

# Technology and Product Reports

## Design, Construction, and Operation of a Demonstration Rainwater Harvesting System for Greenhouse Irrigation at McGill University, Canada

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**SUMMARY.** Increasing stress on urban water demand has led to the exploration of the potential of rainwater use and water recycling to promote sustainable water resources management. Rainwater harvesting (RWH) not only has the potential to reduce water demand but also contributes to other sustainable objectives, including reducing stormwater pollutant loads, reducing erosion, and inducing natural flow regimes by means of flood control, in urban streams. This research involved the design, construction, and field-testing of an RWH system used to irrigate greenhouses at the Macdonald Campus of McGill University in Quebec, Canada. The purpose of the RWH system was to collect rainwater from a roof area of  $\approx 610 \text{ m}^2$  (the Horticulture Services Building on the Macdonald Campus of McGill University) to meet the irrigation demands of the two Horticulture Research Center greenhouses on the campus ( $\approx 149 \text{ m}^2$  each) from May to October. Over its two years of operation, it was found that the amount of rainwater collected did not only meet the peak irrigation demands of the greenhouses (which amounted to almost 700 gal of water per day), but that there was also enough water for the irrigation of the nearby student-run gardens. The harvested rainwater was clear and did not cause any harm to the plants. The major problem that was experienced during the operation of the RWH system was that of algae growth in one of the water collection tanks. This issue was resolved by covering the tank with metallic green wallpaper, thereby blocking most of the sunlight from entering the tank. The RWH system is currently being used for irrigation and as a demonstration project to promote the learning of sustainable technologies on campus and in the surrounding communities.

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As a part of the family of green technologies, RWH can be defined as the capturing of rain runoff from roofs and other surfaces and storing it for a later purpose (Despins et al., 2009). As an ancient practice, RWH cisterns were common in ancient Greek, Etruscan, Roman, Indian, and other civilizations (Boers

and Asher, 1982). In Jordan for example, surface runoff has been collected for over 4000 years. Elsewhere, archaeological research in Venice resulted in the identification of more than 6000 subterranean rainwater cisterns constructed during the Middle Ages for domestic water supply. More recently, the advent of urban sprawl has resulted in a decrease in the amount of forested lands, wetlands, and other forms of open spaces that absorb and clean storm water in the natural system (Leopold, 1968). This has caused degradation in the water quality of water bodies that are now used in the agricultural and domestic sectors. The practice of RWH has been gaining popularity as the usage of rainwater is much cleaner (in terms of carbon dioxide emissions) than the usage of municipal water supplies. Like other water conservation techniques, RWH is considered to be a viable means to manage urban water resources more efficiently and sustainably (Basinger et al., 2010).

Domestic water usage is a significant component of the global water demand. RWH can be used for both nonpotable and potable purposes such as garden use, toilet flushing, washing clothes, hot water systems, and drinking water supply (Khastagir and Jayasuriya, 2010). Catchment area, storage material, and the distribution system are a few design considerations that have to be taken into account when constructing a RWH system. When selecting a rainwater tank, a house owner often only focuses on the location where the tank will be placed, its aesthetics, and the cost. However, other key design variables that need to be considered are: amount of precipitation in the area, extent of catchment area, and the end use of the water. If the tank is sized properly, the volume of rainwater in the tank will be able to supplement the household water demand; this also reduces the chances of the tank being empty or overflowing. Also, if the catchment area is fairly large, a greater number of end-use applications can allow for greater water savings.

According to the United Nations Environment Programme (UNEP, 2012), examples of RWH and its utilization can be found all across the world. For example, with almost 86% of Singapore's population living in high-rise buildings, using RWH has

become an important component of reducing rising urban water demand in the region. In cities and regions such as Tokyo, Thailand, and China, RWH is seen as a way of mitigating water shortages, controlling floods, and securing water for emergencies. In Bangladesh, where the rural population is plagued by arsenic in the drinking water, RWH is being used to provide a potable water supply, and in St. Thomas, U.S. Virgin Islands it is now mandatory to install a RWH system to acquire a residential building permit.

