flush	1	flush	N	1.317
Urinals	413	2	3.8	L/flush	1	flush	N	1.668
Lavatory Faucets	826	3	9.5	L/min	0.25	min	N	3.116
Showerheads	5	1.0	9.5	L/min	5	min	N	0.126
Kitchen Sinks	130	1.0	9.5	L/min	0.25	min	N	0.070
Daily Water Consumption for Indoor Use [m^3/day]:								**10.25**
Design Case								
Toilets (Women's) – 6 L/flush	413	1	6.0	L/flush	1	flush	Y	1.317
Toilets (Women's) – 4.2 L/flush		2	4.2	L/flush	1	flush	Y	1.844
Toilets (Men's) – 6 L/flush	413	1	6.0	L/flush	1	flush	Y	1.317
Urinals	413	2	0.0	L/flush	1	flush	N	0.000
Lavatory Faucets	826	3	1.9	L/min	0.2	min	N	0.500
Showerheads	5	1	5.7	L/min	5	min	N	0.076
Kitchen Sinks (regular)	56	1	8.3	L/min	0.25	min	N	0.062
Daily Water Consumption for Indoor Use [m^3/day]:								**5.116**
Annual Indoor Use Summary								
	Reference Case	**Demand Savings**		**Cistern Savings**		**Total Savings**		**Design Case**
Sewage Only (m^3)	2532	897	35%	801	32%	1698	67%	834
Total (m^3)	3741	1873	50%	801	43%	2674	71%	1067
Total Cost/Savings ($/year)	$5,611	$2,810		$1,202		$4,011		$1,600
Potable Water Displaced by Cistern (Design Case Only) [m^3/year]:								

Assumptions: 1) Water & Sewer Rate = $1.50/$m^3$; 2) Ratio of full-occupancy days to total days in a year = 0.53; 3) cistern savings is based on design model estimates showing that 49% of the demand for nonpotable water would be met by the cistern.
Source: adapted from Enermodal Engineering Ltd, 2006.

Table 3.3: Estimated annual outdoor water use at Brookside Public School

Landscape Type	Area (m^2)	Species Factor (k_s)	Density Factor (k_d)	Micro-Climate Factor (k_{mc})	Landscape Coefficient (k_L)	Landscape Evapo-transpiration Rate (ET_L)	Irrigation Efficiency (IE)	Water From Cistern?	Average Daily Water Demand [m^3/day]
Reference Case									
Trees	678	0.5	1.0	1.0	0.50	69.1	Sprinkler	N	2.418
Green Roof/Baltic Ivy	152.1	0.5	1.0	1.0	0.50	69.1	Sprinkler	N	0.542
Seeded/sod irrigated	10479	0.5	1.0	1.0	0.50	69.1	Sprinkler	N	37.373
Courtyards	150	0.5	1.1	1.0	0.55	76.0	Sprinkler	N	0.588
Sod (soccer field)	3344	0.7	1.0	1.0	0.70	96.7	Sprinkler	N	16.697
Total Average Daily Water Demand in July [m^3/day]:									**57.619**
Design Case									
Trees	678	0.0	1.0	1.0	0.00	0.0	Sprinkler	N	0.000
Green Roof/Baltic Ivy	152	0.9	1.0	1.0	0.92	127.1	Drip	Y	0.693
Seeded/sod not irrigated	10479	0.0	1.0	1.0	0.00	0.0	Sprinkler	N	0.000
Courtyards	150	0.6	1.1	1.0	0.63	87.2	Sprinkler	Y	0.675
Sod (soccer field)	3344	0.7	1.0	1.0	0.70	96.7	Sprinkler	Y	16.697
Total Average Daily Water Demand in July [m^3/day]:									**18.065**

Annual Indoor Use Summary

	Reference Case	**Demand Savings**		**Cistern Savings**		**Total Savings**		**Design Case**
July (m^3)	1786	1226	69%	21	1%	1246	73%	540
Annual (m^3)	8816	6052	69%	102	1%	6154	75%	2662
Annual Costs and Savings ($)	$13,223	$9,078		$153		$9,231		$3,993

Assumptions: 1) Evapotranspiration rate of 138.2 mm/month during the irrigation season; 2) Grounds would be irrigated from May to September (153 days); 3) cistern savings do not include substantial volumes used for soccer field irrigation, and therefore likely underestimate true savings.
Adapted from Enermodal Engineering Ltd, 2007.

4.0 STUDY APPROACH

This section outlines the monitoring and analytical methods used to assess performance of the three RWH systems.

4.1 Monitoring

4.1.1 Commercial Printing Facility

The type and location of the monitoring instruments installed at the printing facility are presented in Figure 4.1.

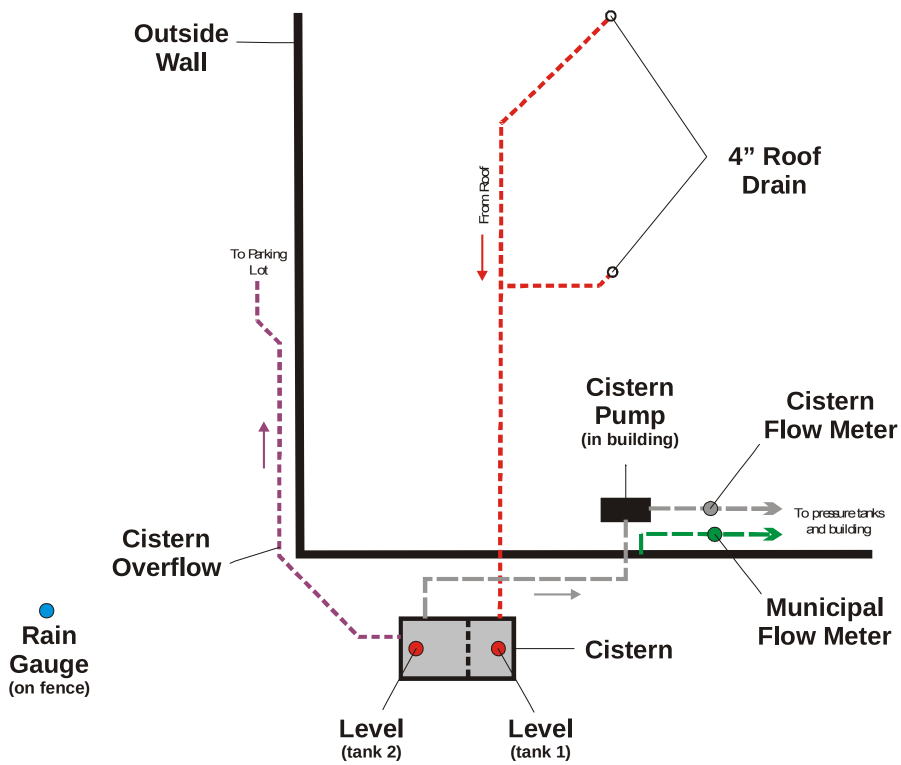

Figure 4.1: Study site monitoring schematic, Metro Label printing facility

Rain and snow were monitored at Buttonville airport approximately 15 km northwest of the site. Back-up measurements were available during the ice-free period from a three season 8 inch diameter tipping bucket rain gauge near the site. Rainfall measurements were recorded every 5 minutes and downloaded bi-weekly.

Two positive displacement magnetic drive flow meters were installed inside Metro Label on the municipal water line (potable) and the cistern water line (non-potable) downstream from the pressurization pump (Figure 4.2). The meters are connected to a four channel logger and are downloaded once every two weeks. The municipal water contribution only occurs when there is insufficient water in the cistern during dry or cold weather, or when the system malfunctions. The municipal supply is controlled using a backflow preventer and solenoid valve.

Figure 4.2: Flow meter schematic inside Metro Label printing facility.

As noted above, the cistern contains two chambers separated by a weir. The first chamber (approx 6.0 m^3) is used for sedimentation and general screening of influent water, while the second chamber (approx 12.0 m^3) is used for system drawdown. Water level in the cistern is monitored by two pressure transducers. Wells were installed parallel to the access ladder in each chamber and sensors was tethered to a well cap and placed inside each well (Figure 4.3). The sensor is designed with an internal logger and records measurements every 5 minutes. Because the level sensors are not vented, an external barometer was also attached to each well cap to compensate for air pressure.

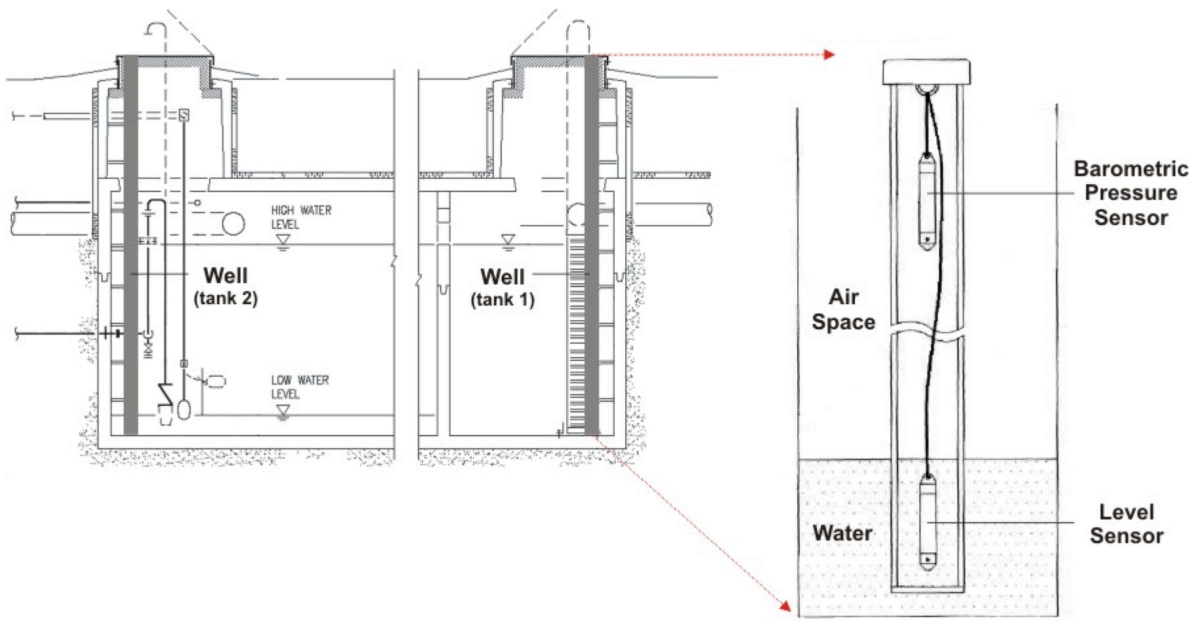

Figure 4.3: Metro Label printing facility cistern water level sensor schematic.

Seasonal grab samples of water and sediment were collected in order to characterize the long term quality of cistern water. Water samples were collected from both cistern chambers using a single 10 litre Teflon bottle. The bottle was carefully lowered into the centre of each chamber to capture a sample representative of water throughout the respective chambers. Water quality groups analyzed include general chemistry, nutrients, bacteria, metals and polycyclic aromatic hydrocarbons (PAHs).

In order to collect sediment samples, the cistern was manually emptied using a 2 inch water pump and drained to a depth of 6 inches. Extra care was taken not to disturb the sediment. All samples were then processed offsite and submitted to the Ontario Ministry of the Environment lab services for analysis immediately following collection. Sediment quality groups analyzed included general chemistry, nutrients, metals and polycyclic aromatic hydrocarbons (PAHs).

4.1.2 High Rise Apartment Building

Monitoring equipment was installed in the fall of 2007. This installation included a four season precipitation gauge, two flow meters, and two level sensors. However, the initiation of monitoring was delayed by an installation defect in the tank, which was repaired in January 2009. This section provides a description of the monitoring protocol.

A four season 8 inch diameter heated tipping bucket rain gauge was installed approximately 5 km north of the site. The data is recorded in 15 minute intervals and is downloaded monthly. Winter data were also compared to rain and snow conditions monitored at Buttonville airport located approximately 20 km northeast of the site.

Figure 4.4: High rise apartment building monitoring equipment. Clockwise starting upper left—view inside the cistern; flow meters; logger; pump (black) for water from cistern; heated rain gauge.

Two transit-time clamp on flow meters were installed inside the underground parking area on the municipal water line (potable) and the cistern water line (non-potable) downstream from the pressurization pump. The meters are connected to two transmitters which log flow in one minute intervals.

Water level in the cistern was monitored by a pressure transducer and compensated for barometric pressure on site (Figure 4.5). The sensors were installed by the wall below the cistern access cover with the barometric sensor well above the water line. The sensors were built with an internal logger that records measurements every 15 minutes. Overflows were determined based on inflow and cistern level measurements.

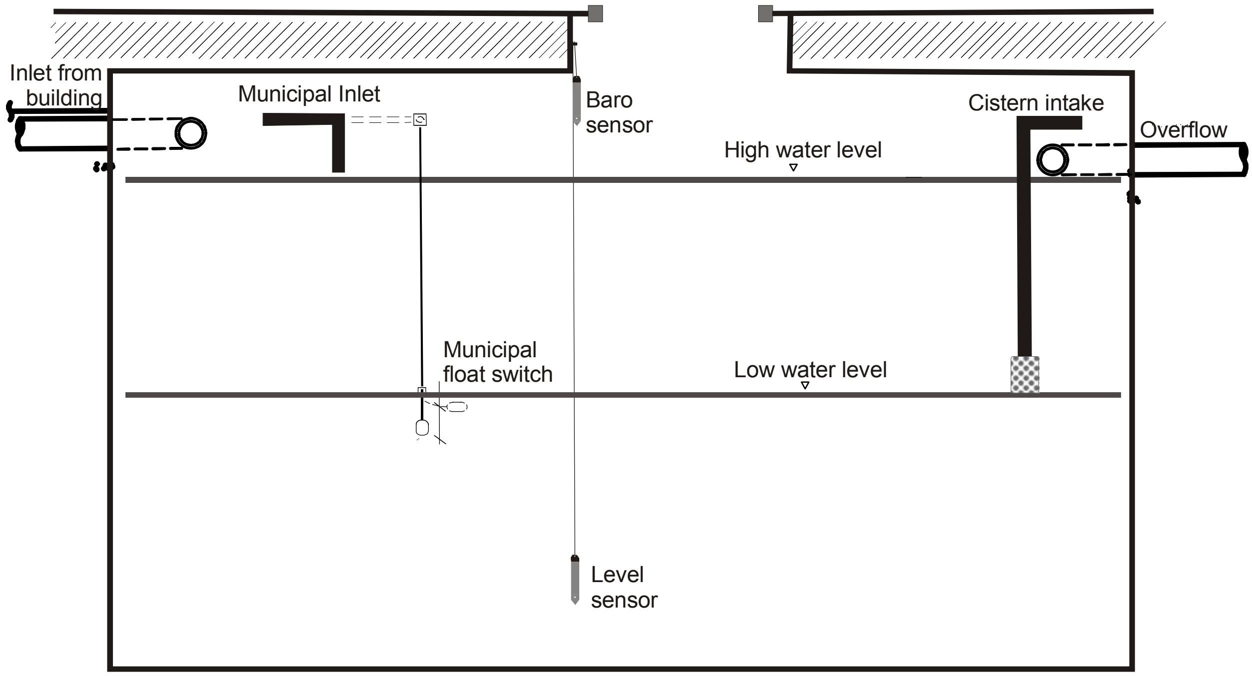

Figure 4.5: High rise apartment building cistern water level sensor schematic.

Grab samples of water were collected in order to characterize the quality of water used in the building and as a measure of comparison with the other sites. Water samples were submitted for analysis of the same parameter groups listed in section 4.1.1.

4.1.3 Public School

Rainfall and snowfall in the area were measured at Buttonville airport, roughly 15 km northwest of the site. Back-up measurements were available from a four season 8 inch diameter heated tipping bucket rain gauge permanently installed on the roof of Milne Dam approximately 5 km away. The rain gauge was connected to a logger that records rainfall every 5 minutes and is downloaded every two weeks.

Two ultrasonic transit time clamp-on flow meters were installed inside Brookside on the municipal water line (potable) and the cistern water line (non-potable) downstream from the pressurization pump. The meters are connected to a four channel logger which records flow every minute and is downloaded every week. The flow meters are powered by two 12 volt batteries connected in series that are continuously charged using trickle chargers plugged into the buildings power system.

Water levels were measured in both of the cistern chambers using ultrasonic level sensors that were installed above the maximum water level (Figure 4.6). The sensors were connected to a four channel current recorder that records level every 15 minutes and is downloaded every two weeks. However, these measurements were not used because of a defect in the system that was investigated but not repaired during the study period.

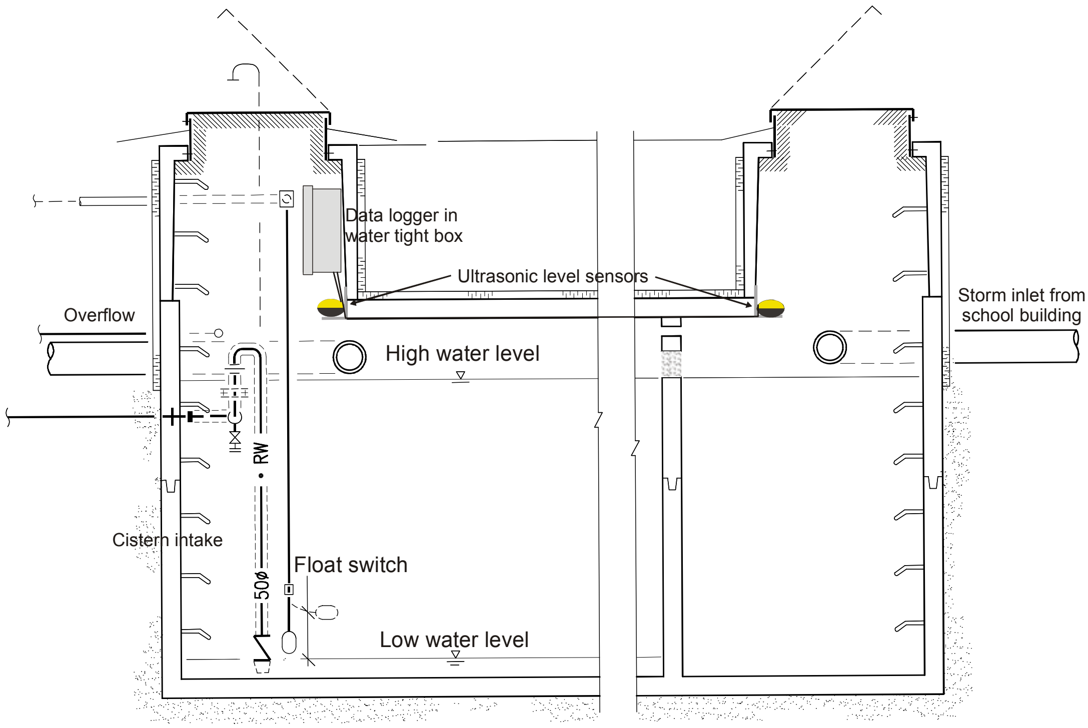

Figure 4.6: Brookside public school cistern water level sensor schematic.

Figure 4.7: Brookside public school monitoring equipment. Clockwise starting from upper left- ultrasonic clamp-on flow meters; flow logger; ground level view of cistern access points; weir inside cistern; ultrasonic level sensor in storage chamber, data logger for ultrasonic level sensors; outside hose bib used for irrigation.

4.2 Model Set-up and Validation

Spreadsheet models for each of the rainwater harvesting systems were developed to assess system 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 provided the basis for simulating cistern water levels, overflows to the storm sewer and the need for municipal make-up water.

The models assume different percentages of rainfall loss due to temperature, wind, and rainfall totals. These losses account for rainfall that has evaporated directly from the roof surface or is conveyed off the roof through a series of openings at elevations that prevent excess ponding of water on the roof during large rain events. A simplified snowmelt equation was used to estimate the timing of rooftop snowmelt entering the cistern during winter months.

The model was 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, where cistern and pumps were not operating for extended periods, the model was based on measured water use and precipitation together with system specifications and calibrated parameter values for roof losses derived from monitoring data at the other two sites.

Tables 4.1 and 4.2 show the match between simulated and monitored data by month from January 2008 to December 2009 at the printing facility, and from February 2009 to February 2010 at the high rise apartment building. Figures 4.8 and 4.9 present simulated and monitored water volumes in the cisterns at the two sites over the same time period. The comparison shows a good match over the years for which data were collected. At the printing facility annual differences in volume represent less than 3% of total measured volumes (Table 4.1). The largest differences occurred when the cistern was drained for cleaning on July 31st, 2008 and cistern volumes fell below the operational limit of 3 m^3 and during other short periods when there were unaccountable discrepancies between measured rainfall and rainfall supply to the cistern from the roof area (see Figure 4.8). At the apartment building the discrepancy between actual and modelled cistern use was greater than at the printing facility but annual differences in volumes were still below 10% (Table 4.2). The discrepancies in this case were caused by variations in the amount of municipal water added during the first months of operation. After the trial period, these variations ceased. Hence the model values for municipal make-up volumes are considered to provide accurate estimates for the prediction of future performance.

Table 4.1: Actual and modelled cistern and municipal water use at Metro Label printing facility.

Month		Model Cistern Use	Actual Cistern Use	Model Municipal Use	Actual Municipal Use
2008	January	39	37	8	11
	February	26	24	25	26
	March	22	22	0	0
	April	24	27	4	1
	May	26	24	1	3
	June	27	27	0	0
	July	24	33	25	16
	August	21	17	8	12
	September	24	25	7	6
	October	36	36	18	18
	November	19	18	5	5
	December	25	25	0	0
	Total	**319**	**317**	**96**	**99**
2009	January	7	7	27	27
	February	18	18	4	5
	March	24	23	8	8
	April	46	43	3	6
	May	28	29	4	3
	June	32	32	10	11
	July	29	26	8	11
	August	34	31	9	12
	September	12	12	58	59
	October	37	35	4	7
	November	27	32	33	29
	December	29	36	54	46
	Total	**328**	**323**	**217**	**223**

Table 4.2: Actual and modelled cistern and municipal water use at the high rise apartment building

Month	Total Water Use	Model Municipal Use	Actual Municipal Use
February	1	0	0
March	2	0	0
April	3	0	0
May	14	5	0
June	46	11	18
July	58	32	32
August	69	43	33
September	66	59	49
October	17	5	5
November	3	0	0
December	2	0	0
January	3	0	0
February	1	0	0
Total	**284**	**157**	**138**