In Canada, a study in Ontario by Farahbakhsh et al. (2009) indicated that if there are no weather anomalies and the precipitation pattern follows the historical trend, then municipal water demand can be reduced by as much as 47% in domestic households in Ontario, Canada, if RWH is used for domestic water supply. In southeast Brazil, Ghisi (2006) estimated that RWH practices can reduce potable water demand by 48% to 100%. In Germany, where RWH has been in use since the 1980s, potable water demand has decreased by 30% to 60% due to the use of roof runoff harvested in 4- to 6-m<sup>3</sup> tanks, which is then used for toilet flushing (Hermann and Schmida, 1999). RWH is being used in the rural areas of the developing world (such as India, China, and Africa), where it is mainly used for irrigation during dry periods. In such environments, RWH is seen as a measure that can help fight food scarcity (Fox et al., 2005).

The quality of water collected in a RWH system is affected by several factors, which include the proximity to roads and heavy industries, presence of wildlife, and meteorological conditions such as temperature and rainfall patterns in the region (Despins et al., 2009). Although these factors may deteriorate the quality of the collected rainwater, Kumar (2004) states that treatment by prestorage treatment devices such as filtration or first flush diversion can help to expel most of the harmful sediments from the roof (catchment area) into the surroundings and also prevent the stagnation of water in the tanks, thereby restricting the breeding of insects. Similarly, poststorage treatment devices such as ultraviolet disinfection, chlorination, or slow sand filtration can further improve the water quality,

in some cases making the harvested rainwater a source of potable water. As an added precaution, storage tanks must be closed at all times to prevent the entry of insects and to reduce evaporation losses. Finally, the most commonly occurring problem of algal blooms in storage tanks can be mitigated by both chemical and physical techniques (Bartsch, 1954). Chemical techniques include the use of copper sulfate in small concentrations such that the algal bloom is destroyed without harming the roots of the plants (if the water is used for irrigation). Even though the solution is effective, it is not viable as the cost of implementation rises with increasing volumes of water in the storage tank. Covering the storage tanks with a reflective material, which prevents sunlight transmission into the water tanks, is an alternative solution (Bartsch, 1954). This is a significantly less expensive and more practical approach. Another issue that must be addressed in the design of RWH systems is the handling of overflows during large rainfall events. Methods for handling overflow may include onsite infiltration, as well as discharging to an existing storm sewer infrastructure (Farahbakhsh et al., 2009).

The cost of a RWH system varies depending on the size of the catchment area, the type of cisterns chosen to store the rainwater, and the piping material used to transport the water for its end use. Cost was by far the biggest barrier identified for the implementation of RWH systems in a recent study conducted by Farahbakhsh et al. (2009); the typical roof area of a domestic household in Canada is  $\approx 230$  m<sup>2</sup> (Canadian Mortgage and Housing Corp., 2012), which translates to a cost in the range of C\$2000

to C\$8000 (in Canadian dollars) or the setup of a RWH system. The yearly maintenance costs and decommissioning cost at the end of the lifespan of the systems costs an additional C\$2000 (Roebuck and Ashley, 2006). It should be noted that RWH systems have one of the lowest payback periods for sustainable engineering systems (maximum 15 years), and government incentives can often offset some of the expenses (Despins et al., 2009).

The Faculty of Agricultural and Environmental Sciences on the Macdonald Campus of McGill University has been active in the promotion of sustainable technologies. The Horticulture Research Center at the Macdonald Campus serves as a training, education, and research center for students involved in vegetable and fruit production and is used by numerous departments on the campus. The Horticulture Services Building is used as a storage, processing, and retail space for the activities that occur in the surrounding gardens and the two greenhouses. Irrigation of the greenhouses consumes  $\approx 700$  gal of freshwater per day. The objective of the RWH project described in this article is to manage urban water resources more efficiently and promote the learning of practical sustainable technologies at the university and the surrounding communities through educational tours to the project site. Although research on domestic RWH systems has been increasing, there are still relatively few publications that describe the construction and advantages of such systems. This article is intended to fill this gap by explaining cost-effective ways for the setup and maintenance of this sustainable water supply option.