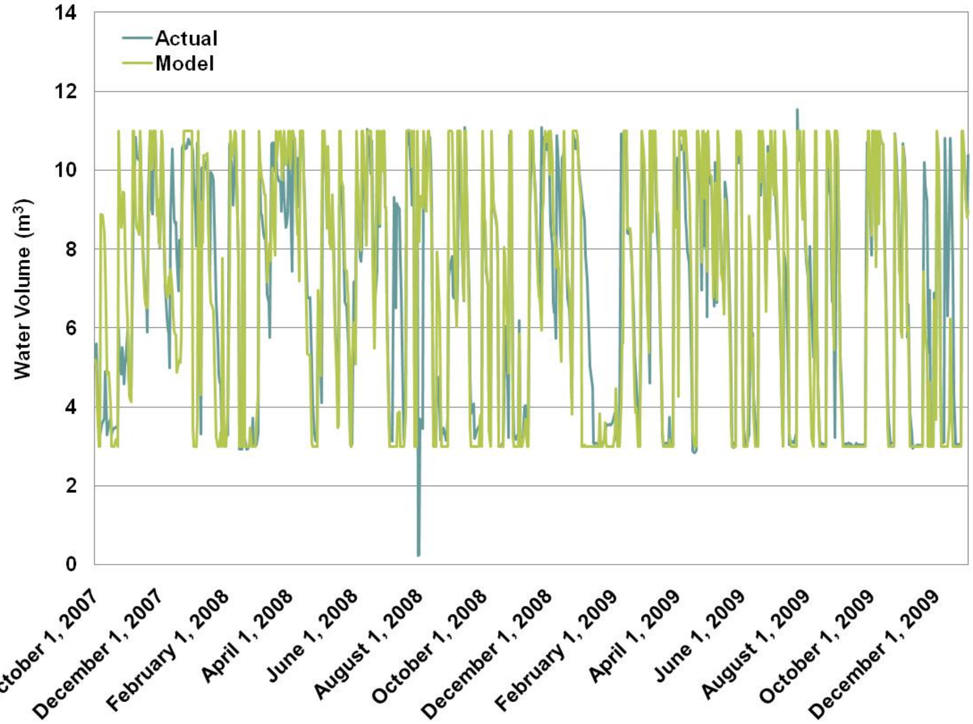

Figure 4.8: Actual and modelled cistern water volumes at the printing facility

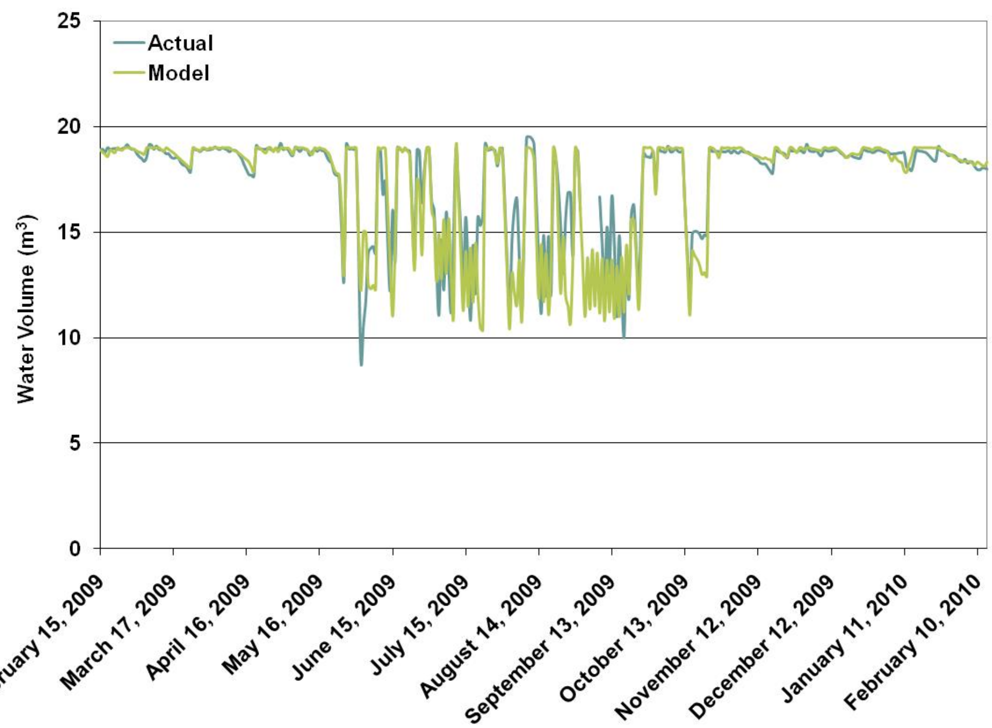

Figure 4.9: Actual and modelled cistern water volumes at the high rise apartment building

5.0 STUDY FINDINGS

5.1 Cistern Performance

This section is divided into two subsections. The first presents monitored data at the three study sites. The second presents and compares model data for the monitoring period, for a 'normal' precipitation year and for different cistern sizing scenarios.

5.1.1 Monitoring Results

Tables 5.1 and 5.2 present precipitation, cistern water use, municipal make-up water and overflow volumes over the monitoring period at the printing facility and high rise apartment building, respectively. Since the cistern pump at the public school was not operating over the monitoring period[2], data from the site include precipitation and total water use only (Table 5.3).

At the printing facility, monthly demand for cistern water ranged between 17 m^3 in December 2007 to 82 m^3 in December 2009 (Table 5.1). The summer months did not show higher levels, as would be expected if the grounds were being irrigated. Total demand for non-potable water rose from 1.0 m^3/day in 2007 to 1.5 m^3/day in 2009 with an increase in the number of employees working at the facility. At these water use rates 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. During periods of heavier water use (greater than 50 m^3/month) municipal make-up water would be required after less than 5 days without precipitation, and during months with lower water use (less than 25 m^3/month), municipal make-up water would be needed after 15 days. In 2008 and 2009, the rainwater harvesting system reduced municipal water use by 76% and 59%, respectively, and diverted roughly 32% of roof precipitation inputs from the storm sewer.

Cistern water at the high rise apartment building was used primarily during the summer for irrigation. Less than 15% of total demand for nonpotable water supplies (284 m^3) occurred during the eight coldest months. Low use during the cooler seasons was anticipated as only three low flow public toilets were connected to the system and these were used relatively infrequently. This resulted in the cistern being undersized during the summer, and vastly oversized during the rest of the year. Nevertheless, the rainwater harvesting system reduced annual municipal water use in 2009/10 by 51% and diverted roughly 13% of total annual roof precipitation inputs from the storm sewer.

At the public school, total demand for non-potable water was 992 m^3/yr or 2.7 m^3/day. Monthly demand rates ranged from 1.5 m^3/day during the summer to 4.4 m^3/day during the busiest month. As expected, water use dropped by roughly 50% during the summer break in July and August, despite an increase in irrigation during these months. At the average annual daily demand rate, the cistern could serve as the sole source of non-potable water supplies for roughly 10 days without rain. As at the printing facility, periods requiring municipal make-up supplies occurred mainly during the cold and dry periods, and during concentrated use times.

[2]The cause of pump failure was being investigated at the time of writing. The pump has since been replaced and the system was fully operational in 2010.

Table 5.1: Actual precipitation and water use volumes at the Metro Label printing facility. Note that the cistern was not fully operating until November 2007.

Month	Rain (mm)	Snow (cm)	Monthly Volume (m^3)				Percent of total water use supplied by the cistern
			Municipal Make-up	Cistern Water Use	Total	Overflow to stormsewer [1]	
January	32.4	27.2	25	0	25	46	0
February	0	30.4	25	0	25	24	0
March	16.4	18.6	25	0	25	27	0
April	55.8	4.6	26	0	26	47	0
May	63	0	32	0	32	49	0
June	28.4	0	42	0	42	22	0
July	47.6	0	50	0	50	37	0
August	27.2	0	32	0	32	21	0
September	43.2	0	38	3	40	31	6
October	39	0	9	18	27	12	67
November	70.4	18.8	0	24	24	45	100
December	49	62.6	0	17	17	69	100
Total 2007	**472**	**162.2**	**305**	**62**	**366**	**430**	**17**
January	36.6	35.8	10	37	48	19	78
February	21.6	81.4	27	24	51	56	47
March	23.4	52.4	0	22	22	37	99
April	55.4	0.2	1	27	28	16	96
May	75.1	0	3	24	27	34	90
June	125.6	0	0	27	27	70	100
July	91.7	0	16	33	49	38	68
August	70.6	0	12	17	30	37	59
September	106.7	0	6	25	31	58	81
October	51.5	2	18	36	54	6	66
November	52.7	36	5	18	23	50	78
December	50	81.8	0	25	25	77	100
Total 2008	**761**	**290**	**99**	**317**	**415**	**497**	**76**
January	0.8	77.2	27	7	34	53	21
February	52	26	5	18	22	43	79
March	67.6	2	8	23	32	30	74
April	116.7	22.8	6	43	49	65	88
May	100.8	0	3	29	32	49	91
June	70.9	0	11	32	42	23	75
July	110.2	0	11	26	37	59	71
August	107.6	0	12	31	43	53	71
September	47	0	59	12	70	25	16
October	78.2	0	7	35	41	26	84
November	38.4	0.4	29	32	60	-2	52
December	55.2	21.9	46	36	82	23	44
Total 2009	**845**	**150**	**223**	**323**	**546**	**448**	**59**

[1]The overflows were calculated as precipitation inputs to the roof minus cistern water use minus roof losses (assumed to be 20% of precipitation)

Table 5.2: Actual precipitation and water use volumes at the high rise apartment building.

Month	Rain (mm)	Snow (cm)	Monthly Volume (m^3)				Percent of total water use supplied by rainwater
			Municipal Make-up	Rainwater Use	Total Water Use	Overflow to stormsewer [1]	
February	9.8	24	0	1	1	34	100
March	67.6	2	0	2	2	70	100
April	141.4	22.8	0	3	3	167	100
May	91.8	0	0	14	14	81	100
June	77.8	0	18	27	46	53	60
July	68.8	0	32	26	58	46	44
August	79.4	0	33	35	69	47	51
September	36.6	0	49	16	66	0	25
October	81.2	0	5	12	17	72	71
November	34.2	0.4	0	3	3	33	100
December	88.4	21.9	0	2	2	113	100
January	20.2	19.4	0	3	3	38	100
February	0	7.2	0	1	1	7	100
Total	**797**	**98**	**138**	**146**	**284**	**759**	**51**

[1]The overflows were calculated as precipitation inputs to the roof less cistern water use and roof losses (assumed to be 20%)

Table 5.3: Actual precipitation and water use volumes at Brookside public school.

Month	Rain (mm)	Snow (cm)	Total Water Use (m^3)
February	25.8	24	55
March	67.6	2	95
April	140.8	22.8	132
May	64	0	92
June	72.2	0	71
July	92.4	0	44
August	107.6	0	48
September	47	0	115
October	78.2	0	70
November	34.6	0.4	90
December	82.2	21.9	96
January	20.2	19.4	62
February	0	6.6	22
Total	**832.6**	**97.1**	**992.5**

5.1.2 Modelling Results

A spreadsheet model was developed for each of the sites, as described in the previous chapter. The model was used to evaluate cistern performance during a 'normal' precipitation year and during periods when the cistern was not operating.

5.1.2.1 Precipitation

Figure 5.1 presents precipitation data used in this evaluation, the 'normal' precipitation record that was used to model cistern performance, and the 30 year Pearson Airport 'normals' (monthly averages for the period from 1971 to 2000). The model 'normals' differ from the Pearson 'normals' because the latter are only available as monthly totals, and a daily data set was needed for modelling purposes. Since there was no one year that adequately represented the historical 'normals', a daily precipitation record was compiled from different months over a series of years (1990-1996). The model 'normals' match the Pearson Airport 'normals' reasonably well with a difference of less than 1% in total annual precipitation. Actual precipitation in 2007 was over 26% drier than normal, with most of the difference occurring in the summer. By contrast, actual precipitation in 2008 and 2009 was over 20% wetter than normal. Precipitation for the other two sites was similar to the printing facility and is therefore not presented here.

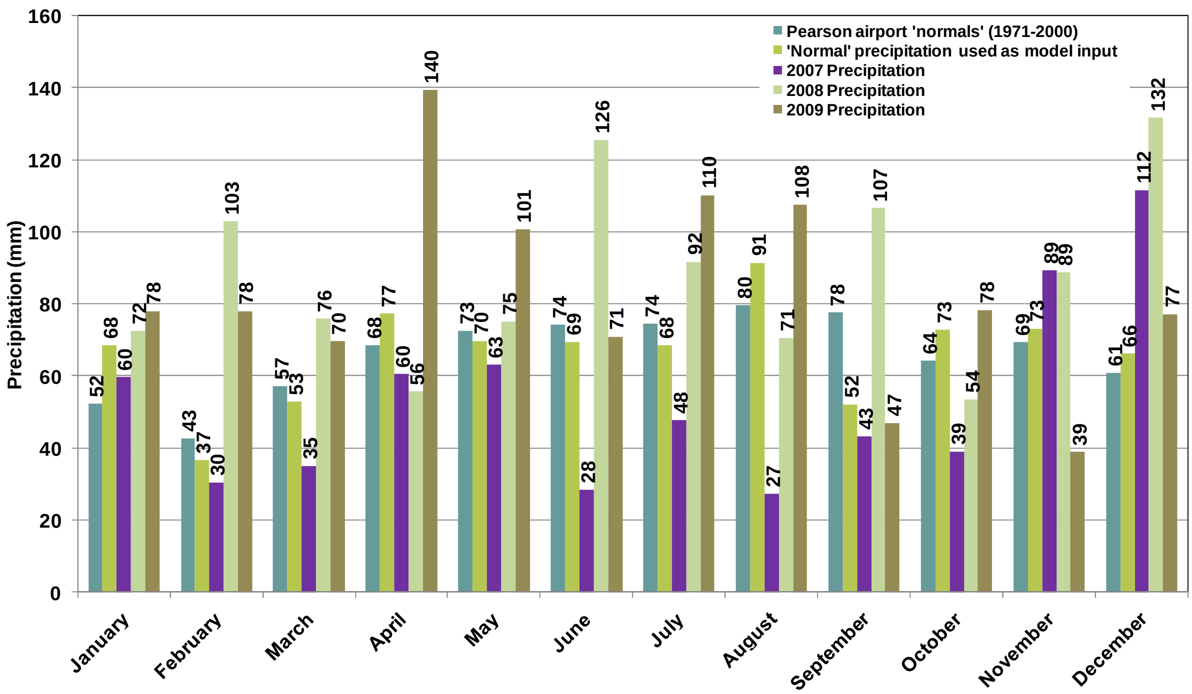

Figure 5.1: Precipitation in 2007, 2008 and 2009 at the Metro Label printing facility, monthly precipitation 'normals' from Pearson airport, and 'normal' precipitation data used as model input (see text for explanation).

5.1.2.2 Modelled performance

Figures 5.2 to 5.4 present the daily model time series for a full year during the monitoring period and for a full year with 'normal' precipitation. Figures 5.5 to 5.7 show annual summary statistics for the two scenarios. Both scenarios use measured water use as input to the model.

Over the three year monitoring period at the printing facility, the cistern supplied between 59 and 76% of total annual rainwater demand, with the remainder made up through municipal supplies (Figure 5.5). Simulations of cistern performance during a 'normal' precipitation year showed a steady decrease in performance as water use increased from 366 m^3 in 2007 to 546 m^3 in 2009. In 2009, actual rainfall was roughly 22% higher than the ‘normals’, but the volume of water supplied by the cistern was the same. Typically, higher rainfall translates into improved cistern performance, but in this case much of the additional precipitation occurred when the cistern was full, resulting in higher volumes of water being diverted to overflows than to indoor/outdoor uses. An extended dry period in September of 2009 also reduced cistern efficiency (Figures 5.2 and 5.5).

Overflows from the printing facility cistern ranged between 35 and 50% of precipitation on the roof catchment area (Figure 5.5). These occurred mostly in the spring and when daily rainfall exceeded 15 mm (Figure 5.2). The storage term in Figure 5.5 represents the difference in cistern volume between the beginning and end of the year. The roof loss component represents the total volume of precipitation that evaporates, runs off (rain) or blows off (snow) the roof and/or patio areas. Model simulations at the three sites showed that roughly 18 to 20% of precipitation inputs are lost during ‘normal’ precipitation conditions, but during dry years with a large number of small rainfall events under 5 mm (such as in 2007 at the printing facility), the percentage of direct roof losses can increase to 28% of total precipitation (Figure 5.5).

As noted previously, water use in the high rise apartment building was concentrated during the summer months when significant quantities of cistern water were used for irrigation. During the remainder of the year, small water volumes were used sporadically for toilet flushing in public areas, but never enough to significantly draw down cistern water supplies (Figure 5.3). Model simulations showed the cistern to supply 45 and 64% of total annual rainwater demand during the 2009/10 and ‘normal’ precipitation scenarios, respectively. Low use during the cold season combined with a relatively large drainage area resulted in a high percentage of precipitation inputs to the cistern being diverted to the storm sewer (Figure 5.6).

The high rise system is operated somewhat less efficiently than the other systems because 5.4 m^3 of municipal water was set to partially fill the cistern when water volumes in the cistern fell below 10 m^3. This reduced the capacity of the cistern to store rainwater resulting in more frequent storm sewer overflows than would have occurred had municipal water been provided directly to the distribution system only when cistern water levels were low (as at the other two facilities). In addition, the trigger for municipal water supply in the high rise system was set such that the bottom 53% of the cistern was not available for use. At the printing facility and public school, the switch over to municipal make-up water occurred when the cistern was 25% and 5% full, respectively, resulting in more efficient use of cistern storage. The larger unused volume in the high rise cistern may have been perceived as a means of preventing re-suspension of previously deposited sediment at the bottom of the cistern since, unlike the other two sites, this cistern did not include a settling chamber.

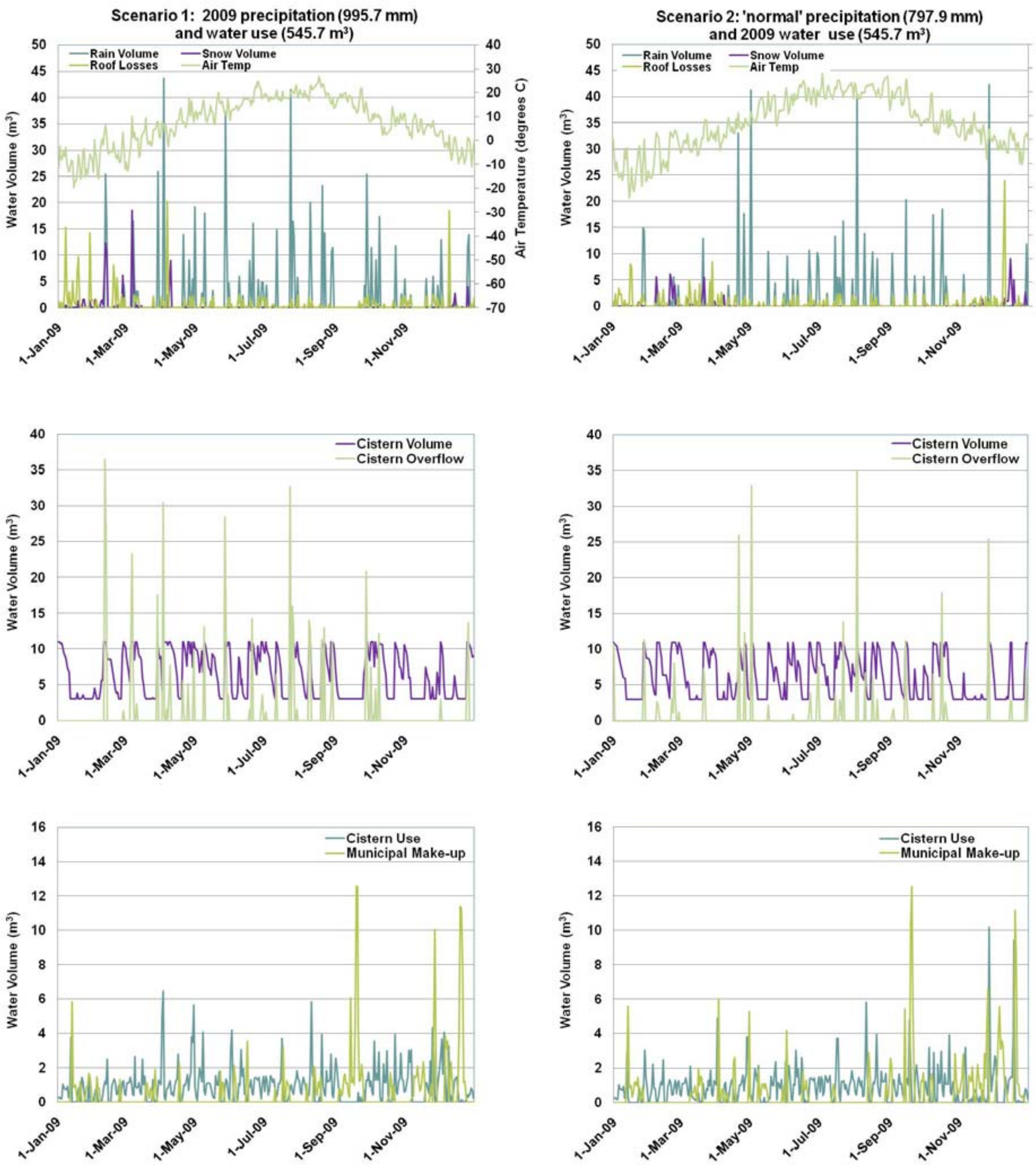

Figure 5.2: Cistern performance for the 2009 and 'normal' year model scenarios at the printing facility

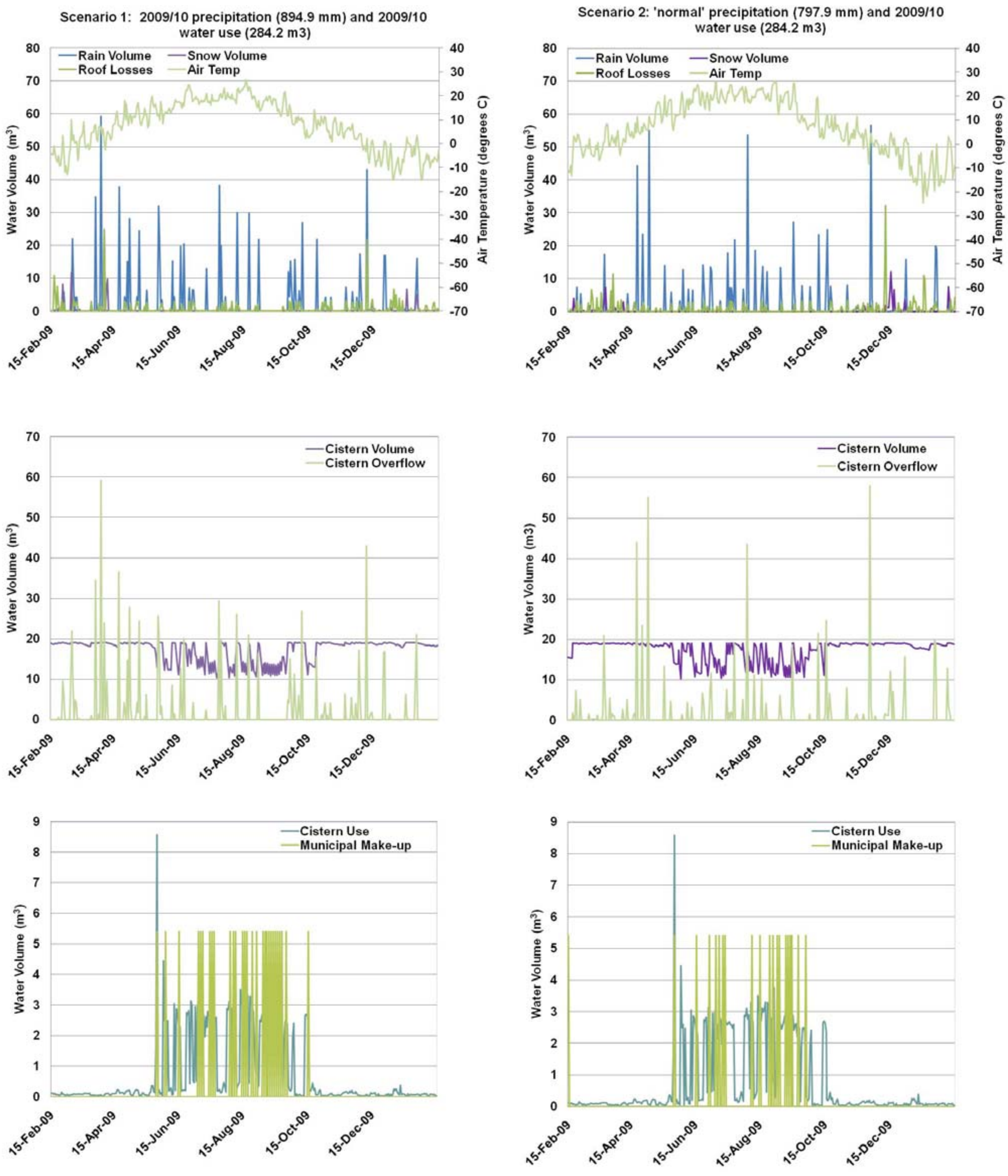

Figure 5.3: Cistern performance for the 2009/10 and 'normal' year model scenarios at the high rise apartment building