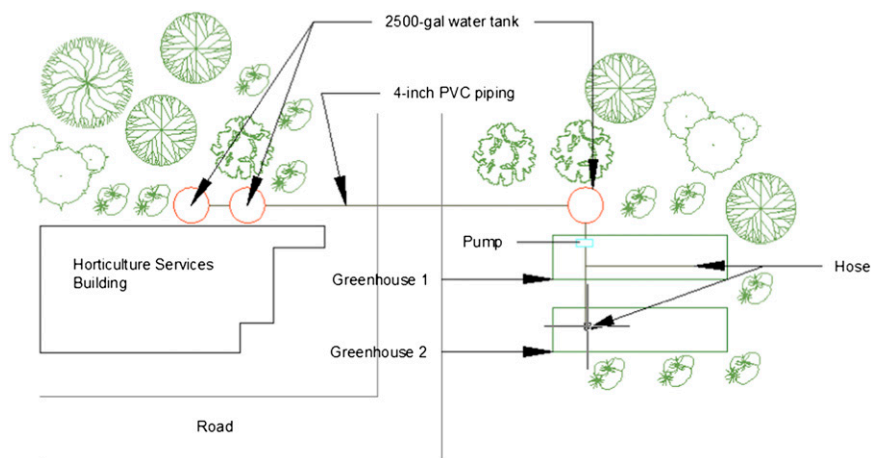
## Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
0.0929	ft <sup>2</sup>	m <sup>2</sup>	10.7639
0.0283	ft <sup>3</sup>	m <sup>3</sup>	35.3147
3.7854	gal	L	0.2642
0.7457	horsepower	kW	1.3410
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
1	ppb	$\mu\text{g}\cdot\text{L}^{-1}$	1
1	ppm	$\text{mg}\cdot\text{L}^{-1}$	1
6.8948	psi	kPa	0.1450
$(^{\circ}\text{F} - 32) \div 1.8$	$^{\circ}\text{F}$	$^{\circ}\text{C}$	$(^{\circ}\text{C} \times 1.8) + 32$

## Methodology

The setup of the RWH system (Fig. 1) comprises the Horticulture Services Building and the two Horticulture Research Center greenhouses ( $\approx 50.3$  m away). Rainwater is collected from a sheet metal roof with a catchment area of  $\approx 610$  m<sup>2</sup>. Roof runoff is redirected using 4-inch aluminum eaves troughs into a 2500-gal polyethylene water tank (part no. 40051; Norwesco, St. Bonifacius, MN), with the help of downspouts. An aluminum mesh attached to the top of the eaves troughs prevents leaves and other large debris from entering the water tank. Weather data collected from Environment Canada helped in the sizing of the water tanks by determining the average annual precipitation pattern along with the longest recorded dry period on the island of Montreal. The average annual amount of rainfall in Montreal over the period of 1971–2000 is 834.9 mm, whereas the most prolonged interval without precipitation is 7 d over the past five years (Environment Canada 2012a, 2012b). However, the system was designed to withstand a 1 in 10 year storm event, resulting in the accumulation of 19 m<sup>3</sup> of rainwater over a period of 15 min. It is estimated that the tanks require 52 mm rainfall to fill up with a collective storage volume of 7500 gal, able to sustain the peak irrigation demands of both greenhouses for 11 d.

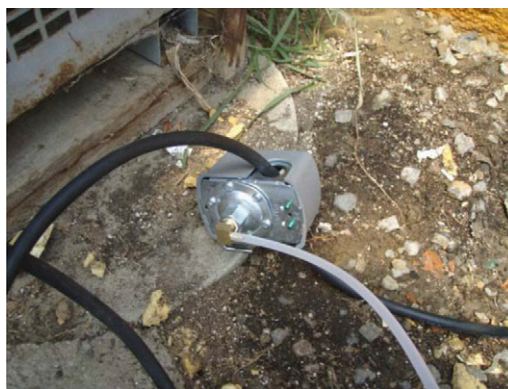
The collection tanks (Fig. 2) are located next to the Horticulture Services Building. The site is covered with vegetation, and the soil contains a large amount of rocks, adding both aesthetics and stability to the system. The first tank is connected in series to two other identical tanks, each at a decreasing elevation. Gravitational pull and the accumulated head pressure in each tank govern the flow of water between the tanks. The tanks are connected to each other via 4-inch polyvinyl chloride (PVC) pipes, with a system of 4-inch valves and overflows allowing one to control the inflow and outflow of water in each tank. The third tank rests beside the greenhouses (which have an area of  $\approx 149$  m<sup>2</sup> each), and it is connected to a 1-horsepower centrifugal water pump (part no. 4011K11; McMaster-Carr, Santa Fe Springs, CA) that supplies the irrigation water to both greenhouses.



**Fig. 1.** Overview map of the rainwater harvesting (RWH) system at the Horticulture Services Building (Macdonald Campus, Sainte-Anne-de-Bellevue, QC, Canada) and at the two Horticulture Research Center greenhouses. Rainwater is collected from a sheet metal roof, directed using 4-inch (10.2 cm) aluminum eaves troughs into a three 2500-gal (9463.5 L) polyethylene water tank.



**Fig. 2.** A side view of the Horticulture Services Building (Macdonald Campus, Sainte-Anne-de-Bellevue, QC, Canada), two 2500-gal (9463.5 L) polyethylene water tanks, and the sheet metal roof directed using 4-inch (10.2 cm) aluminum eaves troughs with downspouts.



**Fig. 3.** A view of the pressure switch at the Horticulture Services Building (Macdonald Campus, Sainte-Anne-de-Bellevue, QC, Canada) that turns the 1-horsepower (0.75 kW) centrifugal water pump on and off for irrigation, when the line pressures are 25 and 40 psi (172.4 and 275.8 kPa), respectively.

With an inlet diameter of 2 inches and an outlet of 1.5 inches, the 1-horsepower centrifugal water pump delivers water at a flow rate of 22 gal/min and 40 psi of pressure at the furthest end of the greenhouses (24 m away). The pump is completely automated with the help of a pressure switch (Fig. 3) that turns the pump on and off when the line pressures are 25 and 40 psi, respectively. The pump helps to meet the peak irrigation needs of the greenhouses from May to October, which can amount up to  $\approx 350$  gal of water per day in each greenhouse. The piping within the greenhouses mainly consists of 1.5-inch semirigid pipes, which allows for flexibility within the structures.

Overflows are designed on all three tanks with 4-inch PVC pipes. The overflows help to discharge the water into the surroundings once the water volume in the tanks reaches 2200 gal. The overflows in the first two tanks are combined together with a "T-junction," and the water is discharged into the nearby vegetation. The entire system performs efficiently, since it requires no manual labor from the beginning (collection of rainwater) to the end (irrigation of plants).

To verify the chemical and biological composition of the collected rainwater, a thorough water analysis was carried out. Two rainwater samples were collected in 25-mL containers from the first and second storage tanks. The samples were collected 1 week after a rainstorm event (25 Sept. 2012) and stored in ambient temperature ( $\approx 25^\circ\text{C}$ ). A third sample was collected from the tap that was previously used to supply irrigation water to the two greenhouses, for comparison. The samples were bottled and shipped to a water analysis laboratory that analyzed the samples for various heavy metals as well as the total Kjeldahl nitrogen content using inductively coupled plasma mass spectrometry. Three water samples were collected and stored in the same fashion for the bacterial count. The samples were shipped to the same water analysis laboratory where the total bacterial count was carried out using different plating techniques.

## Results and discussion

This project was the first of its kind to be undertaken at McGill University and serves as a tool for

both irrigation and education. Similar projects can be found at the University of Guelph and McMaster University in Canada, where research is being done to design and operate household RWH systems for flushing toilets, watering gardens, and drinking purposes. To date, the RWH system at the Macdonald Campus of McGill University has been successful throughout the summer and fall in meeting the irrigation demands of both greenhouses combined. Before the RWH system, the town of Sainte-Anne-de-Bellevue, QC, Canada, mainly supplied the irrigation water with some water provided by the Macdonald Campus water supply system ( $<10\%$ ). A decentralized water supply that uses its own source of water is a more sustainable way of providing water for irrigation purposes at the Macdonald Campus. In addition, rainwater is naturally soft water without any minerals, chlorine, fluoride, and other chemicals.