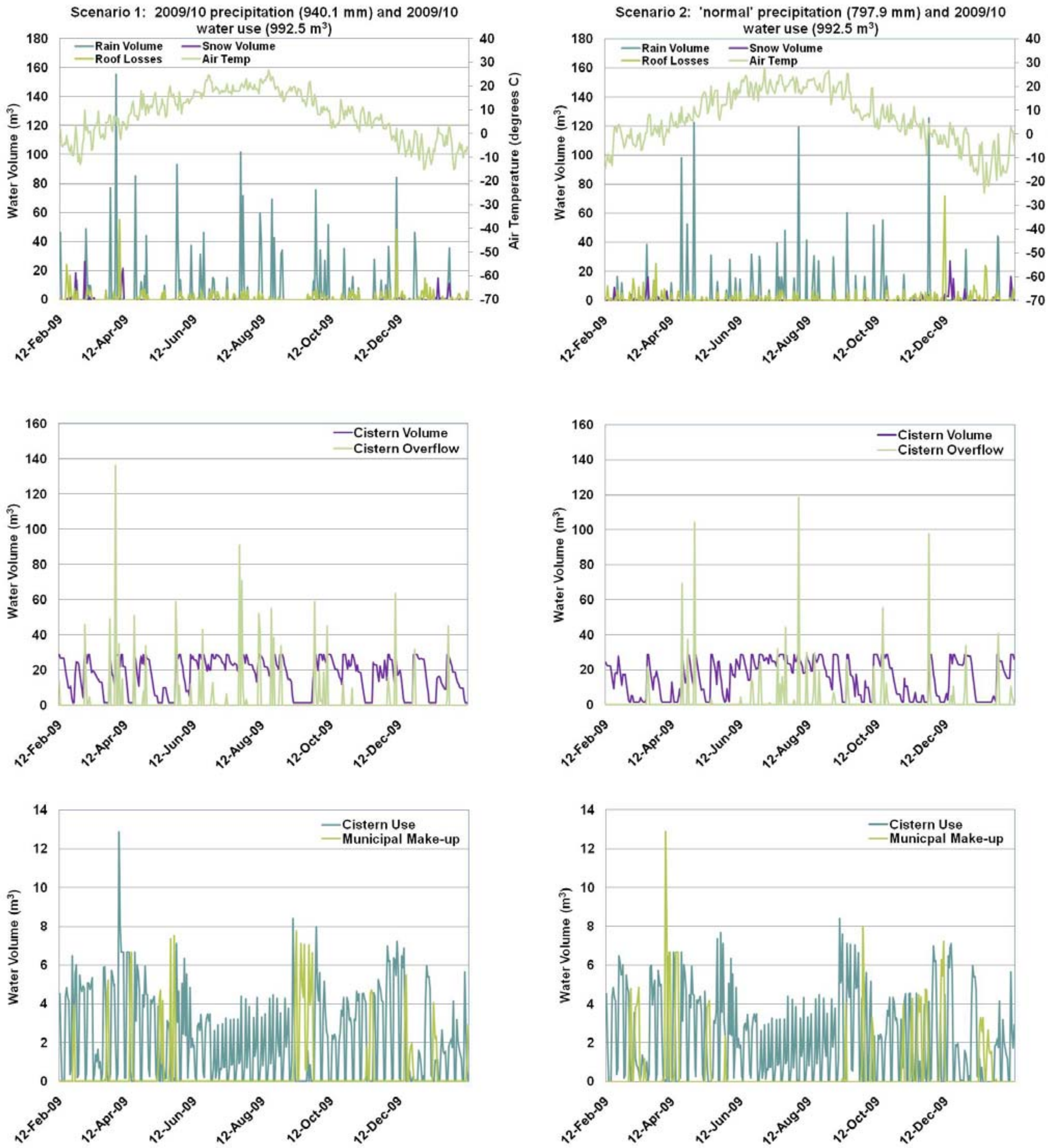

Figure 5.4: Cistern performance for the 2009/10 and 'normal' year model scenarios at Brookside public school

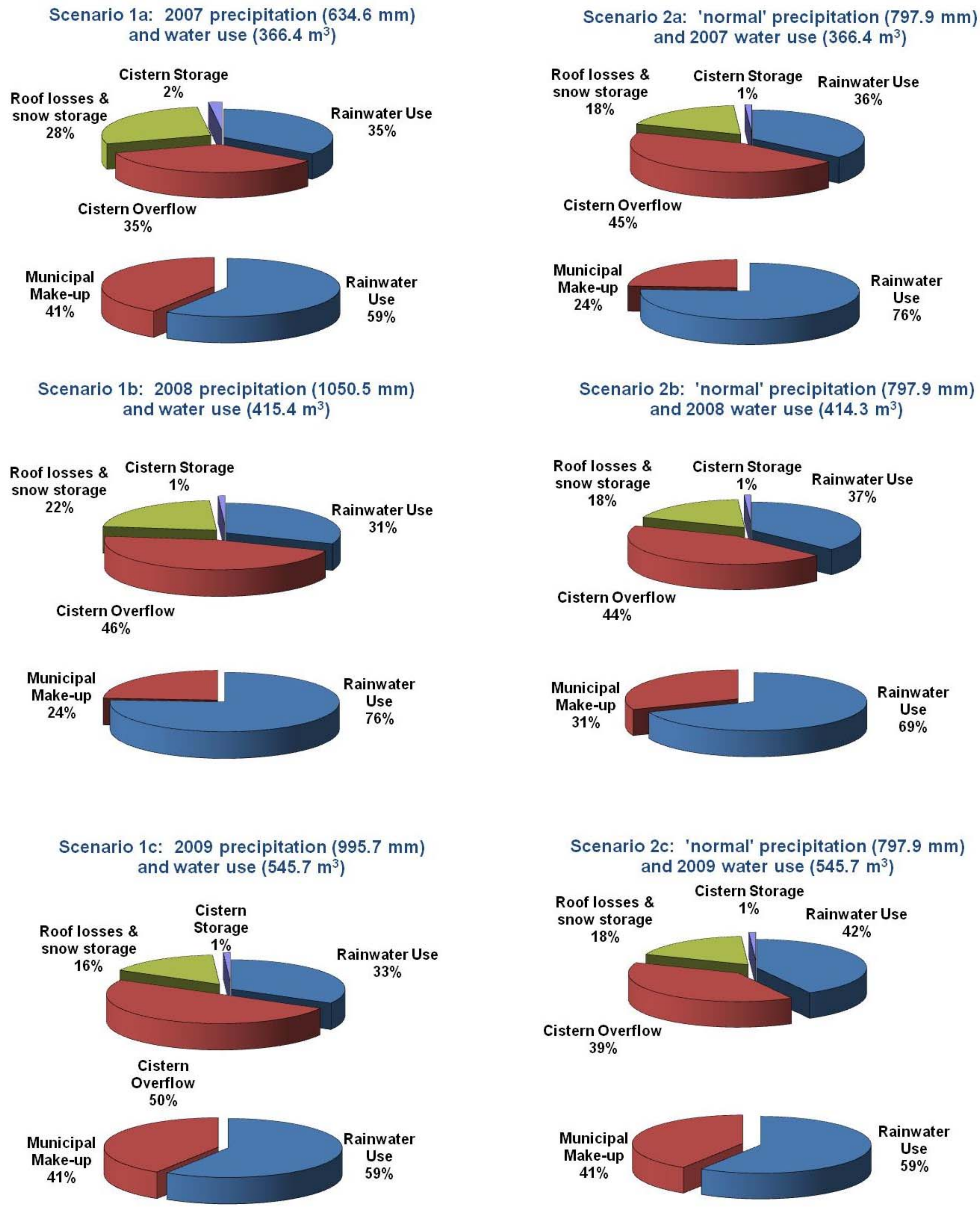

Figure 5.5: Summary statistics for the 2007, 2008, 2009 and 'normal' year scenarios at the Metro Label printing facility.

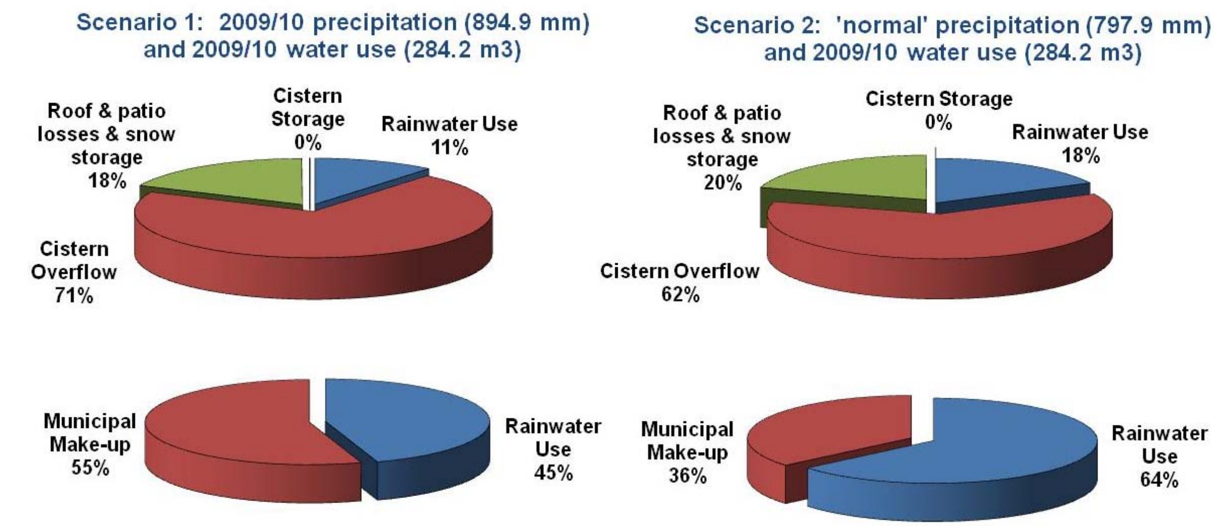

Figure 5.6: Summary statistics for the 2009/10 and 'normal' year scenarios for the high rise apartment building.