The RWH system not only stores enough rainwater for watering the greenhouses but it has also been able to water the nearby student-run gardens. The design includes steps for collection, filtering, storage, and delivery of the water for irrigation. Although the system did not include steps for the chemical treatment of the stored rainwater, the water that was used for irrigation in the greenhouses was clear and did not have any odor associated with it. Since the

catchment area was a sheet metal roof, it limited the leaching of harmful substances such as lead, mercury, and polycyclic aromatic hydrocarbons into the captured rainwater that would have otherwise been present if the roof was made of asphalt shingles (Van Metre and Mahler, 2003). At the same time, the presence of dissolved and particulate copper is minimized due to the absence of clay or concrete tiles on the roof (Forster, 1996).

Storage tank material can also affect the pH of rainwater that has been collected and change its chemical quality (Despins et al., 2009). The use of high-density polyethylene water tanks in the setup was because plastic tanks create no changes in the pH and chemical composition of the stored water (Hart and White, 2006). Concrete cisterns have reported a rise in the pH from 5 on the roof surface to 9.4 in the tank (Hart and White, 2006). There is also a significant concern about chemical leaching of zinc from metal tanks. In the RWH system at McGill University, sedimentation has played a major role in reducing the contaminant load of the stored rainwater. Sedimentation allows the water to rest in order for the flocculated or coagulated particles to settle out. Ideally the water should be allowed to rest for more than 4 h for the sedimentation process to be effective. The collected rainwater was allowed to rest for 24 h after every

**Table 1. Comparison of levels of heavy metals in rainwater (collected on 25 Sept. 2012, from the roof of the Horticulture Services Building, Macdonald Campus, Sainte-Anne-de-Bellevue, QC, Canada) and a municipal tap water sample (at the same location) to determine water quality of the rainwater harvested for greenhouse irrigation purposes. Samples were collected 1 week after a rainstorm event, stored at ambient temperature [ $\approx 25^\circ\text{C}$  ( $77.0^\circ\text{F}$ )], and analyzed for various heavy metals using inductively coupled plasma mass spectrometry.**

Parameter	Unit <sup>a</sup>	Reported detection			
		limit	Rain 1 <sup>y</sup>	Rain 2 <sup>y</sup>	Tap 1 <sup>x</sup>
Copper	$\mu\text{g}\cdot\text{L}^{-1}$	3.0	$<3.0$	$<3.0$	9.3
Lead	$\mu\text{g}\cdot\text{L}^{-1}$	1.0	$<1.0$	$<1.0$	$<1.0$
Zinc	$\mu\text{g}\cdot\text{L}^{-1}$	3.0	285	359	7.4
Aluminum	$\mu\text{g}\cdot\text{L}^{-1}$	30	$<30$	$<30$	45
Iron	$\mu\text{g}\cdot\text{L}^{-1}$	300	$<300$	$<300$	$<300$
Manganese	$\mu\text{g}\cdot\text{L}^{-1}$	5	$<5$	$<5$	$<5$
Sodium	$\mu\text{g}\cdot\text{L}^{-1}$	2000	$<2000$	$<2000$	9720
Selenium	$\mu\text{g}\cdot\text{L}^{-1}$	2	$<2$	$<2$	$<2$
Total mercury	$\text{mg}\cdot\text{L}^{-1}$	0.0001	$<0.0001$	$<0.0001$	$<0.0001$

<sup>a</sup>1  $\mu\text{g}\cdot\text{L}^{-1}$  = 1 ppb, 1  $\text{mg}\cdot\text{L}^{-1}$  = 1 ppm.

<sup>y</sup>Two rainwater samples (Rain1 and Rain2) were collected in 25-mL (0.85 fl oz) containers from the first and second storage tanks.

<sup>x</sup>Sample (Tap 1) was collected from the tap that was previously used to supply irrigation water to the two greenhouses, for comparison. The sample was bottled in a 25-mL container.

rainstorm before it was used for irrigation. This provided a source of primary treatment to the collected water.

Water quality also is significantly affected by the type of piping material that is used to transport the water for its end use. PVC pipes were used in this project since they are relatively inert and do not affect the water quality in any significant way. In a comparison between concrete and PVC pipes, Davies et al. (2010) found that concrete drainage systems have a significant influence on water chemistry, particularly where the inflow is acidic. The major factor identified in the research was the presence of calcium, bicarbonate, and potassium ions from the concrete pipes.

As can be seen in Table 1, the chemical composition of the harvested rainwater is fairly similar to tap water. Among the various heavy metal concentrations analyzed, a notable difference can be found between the concentrations of zinc and copper (which are micronutrients for plants). Since the catchment area is made of sheet metal, the average concentration of zinc in the two rainwater samples is  $322 \mu\text{g}\cdot\text{L}^{-1}$ . Although this is  $\approx 43.5$  times higher than the zinc concentration in the tap water sample, the Canadian Council of Ministers of the Environment (CCME, 2011) states that the threshold limit for zinc in irrigation water is  $1000 \mu\text{g}\cdot\text{L}^{-1}$  when the soil pH is below 6.5. Thus, the zinc concentration in the rainwater is not toxic to the greenhouse plants. Copper concentrations however are on average three times lower in the rainwater when compared with tap water. This is can be mainly attributed to the fact that copper pipes are used as a means of delivering the municipal water to the greenhouses, whereas the stored rainwater is transferred to the greenhouses with the help of PVC and plastic piping. Plant deficiency in copper can easily be avoided by fertilization.

Table 2 displays the total nitrogen content and bacterial count for the rainwater and tap water samples. The total nitrogen content in both samples was the same, but the bacterial count in the rainwater was  $\approx 473$  times higher, when compared with the tap water. This indicates that the rainwater cannot be used as a potable water supply, but it does not make

a difference when it is solely used for irrigation.

The tanks in this study were sized to incorporate a suitable safety factor to prevent perpetual overflows and the flooding of the project site. It was calculated that a combined storage volume of 7500 gal would be able to withstand a 1 in 10 year rainstorm event lasting 15 min. Sizing the tanks to have a large storage volume also ensured that the Horticulture Research Center will not deplete its supply of irrigation water during the summer months. However, even with such a considerable storage capacity, some of the water in the tanks had to be expelled (through the overflows) since the tanks did not have enough volume to store the large amounts of water that were sometimes obtained (after big rainstorms). Since the irrigation water demand in the greenhouses declined from September onwards, unused rainwater in the storage tanks accounted for the overflowing of the cisterns. The approximation of the tanks being able to survive a 1 in 10 year rainstorm for 15 min was therefore an underestimate. Addition of another 2500-gal tank (amounting to a total storage volume

to 10,000 gal) should solve the problem of overflows.

There were no problems with the breeding of insects and the entry of foreign objects into the water tanks, as they were sealed with the plastic caps that were provided by the manufacturers. Overall, the cost of the project was  $\approx \text{C}\$8000$  (Table 3). Most of this cost was associated with the installation of the eaves troughs on the roof of the Horticultural Services Building. For ordinary domestic households, this cost would be significantly lower, especially if the eaves troughs are already installed on the roof. For an average household with a roof area of  $230 \text{ m}^2$ , the cost of installation may range between  $\text{C}\$1500$  and  $\text{C}\$2000$  (Save the Rain Campaign, 2010). This cost may change depending on the historic precipitation data of the region and the end use of the harvested rainwater. If new eaves troughs need to be installed, the cost could increase to  $\approx \text{C}\$3000$  to  $\text{C}\$5000$ .