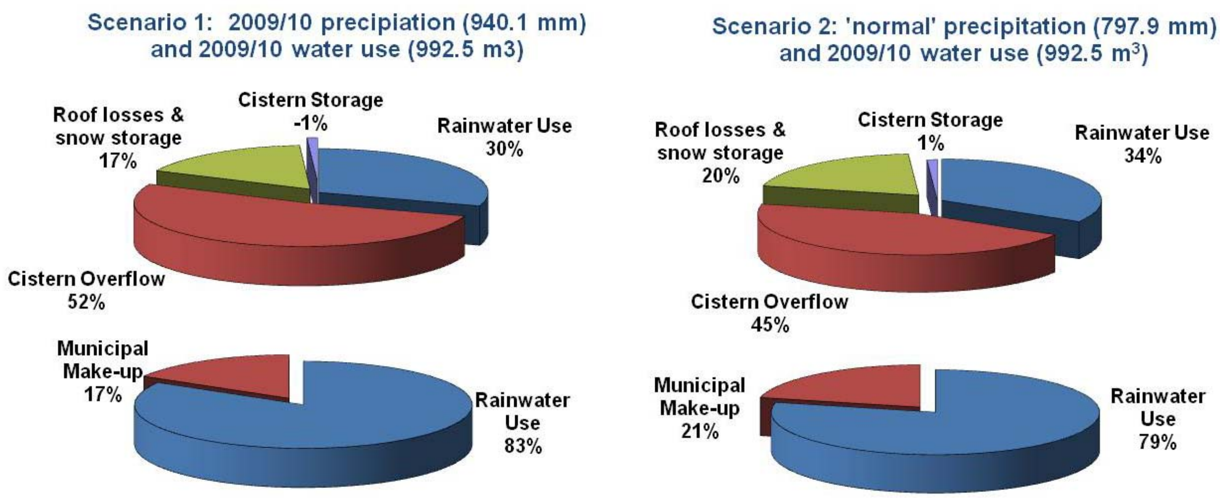

Figure 5.7: Summary statistics for the 2009/10 and 'normal' year scenarios for Brookside public school

Model simulations indicated that the public school cistern would have supplied an estimated 45 and 64% of total annual rainwater demand for the 2009/10 and 'normal' precipitation scenarios, respectively (Figure 5.7). Overflows at this site for the same two scenarios were estimated at 71 and 62% of total precipitation on the roof and patio catchment area. Most of these overflows would have occurred during the spring and during periods of lower water use in the summer (Figure 5.4).

In cold climates, the contribution of snow to cistern supply is often overlooked or underestimated. 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 (Figures 5.2 to 5.4). 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 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 overflow volumes. Heat from inside the building combined with direct solar radiation caused snow to melt even when average daily temperatures were as low as -5°C.

The size of the cistern exerts an important influence on the proportion of water demand met by rainwater supplies and the corresponding volume of cistern overflows. Figures 5.8 to 5.10 shows, for each site, the modelled relationship between cistern size and two indicators of cistern performance: (i) percent of total precipitation inputs to the roof catchment area that were diverted for building uses (cistern water use), and (ii) the percent of total precipitation inputs to the system that overflow to the storm sewer (cistern overflow). Results are for a 'normal' precipitation year with 2009 (or 2009/10) water use.

As shown, the performance of all systems improves as the size of the cistern is increased, 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. An optimally sized system will provide a balance between collection efficiency and cistern cost. To achieve this balance, it has been suggested that the cistern should be sized to provide at least a 2.5% improvement in water savings following an increase of 1 m^3 in storage capacity (University of Guelph, 2010).

At the printing facility, this 'optimum' volume of available rainwater storage (not including the minimum unused volume) is achieved at 12 m^3 under 2007 and 2008 non-potable water demand conditions, and at 14 m^3 under the higher demand volumes observed in 2009. This latter storage volume is 5 m^3 larger than the 9 m^3 of rainwater storage available for use at the printing facility under current operating conditions; hence the system is undersized.

At the high rise apartment building, the optimum volume of available rainwater storage is only 13 m^3, which is 4 m^3 larger than the current available volume of 9 m^3, but considerably smaller than the potential volume available (17 m^3) if the sensors were reconfigured to provide municipal make-up water only when the cistern volume falls below 2 m^3. Increasing the available rainwater storage by reducing the trigger level for top-up municipal water from the existing 10 m^3 to 6 m^3 (or lower) would improve water conservation by optimizing available storage in the cistern.

The public school system was found to be considerably oversized with an optimal size just over half that of the existing available rainwater storage. The curves for the school are flatter than the other sites, resulting in lower incremental rates of improvement as cistern size increases. This can be caused by a number of factors including the inter-relationship between catchment size, cistern size and water demand, as well as by the pattern of water use in relation to the supply of rainwater to the cistern. Both the high rise and public school systems have the capacity to incorporate additional future uses if available.

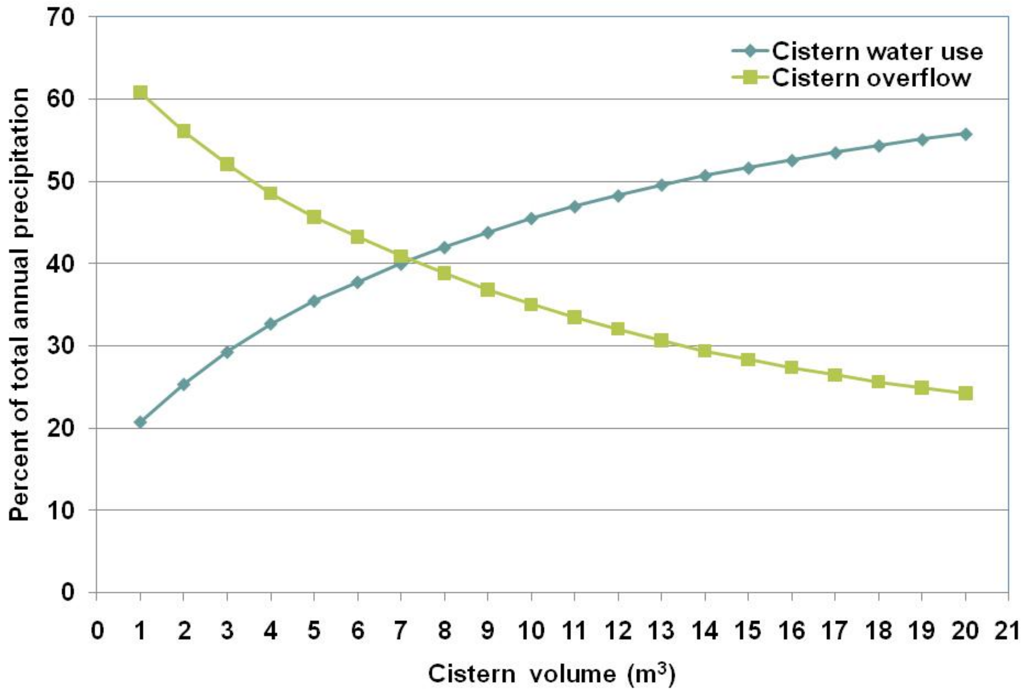

Figure 5.8: Model estimates of cistern water use and cistern overflows in relation to cistern volume for the printing facility.

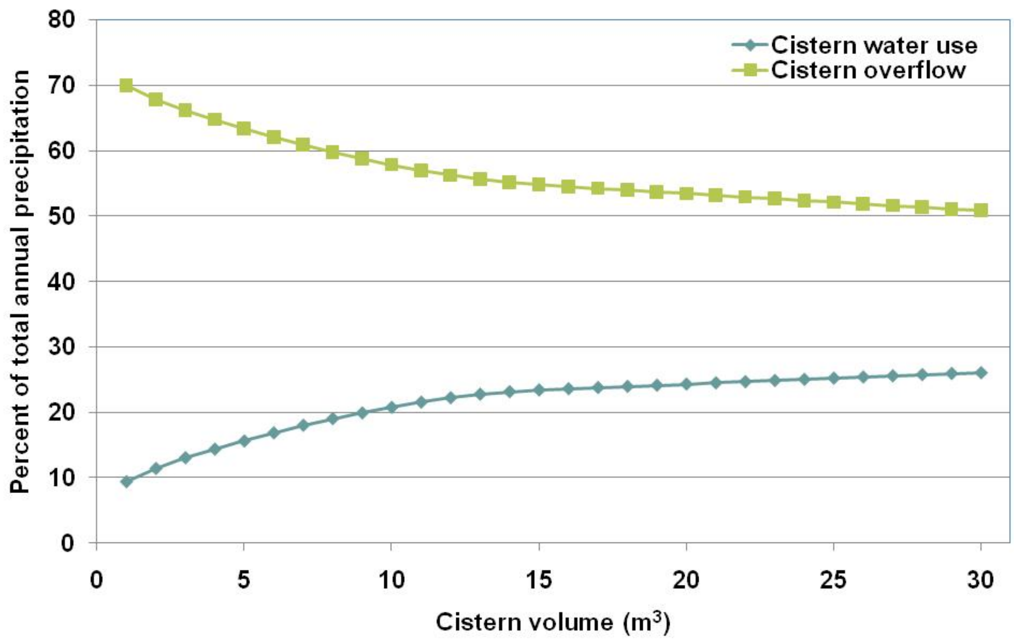

Figure 5.9: Model estimates of cistern water use and cistern overflows in relation to cistern volume for the high rise apartment building. [3]

[3] The model was altered such that municipal make-up was provided only when needed, rather as a set volume added to the cistern. This allowed for a range of cistern sizes to be modelled.

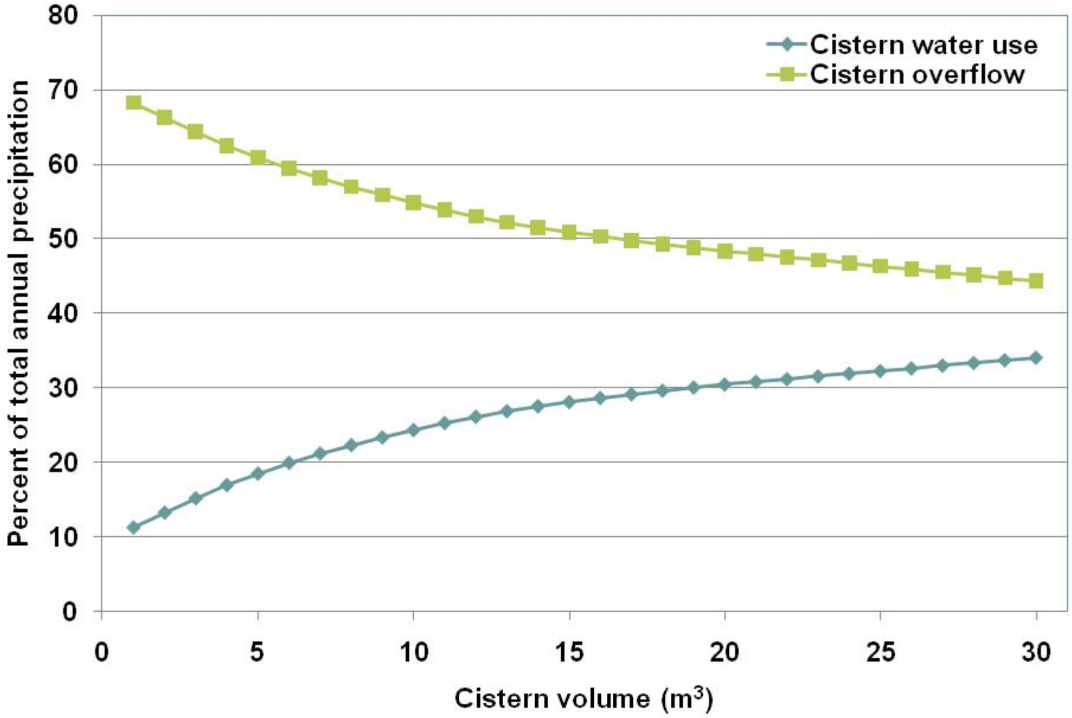

Figure 5.10: Model estimates of cistern water use and cistern overflows in relation to cistern volume for the public school.