Based on the 2011 annual precipitation data collected from a local weather station,  $411.5 \text{ m}^3$  of rainwater (including overflows) was collected by the RWH system from May to

**Table 2. Comparison of total Kjeldahl nitrogen (TKN) content and the bacterial count (BHAA) in the harvested rainwater (collected on 25 Sept. 2012, from the roof of the Horticulture Services Building, Macdonald Campus, Sainte-Anne-de-Bellevue, QC, Canada) and a municipal tap water sample (at the same location) to determine water quality of the rainwater harvested for the greenhouse irrigation purposes. Samples were collected 1 week after a rainstorm event, stored at ambient temperature [ $\approx 25^\circ\text{C}$  ( $77.0^\circ\text{F}$ )], and analyzed for TKN and BHAA (using dilution plating techniques).**

Parameter	Unit <sup>a</sup>	Rain 1 <sup>b</sup>	Rain 2 <sup>b</sup>	Tap 1 <sup>b</sup>
TKN	$\text{mg}\cdot\text{L}^{-1}$	<1.0	<1.0	<1.0
BHAA	cfu/mL	120,000	230,000	370

<sup>a</sup>1  $\text{mg}\cdot\text{L}^{-1}$  = 1 ppm, 1 cfu/mL = 29.5735 cfu/fl oz.

<sup>b</sup>Two rainwater samples (Rain 1 and Rain 2) and one tap water sample (Tap 1) were collected in 25-mL (0.85 fl oz) containers from the first and second storage tanks along with the tap that previously supplied irrigation water to the two greenhouses.

**Table 3. A detailed cost analysis for the setup of the rainwater harvesting system at the Horticulture Services building located on the Macdonald Campus of McGill University, Sainte-Anne-de-Bellevue, QC, Canada.**

Type of cost	Value (Canadian dollars)
Purchase and installation of eaves troughs	2000
Purchase of 200 ft (61.0 m) of 4-inch (10.2 cm) PVC (PVC) pipes	1000
Purchase of three 2500-gal (9463.5 L) water tanks	3300
Purchase of water pump	300
Purchase of pressure switch	36
Purchase of 100 ft (30.5 m) of semirigid piping	150
Pump and pipe fittings	1200

October. Since the irrigation of the greenhouses required  $\approx 318 \text{ m}^3$  of water during this period of time, all of the irrigation water was supplied by the RWH system. In the city of Montreal, water is priced at a very low rate of C\$0.22/ $\text{m}^3$ . If all of the collected water was used for irrigation, it would lead to a saving of C\$90.53 every year, which results in a payback period of  $\approx 88$  years. Although this is a very long period of time, for water-scarce regions where the price of water is much higher (such as Las Vegas, NV, or the Republic of Cyprus) the payback period will be much faster.

The major problem that was faced in the project was that of algae growth in the final storage tank. The first two tanks were located behind the Horticulture Services Building and were not subjected to large amounts of sunlight throughout the day, reducing problems with algae growth.

However, the final tank was situated in an open space beside the greenhouses, maximizing its exposure to sunlight, particularly during dawn and midday. Although the high-density polyethylene wall of the tank was 1-inch thick, almost 20% of the sunlight was still transmitted to the stored rainwater (MS-01; Apogee Instruments,

North Logan, UT). This created an algal bloom (that was restricted to the surface of the stored water). Before the algae could spread throughout the water body, the tank was flushed and refilled. The tank was then completely wrapped with metallic green wallpaper (as shown in Fig. 4), which helped to reflect almost all the sunlight, preventing any algal blooms. The tank has to be re-wrapped every year due to wear and tear of the wallpaper.

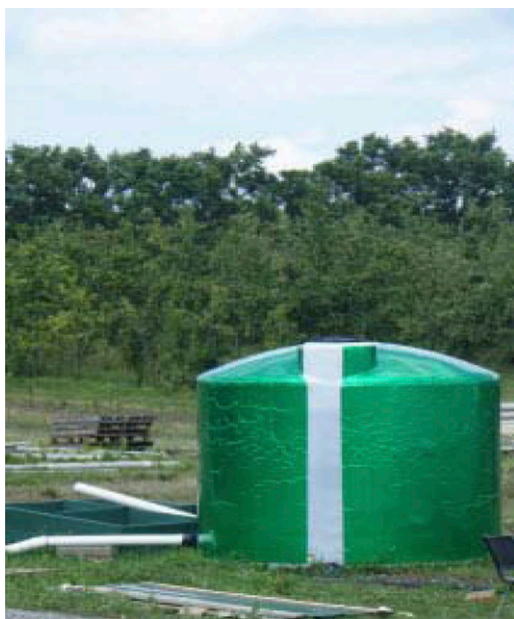
Fresh water scarcity is a major concern around the world, with many regions beginning to lack the water resources necessary to meet the demands of ever growing populations, as well as ecosystems. This project was able to introduce and demonstrate a simple method that can help to address the problem of freshwater scarcity. RWH systems require no treatment of the water (if it is used for irrigation), thereby reducing installation and operational costs. For this project, municipal water for greenhouse irrigation is no longer purchased from the town of Sainte-Anne-de-Bellevue, Quebec, thereby creating a savings of  $\approx$ C\$70 from the month of May to October.

Finally, an additional important outcome was the implementation of a simple and sustainable technology to increase awareness of

RWH on the McGill campus and its surroundings. The project is mainly being used as a demonstration tool to enrich learning on and around the campus on the topic of simple sustainable water technologies. The project helps to show that the setup of a RWH system is relatively simple and is an example of how individual stakeholders can begin to help the transition to more sustainable and decentralized water supply systems. The project allows visitors to appreciate that along with economic incentives (especially in regions where water prices are very high), RWH systems also provide other advantages such as reducing flooding and erosion, as well as decreasing the amount of water that needs to be produced via water treatment plants. Since the completion of the setup, a number of classes from McGill University (as well as outside visitors) have visited the site, including the following courses: BREE-327 (Bioenvironmental Engineering), BREE-510 (Watershed Systems Management), and PLNT-312 (Urban Horticulture).

## Conclusion

Various measures to meet urban water demand and to help communities transition to sustainable water use are currently being explored around the world. For example, rainwater and reclaimed wastewater have been used for a variety of purposes ranging from potable water supply to irrigation and greywater recycling used in toilets and for household cleaning. Rainwater harvesting on a small scale provides an example of one approach to help communities transition to more sustainable water resources management. The effectiveness of RWH systems mainly depend on their geographic locations due to varying amounts of precipitation in different places, the size of the catchment area, and the end use of the harvested rainwater. The Macdonald Campus of McGill University functioned as an ideal study site for such a project. Although the setup of a RWH system in Montreal has very little economic incentives, this may not be the case in water-scarce regions. The system at the Horticulture Research Center was designed to withstand a 1 in 10 year storm event lasting 15 min, to prevent any water shortage that could be



**Fig. 4.** A 2500-gal (9463.5 L) polyethylene water tank at the Horticulture Services Building (Macdonald Campus, Sainte-Anne-de-Bellevue, QC, Canada) wrapped with metallic green wallpaper to reflect almost all the sunlight, preventing any algal blooms.

faced during irrigation. With a catchment area of 610 m<sup>2</sup>, the RWH system located beside the Horticulture Research Center was able to supply all of the water required for irrigation of the two 149-m<sup>2</sup> greenhouses on the Macdonald Campus of McGill University from the beginning of the summer to the end of the fall. Due to the materials used for the roof (the catchment area), the storage tanks, and the piping, the collected rainwater was clean with very little change in the water chemistry. This made the harvested rainwater ideal for irrigation purposes. The only obstacle that was faced during the operation of the RWH system was algae growth in the final water tank. This issue was resolved by flushing the tank and wrapping it with metallic green wallpaper that reflected most of the sunlight away from the stored water. Not only is the system beneficial for the Horticulture Research Center and the student-run gardens, it also plays an important part in educating the student population at McGill University and the surrounding communities about the benefits of sustainable water resources technologies. Moreover, the RWH system can be expanded in the future to include other buildings located on campus to supply the buildings with their own source of greywater for toilet flushing, floor cleaning, and other purposes. As urbanization continues around the world, RWH provides a useful approach to save water resources.

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