5.2 Water and Sediment Quality

Water samples were collected from the settling chamber (used for pre-treatment of roof runoff), main storage chamber and hosebib taps at the printing facility. These samples were collected once in 2006 prior to full system operation, once in each of 2007 and 2008, three times throughout the year in 2009 and once during the winter of 2008. The public school cistern was operating only sporadically, hence samples collected at this site were not considered to be representative. Since the high rise apartment did not have a settling chamber, water samples were collected from the cistern and hose bibs only (3 in 2009 and 1 in early 2010). Roof materials at both facilities sampled were surfaced with asphalt and gravel.

Water quality results for both sites are presented in Appendix A (Table A1). The quality of cistern water can be considered generally suitable for toilet flushing, irrigation and other non-potable uses. The printing facility system produced slightly cleaner water than the apartment building system. At the former site, turbidity, colour and suspended solids met drinking water standards in all samples collected from the storage chamber and hose bibs. Solvent extractables (oil and grease) were elevated in the first set of samples taken prior to full system commissioning in 2006, but decreased to below detection levels in subsequent samples. Concentrations of several water quality variables decreased from the settling chamber to the storage chamber, showing that pre-settling is an effective means of improving the quality of harvested rainwater.

The high rise apartment system was originally equipped with a pool filter, but the filter could not withstand the pressure of flows exiting the cistern and had to be removed. Even without the filter, however, the quality of cistern water was good, but not as good as the other sites because there was no settling chamber for pre-treatment of solids. The increase in some heavy metals from the cistern to hose bibs at the apartment complex indicated that the distribution system was a source of these contaminants. The highest levels occurred 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 of metals.

In both systems, treatment would be needed if the harvested rainwater were to be used as a potable water supply. *E.coli* densities were above drinking water standards, and there were trace levels of pyrene and phenanthrene in one early sample from the storage chamber of the printing facility (PAHs were not sampled in the apartment building). Subsequent samples taken in 2008 and 2009 showed no detectable levels of polycyclic aromatic hydrocarbons (PAHs), but higher levels of *E.coli*. While these higher *E.coli* levels were above drinking water standards, they were well below standards used in Europe for toilet flushing and irrigation applications (as summarized by Roebuck, 2007).

Only a very small amount of sediment had accumulated in the printing facility cistern after two years of operation. Samples of this sediment collected from the settling chamber of the cistern consisted of 17% sand, 45% silt, and 38% clay. Deposited sediment in the second compartment of the cistern was finer, consisting of 46% silt, 54% clay and no sand sized particles. These data indicate that inclusion of a pre-treatment compartment within the cistern is an effective means of removing coarser sediments and potentially improving water clarity.

The quality of sediments collected from the two cistern chambers at the printing facility is compared to MOE criteria for agricultural surface soils where groundwater is used for drinking in Appendix A (Table A2). These criteria were not intended to apply to rainwater cistern sediments, and are presented here only because a more appropriate Ontario standard specifically relevant to rainwater cisterns was not available. The results show that the sediment quality meets the criteria for most variables, with the exception of PAHs. Sediment quality in tank 1 and 2 (settling and storage chambers) were generally comparable.

5.3 Operation and Maintenance Considerations

Typical maintenance activities associated with rainwater harvesting systems include clean out of sediment from settling chambers (every 3 years), cleaning 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.

The frequency of maintenance and inspection activities will vary depending on the complexity of the system. The RWH systems evaluated in this study would require seasonal cleaning of the inlet debris filter and monthly system checks. Sedimentation tanks should be inspected once a year, and cleaned less frequently depending on the volume of sediment accumulation. Detailed recommendations on the frequency and type of inspection and maintenance to be performed on different system components are provided in the Ontario and Alberta Rainwater Harvesting Manuals (University of Guelph, 2010).

Since the initiation of monitoring, the printing facility RWH system has encountered a number of operational problems. The primary setback was a loss of pressure in the system due to a cracked draw pipe below grade, which was repaired in the spring of 2007. The cause of the damage is unknown, but slight movements in the tank due to settling or frost are thought to have contributed to the problem. For this reason, pipe connections to the cistern should be installed to allow for minor shifting and elevation adjustments over time.

Both at the printing facility and the newly constructed apartment complex, minor leaks were detected early on in the cisterns. Both tanks have since been repaired. All seams/joints in pre-cast tanks should be thoroughly parged with a non-toxic sealant or concrete to avoid leaks. Seamless tanks may be an option in other applications.

The system at the public school was subject to a problem with the pump, which resulted in a lengthy period of time when the system was not operational. The pump was eventually replaced and the system has since experienced few problems. Most rainwater harvesting systems are under warranty for at least a year after installation. To avoid unanticipated costs, systems should be carefully commissioned, closely monitored and, if necessary, repaired prior to the end of the warranty period.

The set-up of the systems also has an important influence on overall performance. At the apartment building, for instance, the cistern was set to fill with municipal water when water volumes fell below 10 m^3. This is much higher than is normally recommended and resulted in more frequent inputs from municipal supplies than would have been the case had the trigger for top-up supplies been set at a lower level. It is thought that this lower 10 m^3 volume was regarded as a settling area below which the quality of the water would be less suitable for use. Appropriate filtration of water prior to pumping may be an easier and less costly means of ensuring suitable quality of distributed water. Set-up of the system to supply municipal only when needed (as at the printing facility and school) results in significantly better performance than if municipal water is supplied to the cistern itself (as at the apartment building).

6.0 CONCLUSIONS

Results indicate that rainwater harvesting systems on commercial properties have the potential to provide significant water conservation and stormwater management benefits. Model simulations under 'normal' precipitation conditions (798 mm) showed that the RWH systems monitored in this study would supply between 59 and 79% of total demand for non-potable water supplies, and reduce stormwater runoff by between 18 and 43%. The high rise apartment displayed the lowest rate of stomwater runoff reduction (18% compared to 34 and 43% at the other two sites) in part because of the relatively large drainage area, and the fact that water was used primarily for irrigation, resulting in high rates of overflow to the storm sewer during the 8 coolest months.

Measured monthly water use rates at the printing facility and public school averaged 1.5 and 2.7 m^3/day in 2009, respectively. At these rates, the cisterns could satisfy non-potable water uses without precipitation for 6 days at the printing facility and for 10 days at the public school. Extended cold periods during the winter and days with heavy use accounted for the majority of days when the cistern supply would need to be supplemented with municipal water to meet building demands. The high rise apartment was unique in that water was used intensively during the summer (3.0 m^3/day), and only lightly (0.2 m^3/day) during the remaining months for toilet flushing in 3 common areas. During the latter time period, the cistern easily satisfied demands, but during the summer over a third of total demand on the system was supplied directly to the cistern as top-up from the municipal water line.

Cistern sizing scenarios showed performance increasing with cistern size, but at a diminishing rate. Application of a simple sizing rule based on the slope of the curve relating cistern size to performance showed that the public school cistern was oversized by roughly 13 m^3, while the printing facility and high rise apartment cisterns were undersized by approximately 5 and 4 m^3, respectively (based on 2009 water use). These results suggest that the public school system has the capacity to incorporate additional future uses if available, particularly during low water use days in the summer. The high rise system, on the other hand, was undersized over the full year because of high summer use, but oversized during the winter when demand for non-potable water was low. This system would operate more efficiently if seasonal uses were more effectively balanced.

Water quality sampling from the cisterns and hose bibs revealed that water from the system was suitable for non-potable water use. Total suspended solids and turbidity levels in the cisterns were generally low (< 5 NTU). The apartment complex cistern water had higher turbidity and colour values than the printing facility due to the absence of a settling chamber but the water was still visually comparable to municipal water. If used as a potable water source, treatment would be needed at all sites to remove low levels of bacteria and trace levels of polycyclic aromatic hydrocarbons and pesticides.

The costs of the three systems were not well documented but estimates from other Canadian sources suggest initial capital costs to be roughly $1 per litre of storage. Assuming a municipal water rate of \$1.6/m^3 and water savings for a 'normal' precipitation year documented in this study, the simple pay back for both the printing facility and public school would be roughly 34 years. These calculations do not take into account annual maintenance, annualized discount rates, LEED point benefits where appropriate, and other factors such as the rising cost of municipal water. Storage cisterns can also supply water for landscape irrigation during extreme dry periods when municipal water restrictions are in place, which could be an important benefit in some jurisdictions. The high rise apartment system was used both for rainwater use and to satisfy site requirements for stormwater control. Therefore, the simple payback calculations for this system would need to consider both the water saved ($298/yr) as well as the cost of providing equivalent stormwater detention elsewhere on the site (which was not available).

RHW systems should be implemented as part of an integrated water efficiency plan for buildings. This plan should include demand management measures such as low flow fixtures, waterless urinals and conservation approaches to irrigation, all of which are less expensive than RWH per unit of water conserved.

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

7.0 REFERENCES

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APPENDIX A

Water and Sediment Quality

Table A1: Chemical quality of cistern water. Surface and drinking water detection limits apply to 2006 and 2007 samples respectively.

Parameter	Units	Surface Water Detection Limit	Surface Water Guideline	Drinking Water Detection Limit	Drinking Water Guideline	Printing Facility					High Rise Apartment	
						2006		2007 to 2010[2]			2009/10	
						Settling Tank (n=1)	Main Tank (n=1)	Settling Tank (n=7)	Main Tank (n=7)	Hose Bib (n=7)	Tank (n=4)	Hose Bib (n=4)[3]
General Chemistry												
Chloride	mg/L	0.2		1	≤ 250[1]	0.5	0.7	6.8	3.4	9.2	59.3	55.3
Mercury	ug/L	0.02	0.2		0.001	<dl	<dl	-	-	-		
Arsenic	ug/L	1	100	1	25	<dl	<dl	<dl	<dl	<dl	-	-
Selenium	ug/L	1	100	5	10	<dl	<dl	<dl	<dl	<dl	-	-
Calcium	mg/L			0.25		16.9	18.4	16	15	21	34	33
Magnesium	mg/L			0.1		1.5	1.7	1.7	1.7	4.0	3.3	2.9
Sodium	mg/L			0.1	≤ 200[1]	0.5	0.6	30.7	2.8	5.9	39.5	38.8
Potassium	mg/L			0.05		0.66	0.84	36.71	7.81	7.89	6.49	6.39
Hardness	mg/L			1	80 to 100[1]	48	53	55	50	74	98	95
Sulphate	mg/L	0.5		2.5	≤ 500[1]	3.2	6.1	5.9	6.4	13.6	23.2	21.1
Fluoride	mg/L	0.01		0.05		0.03	0.04	2.58	1.76	1.88	0.14	0.10
Solids; suspended	mg/L	2.5		2.5		25	3	7	<dl	<dl	<dl	6.40
Solids; total	mg/L	10		50		94	77	81	70	113	243	239
Solids; dissolved	mg/L	10		50		69	74	75	69	112	241	232
Solvent extractable	mg/L	1		1		5.4	3.8	<dl	<dl	<dl	1.0	1.0
Conductivity	uS/cm	1		5		107	114	127	113	176	404	388
pH	none		6.5-9.5		6.5-8.5[1]	8.1	7.9	7.8	7.8	7.9	7.9	7.9
Alkalinity; total fixed endpt	mg/L $CaCO_3$	2.5		2.5	30 to 500[1]	52	49	44	41	57	79	80
Turbidity	FTU	0.01		0.25	5	24.3	2.7	10.6	2.1	2.4	3.1	7.0
Carbon; dissolved organic	mg/L	0.1		0.5		1.7	2.3	1.9	2.0	2.2	3.3	4.2
Carbon; dissolved inorganic	mg/L	0.2		1		12.4	11.9	10.3	9.6	13.7	18.7	18.6
Silicon; reactive silicate	mg/L	0.02		0.1		0.6	0.8	0.5	0.5	0.6	2.7	2.7
Colour; true	TCU			1	5	-	-	5	5	4	15	15

Parameter	Units	Surface Water Detection Limit	Surface Water Guideline	Drinking Water Detection Limit	Drinking Water Guideline	Printing Facility					High Rise Apartment	
						2006		2007 to 2010[2]			2009/10	
						Settling Tank (n=1)	Main Tank (n=1)	Settling Tank (n=7)	Main Tank (n=7)	Hose Bib (n=7)	Tank (n=4)	Hose Bib (n=4)[3]
Oxygen demand; chemical	mg/L as O2			10		-	-	<dl	11	<dl	16	10
Pesticides												
2-methylisoborneol	ng/L			1	-	-	-	0.7	0.5	0.5	1.8	1.9
Geosmin	ng/L			1	-	-	-	3.6	3.1	2.3	1.9	1.8
2-isopropyl-3-methoxypyrazine	ng/L			1	-	-	-	0.5	0.5	0.5	1.0	1.0
2-isobutyl-3-methoxypyrazine	ng/L			1	-	-	-	0.5	0.5	0.5	1.0	1.0
2,3,6-trichloroanisole	ng/L			2	-	-	-	<dl	<dl	<dl	2	2
2,4,6-trichloroanisole	ng/L			2	-	-	-	<dl	<dl	<dl	2	2
Nutrients												
Nitrogen; ammonia+ammonium	mg/L	0.002		0.25		0.051	0.100	2.866	0.503	0.503	<dl	<dl
Nitrogen; nitrite	mg/L	0.001	0.06	0.025		0.016	0.068	0.051	0.065	0.038	<dl	<dl
Nitrogen; nitrate+nitrite	mg/L	0.005		0.25	10	0.51	0.95	<dl	0.79	0.70	1.82	1.24
Phosphorus; phosphate	mg/L	0.005		0.1		<dl	<dl	<dl	<dl	<dl	<dl	<dl
Phosphorus; total	mg/L	0.002	0.03	0.1		0.034	0.018	0.277	0.123	0.103	0.095	<dl
Nitrogen; total Kjeldahl	mg/L	0.02		0.25		0.32	0.49	<dl	0.25	<dl	0.36	0.42
Bacteria												
Escherichia coli	c/100 mL	10	100		not detectable	90	20	82	45	42	14	18
Fecal streptococcus	c/100 mL					430	140	399	241	202	24	16
Pseudomonas aeruginosa	c/100 mL					76	28	2	3	2	4	33
Metals												
Aluminum	ug/L	11	75	3	≤100[1]	144	51	255	62	115	88	300
Barium	ug/L	0.2		0.2	1000	11	8.0	9.1	6.7	12.0	18.7	20.2

Parameter	Units	Surface Water Detection Limit	Surface Water Guideline	Drinking Water Detection Limit	Drinking Water Guideline	Printing Facility					High Rise Apartment	
						2006		2007 to 2010[2]			2009/10	
						Settling Tank (n=1)	Main Tank (n=1)	Settling Tank (n=7)	Main Tank (n=7)	Hose Bib (n=7)	Tank (n=4)	Hose Bib (n=4)[3]
Beryllium	ug/L	0.2	11	0.03		<dl	<dl	0.03	<dl	<dl	<dl	0.03
Cadmium	ug/L	0.6	0.1	0.8	5	0.86	<dl	<dl	<dl	<dl	<dl	<dl
Cobalt	ug/L	1.3	0.9	1.5		<dl	<dl	<dl	<dl	<dl	<dl	<dl
Chromium	ug/L	1.4	8.9	1	50	<dl	<dl	<dl	<dl	<dl	<dl	1.2
Copper	ug/L	1.6	5	1	≤1000[1]	30.2	26.3	5.2	3.7	123.8	16.4	38.9
Iron	ug/L	0.8	300	3	≤300[1]	184	29.7	135.1	12.0	19.7	65.4	319.7
Manganese	ug/L	0.2		0.3	≤50[1]	42.2	5.27	27.9	4.0	4.8	4.0	26.4
Molybdenum	ug/L	1.6	10	1.5		<dl	<dl	<dl	<dl	<dl	<dl	<dl
Nickel	ug/L	1.3	25	1.5		1.8	<dl	<dl	<dl	4.9	<dl	19.9
Lead	ug/L	10	5	11	10	<dl	<dl	<dl	<dl	<dl	<dl	22
Strontium	ug/L	0.1		0.3		34.9	36.0	36.4	34.6	80.3	122.3	116.1
Titanium	ug/L	0.5		0.3		3.5	<dl	3.8	0.8	0.8	2.3	3.7
Vanadium	ug/L	1.5	7	1		<dl	<dl	1.0	<dl	<dl	1.9	2.3
Zinc	ug/L	0.6	20	0.8	≤5000[1]	66.5	23.8	35.5	14.9	46.6	31.9	97.1
Silver	ug/L			0.5		-	-	<dl	<dl	<dl	-	-
Thallium	ug/L			0.5		-	-	<dl	<dl	<dl	-	-
Uranium	ug/L			0.5		-	-	<dl	<dl	<dl	-	-
Boron	ug/L			10	5000	-	-	12.05	16.6	15.0	-	-
Antimony	ug/L			0.5	6	-	-	1.0	1.1	1.1	-	-
Polycyclic Aromatic Hydrocarbons												
Phenanthrene	ng/L	10	30	10		96	46	<dl	<dl	<dl	-	-
Anthracene	ng/L	10	0.8	10		<dl	<dl	<dl	<dl	<dl	-	-
Fluoranthene	ng/L	10	0.8	10		<dl	<dl	<dl	<dl	<dl	-	-
Pyrene	ng/L	10		10		17	<dl	<dl	<dl	<dl	-	-
Benzo(a)anthracene	ng/L	20	0.4	20		<dl	<dl	<dl	<dl	<dl	-	-
Chrysene	ng/L	10	0.1	10		<dl	<dl	<dl	<dl	<dl	-	-
7,12-dimethylybenz(a)anthracene	ng/L	10		10		<dl	<dl	<dl	<dl	<dl	-	-

Parameter	Units	Surface Water Detection Limit	Surface Water Guideline	Drinking Water Detection Limit	Drinking Water Guideline	Printing Facility					High Rise Apartment	
						2006		2007 to 2010[2]			2009/10	
						Settling Tank (n=1)	Main Tank (n=1)	Settling Tank (n=7)	Main Tank (n=7)	Hose Bib (n=7)	Tank (n=4)	Hose Bib (n=4)[3]
Benzo(b)fluoranthene	ng/L	10		10		<dl	<dl	<dl	<dl	<dl	-	-
Benzo(k)fluoranthene	ng/L	10	0.2	10		<dl	<dl	<dl	<dl	<dl	-	-
Benzo(e)pyrene	ng/L	10		10		<dl	<dl	<dl	<dl	<dl	-	-
Benzo(a)pyrene	ng/L	1		3	0.00001	<dl	<dl	<dl	<dl	<dl	-	-
Perylene	ng/L	10	0.07	10		<dl	<dl	<dl	<dl	<dl	-	-
Ideno(1,2,3-c,d)pyrene	ng/L	20		20		<dl	<dl	<dl	<dl	<dl	-	-
Dibenzo(a,h)anthracene	ng/L	20	2	20		<dl	<dl	<dl	<dl	<dl	-	-
Benzo(g,h,i)perylene	ng/L	20	0.02	20		<dl	<dl	<dl	<dl	<dl	-	-

Notes: Surface water quality guidelines are Provincial Water Quality Objectives (OMOE, 1994) or Canadian Water Quality Guidelines (2006) when a PWQO is not available. Drinking water quality guidelines are Ontario standards (OMOE, 2006). Underlined values indicate exceedance of drinking water standards. Samples were analyzed by the lab as 'surface water' in 2006 and 2007, and as 'drinking water' thereafter - note differences in detection limits.
1. operational or aesthetic objective. 2. n =1 and 6 for PAHs and Colour in 2007 to 2010, respectively. 3. Elevated levels of zinc, iron, lead and aluminum are largely due to high concentrations in the first sample collected in May, when the taps were used for the first time.

Table A2: Chemical quality of cistern sediments at the printing facility

		Guideline (ug/g)[1]	Settling Tank	Settling Tank	Main Tank	Settling Tank	Main Tank
General Chemistry			**2006**	**2006**	**2006**	**2008**	**2008**
Carbon; total organic	mg/g dry		30	34	37	31	16
Chloride, water extractable	ug/g dry		4.3	2.8	5.3	6.2	6.1
Sulphate, water soluble	ug/g dry		155	265	179	382	156
Nitrogen; total Kjeldahl	mg/g dry		0.7	0.7	0.9	0.5	0.6
Phosphorus; total	mg/g dry		0.68	0.59	0.69	0.58	0.59
Metals							
Mercury	ug/g dry	10	0.02	0.03	0.03	0.03	0.03
Beryllium	ug/g dry	1.2	0.6	0.6	0.6	1	1
Magnesium	ug/g dry		41000	45000	38000	46000	19000
Aluminum	ug/g dry		12000	12000	14000	12000	11000
Calcium	ug/g dry		140000	140000	140000	140000	110000
Vanadium	ug/g dry	200	27	26	29	26	24
Chromium	ug/g dry	750	20	21	27	22	20
Maganese	ug/g dry		960	1000	960	1100	690
Iron	ug/g dry		18000	18000	20000	21000	16000
Cobalt	ug/g dry	40	7.7	7.8	8.1	8.6	6
Nickel	ug/g dry	150	19	20	21	22	17
Copper	ug/g dry	150	57	63	73	74	42
Zinc	ug/g dry	600	550	620	860	820	480
Molybdenum	ug/g dry	5	0.5	0.7	0.9	1	1
Cadmium	ug/g dry	3	0.5	0.7	0.8	1	0.4
Barium	ug/g dry	750	90	92	90	8	70
Lead	ug/g dry	200	33	40	40	44	26
Strontium	ug/g dry		130	120	140	120	160
Titanium	ug/g dry		260	240	170	120	240
Polycyclic Aromatic Hydrocarbons							
Naphthalene	ng/g dry	4.6	28	-	57	84	56
Acenaphthylene	ng/g dry	100	3.5	-	6	13	12
Acenaphthene	ng/g dry	15	10	-	8	21	14
Fluorene	ng/g dry	340	25	-	22	32	21
Phenanthrene	ng/g dry	40	150	-	170	310	210
Anthracene	ng/g dry	28	16	-	14	35	20
Fluoranthene	ng/g dry	40	200	-	190	540	340
Pyrene	ng/g dry	250	460	-	460	890	500
Benzo(a)anthracene	ng/g dry	6.6	46	-	52	130	92
Chrysene	ng/g dry	12	120	-	150	320	230
Benzo(b)fluoranthene	ng/g dry	12	99	-	160	300	250
Benzo(k)fluoranthene	ng/g dry	12	98	-	140	250	210
Benzo(e)pyrene	ng/g dry		100	-	170	270	230
Benzo(a)pyrene	ng/g dry	1.2	65	-	94	200	160
Perylene	ng/g dry		16	-	20	38	32
Indeno(1,2,3-c,d)pyrene	ng/g dry	12	79	-	150	260	230
Dibenzo(a,h)anthracene	ng/g dry	1.2	16	-	38	33	32
Benzo(g,h,i)perylene	ng/g dry	40	130	-	170	350	320

[1] Surface soil remediation criteria for a potable groundwater situation (OMOE, 1997)